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The Effects of Courtyard Envelope on the Energy Required for Cooling in the Hot Desert Climate

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Abstract: The objective of this paper is to investigate how various aspects of the courtyard envelope affect the amount of energy required to maintain a comfortable temperature in Egypt's hot deserts. Two different courtyard ratios (R1 and R2) were simulated using a wide range of parameters representing the courtyard envelope's features. The parameters of two courtyards, R1 (width-to-length ratio=0.5) and R2 (width-to-length ratio=1), were studied. They included the Window-to-Wall Ratio (WWR), the surface albedo of the courtyard walls, and the orientation of the courtyard. For this study, the annual energy needed to cool an office building in New Aswan was calculated using the Design-Builder software. The results demonstrate that the courtyard envelope significantly influences the annual cooling energy demand. In addition, the efficiency of a building's cooling system improves with the increase of parameters that have a direct impact on the amount of energy required for cooling, such as WWR and surface albedo for the courtyard envelope, as opposed to those that have an indirect impact, such as courtyard proportions. More specifically, the courtyard envelope's surface albedo has the potential to reduce annual cooling energy use by more than 2.8%.

Keywords: Energy Efficiency, Courtyard Envelope, Surface Albedo, Window to Wall Ratio WWR.

1 Introduction

Energy consumption in Egyptian buildings has increased dramatically, owing mostly to cooling requirements in Egypt's hot desert regions. Using climatic elements to attain indoor comfort in these hot desert areas is crucial to avoiding absolute reliance on air conditioners[1]. Whereas the use of air conditioning equipment will significantly increase energy consumption. As a result, it would be advantageous if we could minimize our usage of air conditioning, as it is well known that global energy costs have grown[2]. Consequently, there is an urgent need to design buildings with several environmental features and characteristics that assure energy consumption decreases in these buildings[3, 4]. In hot desert regions, one of the most important environmental elements used to lower building cooling demands is the courtyard.

The Courtyard is a global building design element that has been recognized and used for ages in all parts of the world, most notably in residential buildings[5]. Courtyard buildings have been constructed in China for over 5000 years. Recently, it was demonstrated that courtyards have a significant potential for energy savings, which is based on design features such as courtyard shape, size, envelope, vegetation, and orientation. Earlier studies have discovered that the amount of solar radiation has a substantial impact on the energy performance of courtyard buildings[6]. As a result, one of the really major aims of courtyard design is to limit solar heat gain mostly during the summertime while increasing daylight and sunlight during the cooler months[7].

This study looks at the impact of courtyard envelopes on the energy demand of office buildings in New Aswan city, Egypt, which has hot desert climates. As a result, the study focused on the courtyard orientation, Window to Wall Ratio (WWR), and surface albedo of the courtyard envelope as the most efficient characteristics that directly affect thermal efficiency and energy required for cooling. Several studies have been performed to investigate the impact of courtyard design on energy use. According to the previous studies, the energy performance of courtyard buildings varies depending on the local climate and microclimate[8].

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courtyard proportions, courtyard orientations[9-17], materials and surface albedo of the courtyard walls, and window to wall ratio (WWR) are the most efficient parameters that affect both thermal performance and energy efficiency in these buildings.

Muhaisen[18] found that courtyard form proportions have a significant impact on the shading of the internal courtyard. Furthermore, his study highlights the differences in the courtyard's daily shade and exposure performances as a result of changing the site latitude and, thus, the sun's position in the sky. Another study that focuses on the courtyard proportions has been conducted by Manioğlu et al[19]. Their findings revealed that the width/length ratio has a substantial effect on energy consumption and that the proportion's influence on energy performance in cold season was more efficient than in summertime in Turkey's hot–dry region. Another study on courtyard proportions discovered that a small courtyard could improve airflow and release heat at night[20].

Abdallah et al[21] compare the thermal performance of courtyards with different widths and ratios, as well as their impact on the overlook space in university buildings. During the hot season, they discovered that courtyards with a H/W ratio of (1.2) provided better thermal comfort for students than courtyards with a H/W ratio of (0.7). It also increases the thermal performance of overlooking spaces on studied courtyards.

Both aspect ratio and courtyard orientation were investigated since they are the most influential parameters that influence the energy usage for cooling and heating in buildings. It was discovered that aspect ratios less than 1 are not appropriate unless they have sun shading parts in the central area of the courtyard. Furthermore, thermal conditions are better on the east side of the N-S and E-W courtyards in the morning and on the west side in the afternoon[22]. Another study was performed in the traditional Iranian courtyards considering both courtyard proportions and orientations. This study relied on a field investigation that was conducted to examine the design characteristics of six notable traditional courtyard housing in two ancient cities in Iran. The findings revealed that the majority of the Iranian courtyards surveyed were specifically constructed to allow orientation, dimension, and proportion to work as microclimate modifiers[23].

Window to wall ratio (WWR) has a significant impact on the thermal performance of the exterior walls[24]. However, there is a few studies that deal with the effect of this parameter on the thermal performance of the courtyard envelope. For instance, Tabesh et al[25] explored the effect of using different types of materials on the thermal performance and energy efficiency of a courtyard envelope in the adjacent spaces considering different window to wall ratios. It was discovered that the window-to-wall ratios of courtyard envelopes have a considerable impact on total energy conservation and should be thoroughly discussed with the material of the courtyard envelope. Another study was conducted to investigate how using an atrium and a courtyard might improve a building's energy performance when different WWR values are used. WWR ratios have a considerable impact on the total energy usage of a courtyard building, according to the conclusions of this study. The findings of this study demonstrated that replacing glazing types with more energy-efficient glazing could reduce energy consumption in buildings across all tested Window to wall ratios[15]. Due to the lack of intensive studies on the effect of WWR on the thermal performance of the courtyard envelope, as well as the necessity to obtain quantitative data for achieving optimum courtyard envelope characteristics in terms of energy efficiency in buildings.

2 Martial and Methods

Prior studies have shown that the amount of energy required for cooling is significantly affected by heat transfer across the envelope of the courtyard, mainly via the courtyard windows [26, 27]. This study examined the impacts of varied courtyard envelope parameters on the cooling energy demand of an administrative building in the city of Aswan, which has a hot, dry environment.

2.1 Study Area and Climatic Properties

This study was conducted in New Aswan city, which is located north of the current city of Aswan on the west bank of the Nile. New Aswan is located in the north latitude 24° in Egypt's hot desert region according to the region’s classification of Housing and Building Research Centre (HBRC)[28]. As a result, summer seasons are extremely hot, with temperatures exceeding 40 °C, resulting in increased energy usage for cooling. While the lowest air temperature is below 5 °C[29]. **Table 1** presents the main climatic conditions of New Aswan city.

Table 1. Climatic conditions of New Aswan city, source: Aswan University meteorological station (Hobo U30).

Climatic elements	characteristics
Climatic zone	Southern Egypt zone
Recorded high	51 °C

temperature	
Recorded low temperature	2.4 °C
Precipitation range per month	0 - 0.25 mm

2.2 Geometrical characteristics of a building model

Most cities in hot desert areas adopt horizontal buildings with an inner courtyard. The administrative buildings were recently built in the same style. To determine the main features of New Aswan administrative buildings, a survey of the city regulations was conducted to determine the proportion of construction for the administrative buildings in New Aswan city.

According to the findings, the inner courtyard takes approximately 20% of the entire land space assigned for these administrative buildings. In this regard, this research looks at two different building models with various courtyard width to length ratios. On the other hand, the two models have the same area for both the total area and the courtyard area.

The first model, R1, has a courtyard with a width-to-length ratio of 0.5, while the second model, R2, has the following attributes (width-to-length ratio = 1). The total area of each model is about 3600 m^2. And each courtyard accounts for 20% of the total area. The studied building models have a height of 4 m, and they have the same characteristics for outer building envelope in terms of both walls and glazing characteristics. The main geometrical attributes for the studied models were presented in **Fig 1**.

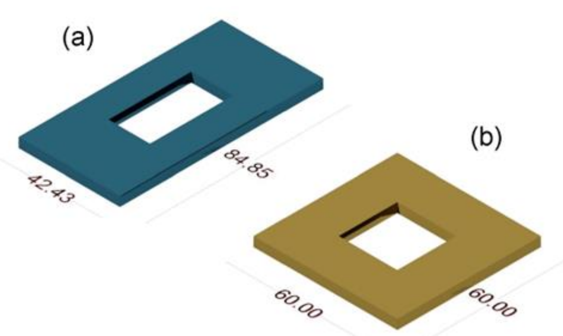


Figure 1. Building models: a) R1 model b) R2 model. (Unit: m), Height=4m.

2.3. Studied Parameters

This study examines the effect of the courtyard envelope on cooling energy consumption. The study highlights the window-to-wall ratio (WWR), surface albedo, and building orientations as the dependent variables of the courtyard envelope that influence the cooling energy requirement. Additional elements like glazing types, texture, and insulation materials were excluded from the research. In this instance, the courtyard ratio (R1) was evaluated in four orientations (0°N, 45°N, 90°N, and 135°N) with two window-to-wall ratios (10%, and 20%) and four surface albedo values (0.2, 0.4, 0.6, and 0.8). while the courtyard ratio (R2) was evaluated under the same circumstances, considering that building orientations 0°N and 90°N provide identical results, while 45°N and 135°N yield identical results, this is due to their same dimensions and properties. **Fig 2** depicts the simulation matrix for the explored parameters.

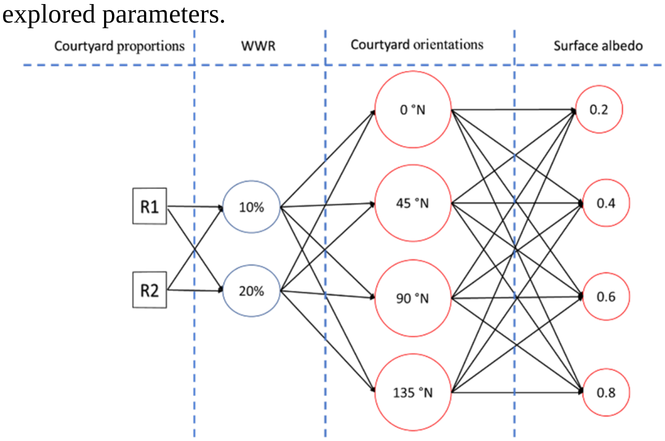


Figure 2. The simulation matrix for the studied parameters

2.4. Simulation Procedures

The research employs Design Builder software to investigate the impact of many parameters representing the most successful courtyard envelops characteristics. Design Builder uses a Genetic Algorithm (GA) (aka Evolutionary Algorithm or EA) based on the NSGA2 method. The simulation was run using real-meteorological data for New Aswan city in 2021.

The weather data file was obtained from Aswan University's weather station (Hobo U30) as a Comma Separated Value file (CSV), and it was then transformed from CSV format to EnergyPlus Weather data EPW file format to meet the needed format of the input weather file in the simulation software Design builder[30-32].

The weather file acquired contains meteorological data for each hour in the year 2021. After the preparation of the building models, the required input data such as activities, construction, and opening have been provided to the simulation software. For example, the occupancy schedule in New Aswan city has been set in accordance with the specified work hours, taking into account the week holidays on Fridays and Saturdays. The construction, and openings properties have been presented in **Table 2**. The simulation has been conducted to determine the annual energy usage of the HVAC system.

Table 2. Characteristics of the walls and windows.

Input data	Wall and window layers	properties
Construction	20 mm Cement Plaster + 250 mm Brick + 20mm Cement Plaster	U-Value (W/m K)^2 = 1.691
Opening	6 mm Clear glass	Solar heat gain coefficient (SHGC)= 0.819 U-Value (W/m K)^2= 5.778 Visible light transmittance= 0.881

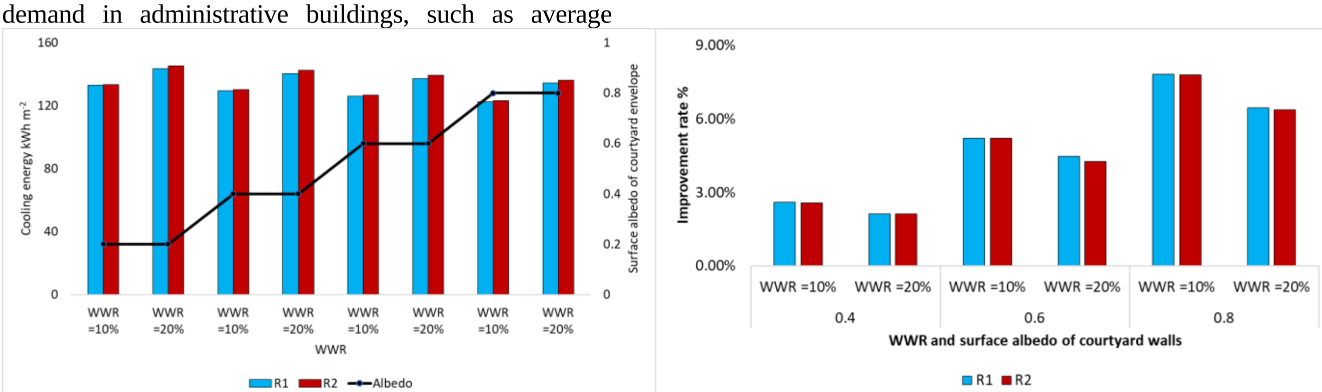
3. RESULTS AND DISCUSSION

Using the two-building ratios R1 and R2, an investigation was done to figure out how much energy would be needed to cool an office building in the city of New Aswan. This analysis took into consideration several criteria, such as the window-to-wall ratio (WWR), the surface albedo of the courtyard envelope, and the orientation of the courtyard. Additional aspects have been taken into consideration as potential constraints on the research. These aspects include the types of glazing, wall insulation for the courtyard envelope, and wall texture.

Different indices are often used to determine energy demand in administrative buildings, such as average annual energy consumption per unit of area, average annual energy consumption per capita, and carbon emission per capita[31, 33]. This study adopted average annual energy consumption per unit of area to measure the energy required in the studied administrative buildings. The following statistics show how surface albedo and WWR affect annual cooling energy demand for the suggested courtyard models in the following orientations.

3.1. The effect of courtyard orientation (0 °N)

The effects of WWR and surface albedo on the annual energy required for cooling in a courtyard with a 0°N orientations were investigated. In all analyzed courtyard envelopes, courtyard envelopes with WWR = 10% are more efficient than courtyard envelopes with WWR = 20%. More specifically, the results reveal that the most efficient characteristics for the courtyard envelope in this orientation occur when WWR = (10%) and surface albedo for the courtyard envelope = (0.8). According to the simulation results, when WWR = 10%, R1 registered 122.67 kWh m^{-2}, whereas R2 registered 123.1 kWh m^{-2}. In the case of WWR = 20%, R1 registered 134.29 kWh m^{-2}, and R2 registered 137.20 kWh m^{-2}. Furthermore, R1 appears to be better than R2 across the entire surface albedo for the court envelope evaluated exclusively in this orientation. Surface albedo = 0.2 appears to have the highest values among all studied models. As a result, it was taken as a reference to compare other results with it. R1 improvement rates in the case of WWR = 10% are 2.59%, 5.21%, and 7.81% for the surface albedo of 0.4, 0.6, and 0.8, respectively. while the improvement rates for R1 in the case of WWR = 20% are 2.13%, 4.47%, and 6.44 for the surface albedo of 0.4, 0.6, and 0.8, respectively. In all evaluated WWR percentages, R2 had nearly identical percentages to R1's improvement rates. The results of all courtyard models investigated in the 0 °N orientation is shown in **Fig 3**.

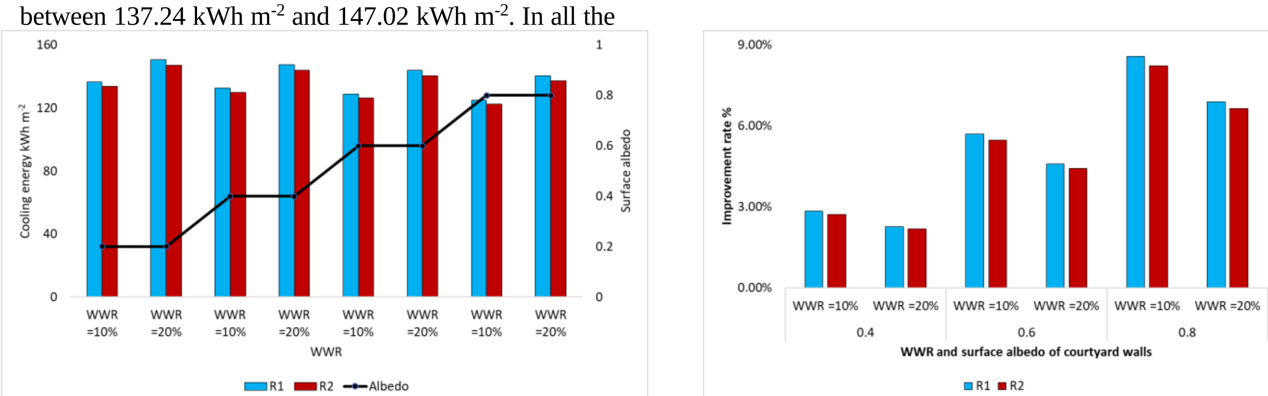


a) b)

Figure 3. Simulation results for the courtyard orientation (0 °N): a) annual energy demand for cooling b) annual energy saving.

3.2. The effect of courtyard orientation (45 °N)

The energy required for cooling of the analyzed courtyard models is higher in this orientation than in the previously illustrated courtyard orientation of 0 °N. For WWR= 10%, the energy required to cool R1 has been calculated to be between 124.77 kWh m^{-2} and 136.45 kWh m^{-2}. While the energy demand for cooling R2 has been calculated to be between 122.61 kWh m^{-2} and 133.59 kWh m^{-2} for the WWR= 10%. The results of R1 with WWR= 20% show that the energy required for cooling ranges between 140.33 kWh m^{-2} and 150.73 kWh m^{-2}. While the results of R2 with WWR= 20% show that the energy required for cooling ranges between 137.24 kWh m^{-2} and 147.02 kWh m^{-2}. In all the analyzed examples, increasing the value of surface albedo for the courtyard envelope was found to be responsible for lowering the energy required for cooling in the studied buildings. The improvement rates for the R1 models in this orientation in case of WWR= 10% are 2.84%, 5.70%, and 8.56% for the surface albedo 0.4, 0.6, and 0.8 respectively. In the case of WWR=20%, the improvement rates for R1 are 2.27%, 4.58%, and 6.9% for the surface albedo 0.4, 0.6, and 0.8 respectively. R2 improvement rates varied slightly from R1. It was between 2.72% and 8.22% for WWR=10% and between 2.19% and 6.65% for WWR=20 %. **Fig 4** shows the results of courtyard models in the 45 °N orientation.

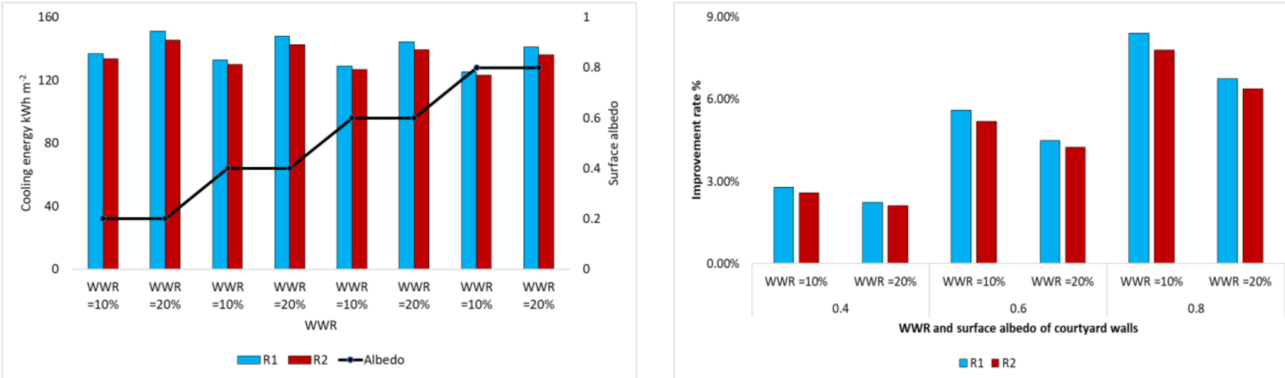


a) b)

Figure 4. Simulation results for the courtyard orientation (45 °N): a) annual energy demand for cooling b) annual energy saving.

3.3. The effect of courtyard orientation (90 °N)

The results of R2 in this courtyard orientation are similar to the same ratio in the 0 °N courtyard orientation. This is due to the fact that they have the same length and width measurements. On the contrary, R1 values are higher than those obtained from the 0 °N courtyard orientation. R1 outcomes are the worst of all tested courtyard orientations. The reported R1 values for WWR=10 % are 136.63 kWh m^{-2}, 132.83 kWh m^{-2}, 128.97 kWh m^{-2}, and 125.13 kWh m^{-2} for the examined courtyard surface albedo of 0.2, 0.4, 0.6, and 0.8, respectively. Based on the preceding findings, it is concluded that, in terms of thermal performance and energy consumption, the courtyard with the largest axis in the north-south direction is the worst option for buildings, particularly when working hours extend till the last hours of the day. Where it permits direct radiation to reach the maximum area of the inner courtyard envelope, increasing heat stress on the courtyard's inner façade and, as a result, increasing energy usage for cooling purposes. Regardless of the inefficiency of this courtyard orientation, when comparing the results of all analyzed models in this courtyard orientation to the case of surface albedo (0.2), both tested WWE percentages showed an inconsiderable improvement. For instance, in the case of WWR=10%, the improvement rates for the R1 ranged from 2.78% to 8.41%. While the WWR=20% varied between 2.23% and 6.76%. **Fig 5** depicts the annual energy required for each model as well as the rate of improvement.

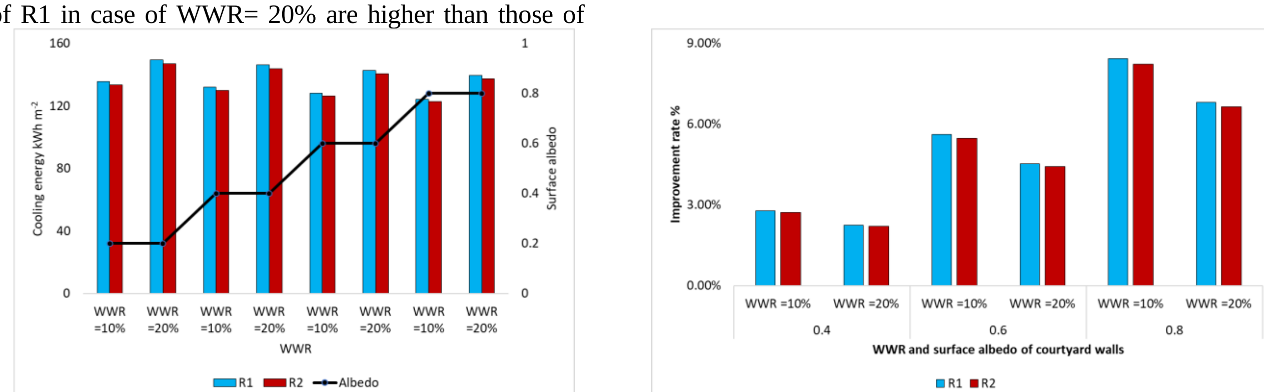


a) b)

Figure 5. Simulation results for the courtyard orientation (90 °N): a) annual energy demand for cooling, b) annual energy saving.

3.4. The effect of courtyard orientation (135 °N)

The results of R2 in this courtyard orientation are consistent with the results of R2 in the previous courtyard orientation 45 °N for the same reasons that were provided in the previous courtyard orientation 90 °N. While R1 outcomes in this orientation are regarded the second most successful option among the tested courtyard orientations. For example, if WWR= 10%, energy demand for cooling in case of R1 are 135.72 kWh m^{-2}, 131.94 kWh m^{-2}, 128.10 kWh m^{-2}, and 124.29 kWh m^{-2} for surface albedo of courtyard envelopes of 0.2, 0.4, 0.6, and 0.8, respectively. Results of R1 in case of WWR= 20% are higher than those of WWR= 10%. However, these results are considerable outcomes compared to the same WWR values in the other studied courtyard orientations. The registered results of R1 in case of WWR= 20% are 149.52 kWh m-2, 146.15 kWh m^{-2}, 142.75 kWh m^{-2}, and 139.35 kWh m^{-2} for the following surface albedo of courtyard envelope 0.2, 0.4, 0.6, and 0.8 respectively. R2 results are slightly less efficient compared to R1. The improvement rates were ranged between 2.58% and 7.8% for the WWR=10%. While it was ranged between 2.11% and 6.38% for the WWR= 20%. The study outcomes in this orientation have been plotted and presented in **Fig 6**.



a) b)

Figure 6. Simulation results for the courtyard orientation (135 °N): a) annual energy demand for cooling b) annual energy saving.

Table 3 presents the energy needed for cooling considering WWR= 10%. The findings are summarized as follows:

- Increasing the surface albedo could decrease the energy needed for cooling in all models.
- R1 is mildly better than R2 in terms of energy required for cooling in 0 °N orientation. While when excluding 0 °N orientation, R2 has the ability to minimize cooling energy consumption more than R1.
- The best option among allover studied models in terms of WWR=10% is R2 with surface albedo (0.8) and courtyard orientation 45 °N or 135 °N.

Table 3. The energy required for cooling (kWh m^{-2}) in case of WWR= 10%.

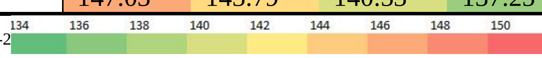
Courtyard orientations	0 °N				
Surface albedo	0.2	0.4	0.6	0.8	
	133.07	129.63	126.14	122.68	R1
	133.52	130.07	126.58	123.11	R2
Courtyard orientations	45 °N				
Surface albedo	0.2	0.4	0.6	0.8	
	136.46	132.59	128.67	124.77	R1
	133.60	129.96	126.28	122.61	R2
Courtyard orientations	90 °N				
Surface albedo	0.2	0.4	0.6	0.8	
	136.63	132.83	128.97	125.13	R1
	133.52	130.07	126.58	123.11	R2
Courtyard orientations	135 °N				
Surface albedo	0.2	0.4	0.6	0.8	
	135.73	131.94	128.11	124.29	R1
	133.60	129.96	126.28	122.61	R2

kWh m^{-2}


The findings of the simulation process in terms of energy required for cooling in the case WWR=20 % follow the same trend as the results obtained for WWR=10 %. However, the energy required for cooling is less efficient when WWR=20% than when WWR=10%. Table 4 displays all obtained results for WWR=20 %.

Table 4. The energy required for cooling (kWh m^{-2}) in case of WWR= 20%.

Courtyard orientations	0 °N				
Surface albedo	0.2	0.4	0.6	0.8	
	143.54	140.49	137.12	134.30	R1
	145.49	142.42	139.31	136.21	R2
Courtyard orientations	45 °N				
Surface albedo	0.2	0.4	0.6	0.8	
	150.73	147.30	143.82	140.34	R1
	147.03	143.80	140.53	137.25	R2
Courtyard orientations	90 °N				
Surface albedo	0.2	0.4	0.6	0.8	
	151.29	147.91	144.48	141.07	R1
	145.49	142.42	139.31	136.21	R2
Courtyard orientations	135 °N				
Surface albedo	0.2	0.4	0.6	0.8	
	149.52	146.15	142.76	139.36	R1
	147.03	143.79	140.53	137.25	R2

kWh m^{-2}


It was discovered that courtyard R1 is slightly better than R2 in the 0 °N orientation. This is due to the courtyard's east-west axis, which results in a narrow courtyard width in the north-south direction. Considering both the movement of the sun in the sky of New Aswan city and the aspect ratio of this courtyard (width/height), the amount of shading in this courtyard is substantially more than in courtyards with a north-south axis. As a result, the heat stress on the interior spaces overlooking the courtyard is reduced, increasing the building's energy efficiency. This efficiency could be improved gradually by increasing the courtyard height. On the other side, in all other courtyard orientations, the courtyard model R2 is more effective than the R1 due to the lack of direct solar radiation reaching the inside facades of the courtyard in this case. Therefore, after comparing R2 with R1, the improvement rates of R2 among all courtyard orientations were analyzed and presented in Fig 6. Even though R2 shows the same results in both 0 °N and 90 °N, the findings indicate that R2 efficiency has been significantly improved in this courtyard orientation when compared to R1. This could be ascribed to R1's poor performance in the 90 °N orientation when compared to R2.

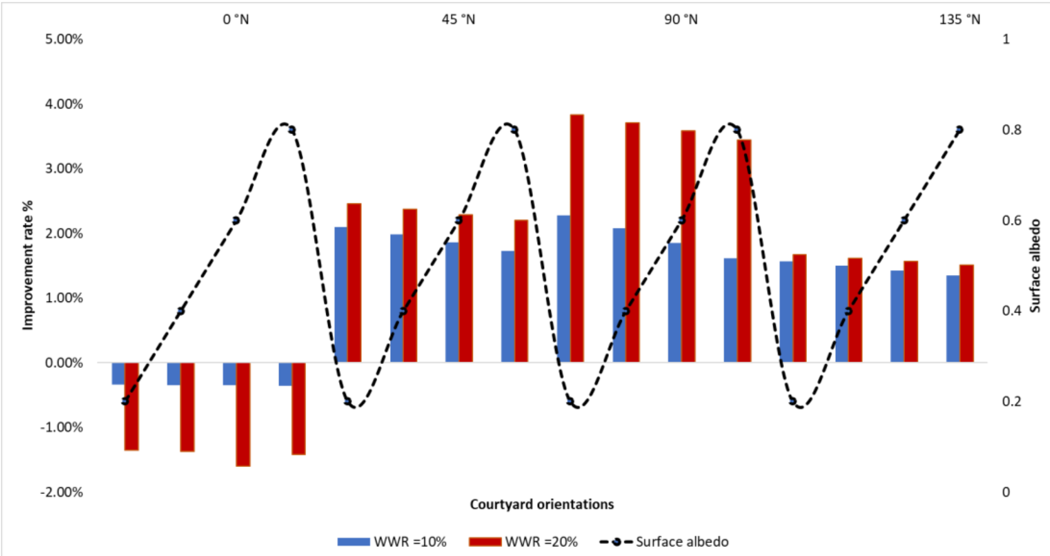


Figure 6. The improvement rates of R2 model considering the characteristics of courtyard envelope.

In general, the surface albedo of the courtyard walls contributes the greatest amount of energy savings in the studied models. It has the potential to save more than 7.8% and 5.69% of the annual energy required for cooling, respectively, for WWR=10% and WWR=20%. Using surface albedo for the courtyard envelope (0.8) resulted in a considerable improvement for WWR=10%. WWR (10%) could also save 8.65%, 11.09%, 11.29%, and 10.28% for R1 in the following orientations: 0 °N, 45 °N, 90 °N, and 135 °N. While R2 with the same WWR (10%) may save 9.62% in the 0 °N and 90 °N orientations and 10.67% in the 45 °N and 135 °N orientations.

The courtyard proportions, on the other hand, such as the width to length ratio and the aspect ratio, have little effect on the energy consumption for cooling. It can be concluded that both the surface albedo and the WWR of the courtyard are the primary drivers of energy savings in the analyzed buildings. As a result, the results clearly indicate that the parameters with direct impacts on the energy required for cooling in buildings, such as surface albedo and WWR, are more effective than the parameters with indirect effects on the energy required for cooling, such as courtyard proportions.

4. CONCLUSIONS

The impacts of numerous courtyard envelope parameters on the annual energy required for cooling in New Aswan city are investigated in this paper. Two types of courtyards have been studied in this regard. The first courtyard R1 has a length-to-width ratio (0.5), whereas the second courtyard R2 has a length-to-width ratio (1). The proposed courtyards were studied with many courtyard walls parameters such as window to wall ratio WWR, courtyard orientations, and surface albedo of the courtyard walls. The results of this study show that the optimal courtyard walls characteristics in terms of annual energy demand for cooling occur in the 0°N orientation for the courtyard model R1 and the courtyard walls have the following characteristics (WWR=10%, surface albedo for courtyard walls= 0.8). The study concludes that the courtyard's WWR and surface albedo have a significant impact on the energy required for cooling in the analyzed courtyards. As a result, the courtyard envelopes in the studied models could conserve more energy than its geometrical properties such as width to length ratio, aspect ratio, and courtyard orientations. In the future, additional studies might be conducted to evaluate other characteristics of the courtyard envelope, such as glazing types and insulation materials. Furthermore, the study could look into these parameters in other Egyptian climate zones.

REFERENCES

[1] M. Morsy, M. Fahmy, H. Abd Elshakour, and A. Belal, "Effect of thermal insulation on building thermal comfort and energy consumption in Egypt," *Journal of Advanced Research in Applied Mechanics*, vol. 43, no. 1, pp. 8-19, 2018.

[2] A. R. Mahmoud, "The Influence of Buildings Proportions and Orientations on Energy Demand for Cooling in Hot Arid Climate," *SVU-International Journal of Engineering Sciences and Applications*, vol. 3, no. 1, pp. 8-20, 2022.

[3] A. Abd Elrady and M. Hassan, "Conservation of morphological characters as an approach to

thermal comfort," *Signals and Systems: A Primer with MATLAB®*, p. 15, 2015.

[4] D. Tarek, M. El-Naggar, H. Sameh, A. Yousef, and A. Ragab, "Energy Efficiency Coupled with Lightweight Bricks: Towards Sustainable Building: A review," vol. 4, no. 1, pp. 1-28, 2023.

[5] M. Bulus, M. Hamid, and Y. W. Lim, "Microclimatic Performance of Courtyards in Residential Buildings in Kafanchan-Nigeria," *International Journal of Built Environment and Sustainability*, vol. 4, no. 3, 2017.

[6] H. Mahmoud and A. Ragab, "Thermal Performance Evaluation of Unshaded Courtyards in Egyptian Arid Regions," *Smart and Sustainable Planning for Cities and Regions: Results of SSPCR 2019*, p. 109, 2021.

[7] E. Yaşa and V. Ok, "Evaluation of the effects of courtyard building shapes on solar heat gains and energy efficiency according to different climatic regions," *Energy and Buildings*, vol. 73, pp. 192-199, 2014.

[8] C. He, W. Tian, and Z. Shao, "Impacts of Courtyard Envelope Design on Energy Performance in the Hot Summer–Cold Winter Region of China," *Buildings*, vol. 12, no. 2, p. 173, 2022.

[9] O. Al-Hafith, B. Satish, S. Bradbury, and P. De Wilde, "The Impact of Courtyard parameters on its shading level An experimental study in Baghdad, Iraq," *Energy Procedia*, vol. 134, pp. 99-109, 2017.

[10] A. Almhafdy, N. Ibrahim, S. S. Ahmad, and J. Yahya, "Analysis of the courtyard functions and its design variants in the Malaysian hospitals," *Procedia-Social and Behavioral Sciences*, vol. 105, pp. 171-182, 2013.

[11] H. Bagheri Sabzevar, M. Masoomi, and S. Tarzafan, "Dormitory Courtyard Proportion and Orientation in Yazd/Iran on Energy Consumption," *Iran University of Science & Technology*, vol. 27, no. 2, pp. 75-81, 2017.

[12] S. Berkovic, A. Yezioro, and A. Bitan, "Study of thermal comfort in courtyards in a hot arid climate," *Solar Energy*, vol. 86, no. 5, pp. 1173-1186, 2012.

[13] M. A. Cantón, C. Ganem, G. Barea, and J. F. Llano, "Courtyards as a passive strategy in semi dry areas. Assessment of summer energy and thermal conditions in a refurbished school building," *Renewable energy*, vol. 69, pp. 437-446, 2014.

[14] F. Soflaei, M. Shokouhian, and S. M. M. Shemirani, "Investigation of Iranian traditional courtyard as passive cooling strategy (a field study on BS climate)," *International Journal of Sustainable Built Environment*, vol. 5, no. 1, pp. 99-113, 2016.

[15] T. Tabesh and B. Sertyesilisik, "An investigation into energy performance with the integrated usage of a courtyard and atrium," *Buildings*, vol. 6, no. 2, p. 21, 2016.

[16] M. Taleghani, M. Tenpierik, and A. van den Dobbelsteen, "Indoor thermal comfort in urban courtyard block dwellings in the Netherlands," *Building and Environment*, vol. 82, pp. 566-579, 2014.

[17] Z. Zamani, S. Heidari, and P. Hanachi, "Reviewing the thermal and microclimatic function of courtyards," *Renewable and Sustainable Energy Reviews*, vol. 93, pp. 580-595, 2018.

[18] A. S. Muhaisen, "Shading simulation of the courtyard form in different climatic regions," *Building and Environment*, vol. 41, no. 12, pp. 1731-1741, 2006.

[19] G. Manioğlu and G. K. Oral, "Effect of courtyard shape factor on heating and cooling energy loads in hot-dry climatic zone," *Energy Procedia*, vol. 78, pp. 2100-2105, 2015.

[20] T. Kubota and D. H. C. Toe, "Application of passive cooling techniques in vernacular houses to modern urban houses: A case study of Malaysia," *Procedia-Social and Behavioral Sciences*, vol. 179, pp. 29-39, 2015.

[21] A. S. H. Abdallah, D. A. Mohammad, and A.-M. M. Ali, "The influence of different courtyard ratios in university buildings on their thermal performance during the hot period:(Faculties of Agriculture and Education, New Sohag University, Egypt as a case study)," in *IOP Conference Series: Earth and Environmental Science*, 2019, vol. 397, no. 1, p. 012019: IOP Publishing.

[22] J. Rodríguez-Algeciras, A. Tablada, M. Chaos-Yeras, G. De la Paz, and A. Matzarakis, "Influence of aspect ratio and orientation on large courtyard thermal conditions in the historical centre of Camagüey-Cuba," *Renewable energy*, vol. 125, pp. 840-856, 2018.

[23] F. Soflaei, M. Shokouhian, and S. M. M. Shemirani, "Traditional Iranian courtyards as microclimate modifiers by considering orientation, dimensions, and proportions," *Frontiers of Architectural Research*, vol. 5, no. 2, pp. 225-238, 2016.

[24] A. R. Mahmoud, "Investigating the Impact of Different Glazing Types on the Energy Performance in Hot Arid Climate," *Journal of Advanced Engineering Trends*, vol. 42, no. 1, pp. 69-84, 2022.

[25] T. Tabesh and B. Sertyesilisik, "An Investigation into the Thermal Behavior of Courtyards," *American Transactions on*

Engineering & Applied Sciences, 2014.

[26] D. Tarek *et al.*, "Building Envelope Optimization Using Geopolymer Bricks to Improve the Energy Efficiency of Residential Buildings in Hot Arid Regions," p. e01657, 2022.

[27] A. M. Aly, M. H. Hassn, Y. R. Abdel Rady, and A. T. Mohammed, "The effect of using nano-materials in external openings on energy consumption in hot desert climate," *JES. Journal of Engineering Sciences*, vol. 48, no. 3, pp. 468-477, 2020.

[28] A. Ragab and A. Abdelrady, "Impact of green roofs on energy demand for cooling in Egyptian buildings," *Sustainability*, vol. 12, no. 14, p. 5729, 2020.

[29] R. Buizza, J. Barkmeijer, T. Palmer, and D. Richardson, "Current status and future developments of the ECMWF Ensemble Prediction System," *Meteorological Applications*, vol. 7, no. 2, pp. 163-175, 2000.

[30] A. Abdelrady, M. H. H. Abdelhafez, and A. Ragab, "Use of insulation based on nanomaterials to improve energy efficiency of residential buildings in a hot desert climate," *Sustainability*, vol. 13, no. 9, p. 5266, 2021.

[31] H. Mahmoud and A. Ragab, "Urban geometry optimization to mitigate climate change: Towards energy-efficient buildings," *Sustainability*, vol. 13, no. 1, p. 27, 2020.

[32] A. Ragab Abdel Radi, "The impact of phase change materials on the buildings enegy efficiency in the hot desert areas the annexed rooms of the traffic building in new aswan city as a case study," *JES. Journal of Engineering Sciences*, vol. 48, no. 2, pp. 302-316, 2020.

[33] Y. Ma, M. Lu, and J. Weng, "Energy consumption status and characteristics analysis of university campus buildings," in *5th International Conference on Civil Engineering and Transportation*, 2015, pp. 1240-1243: Atlantis Press.