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Thermal Behaviour Assessment For The Different Building Envelope Parts In Egypt Under Climate Change Scenarios

Original Article

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Key words:

Climate change, energy performance, Opaque, Fenestration, Insulation, Thermal comfort

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Abstract

This paper presents a comprehensive evaluation for (of) the results of a recent research effort concerning thermal comfort in residential buildings in Egypt. The energy performance and thermal comfort were considered based on the instructions of the Egyptian Residential Energy Code (EREC) to improve the efficiency of energy use. The conclusions of the aforementioned research on the building envelope (walls / fenestration) were tested together to make sure (prove or demonstrate or verify) that the use of what seems to be the best solutions for external walls (solid part) in addition to the best solutions for fenestration (openings), will results result in a better overall performance in energy consumption and thermal comfort, than (when) implementing (only) one of the two choices. To attain that, two (mixed-mood) [heating, ventilation and air conditioning (HVAC)] case study buildings were dynamically simulated in three dominant Egyptian climatic zones, using current climate conditions (2002) in addition to three other morphed climate change scenarios (2020, 2050 and 2080). Achieving the required rates for thermal comfort, and acquiring (securing) long term financial gains were the basic elements of the evaluation. The results provide what seems to be a functionally and financially successful combination to fulfil the evaluation elements.

I- INTRODUCTION

1.1 Background

The building envelope (skin) consists of structural materials and finishes that enclose space, separating the outdoor environment from (the) indoor space. This includes walls, roofs, windows, doors, openings and floor surfaces[1]. As the building envelope controls the flow of heat between outdoor and indoor environments, a good envelope design plays a major role in determining the amount of energy a building will use in its operation(2), and can show optimization between natural lighting and thermal performance through passive solar techniques(3, 4).The effect of (a) building envelope depends on the selection of its consisting materials and their thicknesses, including the use of new thermal insulation materials to increases(increase) the thermal resistance of the external walls and ceilings, and the selection of appropriate fenestration (i.e. window-to-wall ratio (WWR)), glazing type)with(while) applying the needed vertical and horizontal shading devices[1, 5].

Good external walls and ceiling insulation, are the first step to improve the indoor thermal behaviour and reduce the energy consumption, as about 8% of (the) energy used in buildings (is) wasted through the external walls, and about 6% wasted through the ceilings[3].

Due to the nature of the hot arid climate zone in which Egypt is located, external walls with large thickness have always been preferred in the vernacular architecture as a passive technique to reduce the heat and delay its transfer from the harsh external conditions[6]. Despite the impact of this technique on improving the thermal performance of residential buildings, particularly in hot arid zones, people are no longer using it[5] to cut costs and to save the indoor area. At present, the most widely used (specification) (for) external walls in the residential sector is the half red-brick (12 cm thickness). The reason behind (for) that is its relatively low initial cost compared with (to) other external walls specifications. This ignores the negative impact of the half red-brick wall on indoor thermal comfort, energy consumption and the) associated running costs. Among building envelope elements, the openings are considered the main source of heat penetrating inside the building, as shown in Fig.1penetration varies by according to the type of glass and by its specifications such as transparency and purity grade)[6-8]. They are estimated to be as responsible for about 20% of (the) energy used in buildings by(through) increasing the heat load of the building, (and) thereby air-conditioning loads[3].

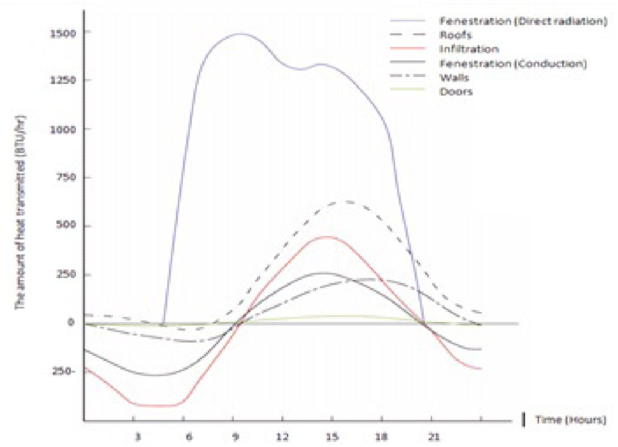

Fig. 1: The difference in the rate of heat permeability through various building envelope components[6, 9].

Therefore, the most effective way to reduce the solar load on the openings is to intercept direct solar radiation before it reaches the glass[8, 10] to control the indoor temperature, improve thermal comfort and reduce cooling loads[11-13]. Consequently, fully shaded openings during hot weather can reduce solar heat gain by as much as 80%[1, 10, 11]. A considerable amount of literature has been published on the importance of the shading techniques in different regions, some with the same climatic conditions as Egypt. A reduction of 1.5°C was achieved using vertical fins and combined shading devices, while Ahmed and Tarek(14) searching the impact of different shading devices on the thermal performance in residential buildings in Egypt. Ahmed(5) concluded that, vertical fins with a depth of 38cm or more result in a decrease of 2°C in indoor temperature for all the four orientation(s), when he was investigating the effect of vertical fins' depth on the thermal performance of residential buildings in Egypt. Another study(15) showed that power consumption from air conditioning is reduced by an average of 25% if external shading is properly installed.

Selecting building materials has a great impact on the performance of the building. Cost analysis over (of) a building's life span is very important to in determining the relative value of using (a) specific material rather than the(over)other products[6]. Therefore, external walls and fenestration were (the focus of)our recent research focus(from) among the elements of the building envelope components.(A) previous research(16) was concerned with studying the effect of using different material specifications for the external walls on the cost of energy consumption (running cost) for achieving internal thermal comfort in Egypt. Four different types of external walls, in two different sets of cooling (natural ventilation and mechanical means) were tested through dynamic thermal simulations. The running cost in turn was compared to initial construction cost for each type of the used external walls. The results supported the use of the Egyptian Code for Improving the Efficiency of Energy Use in Buildings -Part 1: Residential Buildings (hereafter simply) referred to as EREC[17] recommendations to achieve indoor thermal comfort with minimum energy consumption (consequently minimum CO_2 emissions) and the minimum running cost as well. More accurate studies and simulations were conducted(18) to extend(expand) the previous research, by evaluating the effect of external walls with different specifications on the project's initial cost and (the) running cost for achieving internal thermal comfort in the present time(presently) and under climate change. Three different climatic zones in Egypt, as well as three current (2002) and predicted (2020 and 2050) weather data files were used by (a) Building Performance Simulation (BPS) (software) [19] to evaluate four different external wall specifications. The energy analysis suggests different types of external walls according to (depending on) location to optimise for thermal comfort and financial benefits.

The study expanded another direction (the fenestration)[20], investigating the effect of climate change on shading strategies recommended by EREC. A HVAC case study building was dynamically simulated in three Egyptian climatic zones, using current climate condition (2002) in addition to three other morphed climate change scenarios (2020, 2050 and 2080). Then a comparison was held in the four different periods with and without the EREC's recommended shading parameters. The results showed a minor effect of the future climate change on the efficiency of the current shading strategies approved and recommended by EREC, which confirms the effectiveness of using the existing shading specifications in future climatic conditions. The results were encouraging(enough) to develop a new research[21], to investigate the effect of the climate change on the choice of fenestration properties - (WWR) and glass thermal properties- and associated shading devices (as recommended by EREC) in order to optimize energy consumption, as well as the long-term financial aspect of the building project, by running dynamic thermal simulations (for four weather data files) at three different climatic zones in Egypt.

In addition to the 112 simulations that have been carried out in this research, a computerized shading calculation tool[21], based on EREC's recommendations, has been developed to find the best recommendations for the different variable combinations in the three major climatic zones in Egypt. All the different thermal properties (listed in EREC) of the various construction elements were stored in a (Structured Query Language (SQL)) server database (as were). All the required shading settings have been stored as well, with respects to different specifications, such as climatic zone, orientation, etc. For a given experiment parameter settings, a C# program is responsible for taking these parameter values as an input arguments,(and) then querying the database with these parameters to obtains(obtain) the shading specification needed, if any.

The analysis of the simulations resulted in identifying different (WWRs), glass types and shading devices' associated prominence factors according to each climatic zone, to provide what seems to be the optimal combination for thermal comfort and cost benefits.

1.2 Main purpose

It was a prevailing assumption in the past that the climate does not change, meaning that the (a) building designed to provide thermal comfort at the time of its establishment is supposed to maintain the same level of thermal performance in the future until the end of its service life. This assumption is no longer valid as evidenced by the reports of the International Panel on Climate Change[22]. The hours of sunshine and the proportion of direct radiation to diffused radiation are projected to increase in the future, while the modelling studies demonstrate a steady increase in cooling capacity and (the) associated energy consumption required[23].

Therefore, the need to minimize overheating will become an increasing factor in design. Hence, simulating the performance of buildings under future climatic conditions has become of great importance, to provide an indication of the future thermal behaviour of a building and its ability to provide acceptable thermal conditions, probably with some modifications during its service life[23].Therefore, the prediction and evaluation of the thermal behaviour of residential buildings under future climate change scenarios, was the main focus of our recent research, via studying two of the main components of the building envelope : External walls and fenestration.

Previous researches[18] and[21], have revealed what seems to be the best combinations for external walls and for fenestration separately in order to achieve the long-term cost-effective indoor thermal comfort. This work (is) dedicated to check (checking) whether the (combined) use of both of the aforementioned construction materials in the same project will result in higher overall performance in energy consumption and thermal comfort more than the previous unilateral attempts.

II APPROACH (GENERAL SPECIFICATIONS FOR SIMULATION)

As a computerized dynamic building thermal performance simulation tool, "Energy plus", and its architectural friendly interface "DesignBuilder (DB)" take into account all the principal heat-transfer theories that have a direct influence on energy consumption and indoor thermal comfort, such as transmitted solar radiation, air ventilation, convection heat transfer coefficient, etc. In order to achieve the objective, (DB) in its third version ((V.3.0.0.105)[19]) was used to investigate the effect of using three different sets of building materials : (1) Ordinary external wall materials combined with the selected fenestration resulting from the aforementioned papers (OS) ; Selected external wall materials with ordinary fenestration parameters (SO); Selected external wall materials with selected fenestration (SS).The fourth probability: Ordinary external wall materials with ordinary fenestration parameters (OO) was excluded, as it was tested in previous studies[16, 18] and never achieved satisfactory outcomes. The effect of the three selected sets was tested on two stereotypes residential buildings in Egypt with mechanical air conditioning (HVAC) installed in mixed mode operating system. The thermal performance simulations will take (took) place in three climatic zones defined in EREC[17]. These include Cairo and Delta, the North Coast, and the Southern (Egypt) climatic zone. These simulations ran under the current climate conditions (2002), and under (the) different climate change scenarios of three periods: 2020, 2050 and 2080. The simulations will produced two different parameters to help us to clarify our objective: Monthly Energy Consumption (kWh) and Indoor Air Temperature (°C).

2.1 Climatic Zones

Egypt is a large country with an area of approximately 1,000,000 km2, located between 22º N - 31º 37′ N latitude and 24º 57′ E - 35º 45′ E longitude. Egypt possesses diverse climate conditions ranging from extremely hot conditions in the desert regions such as the Western Desert, to cold conditions in Mountain St. Catherine in (the) Sinai Peninsula[24]. However, the overall climate of Egypt is characterized by (being) hot arid climate (Köppen classification: BWh) with very high solar radiation intensity most of the year[25, 26]. Egypt is divided into eight climatic zones: Northern Coast zone, Cairo and Delta zone, Northern Upper Egypt zone, Southern Upper Egypt zone, East (Eastern) Coast zone, Highland’s zone, Desert zone and Southern Egypt zone.

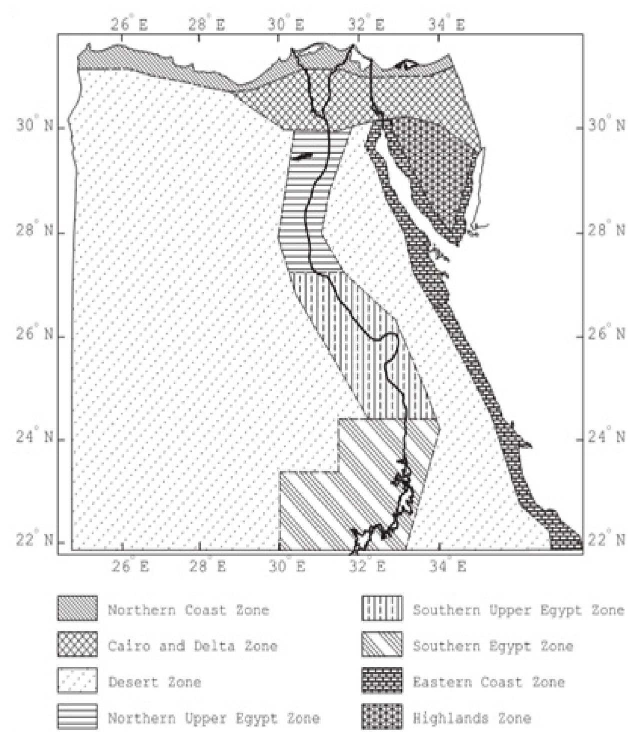

Fig. 2: Egypt's climatic zones classificationmap according to EREC[17, 24].

The paper will focus on the main three climatic zones (shown in Figure 2) defined in EREC[17]. These zones are: Cairo and Delta zone (Cairo governorate); (Northern Coast) zone (Alexandria governorate); and the Southern Egypt zone (Aswan governorate). About50% (About 50%) of the construction projects carried out in Egypt are located in Cairo (in the Cairo) and Alexandria governorates[27] ,while Aswan governorate is considered a very different zone in terms of the climatic aspects compared to the otherzones[6, 17, 28]

2.2 Thermal Comfort Zone

Previous research underpins the theory of Adaptive Comfort[29, 30]. It has shown that people can adapt and can be comfortable at higher temperatures than those conventionally adopted. As mentioned by (Givoni[31]), people who live and acclimatize to prevailing hot environment regions, would prefer higher temperature. Accordingly, the thermal comfort zone (20°C-29°C) was used in the simulations. This is a modification of the original comfort zone (22.2°C-25.6°C) mentioned in EREC[17]. The modification has been applied usingGivoni approach[31] through the inclusion of both mean values of the slightly hot zone (25.6°C-34.5°C) and of the slightly cold zone (17.5°C-22.2°C) to form the new modified thermal comfort zone (20°C-29°C). As we are working with the assumption that higher air temperatures are tolerated in this climatic context, we have not used (the Predicted Mean Vote (PMV)) at all. We are only using air temperature as the indication.

2.3 Model Definition

Two different residential buildings ((state) housing / low-income housing) were used in the simulations[1].

2.3.1 Building 1 (B-1)

The building consists of five floors with (a) total height of 15m, where each floor has four residential flats with an approximate area of 85 m2 each. The average number of occupants per flat is four (See Figures 3 and 4).

Fig. 3: Typical plan for the modeled flat.

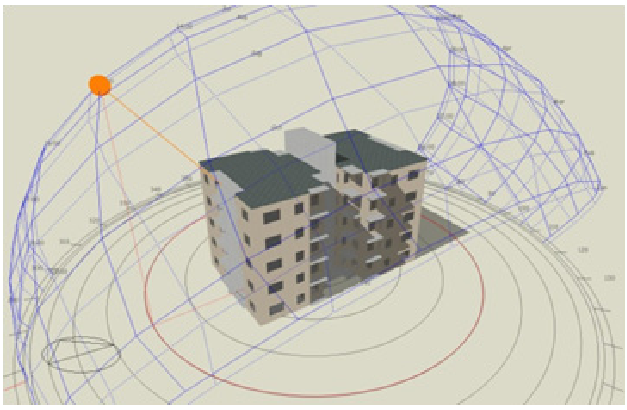

Fig. 4: Solar analysis of the model (used) in Alexandria.

2.3.2 Building 2 (B-2)

The building consists of six floors with a total height of 18m. Each floor consists of four residential flats with an area of 86 m2 per flat.The average number of occupants per flat is four. The building outline contains many corners which casting self-shading, and with no openings on the eastern and western façades. The building's floor plan is shown in Figure 5, and the building model in Figure 6.

Fig. 5: Typical plan for the modeled flat.

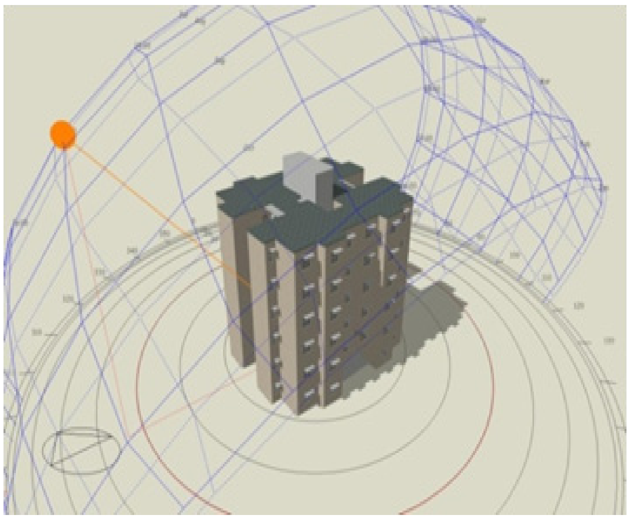

Fig. 6: Solar analysis of the model used in Aswan.

2.4 Simulation sets

The effect of three different sets of building materials will be tested on the aforementioned two residential buildings:

- Ordinary external wall materials in combined with the selected fenestration (OS).
- Selected external wall materials with ordinary fenestration parameters (SO) .
- Selected external wall materials with selected fenestration (SS) .

The ordinary materials (O) are the most commonly used materials in Egypt, most probably due to their low price. While the selected materials (S) were obtained as (the) results of the previous research(18, 21) via numerous tests for the most commonly used materials in Egypt and the recommended materials by EREC (whether building materials for external walls or the various types of glass available in the Egyptian market), nevertheless they not necessarily the cheapest with respect to the initial cost, but seemingly provider the optimal solution for thermal comfort and financial gains on the long term. Table 1 clarifies the different materials for each (O and S) category used in the simulations for the different climatic zones.

Table 1: General description of the materials used in the simulations.

Category	Building Envelope	Alexandria	Cairo	Aswan
Ordinary (O)	External Walls	Half red-brick wall (12cm)	Half red-brick wall (12cm)	Half red-brick wall (12cm)
	Fenestration	Single clear 6.4mm (G1) + 20% WWR	Single clear 6.4mm (G1) + 20% WWR	Single clear 6.4mm (G1) + 20% WWR
Selected (S)	External Walls	Double wall of half red-brick-air gap (Dair)	Double wall of half red-brick-air gap (Dair)	Double wall of half red-brick-insulation (Dins)
	Fenestration	Single clear Reflective 6.4mm (G2) + 20% WWR	Single clear Reflective 6.4mm (G2) + 20% WWR	Single clear Reflective 6.4mm (G2) + 20% WWR

(Following are) detailed specifications for each material will be mentioned in the following:

2.4.1 External Wall Specifications

The specifications for external wall constructions used are presented in Table 2. The thermal properties were obtained from EREC[17], and the Egyptian Specifications for Thermal Insulation Work Items[32]. The used materials were evaluated previously[18], with a recommendation for the use of the double wall of half red-brick with 5 cm of internal expanded polystyrene thermal insulation layer (Dins) wall as the optimum external wall in Aswan, and the use of the double wall of half red-brick with 5 cm air gap in between (Dair) wall for Alexandria and Cairo. These are the optimum specifications shown to achieve indoor thermal comfort, (and) minimize the energy consumption, while guaranteeing maximum cost-effectiveness. The regular half red-brick wall will be tested as the most commonly used material for construction in Egypt, despite its negative impacts on thermal comfort and energy consumption (See Figure 7).

Table 2: External walls main characteristics.

External Walls	ABBRV.	Thick. (cm)	U-Value (W/m2K)
Half red-brick wall.	12cm	12	2.519
Double wall of half red-brick with 5 cm air gap in between.	Dair	29	1.463
Double wall of half red-brick with additional internal 5cm of expanded polystyrene thermal insulation layer.	Dins	29	0.503

Fig. 7: Wall sections used.

2.4.2 Glass Specifications

There are four main glass categories commonly used in Egypt, mentioned and specified in EREC[17]: (1) single glass; (2) SingleReflectiveglass single reflective glass; double glass; (4) double reflective glass. As recent resultsrecommend (results have recommend)(21), the single clear reflective 6.4mm with 8% stainless-steel cover was used in the simulations as the most cost-effective glass type to be used on the long run. The clear 6.4mm glass was used as the regular glass type which is the most commonly used for construction in Egypt (See Table 3).

Table 3: Used glass specifications.

	Name	Category	SHGC*	LT**	U-Value (W/m2K)
G1	Clear 6.4mm	Single	0.71	0.65	5.76
G2	Clear Reflective 6.4mm – (Stainless steel Cover 8%)	Single Reflective	0.18	0.06	5.36

*SHGC: Solar Heat Gain Coefficient.
**LT: Light Transmission.

2.5 Weather Data Files (WDF)

Four different weather data files - 2002, 2020, 2050 and 2080 - were used in the simulations to provide the most comprehensive simulation period available to test the hypothesis, starting from the current weather conditions (2002) and then the predicted weather data files (2020, 2050 and 2080). The current weather data file (2002) was obtained from the official site of the U.S. Department of Energy[33]. By using the Climate Change World Weather File Generator[34, 35], the future weather data files for 2020, 2050 and 2080 were generated, for the climatic zones that have been tested in Egypt, and they cover the periods 2010-2039, 2040-2069 and 2070-2099 respectively[36]. The available weather data files gave a maximum test period of 88 years, with 2012 assumed to be the starting construction year.

The following figure (Fig. 8) shows the predicted scenarios for the future climate change, from the present to the 2080 projections in the three climatic zones (Alexandria, Cairo and Aswan respectively) in Egypt. The left graphs present the outside temperatures for the current and the three future scenarios, while the graphs on the right show the direct solar radiations for the same climatic periods. As noticed, the temperature increases by moving from a climatic period to another with a clear difference in all of the three tested climatic zones. The solar radiation graphs did not show the same rates of change at any of the different zones. On the contrary the solar radiation rates were very close to the existing conditions.

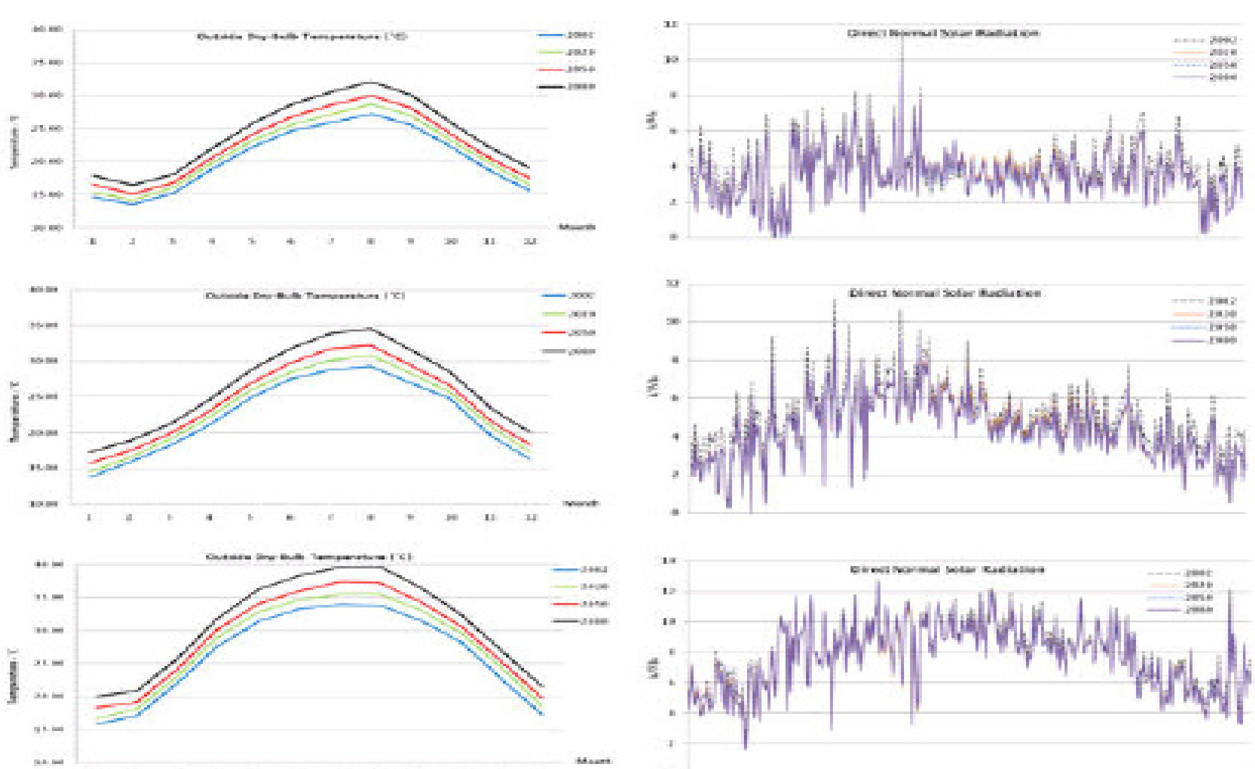

Fig. 8: Future weather projections for Alexandria (top), Cairo (mid) and Aswan (bottom).

2.6 Activities and HVAC Systems

Schedules were used (in conjunction with the cooling and heating set points) to control the timing in DesignBuilder and to define certain activities in the simulations, such as occupancy times, equipment, lighting and HVAC operation[37]. Fixed energy consumption schedules were used in the simulations, and have been defined via fixed activity template based on the common lifestyle of the residents of Egypt (holidays, work hours, etc.)(38). Hybrid systems (mixed mode of HVAC systems and natural ventilation) were used to benefit from passive cooling when available and make efficient use of mechanical cooling systems during extreme periods. Theused heating and cooling systems were modelled using basic loads calculation algorithm (energy + zone HVAC ideal loads)(37), in order to supply hot or cold air to meet the heating or cooling loads according to the required set points. The HVAC specifications include the use of split air-conditioning units (with cooling COP=1.83) that are generally used for domestic purposes in Egypt for the whole day in the summer when the temperature exceeds 29ºC until it drops below 25ºC; Otherwise, natural ventilation was used.

Simulation techniques including modelling, building materials assignment, lighting and HVAC systems configurations have been examined in order to validate the simulated results[39]. The different parameters in the models were calibrated to match the monthly energy consumption real time data, collected from the electricity bills for the two different models in Cairo climatic zone.

2.7 Prices of construction materials and energy

2.7.1 Construction Material Costs

The price list of construction materials, derived from The Engineering Authority Indicative Guide[40], was used to calculate the initial cost of the different building materials in each case tested in the simulations.

2.7.2 Electric Energy Prices

For the financial analysis, the cost of the annual energy consumption per flat was calculated using the electricity tariff set by the Egyptian Ministry of Electricity and Energy for the residential sector[41]. The different categories and prices are shown in Table 4.

Table 4: The electricity tariff.

no.	Category (kWh)	Price (EGP)	no.	Category (kWh)	Price (EGP)
1	50	0.05	4	351-650	0.24
2	51-200	0.11	5	651-1000	0.39
3	201-350	0.16	6	Over 1000	0.48

III- RESULTS AND DISCUSSION

3.1 Simulation Results

The results contain indicators for 72 simulations (for both buildings) that have been conducted through the research. The aforementioned results are divided into three separate graphs : the monthly energy consumption(kWh); annual energy cost in Egyptian pound (EGP); as well as the levels of thermal comfort compared to the outdoor and indoor temperatures (°C). These measures were plotted only for the building (B-1) in Aswan in Figures 9 (a/b), as the results were consistent and followed a similar pattern. Thus, only these results will be presented in this paper. Each graph is divided into four different climatic periods that have been addressed in the study (2002, 2020, 2050 and 2080).The results analysis also includes a financial study of the construction cost (initial cost), and its relation to the cost of the energy consumption (running cost), from the perspective of long-term investment and the financial interests of investors in the real estate sector.

For each climatic period, the upper left graph represents the monthly energy consumption for the three different sets of building materials (OS, SO and SS). As expected, the energy consumption increases when moving from a climatic period to the following, as a result of the temperature increase under climate change(42) in all of the climatic zones. The upper right graph represents the annual energy cost according to the household electricity tariffs used in Egypt[41]. As expected, the results show that the cost is directly proportional to the increase in energy consumption. The lower graph presents the indoor and outdoor mean temperature variations for the whole year, with each number corresponding to the respective month, along with the thermal comfort zone. As expected, these vary for the different climate zones, weather periods and the different sets of building materials used.

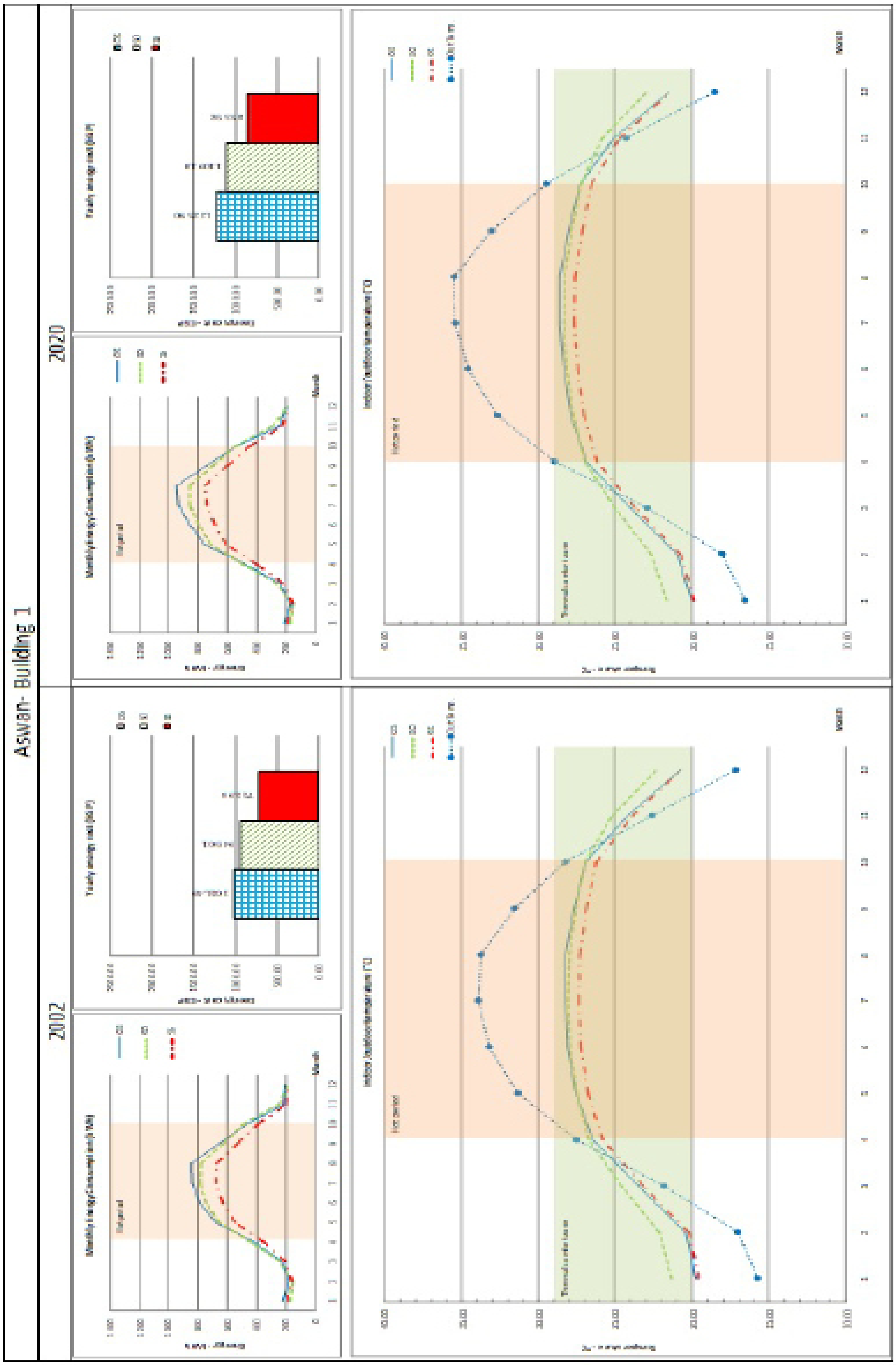

Fig. 9/a: Simulation results for Building-1 in Aswan - 2002 and 2020 weather periods.

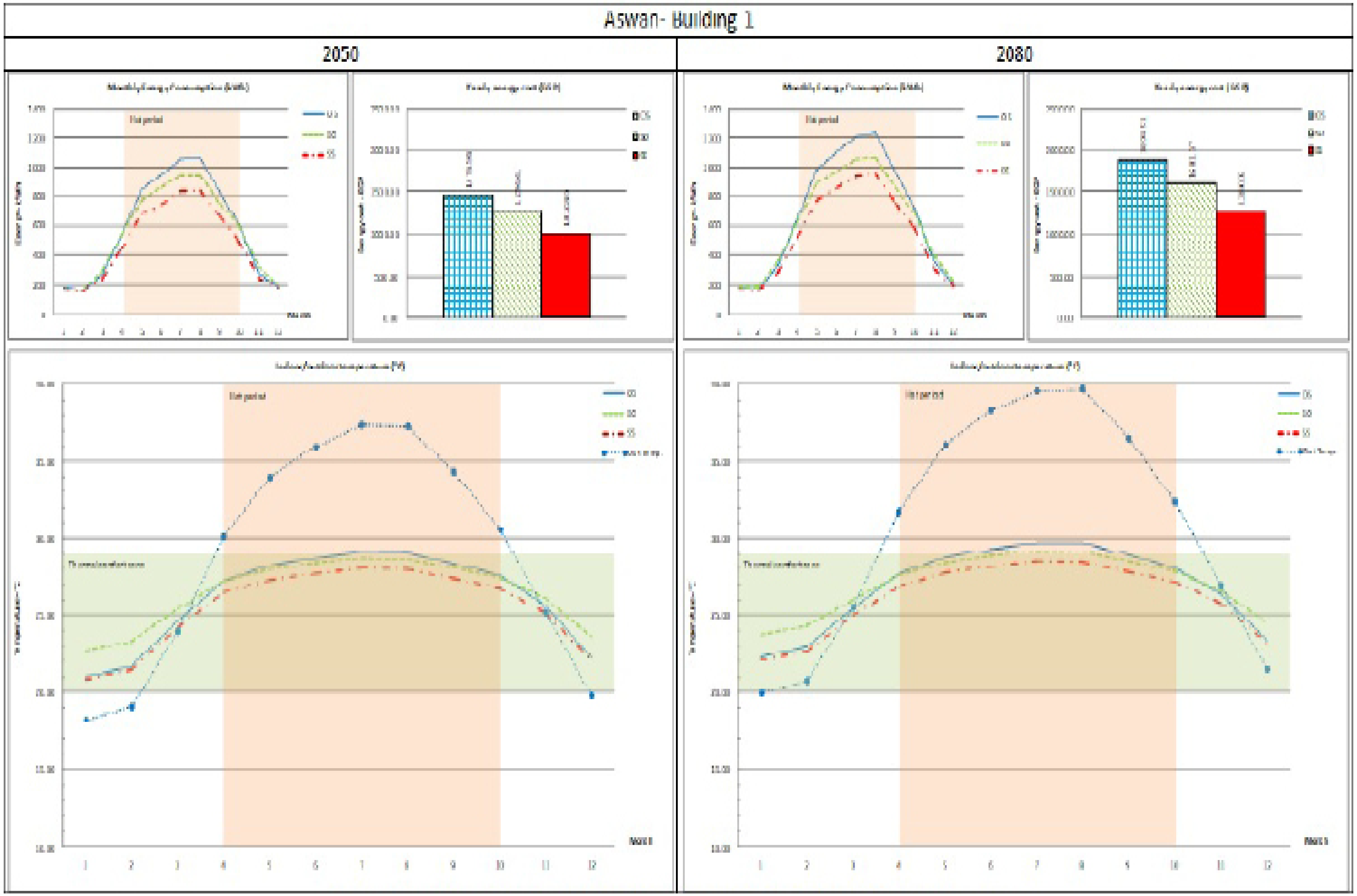

Fig. 9/b: Simulation results for Building-1 in Aswan - 2050 and 2080 weather periods.

3.2 Financial Analysis

Financial equations have been developed based on the Net Present Value (NPV) financial model. The subsidised electricity tariff as well as the interest rate is (are) assumed to be fixed over the study period. Taking into consideration, the increase in the electricity tariffs (the removal of subsidies) or the decrease in the interest rate will reflect into more financial benefits in favour of the search hypothesis as tested in an ongoing research. The financial study idea is simply summarized in finding the difference in the long term financial gains of over a 88-year period (see Section 2.5) between:

1) Those who preferred to invest what seems to be a small amount of money (at first glance) in the initial cost of the construction (referred to as X) and thus chose to use the previous studies recommendations for only one of the building's envelope components, whether it's the external walls or the fenestration only (cases SO or OS). NB: In order to achieve indoor thermal comfort in the SO case additional external shading devices for fenestration will be used according to the requirements of the code. This additional cost will lead sometimes to increasing the total cost as shown in (Table 5).

2) Those who preferred to invest a larger amount of money in the initial cost of the building (refer (referred) to as Y) and thus use the recommendations of the previous studies for (the combined use of) both the external walls and fenestration case SS.

The aim is to point out the best cost effective set of the three different sets of building materials (OS, SO and SS) in each climatic zone, taking into account the total initial cost and the running cost for each set. The total initial cost as mentioned in Table 5 (is) calculated by adding the initial cost of the external walls to the fenestration cost for each building (B-1 and B-2).

Table 5: Total initial cost of the simulated buildings (EGP).

		Climatic zone	Wall cost	Fenestration cost	Total
Building - 1	OS	All	1528	3531	5059
	SO	Alex	3104	3858	6962
		Cairo	3104	4013	7117
		Aswan	5969	4064	10033
	SS	Alex	3104	3531	6635
		Cairo	3104	3531	6635
		Aswan	5969	3531	9500
Building - 2	OS	All	1832	3746	5578
	SO	Alex	3721	3595	7316
		Cairo	3721	3755	7476
		Aswan	7156	3755	10911
	SS	Alex	3721	3746	7467
		Cairo	3721	3746	7467
		Aswan	7156	3746	10902

It has been assumed that, investor X used one of the sets SO or OS, while investor Y used the SS set. For each building materials set, we calculate the initial cost paid by investor X and Y (Table 5). The difference between the initial costs for the different sets of building materials (SO,OS and SS) will be invested in a bank with the regular 9% interest rate in Egypt[43], using the following formula:

$$V_1 = M_1 \times (1 + 0.09)^{N-1} \quad (1)$$

Where: V_1 The amount of money generated after N years of investment.
M_1 The difference in initial costs in Egyptian pound (EGP).
N Number of Years of bank investment.

In addition, the bills paid for the consumed energy by each investor are referred to as the running cost. The difference in the running cost between the sets of building materials (savings in the annual energy bills in EGP) will be invested as well using the following equation:

$$V_2 = (1 + 0.09)^{N-1} \div (0.09 \times M_2) \quad (2)$$

Where: V_2 The amount of money generated after N years of investment.
M_2 The difference in running costs in Egyptian pound (EGP).
N Number of Years of bank investment.

In the financial study, the Case SS will be taken as the baseline as it (has) achieved the lowest monthly energy consumption, thus the lowest annual cost for energy, aswell as it achieved the best level of thermal comfort for the occupants of the architecture spaces in all the simulations. This includes the two buildings (B-1 and B-2) that have been studied, in the different three (three different) climatic regions (Alexandria, Cairo and Aswan), in all the climatic periods that have been studied (2002, 2020, 2050 and 2080).

The financial implications for the results of the simulations are summarised in Tables 6 and 7 for buildings B-1 and B-2 respectively. Each table demonstrates the financial analysis of the three climatic zones (Alexandria, Cairo and Aswan) sequentially. These tables show the running costs for the energy consumed in each zone for each climatic period used in our simulations (sub- total), and the average annual running cost obtained by dividing the running cost of the four climatic periods added together (overall) by 88 years, as well as the initial cost of each building material set (SO, OS and SS). Note that, in each of the results tables, the final total amount of saving (V_1+V_2) shown in negative (and typed in red bold-face) indicates that its corresponding set of material is more cost effective than the baseline set (SS).

Alexandria

Case	WWR	Initial cost	2002: 2001-2015 (14 years) Running cost	Sub total	2020: 2016-2039 (14 years) Running cost	Sub total	2050: 2040-2069 (30 years) Running cost	Sub total	2080: 2070-2099 (30 years) Running cost	Sub total	Overall annual running cost	Average annual running cost (Overall/88)	5% diff in initial cost	88.00 accumulation after 88 yrs	diff in running costs	accumulation after 88 yrs	saving in initial cost vs saving in running cost	
SS	20%	6665	321.73	4504.15	398.32	5576.46	491.38	14741.4	669.53	20084.8	44906.55	510.31	0	0.00	0.00	0.00		
OS		5089	352.16	4930.6	436.97	6116.2	551.07	16532.1	778.85	23365.6	50767.63	576.90	-1,576.00	-2,802,205.15	66.60	1,451,185.07	**-1,350,349.63**	SS under OS
SO		6961	370.37	5185.2	468.51	6559.1	597.36	17920.9	840.65	25219.6	54875.15	624.72	327.00	593,725.80	114.41	1,497,651.31	3,091,422.31	SS over SO

Cairo

Case	WWR	Initial cost	2002: 2001-2015 (14 years) Running cost	Sub total	2020: 2016-2039 (14 years) Running cost	Sub total	2050: 2040-2069 (30 years) Running cost	Sub total	2080: 2070-2099 (30 years) Running cost	Sub total	Overall annual running cost	Average annual running cost (Overall/88)	5% diff in initial cost	88.00 accumulation after 88 yrs	diff in running costs	accumulation after 88 yrs	saving in initial cost vs saving in running cost (EGP)	
SS	10%	6635	493.16	6904.2	550.00	7700.0	676.49	20294.5	920.15	27604.6	62195.54	706.97	0	0.00	0.00	0.00		
OS		9039	513.35	7186.9	621.35	8698.9	774.73	23241.9	1082.21	32466.3	71594.18	813.57	-1,596.00	-2,842,245.15	104.60	2,283,409.69	**-558,835.46**	SS under OS
SO		7117	550.87	7712.19	653.71	9151.9	803.31	24099.3	1105.76	33173.477	74830.71	850.34	482.00	869,265.33	143.36	3,083,983.12	1,951,346.65	SS over SO

Aswan

Case	WWR	Initial cost	2002: 2002-2015 (14 years) Running cost	Sub total	2020: 2016-2039 (14 years) Running cost	Sub total	2050: 2040-2069 (30 years) Running cost	Sub total	2080: 2070-2099 (30 years) Running cost	Sub total	Overall annual running cost	Average annual running cost (Overall/88)	5% diff in initial cost	88.00 accumulation after 88 yrs	diff in running costs	accumulation after 88 yrs	saving in initial cost vs saving in running cost (EGP)	
SS	20%	9500	722.96	10121.4	853.92	11954.9	1011.16	30335.4	1298.02	38940.6	90461.66	1032.53	0	0.00	0.00	0.00		
OS		9059	1021.49	14300.9	1225.90	17162.6	1473.94	44218.3	1894.53	56835.9	132517.19	1505.88	-4,440.00	-8,009,149.85	473.35	10,338,150.05	2,329,056.20	SS over OS
SO		10039	949.01	13286.1	1108.10	15527.1	1294.41	38832.4	1601.37	48041.1	115687.16	1314.63	539.00	960,249.54	281.10	6,358,375.97	7,319,617.30	SS over SO

Table 6: Financial analysis for building B-1

Alexandria

Case	WWR	Initial cost	2002: 2012-2025 (14 years)		2020: 2026-2039 (14 years)		2050: 2040-2069 (30 years)		2080: 2070-2099 (30 years)		Overall annual running cost	Average annual running cost (Overall/88)	9%	88.00				
			Running cost	Sub total	Running cost	Sub total	Running cost	Sub total	Running cost	Sub total			diff in initial cost	accumulation after 88 yrs	diff in running costs	accumulation after 88 yrs	saving in initial cost vs. saving in running cost	
SS		7467	368.18	5154.562	459.17	6428.40785	578.02	17340.676	802.82	24084.5239	53008.17	602.37	0	0.00	0.00	0.00		
OS	20%	5578	416.13	5825.8373	526.97	7377.63618	676.00	20279.988	968.13	29043.9702	62527.43	710.54	- 1,889.00	- 3,406,726.58	108.17	2,361,505.34	-1,045,221.24	SS under OS
SO		7316	377.20	5280.75166	478.23	6695.18948	610.29	18308.608	856.56	25696.8881	55981.42	636.15	- 151.00	- 272,321.71	33.79	737,592.89	465,271.18	SS over SO

Cairo

Case	WWR	Initial cost	2002: 2012-2025 (14 years)		2020: 2026-2039 (14 years)		2050: 2040-2069 (30 years)		2080: 2070-2099 (30 years)		Overall annual running cost	Average annual running cost (Overall/88)	9%	88.00				
			Running cost	Sub total	Running cost	Sub total	Running cost	Sub total	Running cost	Sub total			diff in initial cost	accumulation after 88 yrs	diff in running costs	accumulation after 88 yrs	saving in initial cost vs. saving in running cost	
SS		7467	538.45	7538.29126	651.00	9114.06295	805.24	24157.052	1110.12	33303.5451	74112.95	842.19	0	0.00	0.00	0.00		
OS	20%	5578	624.07	8737.03997	776.86	10876.0262	965.00	28949.858	1362.70	40881.1348	89444.06	1016.41	- 1,889.00	- 3,406,726.58	174.22	3,803,287.60	396,561.02	SS over OS
SO		7477	556.89	7796.47295	681.84	9545.71414	841.90	25256.883	1163.29	34898.5702	77497.64	880.66	10.00	18,034.55	38.46	839,661.78	857,696.33	SS over SO

Aswan

Case	WWR	Initial cost	2002: 2012-2025 (14 years)		2020: 2026-2039 (14 years)		2050: 2040-2069 (30 years)		2080: 2070-2099 (30 years)		Overall annual running cost	Average annual running cost (Overall/88)	9%	88.00				
			Running cost	Sub total	Running cost	Sub total	Running cost	Sub total	Running cost	Sub total			diff in initial cost	accumulation after 88 yrs	diff in running costs	accumulation after 88 yrs	saving in initial cost vs. saving in running cost	
SS		10902	785.97	11003.5177	923.74	12932.3098	1091.09	32732.791	1357.70	40731.0421	97399.66	1106.81	0	0.00	0.00	0.00		
OS	20%	5578	1300.39	18205.462	1553.70	21751.8061	1867.47	56024.029	2409.95	72298.5655	168279.86	1912.27	- 5,324.00	- 9,601,594.65	805.46	17,583,713.54	7,982,118.88	SS over OS
SO		10912	851.19	11916.6287	1000.52	14007.2173	1178.80	35364.029	1456.83	43705.0815	104992.91	1193.10	10.00	18,034.55	86.29	1,883,706.03	1,901,740.58	SS over SO

Table 7: Financial analysis for building B-2

3.3 DISCUSSION

The analysis of the simulation results, along with the financial analysis, will be used in the following discussion, regarding each building (B-1 and B-2) in every climatic zone used in the simulations:

3.3.1 Building-1

1) Alexandria:

• The Case SS achieved the best energy performance (monthly energy consumption and annual cost), in addition to the best thermal performance in terms of thermal comfort.

• As noticed from the thermal comfort curves, all the building specifications (OS, SO and SS) achieved the requirements of the thermal comfort in all the different climatic periods, in addition to the convergence levels of thermal performance for all the specifications especially in the middle of the hot period (July and August), This makes us resort to the financial studies that suggest the use of case OS, as the only case that overcomes the SS financially as shown in Table 6.

2) Cairo:

• The Case SS again achieved the best energy performance, as well as the best thermal performance in terms of thermal comfort.

• Despite higher financial returns (see Table 6) compared to SS, the case OS will not be chosen as the best case for Cairo, because according to the thermal performance curves OS will be so close to the lack of thermal comfort in the 2080 climatic period. So, it seems that SS combination will be the only specification that achieves thermal comfort with financial gains.

3) Aswan:

• The Case SS likewise achieved the best energy performance, the best thermal performance as shown in Figures 9/a and 9/b and the best financial gains according to the financial study (see Table 6).

• The requirements to achieve the thermal comfort necessitate the use of the SS combination, where other specifications do not achieve even asymptotic level of thermal comfort of the SS specifications in all climatic periods, especially in the period of 2080, where they didn't meet the thermal comfort requirements.

3.3.2 Building-2

1) Alexandria:

• The Case SS has achieved the best monthly energy consumption and annual energy cost, in addition to the best thermal performance.

• As noticed from the thermal comfort curves, all the building materials sets achieved the thermal comfort requirements in all the different climatic periods with very close levels of performance, making us resort to the financial studies that suggest the use of case OS, which was the only case that overcomes the SS financially as shown in Table 7.

2) Cairo:

• The case SS, seems to achieve the best energy and thermal performance, as well as the best financial gains according to the financial study (Table 7).

3) Aswan:

• Case SS achieved the best energy performance (monthly energy consumption and annual cost), the best thermal performance in terms of thermal comfort, as well as the best financial gains (see Table 7).

IV- CONCLUSION:

In this paper, the effect of the climate change on the various building material sets used for the external walls and fenestration (as parts of the building envelope) has been evaluated. In the simulations, three different sets of building materials have been tested, applied for two residential buildings, and simulated in three different Egyptian climatic zones. The experiments are based on building performance simulations that take into account the external walls materials, WWR, glass type, shading devices recommended by EREC for each climatic zone, and four weather data files representing the current and future weather scenarios, to evaluate the energy consumption and the thermal comfort of each of the building models. Additionally, a financial analysis based on the results of the simulations has been performed to point out what seems to be the most cost-effective specification (of the threebuilding (three building) material sets used) with respect to the initial and the running costs. The results showed that, in spite of the large area of the solid part in the building envelope, and the high cost needed for its treatment to mitigate the external harsh conditions, the openings effect in allowing the external heat to penetrate in the indoor space through solar radiation makes a big and obvious impact on the monthly energy consumption, hence annual energy cost.

Simulation results showed different performance for each building materials set across the climatic zones. However, in general, the results recommend the use of the half red-brick wall (12cm) for the external walls and the single clear reflective 6.4mm (G2) glass with 20% WWR (OS set), as the most cost-effective combination on the long run in Alexandria. The SS set was recommended for use in Cairo and Aswan climatic zones due to thermal performance and, as the most cost-effective set of building materials. In Cairo the SS set consists of the double wall of half red-brick with 5cm air gap (Dair) for the external walls, and the single clear reflective 6.4mm (G2) glass with 20% WWR. The SS set for Aswan consists of the double wall of half red-brick with additional internal 5cm of expanded polystyrene thermal insulation layer for the external walls, and the single clear reflective 6.4mm (G2) glass with 20% WWR for fenestration.

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