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GREEN RESIDENTIAL DISTRICTS IN HOT DESERT CLIMATE TOWARDS LOW ENERGY CONSUMPTION

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ABSTRACT

The climate of Aswan City is characterized by a hot desert climate. So, the indoor temperature exceeds the thermal comfort through the over-heated period. With this hostile environment, the outdoor spaces suffer from negligence concerning the climatic design. The simulation study, using Autodesk CFD 2016, consists of two models. The first model depends on the current situation of AlSil district in Aswan, while the second model is the modified one. The boundary conditions are placed according to the weather conditions in Aswan City. Then the cooling load was calculated, using the residential heating and cooling load calculation spreadsheet to indicate the efficiency of the energy consumption in a multi-story residential building. The simulation results of the modified model show a significant decrease in the outdoor temperature by nearly 7°C, and the indoor temperature dropped from 4°C : 9°C. On the other hand, the cooling load was decreased by almost 17.7% : 22.5% according to the building floor site.

KEYWORDS: Green District, residential building, energy, Cooling load, Aswan City.

1. INTRODUCTION

The ongoing development in Egypt puts many pressure on the environment's capacity due to the lack of integrating environmental issues in planning and design processes. A report about "the housing study for urban Egypt" based on the survey data indicates that the building and neighborhood conditions in Upper Egypt are of lower standards than the norm. Cities in Upper Egypt have the highest portion of buildings deemed to be in slum areas (53 percent versus 41 percent nationally). They also have the narrowest streets, and only 18 percent of streets are paved in good condition compared to the national average of 31 percent [1].

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On the other hand, it can be argued that at an urban scale, the residential districts are today in severe conditions regarding sustainability, energy efficiency and thus the modern housing and living. The quality of life in these districts, especially the low-income areas, is in constant decline. So, these districts need to upgrade through a concept, which provides a more modern and environmentally sustainable lifestyle for their residents.

There are a few studies on thermal comfort in urban spaces, where concerning planning, studies directly focusing on the consequences of urban design strategies on comfort are dramatically lacking [2].

However, some recent studies for a limited range of urban spaces have been presented [3-5]. Also the human comfort in historic urban spaces was investigated, [6] while the thermal impact of vegetation in the urban environment was identified [7]. Also, some studies seek to achieve a better understanding of the richness of microclimatic characteristics in urban outdoor spaces and the comfort implications for the people using them [8].

Regarding Egypt, some research investigated the microclimatic thermal behavior of hybrid traditional and modern street canyon types of urban form in Cairo, to set an urban planning tool for passive cooling [9]. The measurements were reported as well as the analysis of an experimental campaign performed in different urban streets in Aswan; this study focused on the experimental investigation of thermal characteristics during summer 2012 of five different regions location [10]. Other research investigated how urban form can be designed to act as a passive thermal comfort system in Cairo [11].

In other research, some questions were addressed about the energy conservation potential of urban forests. What is their potential to improve environmental quality and conserve energy? Are trees cost-effective compared to other energy conservation measures? How does the structure of energy efficient landscapes change within a city and across climatic regions؟ This study was conducted on single-family residences [12].

On the other hand, the sustainable residential districts are often considered from a predominantly green perspective. It is only through sustainable solutions that the tensions between residential areas and environmental conditions can be mitigated. Well-designed and inclusive sustainable residential districts have much to offer to this end [13].

The previous review indicates the need for more focus on measuring the effects of green landscape on the reduction of the cooling load in the multi-story residential buildings. So, this research considers a holistic concept to upgrade the residential districts regarding green and sustainable design; this concept seeks to enhance and harmonize the environmental dimensions of the residential district's sustainability. Therefore, indoor thermal comfort can be improved, and examine the upgrading effects on the cooling loads of a multi-story residential building, so that the reduction of the energy consumption can be measured.

2. PROBLEM STATEMENT

Site and Location have an impact on the temperature difference between indoor and outdoor spaces, where Boonyatikarn indicated that the reduction of the temperature difference between the interior and exterior of the home is a core housing design principle almost anywhere in the world [14].

On the other hand, regarding the energy reduction design concept, the cooling load of the building calculated by the simple equation as follows [15, 16]:

$$Q = U * A * \Delta T \tag{1}$$

Where Q = Cooling load (Heat transfer through the single material), U = U-value (Material), A = Building surface area (Building form), and ΔT = Temperature difference (Between outside and inside).

From previous equation, when the building already exists, so the building form, area، and materials are fixed, and one of the primary variables that can be changed is the temperature difference by landscaping the urban spaces surrounding the building.

Based on this perspective, this study investigates how to take advantages of reducing the temperature difference between interior and exterior spaces, and then measures the extent of the impact on the cooling load for the multi-story residential building.

3. OBJECTIVES AND METHODOLOGY

Green architecture aims to study how to design an energy-saving building with access to thermal comfort naturally. It is an intellectual, integrated, and intelligent system, which works toward the integration between nature and the building. This integration can be made after clarifying the mutual influences between the building and the site, and so, declare the effect of the outdoor space on the thermal performance of the building and thus energy consumption, which in turn indicates the green design quality and its efficiency.

This research focuses on the relationship between the outdoor spaces and the energy consumption. So, the key objective of the research is to clarify the impact of sustainable design and greening the urban outdoor spaces on the indoor air temperature. Moreover, to observe the effects on the energy consumption and its acceptability, by calculating the changes in the cooling load required in the different floors of a multi-story residential building connected with these urban spaces. Taking into consideration the climatic conditions in Aswan City, Egypt, this study aims to improve the thermal comfort of the inhabitants in indoor and outdoor spaces, also, to reduce the energy consumption in buildings.

To evaluate the performance of residential district climatic conditions, the Autodesk CFD 2016 simulation program was used to calculate the outdoor air temperature, and indoor air temperature, before and after applying the research concept. The simulation software was validated with field measurements, to obtain the accuracy degree of the program, and then verify the reliability of the results.

On the other hand, to calculate the required cooling load, the residential heating and cooling load calculation spreadsheets (Implemented by Dr. Steve Kavanaugh, which based on the 2001 ASHRAE Fundamentals Handbook) was used to calculate the cooling load on the ground floor and the last floor, to indicate the different effects of adapting the outdoor landscape on the various floors of the building.

4. GENERAL DESCRIPTION OF THE CURRENT SITUATION

4.1 Climatic Conditions

Aswan city is located at 24.1° North latitude and 32.9° East longitude, on the south of Nile Valley and surrounded by eastern and western deserts, so it is considered one of the typical examples of hot desert climate [17]. This climate is considered to be BWh according to the Köppen-Geiger climate classification. The average annual temperature is 26.8°C in Aswan, and about 1 mm of precipitation falls annually [18]. In such climate, the air temperature exceeds the thermal comfort through the overheated period during day and night. Table 1 shows average hourly outdoor dry bulb temperature through a day all over the year in Aswan (in the shade) according to (Climate Design Data 2009 ASHRAE Handbook), with referring to the overheated period.

Table 1. Average hourly statistics for dry bulb temperatures°C.

Hours	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2:00	12.8	13.2	18.1	24.5	27.7	29	30.5	30.1	28	24.9	18.9	13.6
4:00	11.7	12.2	17.4	23.1	26.1	27.4	29.5	28.7	26.7	23.7	17.5	12.6
6:00	11.5	11.3	16	22.3	24.8	25.8	28.3	27.8	25.4	22.6	16.4	11.7
8:00	11.6	11.8	17.6	23.3	27	29.1	30.2	29.3	27.4	22.9	17.2	12.5
10:00	13.3	14.1	20.6	26.1	30.4	32.2	34.1	33.2	30.3	27	20.1	15.8
12:00	17.6	18.3	24.7	30.6	33.9	36.7	37.8	37.2	34.9	31.3	24	20.1
14:00	20.9	20.3	27.3	32.2	36.4	39.1	40	39.9	38	33.7	26	22.1
16:00	20.9	20.9	28.4	32.8	36.4	39.7	40.3	40	38.8	34.8	26.4	22.8
18:00	21	20.9	27.7	32.6	36.4	39.5	40.5	39.9	38.1	33.7	26.4	21.4
20:00	18.5	18.7	24.9	30.1	33.5	36.6	37.8	37.1	34.9	30.4	24	18.9
22:00	16.5	16.6	22.4	28.1	31.2	34	35.2	34.3	32.2	28	22	16.9
24:00	14.6	14.6	20.3	26.4	29.3	31.4	32.6	31.8	29.8	26.2	20.4	15.2

The overheated period determined by using the adaptive comfort standard (ACS) which has been included as the adaptive comfort standard in the revision of ASHRAE Standard 55. The outdoor climatic environment for each building was characterized regarding mean outdoor dry bulb temperature $T_{a,out}$ instead of mean effective temperature ET. So, optimum comfort temperature T_{comf} was calculated based on mean $T_{a,out}$ as follow: [19]

$$T_{comf} = 0.31 \times T_{a,out} + 17.8 \text{ (deg C)} \quad (2)$$

By using the mean minimum and maximum dry bulb temperature in the previous equation (15.9°C, and 34.8°C respectively), the lower and upper limit of the thermal comfort will be equal to 22.7 °C and 28.6°C.

Givoni suggests an elevation of about 2°C more than the ASHRAE limit of the thermal comfort level, in the upper limit of acceptable conditions at still air, for people living in hot developing countries, considering the acclimatization resulting from living in un-air-conditioned buildings in a hot climate [20]. Therefore, the upper comfort limit will be equal to 30.6°C.

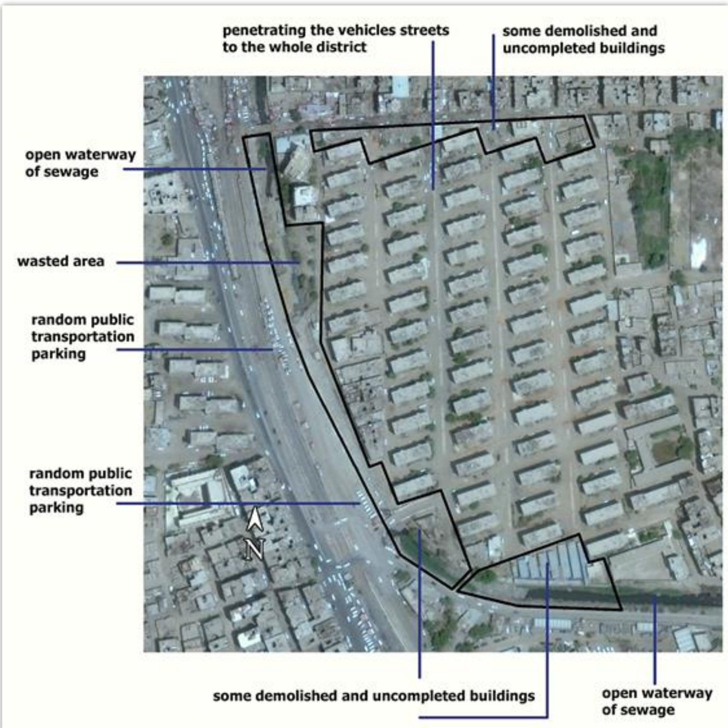
4.2 The Case Study (Alsil District)

For several decades, Egypt is experiencing a rising of the housing crisis. To fulfill the increasing demand for housing, many housing projects, especially for the low-income population, were constructed. Such a policy was adopted and applied since the 1950s, and still up to now with the first attention devoted to producing as many residential units as possible, with less care of units' quality. Consequently, these projects were characterized by their improper design in many cases and illegible featureless visual image. Thus, a wrong impression of these housing projects had widely grown [21].

The economic focus on initial cost reduction is the major factor that compromises the quality of the districts provided by governmental programs. They build housing clusters around undefined spaces that are too expensive to landscape or maintain. They do not realize that alternative layouts would create open spaces and streets about which residents would feel a sense of ownership and where they would invest time and money maintaining, cleaning, beautifying, and protecting it [22].

Previous problems were reflected on the current situation in the study area, where the case study is Alsil district in the south of Aswan City, which built in the seventies of the last century with nearly total area reach to 105,420m^2 (25.1 acres). The district consists of 61 residential buildings arranged in regular rows separated by the main streets which reach to 20 meters width, while the secondary streets reach 12 meters width. This district was selected because it is one of the typical low-income districts and was renovated without considering the climatic conditions. All buildings were organized in rows with the same orientation and exposed to the external environment from all directions.

As shown in Fig. 1, it is obvious to see many of the problems in the outdoor spaces, where, the district suffers from issues such as the absence of open spaces, and green areas, and the lack of trees except for a few scattered trees. As well as penetrating the vehicles streets to the whole district, which causes an increase in pollutants level and CO_2 as well, and there is a random public transportation parking.



A. General master plan for Alsil district (Google Earth)

B. Some shots for the district (the author)

Fig. 1. The current situation of Alsil District, Aswan City.

In addition to paving the entire district with the asphalt and the cement tiles for sidewalks surrounding the buildings, such materials have high reflectivity, and therefore, a significant portion of the incoming solar radiation is reflected, leading to increasing the air temperature. On the other hand, there are very high residential densities (more than 70,000 inhabitants), inadequate services, and there is a wasted area on the side of the district, in addition to the existence of some demolished and uncompleted buildings. All these problems in addition to a severe issue face the inhabitants, which is the presence of an open waterway of sewage, which leads to the spread of the insects and causing many diseases.

Despite the hostile climatic conditions in Aswan City, the construction method used in the building neglects these conditions, where the construction thicknesses and materials are considered as shown in Fig. 2.

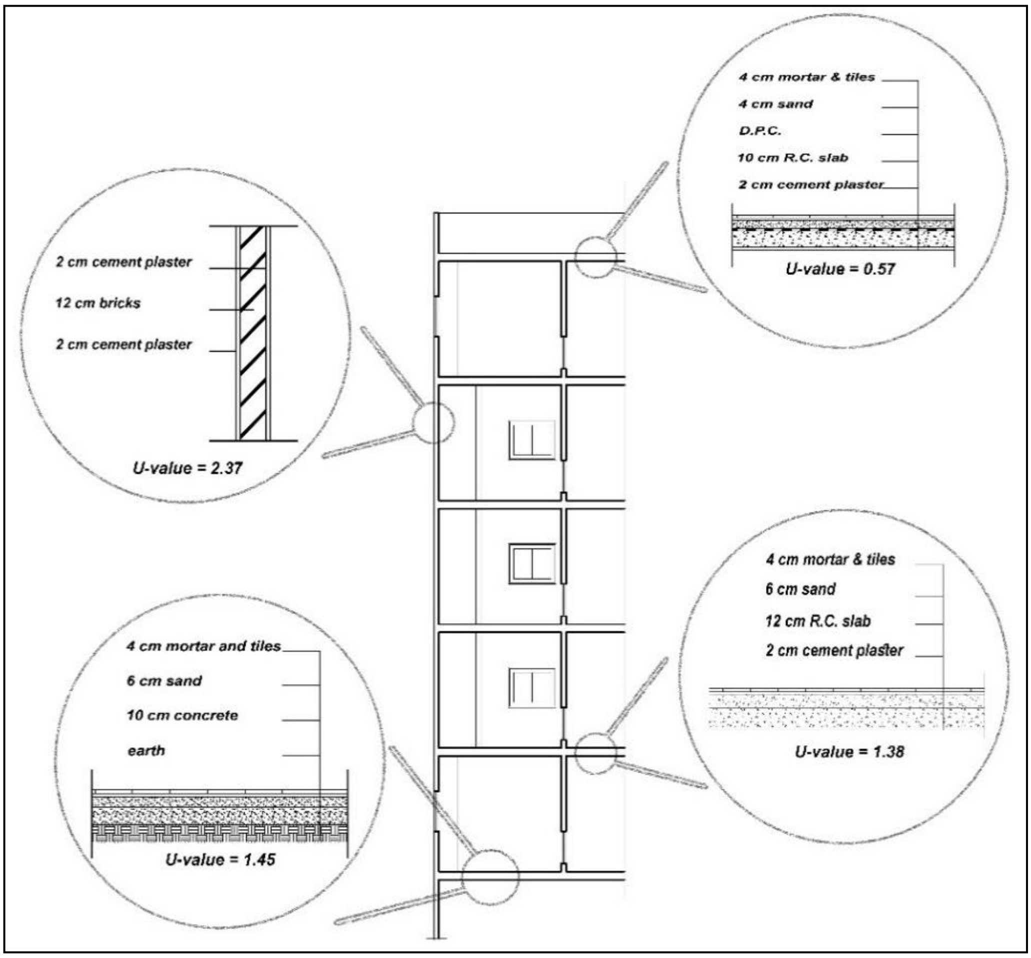


Fig. 2. The construction properties

5. THE FIELD STUDY

5.1. State of the difference between vegetative and non-vegetative landscape

To clarify the difference between the types of landscape, the field measurements for outdoor temperature were carried out at two different sites in Aswan, one of them away from any vegetation elements (non-vegetative landscape: asphalt paving and cement tiles for sidewalk). Moreover, the other location with green elements (vegetative landscape: grass ground and some trees). The measurements were performed through 8 hours during the period from 11:00 am to 18:00 pm for 11-14 July 2016, the time interval of the measuring device is 5 minutes, and then the hourly average was obtained.

The comparison between the two sites as shown in Fig. 3 during measurements period indicates that the air temperature in the site with vegetation elements recorded values less than the other site by more than 6°C.

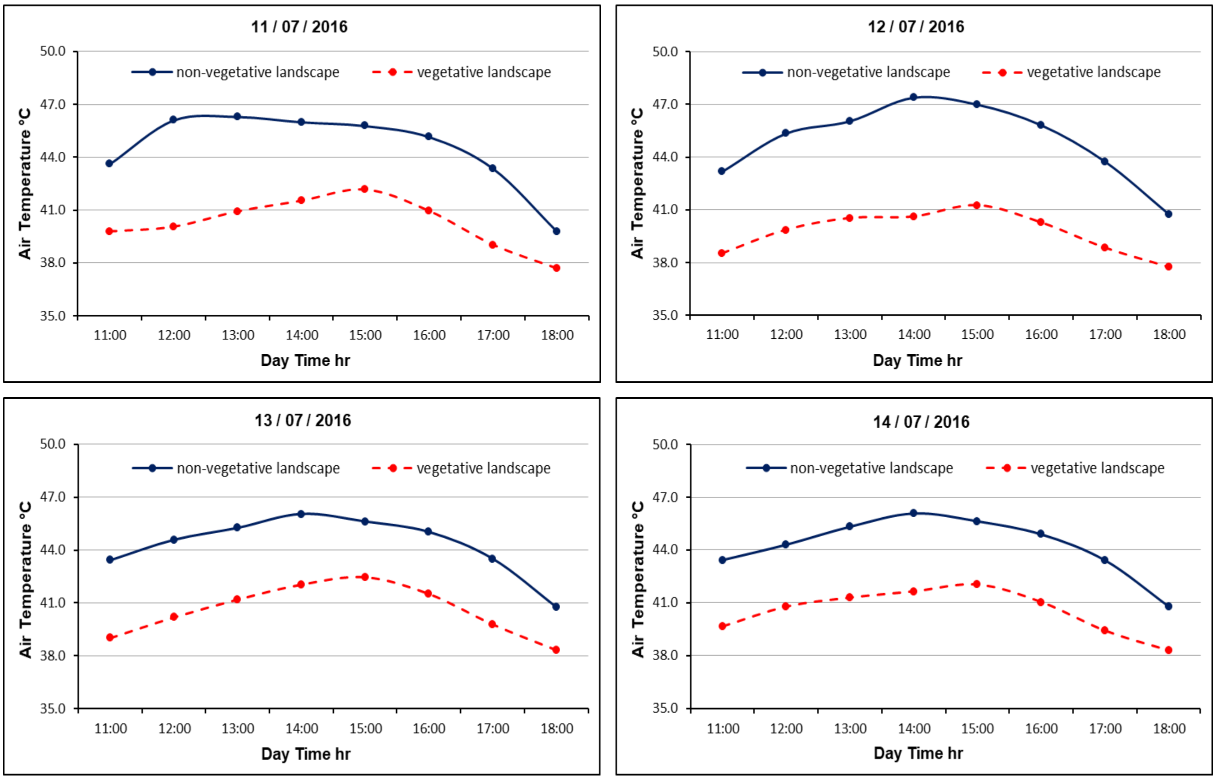


Fig. 3. The results of field measurements at two different sites in Aswan City.

5.2. Experimental validation for Autodesk CFD under the climate of Aswan city

To consolidate the results and achieve the better accuracy, the experimental validation for the simulation program carried out by comparing the simulation results with field measurements for the current situation. This validation carried out for the outdoor temperature in the climatic conditions of Aswan City. The technical specifications for the device which used in the measurements were specified in Table 2.

Table 2. Specifications for the measurements device.

Range	Temp: -20°C to 70°C, RH: 5% to 95%
Accuracy	Temp: ± 0.35°C from 0°C to 50°C RH: +/- 2.5% from 10% to 90%
Resolution	Temp: 0.03°C at 25°C, RH: 0.03%

The days of June 21st, July 21st and August 21st were selected for the experiment. The measurements and the simulation were taken out along 8 hours, from 11:00 am to 18:00 pm. The results obtained from the field measurements and the simulation program represented in Fig. 4.

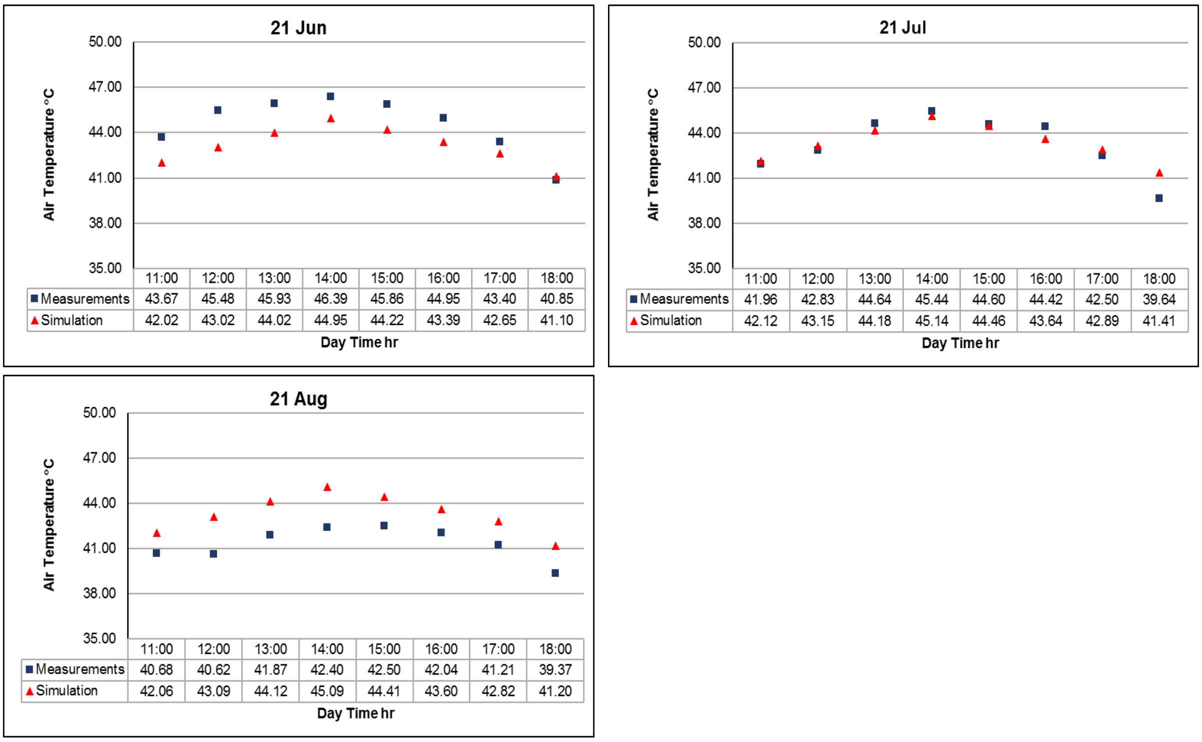


Fig. 4. The temperature difference between field measurements and simulation results.

It is evident to see that the difference does not exceed 2.5 °C (error ratio 5.4%) in June and August, moreover, the results are very close in July.

The measurements result recorded values higher than the simulation results in June and July, but the measurements recorded values less than the simulation results in August. This difference is due to that the meteorological station recorded that Egypt was exposed for an exceptive climate period, which led to decreasing of the outdoor air temperature, these conditions affected on the differences between the results. To ensure this finding, the air temperature was obtained from the meteorological station for the same period of the previous year (2015), and the results were as follows in Table 3.

Table 3. The comparison between the measurements temperature, the simulation results and the meteorological station records for 2015.

Hours	2015	The measurements	The simulation results
11:00	41.00	40.68	42.06
12:00	42.00	40.62	43.09
13:00	44.00	41.87	44.12
14:00	45.00	42.40	45.09
15:00	46.00	42.50	44.41
16:00	45.00	42.04	43.60
17:00	45.00	41.21	42.82
18:00	43.00	39.37	41.20

Also, the correlation coefficient was calculated for each day separately, which record 0.93, 0.97 and 0.94 respectively as shown in Fig. 5.

The results are very convergent between the simulation and the measurements in the three experimental days. It is an axiomatically to note a difference between the measurements and the simulation results, but it can be due to the difference between some elements used in the simulation and its peers in nature, such as color and texture of the surfaces.

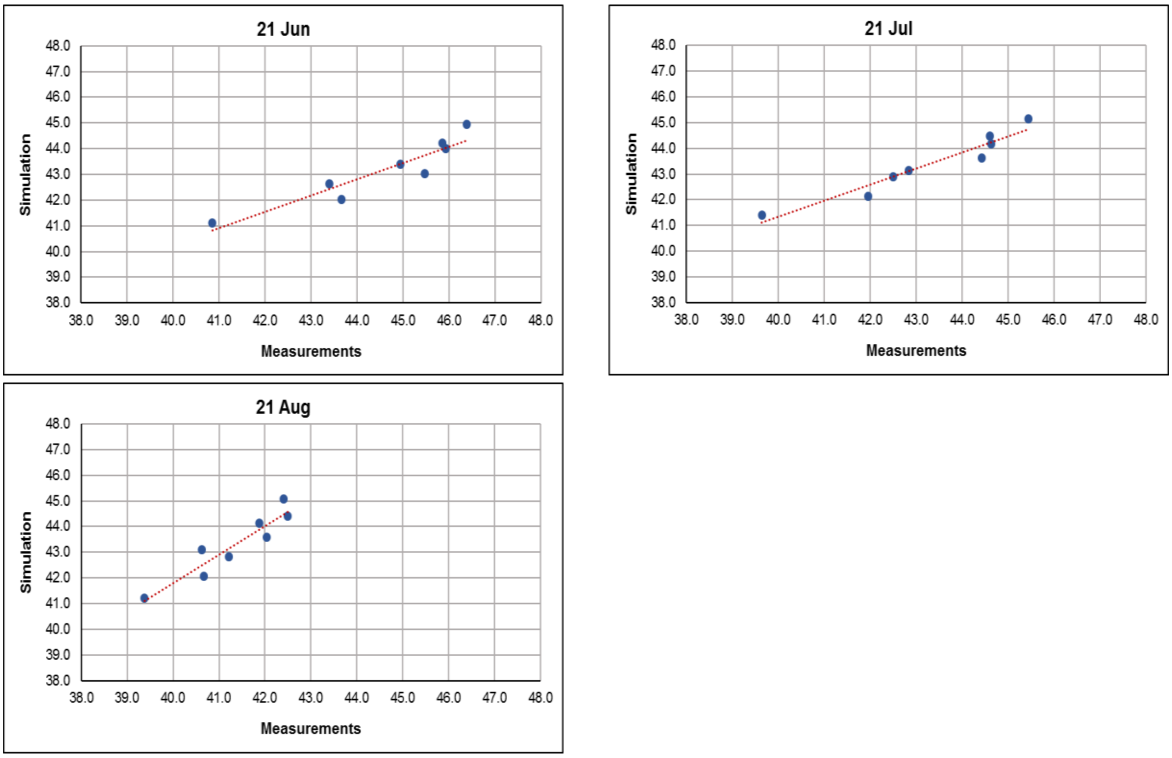


Fig. 5. The correlation coefficient of the simulation results and the field measurements.

6. DESIGN GUIDELINES FOR THE SUSTAINABLE RESIDENTIAL DISTRICTS

The modified design, as shown in Fig. 6, includes the conversion of the whole district to a pedestrian zone only. This doesn't take into account other issues such as the safety and emergency requirements (Ambulance, Fire Engine, ...) and the needs of elderly and disabled people, and for delivering furniture and goods, ... etc. (these requirements will not be discussed because it is not in the focus of the research). Therefore, the parking areas have been located at the edges of the district within not more than 10 minutes' walk of most of the homes (nearly of 150-meter distance), as well as a parking area for the public transportation. The green areas through the spaces between buildings were utilized to create a space for social activities, walking and Children's play area. Also, some shops and stalls on the sides of the district were provided.

Fig. 6. The modified district

Based on the thermal properties of materials, lack of vegetation and air pollution, as the factors influencing the energy performance of urban spaces, [23] the research dealt with the efficient use of resources with a focus on the thermal comfort and energy consumption. In this concern, the green grass ground (Albedo = 0.25 - 0.3) [24] applied instead of the asphalt paving (Albedo = 0.05 - 0.2), [24] where urban canyon surfaces with high albedo and light colors reduce the heat storage in the materials [25].

Moreover, measured data reported by Akbari et al. indicated that increasing pavements albedo by 0.25 decreased pavement temperatures by 10°C [25].

On the other hand, application of urban trees followed the minimum outdoor space coverage percentage according to the Egyptian Guide for Environmental Principles in Urban Spaces EGEPUS, 5%, to alleviate microclimates [26]. Hence, the shading producers' trees such as Casia Nodosa (5m height) [27] and Cassia Leptophylla (12m height) [27] along with the Ficus Nitida (3m height) [27] are used to mitigate the hot spots inside the site.

7. RESULTS AND DISCUSSION

To compare the two different models, Autodesk Simulation CFD 2016 was used to obtain the outdoor and indoor air temperature. The simulation procedures were carried out by preparing the model for the simulation and calculate the outdoor air temperature and the indoor air temperature in each floor separately. According to the average outdoor temperature, the peak-overheated period in July was considered for 8 hours, from 11:00 am to 18:00 pm. The second step is to extract the difference in the cooling load required in the two cases.

7.1 The temperature in the Current Situation

As shown in Table 4, the results of the hourly outdoor and indoor air temperature indicate that the outdoor temperature increased to reach the maximum temperature obtained which is 47.27°C at 14:00, then the temperature reduced gradually. Also, the peak temperature obtained on each floor was in 14:00 then the temperature reduced slightly. The temperature increased towards the higher floors until 17:00 due to the exposure to intense solar radiation, while as we move towards the sunset, the temperature decreased in higher floors more than the lower floors.

Table 4. The hourly temperature for the current situation.

The Current Situation		Temperature (°C)					
		Outdoor	Indoor				
			G. floor	1st floor	2ed floor	3rd floor	4th floor
Hours	11:00	45.55	45.99	46.80	47.27	48.03	50.30
	12:00	45.66	46.29	47.44	47.95	48.50	50.31
	13:00	46.43	46.40	47.64	48.26	49.05	51.23
	14:00	47.27	47.04	48.97	49.71	50.32	51.92
	15:00	46.40	46.85	48.49	48.94	49.16	49.96
	16:00	45.27	46.38	47.50	47.63	47.50	47.52
	17:00	44.01	45.51	46.01	45.98	45.61	45.08
	18:00	41.84	44.13	43.09	42.56	42.23	41.78

7.2 The temperature after Implementation of Research Concept

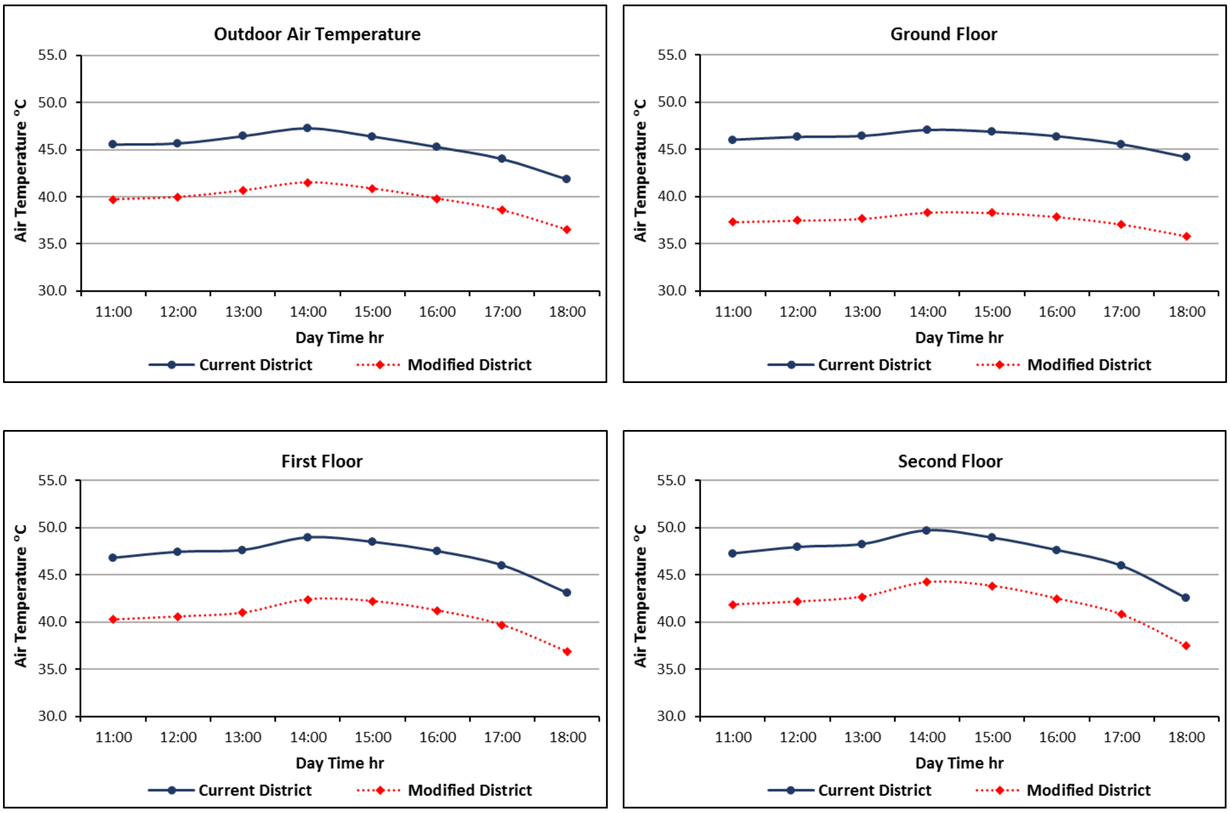
After installing the research concept, it can be seen a noticeable decreasing the temperature either outdoor or indoor temperature. Where Table 5 indicates the results of the modified model, and the hourly air temperature shows that the maximum outdoor temperature obtained is 41.53°C at 14:00, and the temperature reduced gradually.

About the indoor air temperature, it is clear to see the significant drop in the temperature predicted in different floors. Where the indoor air temperature is decreasing by the range between 4 °C : 9°C, and we can notice that the temperature is increased on higher floors. The highest value recorded on the last floor due to the roof exposing to the direct solar radiation, so it can be said that the effect of changes reduced as we move to the higher floors.

Table 5. The hourly temperature for the modified model.

The modified model		Temperature (°C)					
		Outdoor	Indoor				
			G. floor	1st floor	2ed floor	3rd floor	4th floor
Hours	11:00	39.73	37.29	40.26	41.86	43.28	45.89
	12:00	39.97	37.46	40.58	42.16	43.41	46.02
	13:00	40.67	37.65	40.99	42.68	44.10	46.86
	14:00	41.53	38.32	42.41	44.22	45.40	47.48
	15:00	40.88	38.27	42.22	43.84	44.70	46.03
	16:00	39.80	37.85	41.22	42.49	43.05	43.74
	17:00	38.57	37.04	39.68	40.79	41.17	41.37
	18:00	36.49	35.78	36.84	37.47	37.91	38.21

To clarify the difference significantly, the results of the simulation and comparison between the current case and the modified case summarized in Fig. 7.



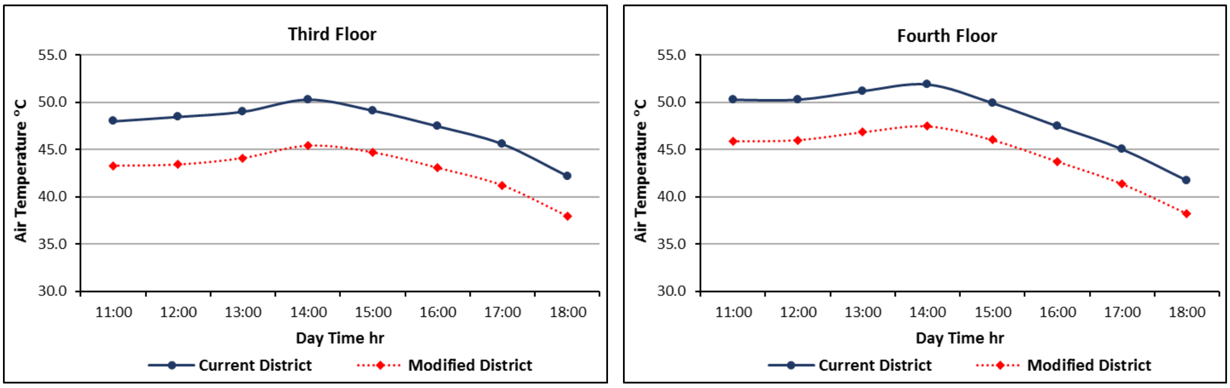


Fig. 7. The simulation results

The previous comparison shows a considerable difference occurred in the temperature because of the thermal properties of the used material, which in turn affected the building thermal performance, where the high reducing of indoor air temperature recorded on the ground floor and the effects reduced towards the higher floors.

7.3 Cooling Load Difference

To indicate the changes in the cooling load required in the two cases, the residential heating and cooling load calculation spreadsheet (Implemented by Dr. Steve Kavanaugh), which based on the 2001 ASHRAE Fundamentals Handbook was used to calculate the cooling load on the ground floor and the last floor as well. The reference temperature is the comfort limit obtained before which equal to 30.6°C, and the maximum outdoor temperature in each case was used (47.27°C and 41.53°C respectively).

The cooling load was calculated in the North-East room which is the most exposed room in the building to the external conditions as shown in Fig. 8.

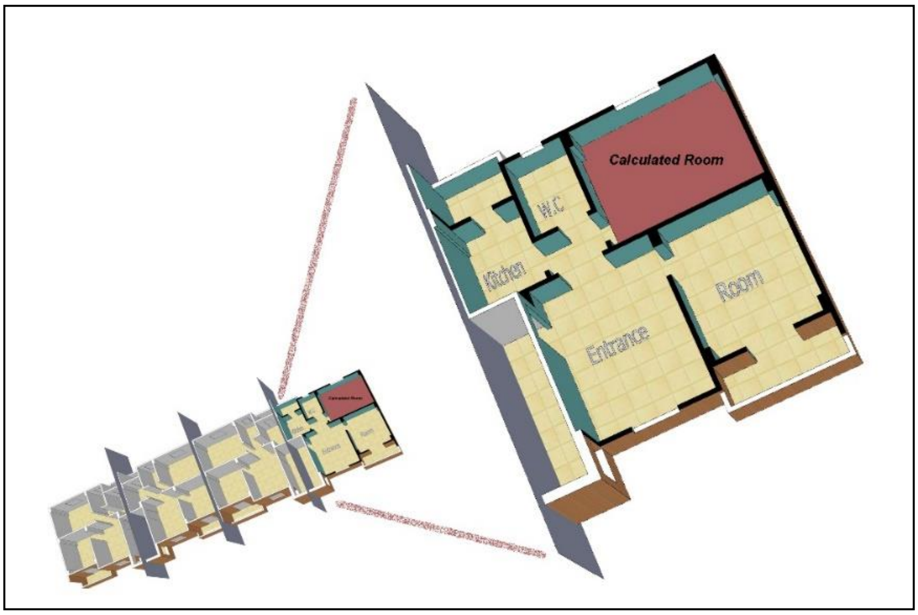


Fig. 8. The position of the calculated room

According to ASHRAE Fundamentals Handbook 2009, the cooling load calculation determines total sensible cooling load from heat gain through opaque surfaces, transparent fenestration surfaces, caused by infiltration and ventilation, and because of occupancy. The latent portion of the cooling load determined due to infiltration, ventilation, and internal load.

It will be taken into consideration that the internal cooling load, which consists of sensible, and latent heat caused by people, lighting, and equipment will be constant in the two cases. On the other hand, the external cooling load which consists of sensible heat only from opaque surfaces and fenestration surfaces, as well as the external load due to sensible and latent heat from infiltration and ventilation, these categories influenced by external climatic conditions, and will be represented in the following results.

In the current situation where the high temperature either outdoor or indoor temperature, it can be seen in Table 6 the cooling load required to reach the thermal comfort limit which records 71.0, and 155.7 W/m^2 on the ground floor, and last floor respectively.

Table 6. The cooling load required in the current situation.

The cooling load in W/m^2	The building floors	
	Ground floor	Last floor
Sensible cooling load (exterior opaque surfaces, exterior transparent surfaces, partitions, and ventilation/infiltration)	61.8	135.1
Latent cooling load (ventilation/infiltration)	9.2	20.6
Total cooling load (sensible and latent)	71.0	155.7

On the other side, in the modified situation, the cooling load required to achieve the thermal comfort was reduced, where record values equal to 55.0, and 128.2 W/m^2 on the ground floor, and last floor respectively as shown in Table 7.

Table 7. The cooling load required in the modified situation

The cooling load in W/m^2	The building floors	
	Ground floor	Last floor
Sensible cooling load (exterior opaque surfaces, exterior transparent surfaces, partitions, and ventilation/infiltration)	48.1	109.9
Latent cooling load (ventilation/infiltration)	6.9	18.3
Total cooling load (sensible and latent)	55.0	128.2

Previous findings indicate the following: The cooling load decreased by 22.5%, and 17.7% on the ground floor, and last floor respectively. So, the significant effect occurs on the ground floor due to the noticeable difference between indoor and outdoor air temperature. The effect of modifying the outdoor spaces reducing as we move towards higher floors. It is noticeable to see efficient use of energy in the case of drawing attention towards the climatic and deliberate design of outdoor spaces.

8. CONCLUSION

It can be said that the sustainable and green design can improve the thermal comfort of the indoor residential spaces, and improve the building energy performance, where the building energy efficiency is a trade-off between different design factors to achieve a target level of energy consumption, which varies according to the climatic design of outdoor spaces.

According to the field measurements, the vegetative landscape reduced the outdoor air temperature by more than 6°C. Simulation results of modified model declared that the outdoor temperature was decreased by nearly 7°C, and the indoor temperature dropped from 4°C : 9°C. On the other hand, the cooling load was decreased by almost 17.7% : 22.5% on the ground floor, and last floor respectively.

It is essential to work on the integration between the building and the external surrounding spaces; the results prove the vitality of using green coverage as an adaptation strategy on the scale of urban development in Egypt. This vitality is not only for the newly constructed developments but also for the already existing ones and gives an impression about how green adaptation can invest in our built environment.

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الأحياء السكنية الخضراء فى المناخ الصحراوى الحار
نحو خفض استهلاك الطاقة

يقدم البحث دراسة المحاكاة باستخدام برنامج Autodesk CFD 2016، ويتناول نموذجين. يعتمد الأول على الوضع الحالى لمنطقة السيل فى أسوان، والثانى هو النموذج المعدل، ثم يتم حساب حمل التبريد، باستخدام جدول حساب التدفئة السكنية والتبريد للإشارة إلى كفاءة استهلاك الطاقة فى مبنى سكنى متعدد الطوابق وقد أظهرت نتائج المحاكاة للنموذج المعدل انخفاض درجة الحرارة في الهواء الطلق بنحو ٧ درجات مئوية، وكذلك انخفضت درجة الحرارة في الفراغات الداخلية من ٤ إلى ٩ درجات مئوية، ومن ناحية أخرى انخفض حمل التبريد بنسبة ١٧.٧٪ : ٢٢.٥٪ تقريباً وفقاً لموقع الأدوار بالمبنى.