PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume 27 pp: 15-23

Investigating Thermal and Daylighting Performance in Residential Buildings by Applying Productive Façades

Basma Nashaat El-Mowafy[1]

[1] *Architectural Engineering Department, Faculty of Engineering, Portsaid University, Portsaid, Egypt,*

Email: Basma_nashaat@eng.psu.edu.eg , *DOI : 10.21608/PSERJ.2023.209429.1235*

ABSTRACT

Productive Facade (PF) is a multi-functional system used in sustainable and productive cities, it is the integration of farming and Photovoltaics PV cells in façade design. Conversely, buildings could play a serious role in energy and food production while transforming cities from consumers to producers. Therefore, this paper reviews the current literature to propose a design strategy for PF. Then, the paper introduces a comparative study between different alternatives of PF in residential buildings in arid desert hot climate. The study evaluates the performance of façade designs depending on PF. The alternatives are the base case, which lacked PV or farming, design 1, which has vertical farming and PV louvers, and design 2, which has a double-skin façade with inner farming and PV. Then, a comparison between measurements of the three alternative models is undertaken to understand how to adjust PF to improve interior daylighting, thermal comfort, energy generation, and food production. The findings confirm that applying PF improves the daylighting and solar heating performance inside a residential building. Especially, design 2 is more efficient than other alternatives and decreases building energy consumption.

Keywords: productive façade, daylighting performance, green façade, energy production, Building Integrated Photovoltaic

1 INTRODUCTION

The implementation of eco-sustainable city ideas has become a necessity in recent years. This involves generating promising environmental effects to create the necessary amounts of energy, food, and water [1–3] Consequently, a fundamental redesign of buildings is required to transform them from consumers of resources to producers [3–6]. The building and construction industry consumes 30 to 40 % of all primary energy worldwide. Building integrated photovoltaic (BIPV) systems and green facades are significant advancements in achieving sustainable building design and energy efficiency for buildings, and enhance the changed nature of cities [4, 7–9]

In the energy field, Egypt receives 3450 hours of solar radiation annually, making photovoltaic (PV) electricity generation the most practical option [10]. Also, Diverse designs of BIPV products have become available on the market in recent years, including silicon-based solar cells, thin films, dye-sensitized solar cells, and organic solar cells, which support a wide range of architectural integration options and can be used on various types of buildings to produce better technical and aesthetic effects [11–14]

On the other hand, a green facade is a key strategy to reduce air and surface temperatures [15], which increases cooling demands in summer. The improvements in winter are due to the green layer’s increased insulation and work as a wind barrier [16][1]. The studies show the living green envelope's potential, particularly in terms of energy use, Co^2 emissions, and food production.[17–19] The two primary categories of green facades GFs are living walls (LWs) and green façades (GFs). In GFs, the green layer can be directly attached to the vertical wall of the structure or indirectly removed (indirect or double-skin GFs) [4, 20]. Formerly, the plant's growth is aided by a supporting framework, between the wall and the canopy, an air gap is made. Different solutions can be adopted as regards plants’ position and typology. Plants can be rooted in the ground at the base of the façade or in pots placed at different heights along the façade. Useable plants can be climbing or cascading, evergreen or deciduous species. [21] .

Productive façades (PFs) concept aims to integrate Vertical farming (VF) and photovoltaic (PV) panels, which are intended to operate as sustainable and flexible building envelope systems. By enabling on-site electricity generation, PFs technologies can make a valuable contribution to building performance, adding aesthetical values, producing fresh vegetables, and bringing nature closer to humans [22, 23]

2 REVIEW OF THE LITERATURE ON BIBLIOMETRIC ANALYSIS

The study uses bibliometric analyses to detect trends in research evolution within the PF field. The Web of Science collection database was searched for articles about productive façades that had been published worldwide between 2013 and 2023. The keywords "green façade," "integrated PV," and "productive facade" were used to locate the pertinent papers. The articles' bibliometric analysis was carried out using VOSviewer.

A total of 1,578 papers on the subject of productive façade were found. The keywords are divided into three clusters, which had a high correlation with the terms: "efficiency"," Temperature", "window", "BIPV " and "green façade". These keywords appeared to be the most popular keywords as illustrated in Figure 1 since they had the most links.

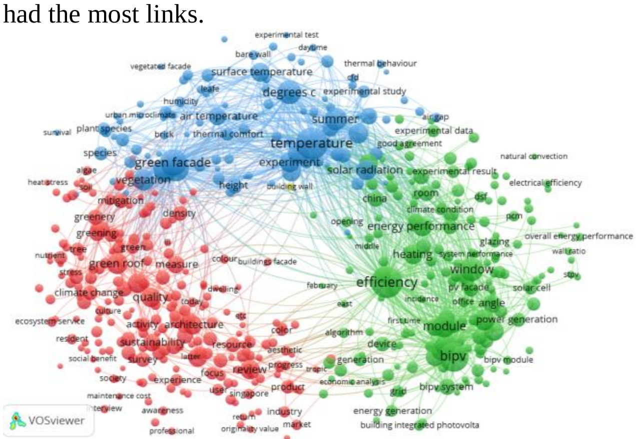


Figure 1: Network and density of the appearance of keywords of PF design using VOS viewer

As a result, the main keywords are BIPV and green façade, the study searches for related studies of the two keywords and PF as the subject that applies the two concepts in façade design. Table 1 illustrated various related studies in the three mentioned fields.

Table 1 Most related studies related to the keywords

Keyword	Author	Year	Methodology	Findings
	Convertino et al [4]	2021	Analyzing and modeling the effects of shade and evapotranspiration using an experimental prototype of the building with the green façade.	Green façades help cities become more environmentally friendly. It can help buildings use less energy when it's hot outside to cool down.
Green facade	Kumar and Shafi [18]	2023	Comparing the possibilities of green facades with coconut coir insulation to reduce room heat addition in the warm, humid weather typical of coastal South India.	Green facade effectively rejects heat during non-solar hours, it is surprisingly just 6.15%. But by including a coir mat, the green facade's capacity to reduce heat can rise to 40.3%.
	Sharad et al [24]	2023	Examining the thermal performance and comfort of indirect green façades in India's composite climate, the research technique utilizes a real-time experimental study.	The southwest-facing green façades recorded temperatures of 8.1°C lower than the bare façade during the day. It is best to install a green facade with a distance of more than 150 mm between the greenery system and the façade surface.
BIPV	Li et al [7]	2017	This study investigates the effects of various PV façade tilt angles on the PV cell efficiency and surface temperature of the naturally ventilated PV facade, the CFD approach is the primary methodology.	Compared to a standard PV facade, the naturally-ventilated PV façade was successful in lowering the surface temperature of the PV module and increasing its power generation efficiency.

Keyword	Author	Year	Methodology	Findings
	Xiang and Matusiak [25]	2022	Methodical approach for high-rise buildings with balconies in the Northern climate to integrate photovoltaics into the façade design.	The findings indicated that side balconies may maximize interior lighting and solar energy harvesting and that FIPV designs with partial balcony railing regions in complementary colors were the most aesthetically appealing type.
	Alhammadi et al	2022	The objective of the comparison study is to comprehend the energy efficiency of BIPV ventilated façade technologies as well as the effects of orientation and high temperatures in Dubai's harsh climate.	The annual energy yield of the south modules is more significant then the east and west modules. The second best-performing orientation is therefore found to be the east.
	ˇCurpek and Cekon [26]	2022	Building energy simulation (BES) was used in a comparison study of two BIPV façades (with and without the PCM layer) to examine how sensitive they were to temperature changes and how much electricity they produced.	The greatest peak power generation from 4.3 to 4.8% can be achieved experimentally with a 10-14 % reduction in PV panel operating temperature by using phase change material in a BIPV system.
	Panicker et al [27]	2023	The study develops and evaluates the viability of an integrated grid-connected Rooftop and Façade Building Integrated Photovoltaic (BIPV) system.	The integration of façade BIPV for low-rise residential buildings boosts system energy generation by up to 62.5%.
PF	Tablada and Zhao [28]	2016	The integration of agricultural and solar systems on building facades at urban and façade scales, respectively. Three density and geometry characteristics were chosen when evaluating 57 examples in total, including plot ratio, site coverage, and building height.	With the slab block and contemporary block typologies, just one case reaches the goal of self-sufficiency, while only two cases do so for the point block typology. Hence, plot ratio and building height are the indicators with the most influence on a community's ability to provide for its own food and energy needs.
	Tablada et al [22]	2018	A methodology used in the creation of modular PF prototypes that provide the best PF options for Singaporean residential structures, by using the Grasshopper parametric tool and VIKOR optimization method.	These systems can be used at higher latitudes, offering a comparable framework for optimization to increase energy and food production while also meeting indoor thermal and optical performance requirements.
	Kosorić et al [5]	2019	The study examines by a survey if the occupants will find PV appearance acceptable in high-rise public housing complexes.	The survey revealed that 58% of respondents thought PFs contributed favorably to the aesthetics of HDB residential buildings.

Other than these pilot studies, no other research has examined the impact of BIPV and building-integrated agriculture (BIA) on the performance of daylighting and heat gain, especially in Egypt. The objective of this study is to design and simulate potential solutions for food and energy production on vertical façades of residential buildings using PF systems, to reduce dependence on food and energy imports, and take into account the social, economic, and environmental advantages of BIPV and urban farming.

3 METHODOLOGY

The general framework of the formation, evaluation, and improvement of PF prototypes is shown in Figure 1.

- Phase 1 involved defining the scope, design concept, and critical implementation techniques for PFs using the reference materials that were accessible and conversations with regional experts on both BIPV panels and BIA systems.
- Phase 2 examined the different variables in PF design like orientation, façade design, farming layer, and PV cells.
- Phase 3 begins with the definition of criteria functions, which are the quantitative and qualitative assessment criteria after the design alternatives had been presented. The acceptable performance ranges taken into account were also established by Egyptian building codes and performance benchmarks suggested in the literature about the criteria functions: potential for indoor daylight and potential for solar exposure.
- Phase 4 presents a simulation of the PF prototypes' designs via simulation software and evaluates the performance of prototypes.
- Phase 5 is related to defining the most effective and suitable system and defining any needed editing in the design to determine execution techniques.

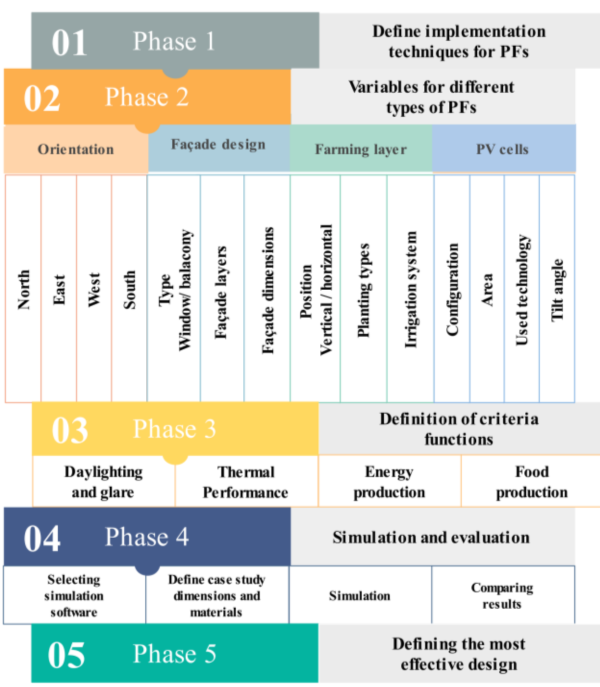


Figure 2: Proposed design strategy of PF

4 RESULTS AND DISCUSSION

The used materials in the base case and the proposed designs are illustrated in Table 2. Also, Figure 3 shows the dimensions of the simulated room. The tilt angle of the PV cell in design 1 is 45 degrees and the distance between the façade double layer in design 2 is 1 meter. The used climate file is Port said, Egypt which has an arid desert hot climate according to the Koppin climate zone. Finally, the tested facade is oriented into south direction.

Table 2. Used materials

layer	Material	R.vis	T.vis
Window	Clear glass	8.4%	87.7%
Ceiling	White ceiling	85.7%	0%
PV	Film PV on white exterior louver	5.6%	0%
Plants	grass	13.2%	0%
Floor	White ceramic tiles	89.1%	0%
walls	White painted wall	87.4%	0%
External glass	Clear glass	14.9%	77.4%

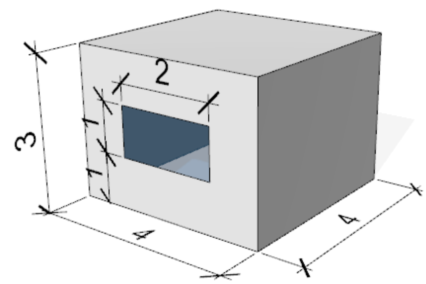
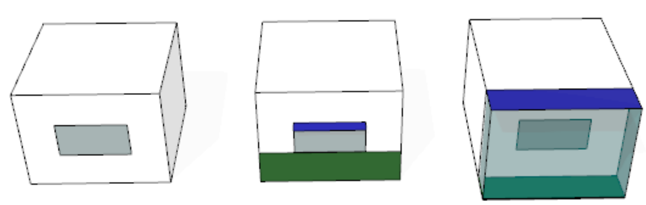


Figure 3: Dimensions of the simulated room

The daylighting and solar exposure simulation was achieved by using Climate Studio (CS) as a plugin for Rhinoceros 3D software. It is validated in various studies like [25, 29–31] The models were established in Rhino and simulation was performed by CS, as shown in Figure 4. This innovative plugin is used as a quick and environmental performance measurement tool as it is built on Energy Plus and a novel Radiance-based path tracing technology. Every simulation was built using data from the local weather (.epw file).



a) Base case **b) Design 1** **c) Design 2**

Figure 4: Simulated designs

In daylighting simulation, the simulation plane is 0.8 meters above the floor level, in the work plane level. On the other hand, the grid is located at ground level in solar simulation. In all cases, the sensors are placed every 0.50 meters.

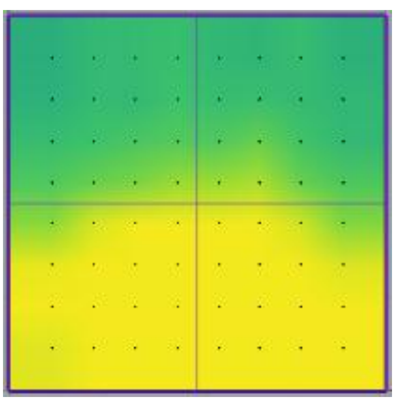
1.1. Daylight factor

Table 3 shows Daylight factor in different cases. As expected, daylight factor has been decreases by adding PV louver and double skin. The medium DF has decreased by 1.08 and 0.9 respectively in design 1 and design 2 receptivity.

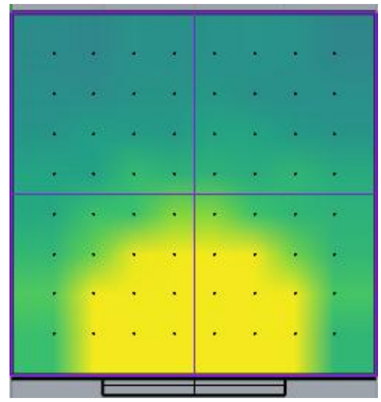
Table 3. Daylight factor in different cases

	Min DF	Mean DF	Median DF	Uniformity
Base case	3.14%	5.93%	4.35%	52.87%
Design 1	2.31%	4.28%	3.27%	53.93%
Design 2	**2.47%**	4.43%	3.45%	55.78%

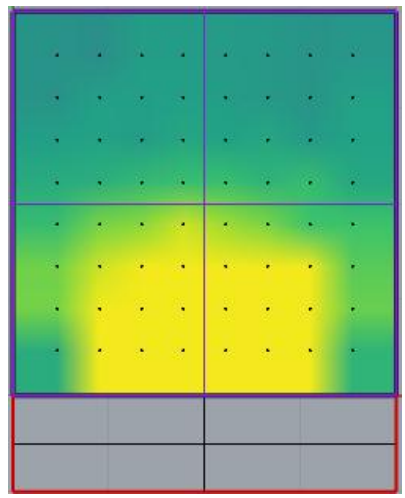
Likewise, Figure 5 shows the distribution of daylighting factor in the room based on sensors places. In general, the base case has higher values of daylight factor, but that doesn`t reflect better daylighting performance as the glare probability is not analyzed yet. Until now, the results conclude that design 2 has a better daylighting performance than design 1.



a) Base case



b) Design 1



c) Design 2

Figure 5: Daylight factor map in different cases

Finally, Figure 5 validates a comparison between the Base design the and two proposed designs. The chart illustrates that the DF in base case is extremely high which can cause glare. While, the two proposed designs achieved satisfied value more than 2.5%, which is operative in residential buildings [32].

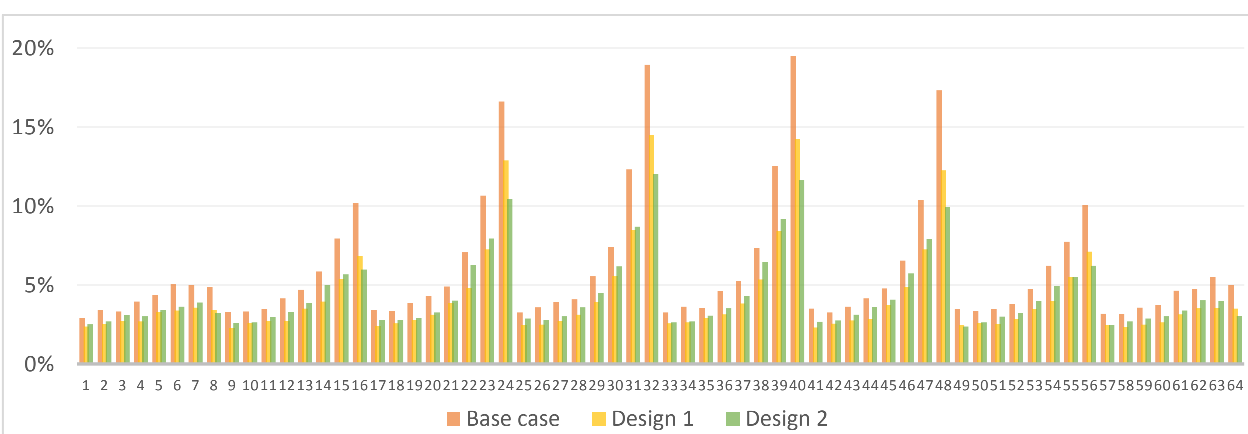


Figure 6: Comparison of Daylight factor values in all sensors in all cases

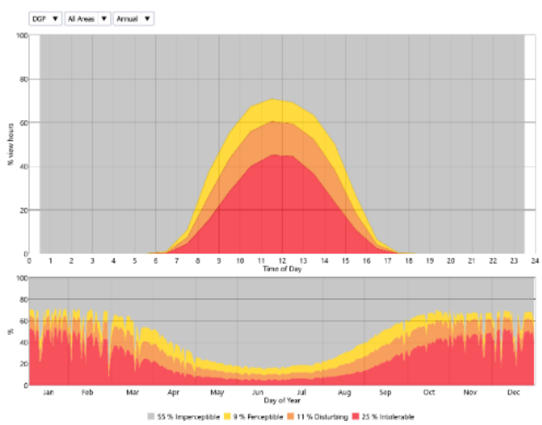
1.2. Glare

The probability of every type of glare is demonstrated in Table 4. As shown the two proposed designs 1 and 2 have increased the percentage of imperceptible glare, by 14%, and 12 % respectively. Similarly, design 2 decreased the probability of intolerable glare by 12%, and by 8% in the case of design 1. Finally, the proposed designs have slightly decreased the percentages of perceptible and distribution by 1% and 2%. Inclusive, design 1 performance is best in decreasing glare inside the room.

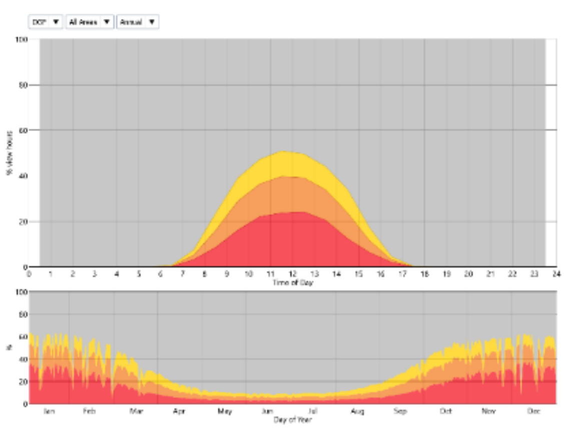
Table 4. Glare percentage in different cases

	Imperceptible	Perceptible	Distribution	Intolerable
Base case	55%	9%	11%	25%
Design 1	69%	8%	10 %	14%
Design 2	67%	7%	9%	17%

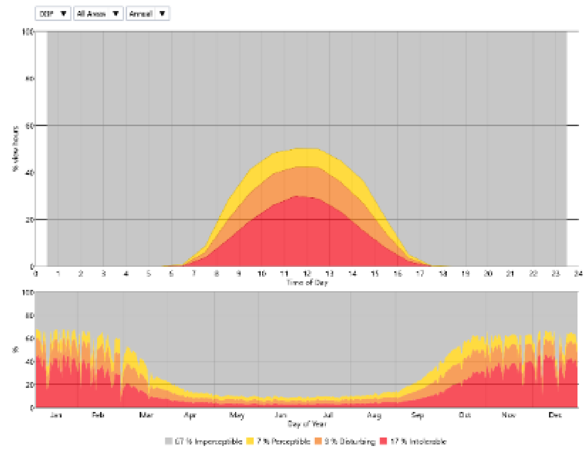
Similarly, Figure 7 illustrates the annual Daylighting Glare Probability DGP in the base case and the two proposed designs. The annual DGP has smaller values in the proposed design compared to the base case.



a) Base case



b) Design 1



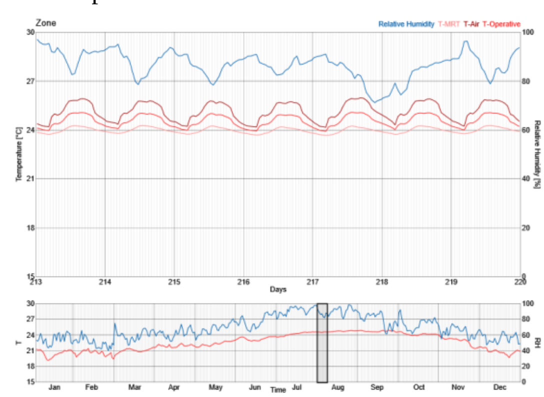
c) Design 2

Figure 7:Annual daylight glare probability DGP in the base case and proposed designs

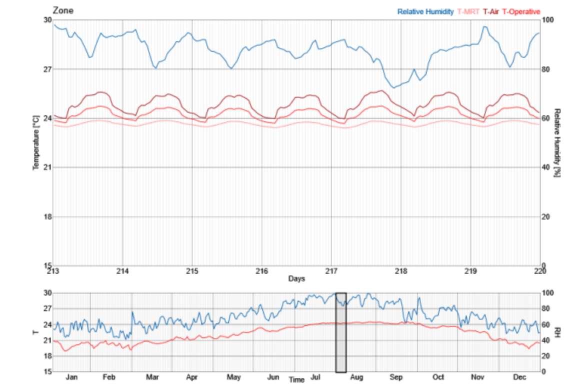
After a detailed judgment, design 2 exhibits superior glare performance with respectable daylight factor values.

1.3. Thermal Analysis

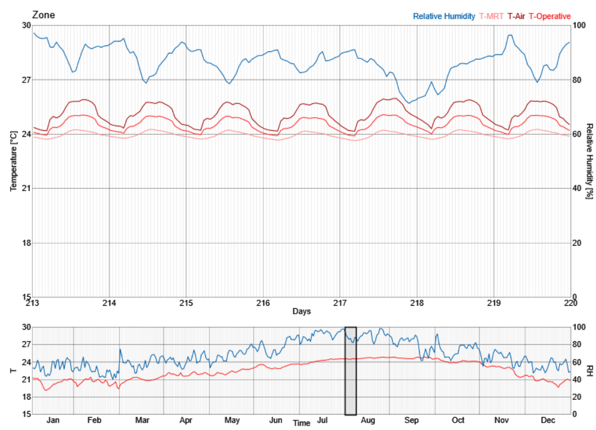
Figure 8 illustrates the temperature in the base case and two designs, the charts are exported from climate studio plugin. The chart illustrates the temperature and humidity inside the room on the first of august (a summer month) and the temperature and humidity around the year. The values in the case of design 1 and design 2 are lower than the base case Finally, Figure 9Figure 9 proves design 2 decreased the average radiation temperature by 0.4^{o} c degrees and the minimum and maximum radiance temperature by 0.3 and 0.7. In conclusion, PF doesn`t affect the radiance temperature inside the space.



a) Base case



b) Design 1



c) Design 2

Figure 8: Annual temperature of base case and proposed designs

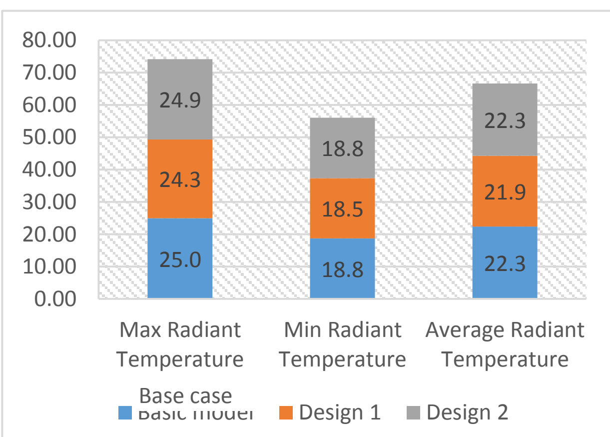


Figure 9: Mean Radiation Temperature of base case and proposed design

1.4. Energy generation and food production

The next step is the energy generation prediction of PV in the case of the two proposed designs. As demonstrated in Figure 10, the total solar exposure of the PV cell of design 1 is 2302 kwh/m^2-year. In design 2, it is projected as 1971 kwh/m^2-year as shown in Figure 11.

In conclusion, design 1 has a better ability for energy production, as the tilt angle help in gaining more solar exposure.

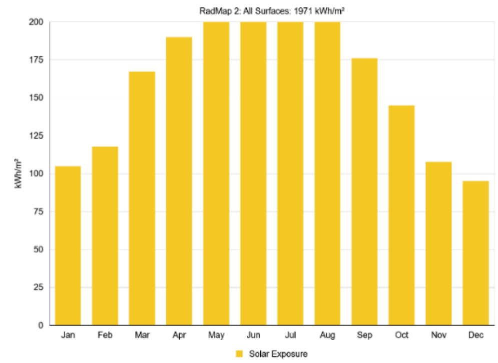


Figure 10 total solar exposure on PV cell in design 1

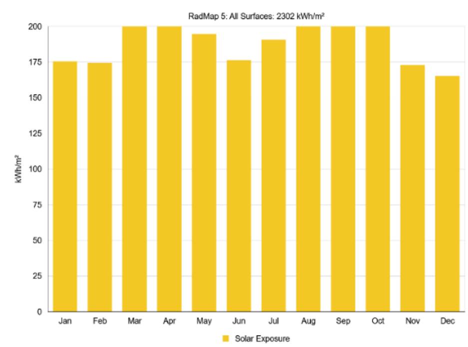


Figure 11 total solar exposure on PV cell in design 1

Consequently, the real power generation can be calculated as by next equation [33]:

$$PRG = P_n \times \left({}^{E}/{}_{S_n} \right) \times PR \qquad (1)$$

Where:

P_n the nominal power which the module can pro- duce under standard test conditions

E effective solar irradiance w/m^2

S_n solar irradiance for standard test condition

PR performance ratio

Real power generation is related to the area of PV, therefore, despite the total solar exposure in design 1 being more than in design 2, the real power generation of design 1 is expected to be greater.

In food production, horizontal planting enables more types of plants with different soil depths. So, Design 2 allows more opportunities, but it needs an additional supported structure. [34, 35]

5 CONCLUSION

This study presents a systematic method to design PF for residential buildings in a hot arid climate. It starts with facade geometry design, daylight simulation, continues with thermal simulation, and finally a comparison between a room base case and two different proposed designs. It shows that interior daylighting, solar heat gain, and energy productivity performance can be enhanced through this integrative approach and applying productive façade in residential buildings.

The study proposed two designs, the second design (design 2) has achieved better daylighting and glare performance. The two designs didn't achieve a large enhancement in thermal performance. But, design 1 results are better in total temperature inside the space, since the vertical planting layer works as a heat insulator. In energy generation, design 2 has a greater potential as it allows a wider area covered with PV cells, and its power generation can be enhanced by changing the tilt angle, avoiding shade areas. Generally, design 2 achieved better performance as a productive façade.

Finally, applying PF allows great potential in enhancing daylighting, and thermal performance, besides energy and food production. However, it required a supported structure, and regarding athletically values of the facade.

Declaration of competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Funding

List funding agencies in a standard way to facilitate compliance with the funder's requirements.

6 REFERENCES

1. Naroo, S.A., Morgan, P.B., Shinde, L., Ewbank, A.: The Impact of COVID-19 on Global Contact Lens Education. J. Optom. (2020). https://doi.org/https://doi.org/10.1016/j.optom.2020.11.002.
2. Abd Elraouf, R., Elmokadem, A., Megahed, N., Eleinen, O., Eltarabily, S.: The impact of urban geometry on outdoor thermal comfort in a hot-humid climate. Build. Environ. 225, 109632 (2022). https://doi.org/10.1016/j.buildenv.2022.109632.
3. Hassan, A., Megahed, N.: IMPROVING URBAN ENERGY RESILIENCE WITH AN INTEGRATIVE FRAMEWORK BASED ON MACHINE LEARNING METHODS. Archit. Eng. 7, 17–35 (2022). https://doi.org/10.23968/2500-0055-2022-7-4-17-35.
4. Convertino, F., Vox, G., Schettini, E.: Evaluation of the cooling effect provided by a green façade as a nature-based system for buildings. Build. Environ. 203, 108099 (2021). https://doi.org/10.1016/j.buildenv.2021.108099.
5. Kosorić, V., Huang, H., Tablada, A., Lau, S.K., Tan, H.T.W.: Survey on the social acceptance of the productive façade concept integrating photovoltaic and farming systems in high-rise public housing blocks in Singapore. Renew. Sustain. Energy Rev. 111, 197–214 (2019). https://doi.org/10.1016/j.rser.2019.04.056.
6. Noaman, D., Moneer, S., Megahed, N., El-Ghafour, S.: Integration of active solar cooling technology into the passively designed facade in hot climates. J. Build. Eng. 56, 104658 (2022). https://doi.org/10.1016/j.jobe.2022.104658.
7. Li, Y., Zhuang, Z., Tan, H., Su, W.: Simulation Study of a Naturally-ventilated Photovoltaic (PV) Façade for High-rise Buildings. Procedia Eng. 205, 1381–1388 (2017). https://doi.org/10.1016/j.proeng.2017.10.291.
8. Alhammadi, N., Rodriguez-Ubinas, E., Alzarouni, S., Alantali, M.: Building-integrated photovoltaics in hot climates: Experimental study of CIGS and c-Si modules in BIPV ventilated facades. Energy Convers. Manag. 274, 116408 (2022). https://doi.org/10.1016/j.enconman.2022.116408.
9. Elzeni, M., Elmokadem, A., Badawy, N.: Genetic Algorithms Application in Urban Morphology Generation. Port-Said Eng. Res. J. (2021). https://doi.org/10.21608/pserj.2021.87367.1129.
10. Khamees, A.S., Rahoma, U.A., Hassan, A.H., Sayad, T., Morsy, M.: Investigation of Solar Energy Potential and PV-Outputs in Rural and Desert Areas: Case Study Egypt. IOP Conf. Ser. Mater. Sci. Eng. 1269, 012006 (2022). https://doi.org/10.1088/1757-899x/1269/1/012006.
11. Jing, Y., Zhu, L., Yin, B., Li, F.: Evaluating the PV system expansion potential of existing integrated energy parks: A case study in North China. Appl. Energy. 330, 120310 (2023). https://doi.org/10.1016/j.apenergy.2022.120310.
12. Thebault, M., Gaillard, L.: Optimization of the integration of photovoltaic systems on buildings for self-consumption – Case study in France. City Environ. Interact. 10, (2021). https://doi.org/10.1016/j.cacint.2021.100057.
13. Hassan, S.R., Megahed, N.A., Abo Eleinen, O.M., Hassan, A.M.: Toward a national life cycle assessment tool: Generative design for early decision support. Energy Build. 267, 112144 (2022). https://doi.org/https://doi.org/10.1016/j.enbuild.2022.112144.
14. Badawy, N., Elsamaty, H., Waseef, A.: Relevance of monocrystalline and thin-film technologies in implementing efficient grid-connected photovoltaic systems in historic buildings in Port Fouad city, Egypt. AEJ - Alexandria Eng. J. 61, 12229–12246 (2022). https://doi.org/10.1016/j.aej.2022.06.007.
15. Nashaat, B., Waseef, A.: Responsive Kinetic Façades: An Effective Solution for Enhancing Indoor Environmental Quality in Buildings. In:

The First Memaryat International Conference (MIC 2017) Architecture of the Future: Challenges and Visions. , Saudi Arabia (2017).
16. Patil, M., Boraste, S., Minde, P.: A comprehensive review on emerging trends in smart green building technologies and sustainable materials. Mater. Today Proc. 65, 1813–1822 (2022). https://doi.org/10.1016/j.matpr.2022.04.866.
17. Kapusuz, K.Y., Can, S.: A Survey on Lifelong Learning and Project-based Learning among Engineering Students. Procedia - Soc. Behav. Sci. 116, 4187–4192 (2014). https://doi.org/10.1016/j.sbspro.2014.01.914.
18. Sigi Kumar, T.S., Shafi, K.A., Thomas, R.J., Mohammed, J.: Experimental evaluation of the thermal performance of coir mat and green facade as wall insulation in a tropical climate. Therm. Sci. Eng. Prog. 40, (2023). https://doi.org/10.1016/j.tsep.2023.101757.
19. Blanco, I., Vox, G., Schettini, E., Russo, G.: Assessment of the environmental loads of green façades in buildings: a comparison with un-vegetated exterior walls. J. Environ. Manage. 294, 112927 (2021). https://doi.org/10.1016/j.jenvman.2021.112927.
20. Widiastuti, R., Zaini, J., Caesarendra, W.: Field measurement on the model of green facade systems and its effect on building indoor thermal comfort. Meas. J. Int. Meas. Confed. 166, 108212 (2020). https://doi.org/10.1016/j.measurement.2020.108212.
21. Ling, T.-Y.: Rethinking greening the building façade under extreme climate: Attributes consideration for typo-morphological green envelope retrofit. Clean. Circ. Bioeconomy. 3, 100024 (2022). https://doi.org/10.1016/j.clcb.2022.100024.
22. Tablada, A., Kosorić, V., Huang, H., Chaplin, I.K., Lau, S.K., Yuan, C., Lau, S.S.Y.: Design optimization of productive Façades: Integrating photovoltaic and farming systems at the tropical technologies laboratory. Sustain. 10, (2018). https://doi.org/10.3390/su10103762.
23. Tablada, A., Kosorić, V., Huang, H., Lau, S.S.Y., Shabunko, V.: Architectural quality of the productive façades integrating photovoltaic and vertical farming systems: Survey among experts in Singapore. Front. Archit. Res. 9, 301–318 (2020). https://doi.org/10.1016/j.foar.2019.12.005.
24. Nagdeve, S.S., Manchanda, S., Dewan, A.: Thermal performance of indirect green façade in a composite climate of India. Build. Environ. 230, 109998 (2023). https://doi.org/10.1016/j.buildenv.2023.109998.
25. Xiang, C., Matusiak, B.S.: Façade Integrated Photovoltaics design for high-rise buildings with balconies, balancing daylight, aesthetic and energy productivity performance. J. Build. Eng. 57, 104950 (2022). https://doi.org/10.1016/j.jobe.2022.104950.
26. Čurpek, J., Čekon, M.: Building performance simulation of a photovoltaic façade enhanced with latent heat storage: Model validation and power generation prediction. J. Energy Storage. 56, (2022). https://doi.org/10.1016/j.est.2022.106143.
27. Panicker, K., Anand, P., George, A.: Assessment of building energy performance integrated with solar PV: Towards a net zero energy residential campus in India. Energy Build. 281, 112736 (2023). https://doi.org/10.1016/j.enbuild.2022.112736.
28. Tablada, A., Zhao, X.: Sunlight availability and potential food and energy self-sufficiency in tropical generic residential districts. Sol. Energy. 139, 757–769 (2016). https://doi.org/10.1016/j.solener.2016.10.041.
29. Aguilar-Carrasco, M.T., Díaz-Borrego, J., Acosta, I., Campano, M.Á., Domínguez-Amarillo, S.: Validation of lighting parametric workflow tools of Ladybug and Solemma using CIE test cases. J. Build. Eng. 64, (2023). https://doi.org/10.1016/j.jobe.2022.105608.
30. Rehman, A., Surapaneni, A.: Multi-objective optimization of Indian Jaali fenestration system for visual, thermal and perceptual performance using computational methods. Proc. Build. Simul. 2021 17th Conf. IBPSA. 17, (2022). https://doi.org/10.26868/25222708.2021.30453.
31. Dabaieh, M., Iarkov, I.: The Z free home from conceptual design to simulation results. E3S Web Conf. 362, 11001 (2022). https://doi.org/10.1051/e3sconf/202236211001.
32. Sepúlveda, A., De Luca, F., Thalfeldt, M., Kurnitski, J.: Analyzing the fulfillment of daylight and overheating requirements in residential and office buildings in Estonia. Build. Environ. 180, 107036 (2020). https://doi.org/10.1016/j.buildenv.2020.107036.
33. Yoo, S.H.: Simulation for an optimal application of BIPV through parameter variation. Sol. Energy. 85, 1291–1301 (2011). https://doi.org/10.1016/j.solener.2011.03.004.
34. Zhang, T., Spence, C., Qi, F., Yang, W., Song, T.: Influence of tree location on thermal radiation disturbance of the west wall of summer buildings. Energy Build. 273, (2022). https://doi.org/10.1016/j.enbuild.2022.112359.
35. Perera, T.A.N.T., Jayasinghe, G.Y., Halwatura, R.U., Rupasinghe, H.T.: Modelling of vertical greenery system with selected tropical plants in urban context to appraise plant thermal performance. Ecol. Indic. 128, (2021)..