EVALUATION OF SHADING THE SOLID PARTS OF BUILDING ENVELOPES UNDER CLIMATE CHANGE SCENARIOS IN EGYPT

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Abstract:

As a vital method for mitigating the solar radiation effect on buildings, shading is considered of paramount importance, especially in Egypt as a hot arid climate country, with very high solar radiation intensity most of the year. Hence, the importance of studying shading strategies against future climate change emerged. Therefore, current practice of construction industry in Egypt needs to consider passive architectural design for residential buildings, which consume about 20% of the energy consumed in the built environment, and emit about 4% of CO2. Wherefore, this paper focuses on the determination of the optimum ratios for shading the solid parts of the building envelope in three main climatic zones in Egypt, under different climate change scenarios, to support both policy and decision makers taking steps forward towards energy efficiency obligations in Egypt. To achieve this objective, multiple dynamic thermal simulations have been conducted in order to evaluate the effect of the solid parts shading while maintaining the optimum thermal comfort conditions, reducing energy consumption and gaining long-term financial benefits. All the possible combinations (for a certain set of assumptions) of shading the solid parts of the envelope were tested for the different orientations (South, East, and West). The findings confirm the secondary role of shading the solid part of the building envelope once appropriate thermal insulation and fenestration have been selected to achieve thermal comfort and long term cost effectiveness, while minimising the energy consumption.

Keywords: *Bioclimatic Architecture, Shading techniques, Fenestration, Energy Consumption, climate change.*

1. Introduction

Buildings provide many of the necessary requirements to humans, such as shelter, security and comfort. For thermal comfort it's essential to control the heat flow between outdoor and indoor spaces, through the thermal characteristics of the building envelope (Bradley and Johnston 2011, USDoE 2004, Okba 2005). In addition to the high temperatures, another environmental contributor to a building's heat gain is solar radiation (radiant energy), the primary source of heat gains (Al-Temeemi 1995) in the hot arid zones with little cloud cover and high solar radiation most of the year, such as Egypt. When the sun's energy impacts a building envelope, heat will enter either directly through transparent areas, or it will be absorbed through the building fabric and heat will enter the building through conduction. Protection against strong solar radiation in the hot arid zones is essential to reduce cooling loads required to achieve thermal comfort within the indoor spaces, especially in the summer, as facade configurations responsible for up to 45% of the building's cooling loads (Hamza 2008). Appropriate envelope design can be optimized for natural lighting and efficient thermal performance through passive solar techniques (Makram 2008, Kassim and Bathis 2003). Vernacular architecture demonstrate such examples (El-Wakeel and Serag 1989). Shading the external envelope was achieved in different ways, E.g. by surrounding the building by a group of trees that hinder the exposure to the solar radiation, by cultivation of green areas to reduce the reflection of the solar radiation on the walls, or by clustering the buildings to reduce the exposure of the external surfaces to direct sunlight. The different heights of the buildings and the small width of the pedestrian streets, lead these buildings to shade each other, resulting into less thermal energy penetrating indoors. However, modern development and vehicular traffic, it was difficult to keep the narrow roads with human scale and the previous climatic advantages (El-Wakeel and Serag 1989).

Not all the design features of the traditional houses might be appropriate today, although the traditional house considered the climate as a main determinant. Solar screens were widely used in the Middle-Eastern countries for centuries to reduce the required cooling energy. However, there is a lack in understanding of their performance quantitatively, in addition to the unavailability of scientific means to develop new efficient designs to suit the harsh desert conditions nowadays (Sherifa et al. 2012). A considerable number of publications have addressed the effect of shading wall openings (such as windows) on energy consumption in different regions, some with the same climatic conditions as Egypt, all stressing the importance of the shading technique (Ali and Ahmed 2012, Ahmed 2012, Al-Tamimi et al. 2011, Yang and Hwang 1995). However, these studies considered the effect of shading devices over fenestration or on a combination of walls including windows. In sharp contrast, a limited number of publications addressed the effect of shading the solid parts of the building envelope (opaque solid walls) specially in such a hot arid climatic zone like Egypt (Sherif et al. 2011, Sherifa et al. 2012). Of these very rare manuscripts, El-Wakeel (El-Wakeel and Serag 1989), who only mentioned the technique of using another wall to shield the main wall, Kravchuk and Boland (Kravchuk and J. W. Boland 2000), who concluded that the wall shading will improve the indoor thermal comfort in Adelaide city in South Australia. Ahmed al-Sharif, et al. (Sherif et al. 2011), paid attention to the effect of shading the external opaque walls on the potential savings in energy consumption, in order to conclude the best utilization of external wall shading methods.

In this work the solid parts of the external walls is addressed for exposure to different proportions of direct or reflected solar radiation, subject to the direction of the sun during the daylight hours and to the changing in the ray's incidence angles in the different seasons of the year. One of the solutions for solid walls treatment is shading it using the sun breakers, such as those used for fenestration (the non opaque parts) or by using double walls (Gomez-Munoz and Porta-Gandara 2003a, El-Wakeel and Serag 1989, Gomez-Munoz and Porta-Gandara 2003b). The latter will be used (with some adjustment) to determine the optimum ratios for shading the solid parts of the building envelope using solid screens to increase the energy conservation for cooling. This is additional to the integration of thermal insulation of the external wall types commonly used in Egypt as examined in (Mahdy and Nikolopoulou 2012, Mahdy and

Nikolopoulou 2013), and dealing with different fenestration and shading parameters (Mahdy et al. 2013, Mahdy and Nikolopoulou 2014) mentioned in the Egyptian Code for Improving the Efficiency of Energy Use in Buildings – Part 1: Residential Buildings (HBRC 2008), (for simplicity it will be referred to as EREC for Egyptian Residential Energy Code), in terms of a long term financial study of these parameters, to achieve thermal comfort with minimum energy consumption and consequently minimum CO_2 emissions, along with optimum initial investment and running costs. The effect of the solid envelope will be examined in three different climatic regions in Egypt, under the different scenarios of climate change, essential to evaluate the building's thermal performance over the long term. 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 building's cooling capacity and associated energy consumption (Levermore et al. 2012). Hence, the importance of studying shading strategies against future climate change emerged to minimize the expected overheating.

The focus of the current study aims beyond the energy consumption at the present time to address climate change scenarios in the future, as well as the long-term consumption, based on financial analysis for the economic returns in the long-term, taking into consideration the project's initial cost (capital cost) as well as the running cost. Our results are likely to be of interest to a wide range of designers, architects and to support both policy and decision makers taking steps forward towards energy efficiency obligations, particularly in Egypt

2. Methodology

Dynamic thermal simulations were employed for this research using Energy plus, and its architectural friendly interface DesignBuilder (DB) in its third version (V.3.0.0.105) (DB 2012). For the simulations, a model of a typical residential building (one of the commonly used prototypes for the governmental housing in Egypt) in Cairo with mechanical air conditioning installed was employed, which was then tested in three of the Egyptian climatic zones defined in EREC (HBRC 2008, OEP 1998), Cairo and Delta, the North coast and the Southern climatic zone, while keeping the same orientation. Overall:

1) 768 dynamic thermal simulations have been carried out, to evaluate the effect of various parameters on monthly energy consumption (kWh), indoor air temperature (°C) and associated consumed energy cost on the long term. These have been tested under the current climate conditions (2002), and the different climate change scenarios for three periods: 2020, 2050 and 2080.
2) A new code (EPP) (discussed in section 2.2) has been developed and used to facilitate the huge number of simulation processes and to ensure the accuracy of the results.
3) Modelling of long-term financial analysis was carried out (section 4.2) to identify the most cost-effective technique to be used in each climatic zone in Egypt. This takes into account the initial cost as well as the running cost of each case.

For the purpose of this work, the following assumptions have been made:

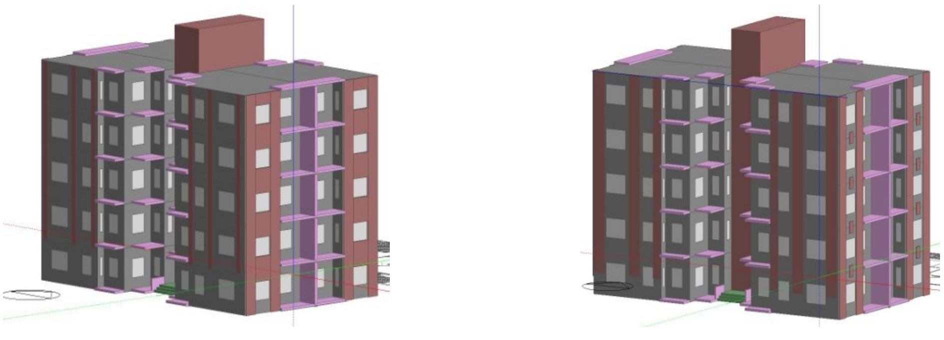
1) As shown in EREC and previous work (Mahdy and Nikolopoulou 2014), the maximum Window to Wall Ratio (WWR) allowable for the entire climatic zones in Egypt is 20%, which will be used in the work.
2) To represent the effect of the external shading provided by the surrounding buildings, vegetation and other obstacles. A ratio of 30% has been assumed for each façade.
3) The building self shading produced by the balconies and the other prominence elements in the building, assumed to cover another 10% of the building's envelope.

This set of assumptions does not represent all the possible eventualities in real life, but it's a start for more investigations in the same field to prove whether it is efficient to use this kind of shading techniques.

2.1. Solid shading screens

According to the aforementioned assumptions, there will be about 60% of the building's envelope covered, and about 40% of each façade left without protection against the direct and indirect solar radiation. The cost effective protection for these remaining parts will be evaluated, by taking into account all the possible probabilities in shading these remaining 40% of each façade using solid screens mounted on the external walls. The screens are assumed to be 10 cm away from the main walls, made of light steel frames with iron mesh covered with cement, then painted in light colours, with a total thickness of 5 cm.

All the shading probabilities for the South, East and West façades have been addressed by altering the different percentages from 10% to 40% of unprotected parts of each façade (see Fig.1 for examples, 10-40-20% refers to the shading screen’s area: 10% of the total façade area for the Southern façade, 40% for the Eastern façade and 20% for the Western façade). All the percentages alternatives are shown in Table 1 (64 probabilities). This process is repeated for the three climatic zones (Alexandria, Cairo and Aswan) resulting in 192 simulations, while repeating the process for the four current and future Weather Data Files (WDF) (2002, 2020, 2050 and 2080) gives a total of 768 simulation, providing the results for this work.



10-40-20%

20-30-20%

Figure 1: Examples for the different probabilities of shading the solid parts.

Table 1: Building's shading probabilities for one climatic zone for one WDF.

South Façade		East Façade			
10%		10%	20%	30%	40%
West Façade	10%				
	20%				
	30%				
	40%				

South Façade		East Façade			
20%		10%	20%	30%	40%
West Façade	10%				
	20%				
	30%				
	40%				

South Façade		East Façade			
30%		10%	20%	30%	40%
West Façade	10%				
	20%				
	30%				
	40%				

South Façade		East Façade			
40%		10%	20%	30%	40%
West Façade	10%				
	20%				
	30%				
	40%				

2.2. Automation of the simulation processes

The initial simulation execution strategy (Fig.2) was to use DesignBuilder (DB) and its Energy Plus integration. Three parts are included, a model, a location setting on the model and a WDF per location and year settings. The simulation is then run and the results are observed by exporting the simulation results as a CSV file through DB for the visual representation. The approach was sufficient as a proof of concept and for initial tweaking of the model and other parameters. However, the plan was to run 768 simulations, which led to the need of a faster less human dependent solution. Thus, Energy-Plus-Plus (EPP) was born.

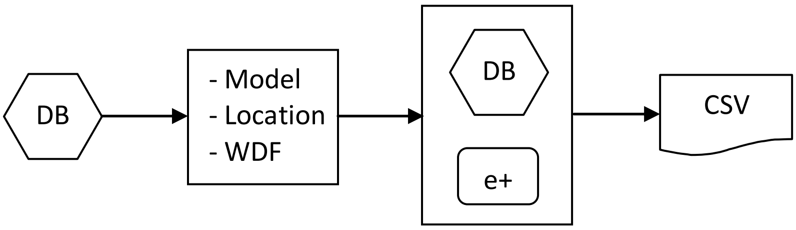


Figure 2: The ordinary method used to conduct simulations.

A Java automated runner for Energy Plus simulations (e+), the first version (see Fig.3) of which was used to produce the results in this work. This version provides automation for the simulation step, the most time consuming step of the process. The simulation scripts (IDF files) are produced using DB after configuring the location and are independent of the yearly weather files. I.e. A single simulation script can run against all four weather data files the study is concerned with (2002, 2020, 2050 and 2080). So all scripts of a specific model and location is then gathered in batches and then passed as inputs to EPP along with all the weather files of the specific location. It is then run to generate Energy Plus output (ESO files), that is parsed using DB later on and then exported into CSVs. EPP is modular in design and built with the intention of streamlining the entire process including script generation, output parsing and parallel simulation execution. EPP yet is under development aiming to reduce the human intervention in the multiple simulations execution as much as possible, granting the ability to execute more simulations and cover a broader spectrum of possibilities with more supporting evidence.

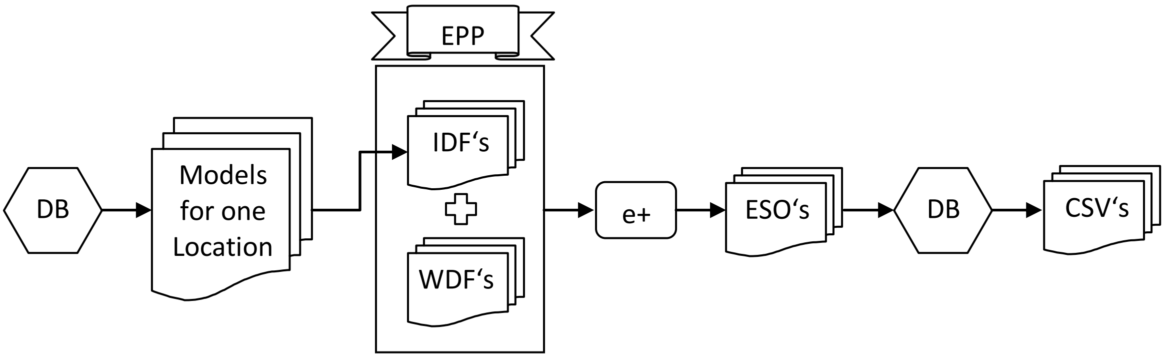


Figure 3: New technique used to handle the simulations.

3. Parameterization

Egypt is a large country with an area of approximately 1,000,000 km^2, located between 22° N - 31° 37′ N latitude and 24° 57′ E - 35° 45′ E longitude. Egypt possesses a diversity of climate conditions ranging from extremely hot conditions in the desert regions such as the Western Desert, to cold conditions in Mountain St. Catherine in Sinai Peninsula (Mahmoud 2011). However the overall climate of Egypt is characterized by the hot arid climate (Köppen classification: BWh) with very high solar radiation intensity most of the year (Solar-GIS 2013, SODA 2013). Egypt is divided into eight climatic zones. The current experiments will take place in three climatic regions in Egypt: (1) Cairo and Delta zone (Cairo governorate), (2) North coast zone (Alexandria governorate) and (3) the Southern Egypt zone (Aswan governorate). About 50% of the construction projects carried out in Egypt are located in Cairo and Alexandria governorates (Huang and Berkeley 2003), while Aswan governorate is considered a very different zone in terms of the climatic aspects compared to the other zones (El-Wakeel and Serag 1989, HBRC 2008, Gira 2002).

Depending on the theory of Adaptive Comfort (Humphreys et al. 2013, Humphreys 1996), and according to Givoni (Givoni 1998), the thermal comfort zone 20°C-29°C, has been used in the experiments. This is an modification of the original comfort zone (22.2°C-25.6°C) mentioned in EREC (HBRC 2008).

Four different WDFs ranging from the current weather conditions (2002), to the predicted WDFs (2020, 2050 and 2080) have been used to provides a maximum test period of 88 years, as 2012 was assumed to be the starting construction year (the WDFs were divided as shown in Table 2. The current weather data file (2002) was obtained from the official site of the U.S Department of Energy (USDoE 2012). Then by using the Climate Change World Weather File Generator (CCWorldWeatherGen) (SERG 2012), the future WDFs for 2020, 2050 and 2080 were generated. The new weather data files have been used accordingly for the simulations, after using the DB weather data converter tool to convert them into an hourly weather data files that can be used with DB. Figure 4 demonstrates the future climate change scenarios for the different climatic regions involved in the study (Alexandria, Cairo and Aswan respectively), starting with the present climate conditions until the 2080 projections. The left graphs presents the outside dry-bulb temperatures for the current and the three future scenarios, while the graphs on the right shows the direct solar radiations for the same climatic periods. Out of the diagrams, the apparent increase in the temperatures from a climatic period to the period following can easily observable. On the contrary the solar radiation rates were very close to the existing conditions.

A fixed schedules for energy consumption were used in all the different simulations (in conjunction with the cooling and heating setpoints) to control the timing in DesignBuilder and to define certain activities in the simulations, such as occupancy times, equipment, lighting and HVAC operation (DB 2011). The schedules were defined through a fixed activity template, based on the common lifestyle for the residents of Egypt (holidays, work hours, etc.) (Attia et al. 2012). A 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. Simple HVAC systems setup were used in the simulations, where the heating and cooling systems are modelled using basic loads calculation algorithm (Energy Plus zone HVAC ideal loads) (DB 2011). The HVAC specifications include the use of split air-conditioning units (with cooling COP=1.83) for the whole day in the summer when the temperature exceeds 29ºC until it drops below 25ºC; otherwise, natural ventilation was used. It should be noted that, the aforementioned parts of the methodology has been discussed extensively in the previous work (Mahdy and Nikolopoulou 2014, Mahdy and Nikolopoulou 2013).

The simulation techniques including modelling, building materials assignment, lighting and HVAC systems configurations have been examined in order to validate the simulated results. To attain this objective, the monthly energy consumption data for two different flats (in Cairo) were obtained out of the energy bills, then the exact energy consumption was compared with the simulated results for each model. The accuracy reached almost 90% for one of the cases and about 87% for the other. This reflects that the predictions are in good agreement with the on-site measured data, thus this simulation processes can be used to validate the research objectives in the current weather conditions, and under future climate change scenarios.

Table 2: Different time periods covered by the WDFs.

WDF	Covered period (years)	From - to
2002	14	2012 - 2025
2020	14	2026 - 2039
2050	30	2040 - 2069
2080	30	2070 - 2099

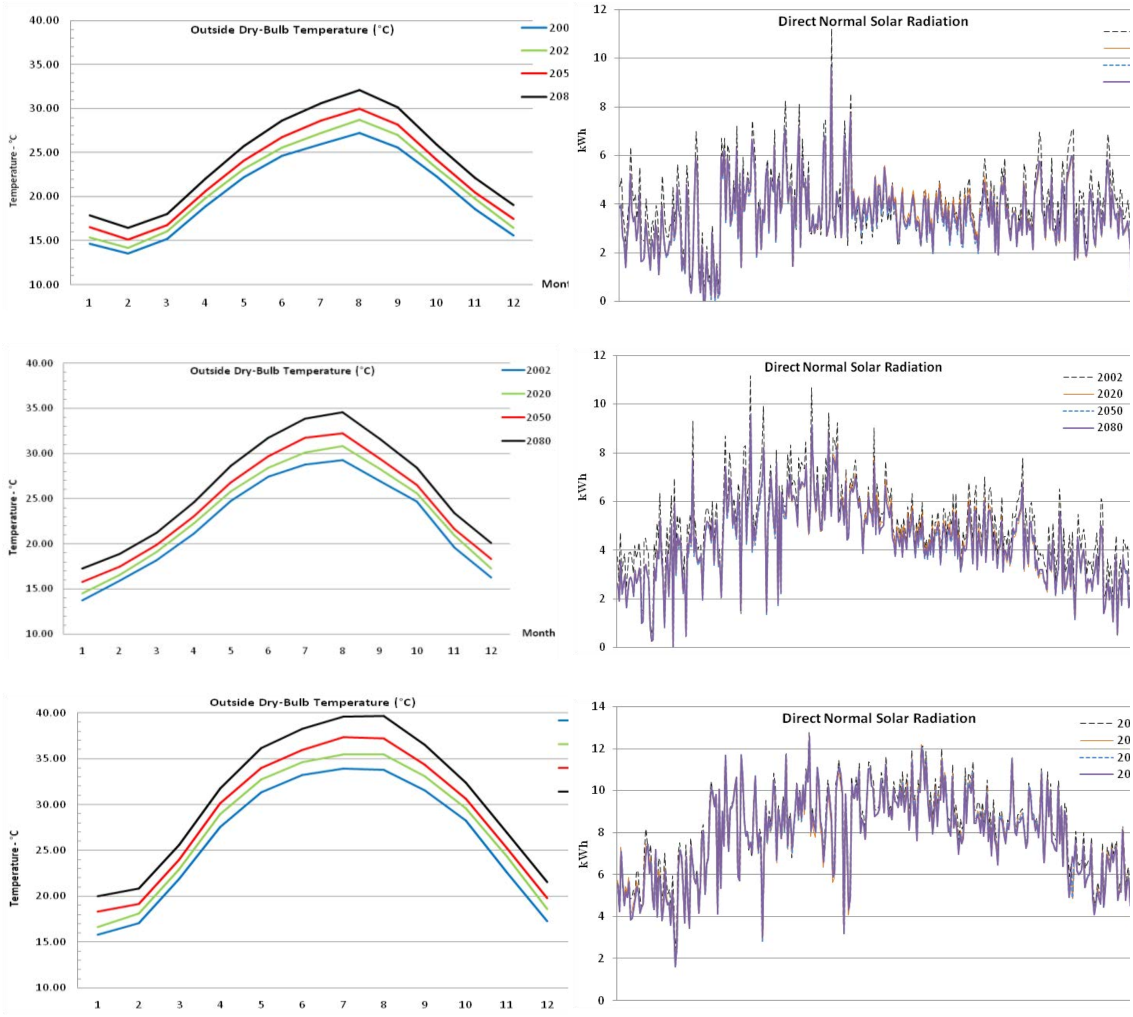


Figure 4: Future weather projections for Alexandria, Cairo and Aswan.

3.1. *Model definition*

The building which underwent treatment processes and simulations is a governmental housing building consists of six floors, where each has four residential flats with an approximate area of 86 m^2. The average number of occupants per flat is four. The building floor plan is shown in Fig 5.

Figure 5: Typical plan for the Modelled flat.

3.2. Building materials specifications

A set of materials were used for the model's construction in the different three climatic zones, evaluated in previous work (Mahdy and Nikolopoulou 2014, Mahdy and Nikolopoulou 2013), which recommended the use of:

(1) External walls: the double wall of half red-brick with 5cm 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 (see Fig. 6 and Table 3 for the thermal specifications).

(2) Fenestration: the Single Clear Reflective 6.4mm, with 8% Stainless-Steel Cover, along with 20% WWR, as the most cost-effective glass type and WWR to be used for the long run in the three climatic zones (see Table 4 for characteristics).

These are the optimum specifications shown to achieve indoor thermal comfort, minimize the energy consumption, while attaining the maximum financial benefits. The models which used these materials only without any shading for the solid parts will be known as the "Base case" model. The thermal properties for the building materials were obtained from EREC (HBRC 2008), and the Egyptian Specifications for Thermal Insulation Work Items (HBRC 2007).

Table 3: External Walls main characteristics.

External Walls	**ABBRV.**	**Thick. (mm)**	**U-Value (W/m^2K)**
Double wall of half red-brick with 5 cm air gap in between.	*Dair*	290	1.463
Double wall of half red-brick with additional internal 5cm of expanded polystyrene thermal insulation layer.	*Dins*	290	0.503

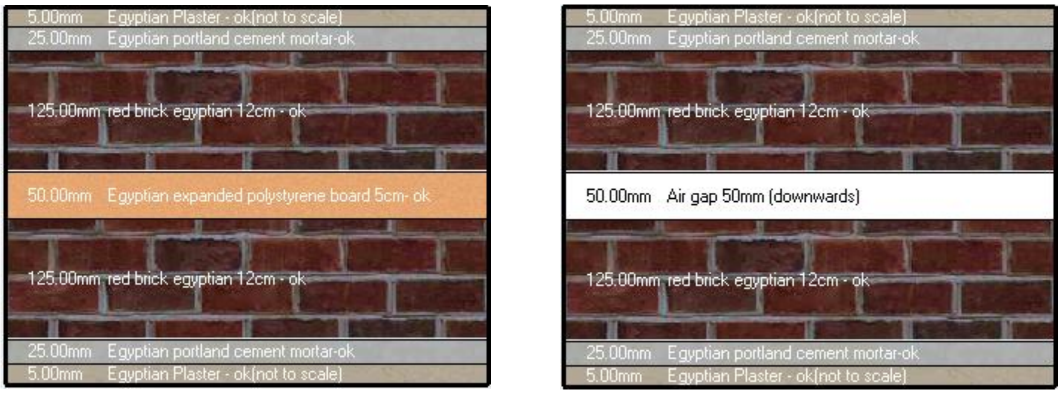


Figure 6: Wall sections used.

Table 4: Used glass specifications.

Name	**Category**	**SHGC**[*]	**LT**[**]	**U-Value** (W/m^2K)
Clear Reflective 6.4mm – (Stainless steel Cover 8%)	Single Reflective	0.18	0.06	5.36

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

3.3. *Financial information*

3.3.1. Construction materials costs

The price-list of Construction materials, obtained from The Engineering Authority Indicative Guide (EAAF 2012) was used to calculate the initial cost of project. These numbers were used later for the financial analysis (section 4.2).

3.3.2. Electric energy prices

For the financial analysis, the cost of the energy consumption per flat per year was calculated using the electricity tariff derived by the Egyptian Ministry of Electricity and Energy for the residential sector (MOEE 2012), which is referred to as operation cost or running cost. The different categories and prices are shown in Table 5.

Table 5: The electricity tariff.

no.	Category (kW)	Price (EGP)	no.	Category (kW)	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

4. **Results and discussion**

A huge reduction in energy consumption was expected. However, a very small reduction resulted due to the appropriate construction materials that have been used, which obtained from the previous work (see section 3.2). The analysis process will address three phases: (1) Thermal comfort results, (2) Financial analysis and (3) Assessment of different alternatives.

The results obtained from the different simulations are divided in three separate graphs: Monthly Energy Consumption (kWh), Annual Energy Cost in Egyptian Pound (EGP) and Indoor/outdoor temperature (°C). These measures were plotted for the three climatic zones, different shading alternatives and different climate change scenarios in 48 graphs. However, as the results for the three different climatic zones were consistent, almost with the same indications, therefore, the results for Cairo climatic zone (16 graphs) were discussed and some of its graphs were displayed (Figs.7-14) as a representative for the other obtained results, which generally followed the same patterns, but with some decrease in energy consumption, subsequently the annual energy cost in Alexandria (to the North), and some increase in energy consumption in Aswan (to the South), due to the general weather conditions in each climatic zone. The graphs were listed according to the climatic periods (2002, 2020, 2050 or 2080) and to the solid parts shading ratio which named after the Southern façade (10, 20, 30 or 40%). For each weather period, the upper left graph represents the monthly energy consumption for the different shading ratio's alternatives of the solid parts of the building envelope. As expected for the same climatic region, the energy consumption increases from a climatic period to the following period due to the temperature increase under climate change (Crawley 2007), this applies to all climatic zones. The upper right graph in each weather period represents the annual energy cost according to the household electricity tariffs used in Egypt (MOEE 2012). As predictable, the results show that the cost is directly proportional to the increase in energy consumption. Finally, 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, climatic periods, types of construction for the external walls and its different shading ratios.

4.1. Thermal comfort results

The thermal comfort is one of the main and the most influential concerns in the design process. The thermal comfort (in cost effective way) was already achieved for all the tested models with different shading probabilities in all the different climatic zones and periods, due to using of the proper building envelope insulation and fenestration treatment (the base case itself already achieved thermal comfort from the beginning). Nevertheless, the goal was to decrease the energy consumption and enhance the financial aspects using the solid parts shading technique while maintaining the thermal comfort conditions.

As it turns out, the simulations did not show any remarkable development in the thermal comfort curves (see Figs.7-14), just a very small improvement (reduction in the indoor air temperature) of 2-3% achieved as the best result in Cairo, and from 1-2% in Alexandria and Aswan according to the Indoor Air Temperatures resulted from the simulations, but as mentioned before within the acceptable range of the thermal comfort zone. At the same time this slight improvements have not shown any noticeable effects on the financial aspects.

4.2. Financial analysis

As all the cases achieved the thermal comfort, a long term financial analysis has been conducted to find out which case is more effective than the base case on the long term. The different solid shading alternatives used in our simulations were compared with respect to a long term financial aspect of 88 years period. The aim was to point out the best cost effective solid shading ratio for the whole building to be used in each climatic zone, and in all the future climate change scenarios taking into account the initial cost and the running cost of each alternative when applied. As a non professional financial study, some financial equations have been developed and derived based on the Net Present Value (NPV) financial model. The subsidized electricity tariff as well as the interest rate are assumed to be fixed over the study period. Putting into consideration that, the increase in the electricity tariffs (the removal of subsidies) or the decrease in the interest rate will not affect the general conclusion, to verify this several attempts were conducted on the economic model. The interest rate was reduced to 2% and the price of energy was increased up to six-fold, despite of this the general indicators of the results remained stationary, although the figures have been changed.

The financial implications for the results of the simulations in Cairo (representative for the rest of the climatic zones Alexandria and Aswan) are summarized in Table 6. The table shows the running costs for the energy consumed in Cairo for each climatic period (sub-total), as well as the average annual running cost obtained by dividing the running cost of the four periods added together (Overall annual running cost) by 88 years. The financial study has been performed for each climatic zone separately. For each tested probability, the initial cost has been calculated according to the area that has been shaded in each case. The difference in the initial cost of any case and the base case (with zero solid shading) is invested by saving the money in a bank with the regular 9% interest rate in Egypt (NBE 2012), following the formula:

$$V \qquad \text{(Eq.1)}$$

Where:
M : The difference in the initial cost in Egyptian pound (EGP).
N : The investment period in years.
: The amount of money rose after N years.

In addition, the bills paid for the consumed energy in each different case is referred to as the running cost. The difference in the running cost between any case and the base case will reflect in saving M_2 in EGP in the annual energy bill. After N years the amount of money V_2 raised from the running costs savings which calculated using the following formula:

(Eq.2)

However, none of the different alternatives has out paten the base case in any of the different three climatic zones. As indicated in table 6, only the negative numbers in the column "saving in initial cost vs. saving in running cost" according to the mathematical equations, indicates financial gains on the long term for any of the various alternatives of the study versus the base case, which proves that a proper thermal insulation and fenestration treatment are sufficient to achieve thermal comfort in cost effective way on the long term and under the climate change scenarios.

4.3. Assessment of different alternatives

In spite of the ineffectiveness of the different tested ratios and the sufficiency of using the insulation and fenestration treatments, the energy consumption (running cost) and initial cost analysis has been conducted to point out the optimum solid shading ratio in case of the desire of improving the thermal comfort and energy consumption even by a small amount. The ratio 10-10-10 was found to be the most cost effective case among the other ratios in all the climatic zones, when the running cost compared to the initial cost on the long term, due to the very small differences in the running cost between the different shading ratios, while the differences in the initial costs was higher (see Table 6).

5. Conclusions

In this paper, we have evaluated the effect of different ratios for shading the solid parts of the building envelope, on thermal comfort, energy consumption and cost effectiveness, in three main climatic zones in Egypt (Alexandria, Cairo and Aswan) under different climate change scenarios. In the simulations, many probabilities for shading the building envelope's solid parts combinations have been tested for the different façades of the model (Southern, Eastern and Western facades) all in the same time. The experiments are based on building performance simulations that take into account the external walls construction, WWR, glazing type, shading devices recommended by EREC and previous work findings for each climatic zone, and four weather data files representing the current and future climate change scenarios (2002, 2020, 2050 and 2080), to evaluate the energy consumption and the thermal comfort of the building model. In addition, a long term financial analysis was carried out based on the results of the simulations to reveal the effectiveness of using the solid part's shading strategy, with respect to the initial investment and the running costs. Simulation results as well as the associated financial analysis showed that, there is no need to use the solid parts shading technique in the presence of the proper external walls insulation and fenestration treatments for each different climatic zone, as it is not achieving significant improvements to the indoor thermal comfort, and moreover it is not cost effective for any tested ratio as well.

The initial investment and running costs were the main focus in this paper, as they are of primary importance for people developing and living in the buildings; so the focus has been on energy costs for keeping the building comfortable along with the associated financial costs (from construction to operation), as these are the costs that the user would have to bear. Although we agree that the life cycle cost is important, it is beyond the focus of this paper.

6. Further research

Fenestration's solar screens proved to provide high energy savings in severe desert environments, unlike the solid parts shading technique which this study advise not to use it in the presence of external wall's appropriate construction materials and suitable fenestration treatments. However, the preference of the use of heat treatments for walls with the fenestration treatments or solid parts shading techniques separately are under investigation by the authors, to find out which is better to achieve thermal comfort and financial profits on the long term, and the applicability of using the best techniques in the other Egyptian climatic zones is under investigation as well. Future work may include extending the set of assumptions that have been tested in this paper and simulating more models, to represent as much as possible the probabilities in real life and in order to assure generalizing the results.

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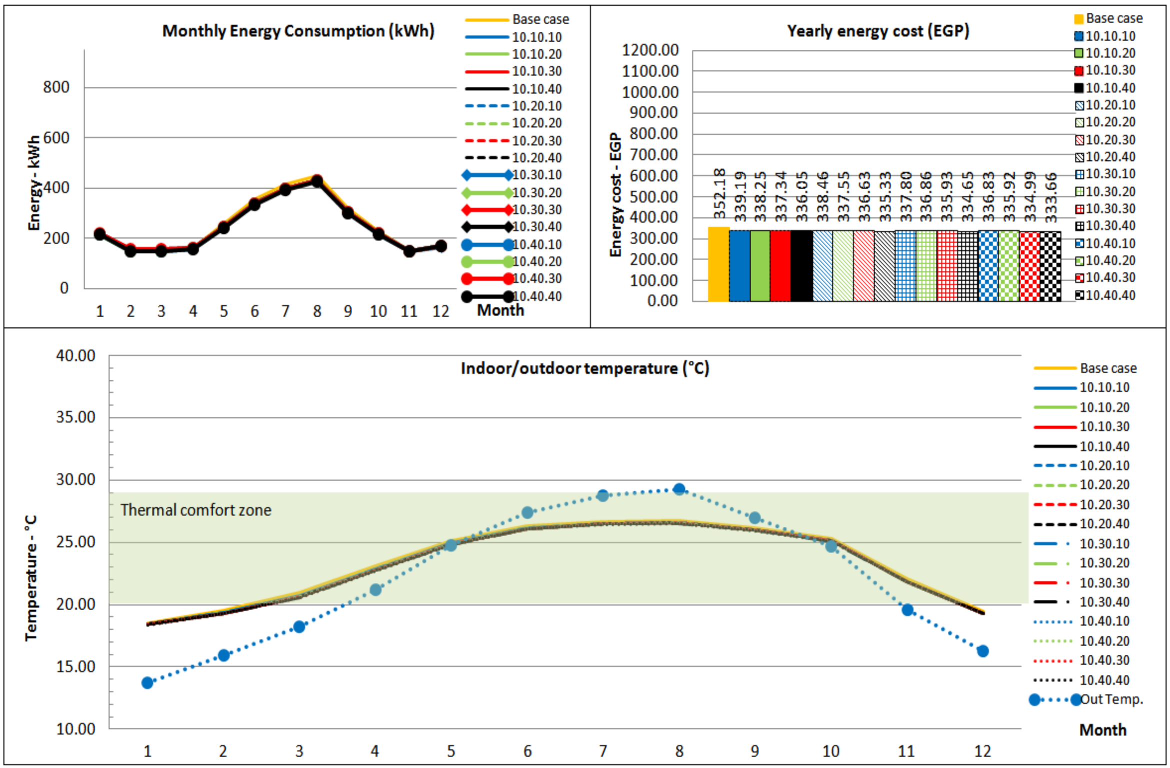

Figure 7: Simulation results for Cairo climatic zone - Southern Façade shading 10% - climatic period 2002

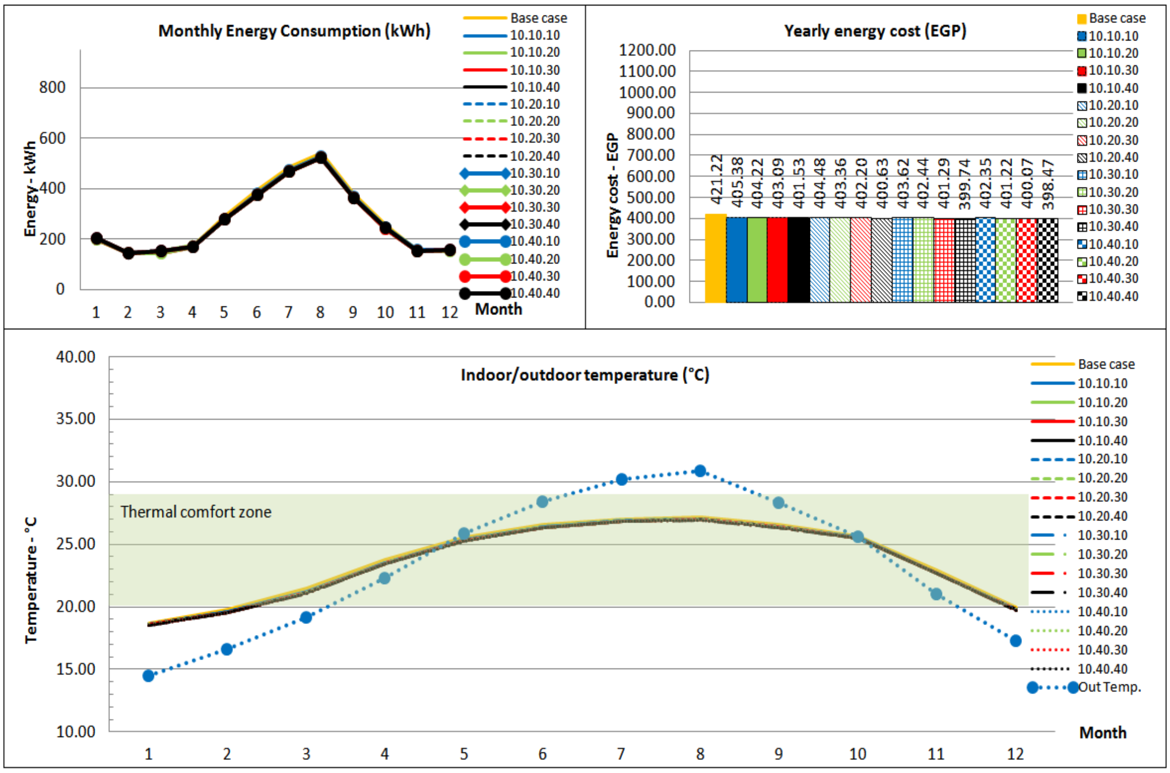

Figure 8: Simulation results for Cairo climatic zone - Southern Façade shading 10% - climatic period 2020

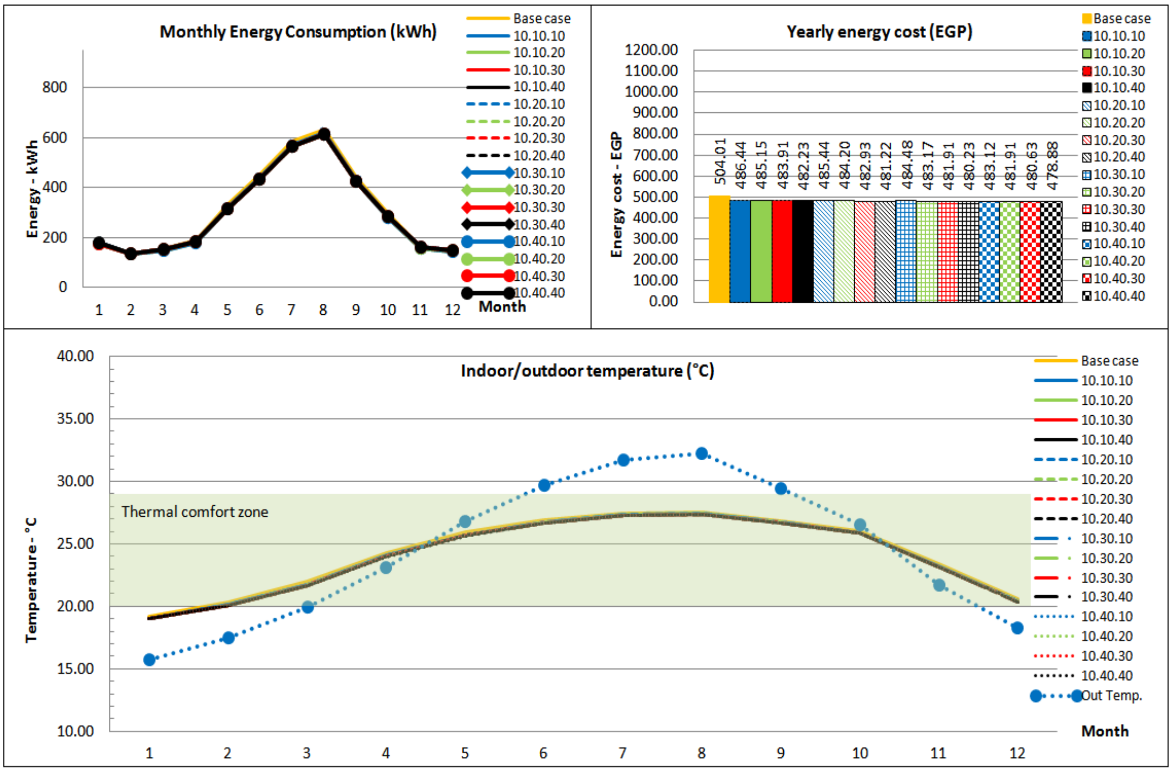

Figure 9: Simulation results for Cairo climatic zone - Southern Façade shading 10% - climatic period 2050

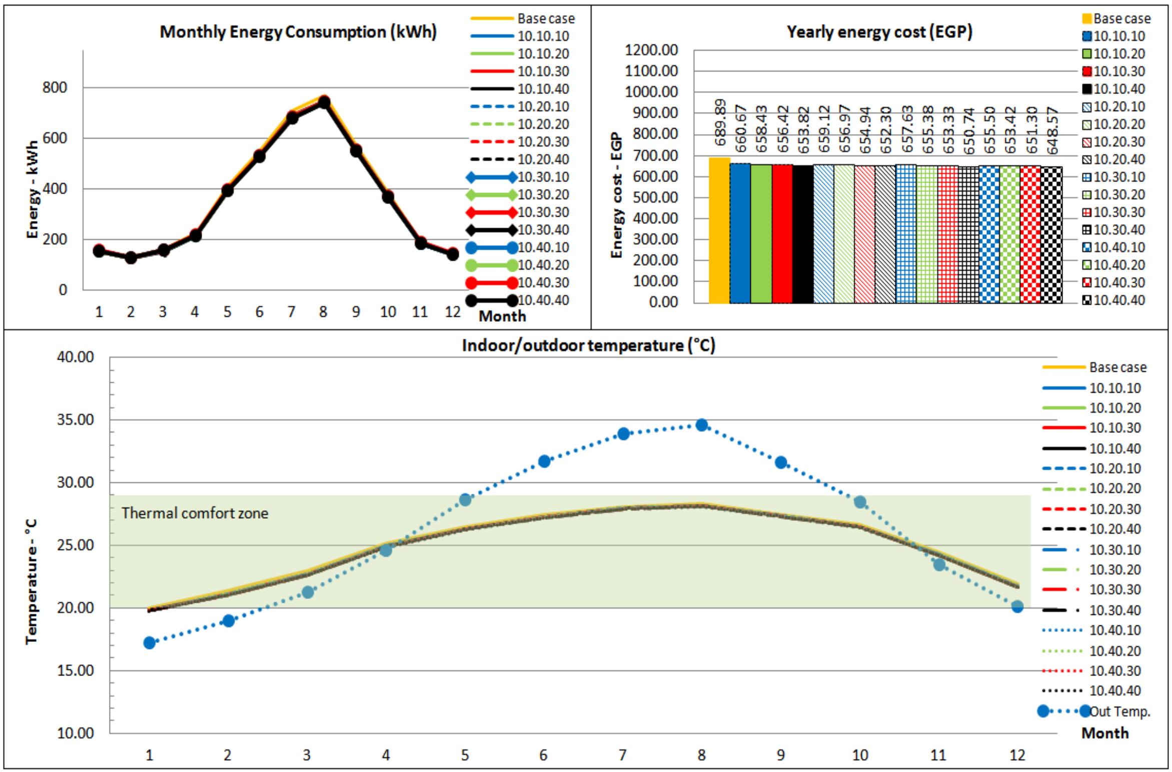

Figure 10: Simulation results for Cairo climatic zone - Southern Façade shading 10% - climatic period 2080

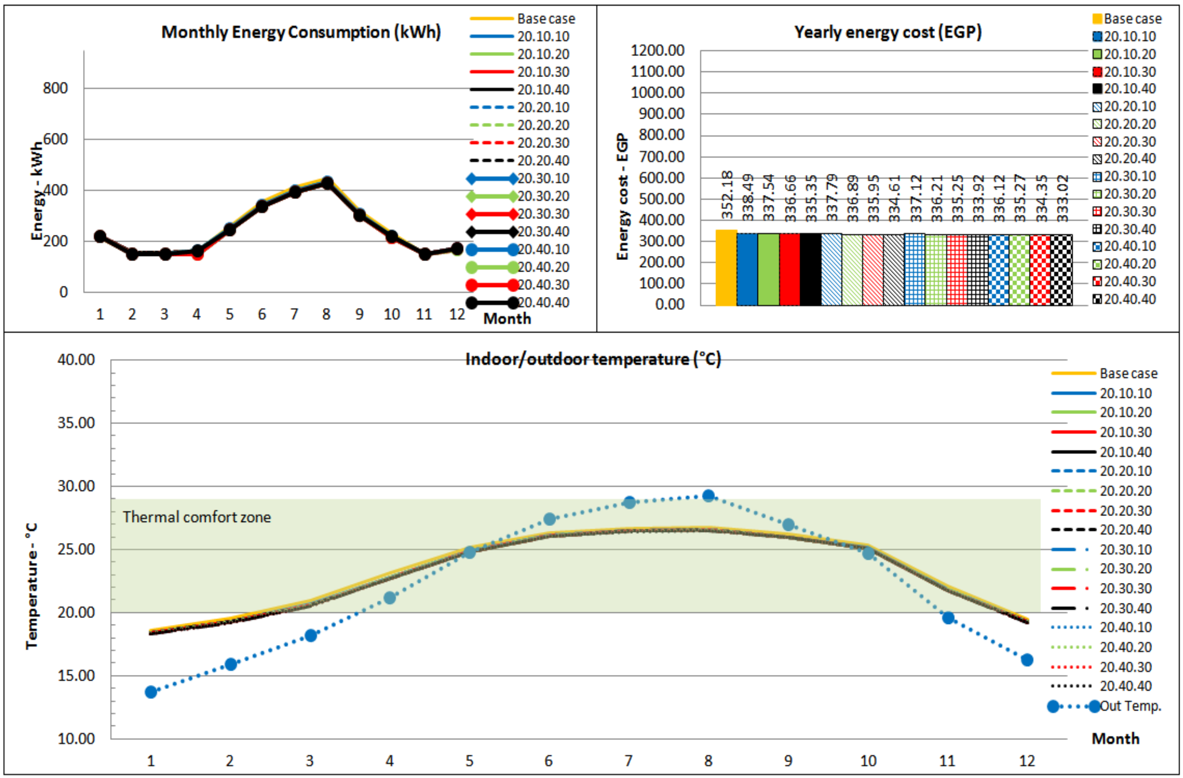

Figure 11: Simulation results for Cairo climatic zone - Southern Façade shading 20% - climatic period 2002

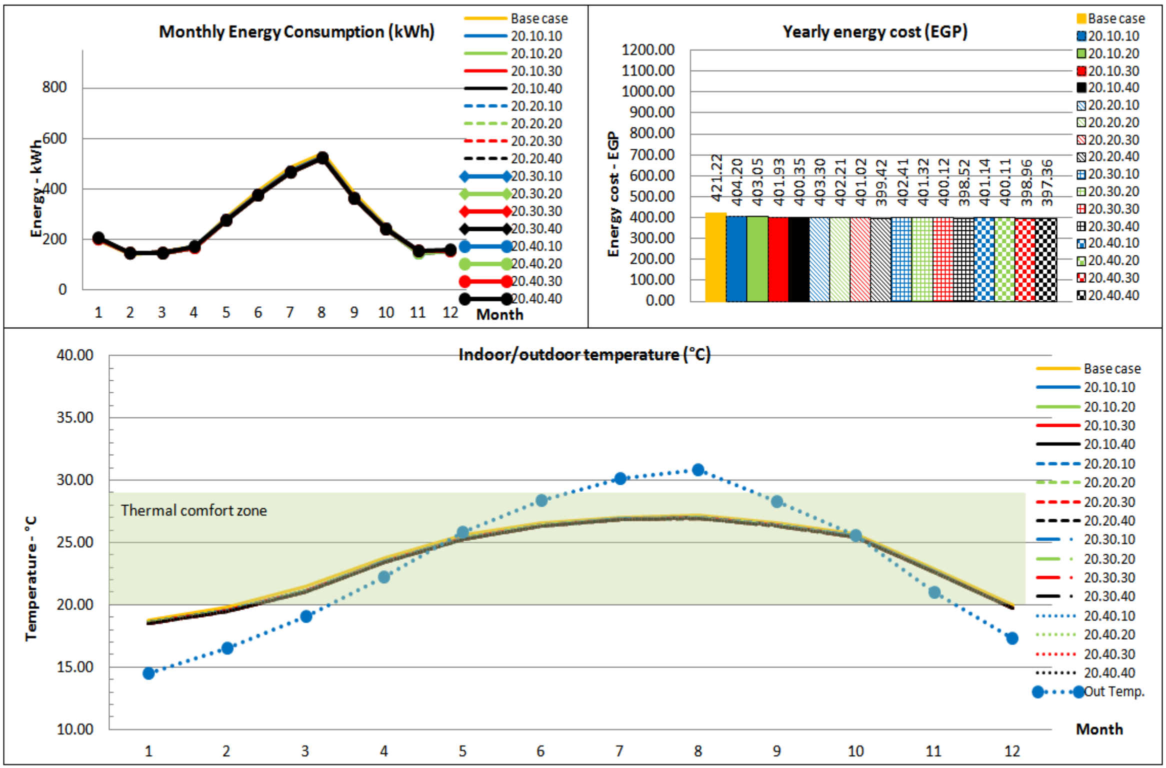

Figure 12: Simulation results for Cairo climatic zone - Southern Façade shading 20% - climatic period 2020

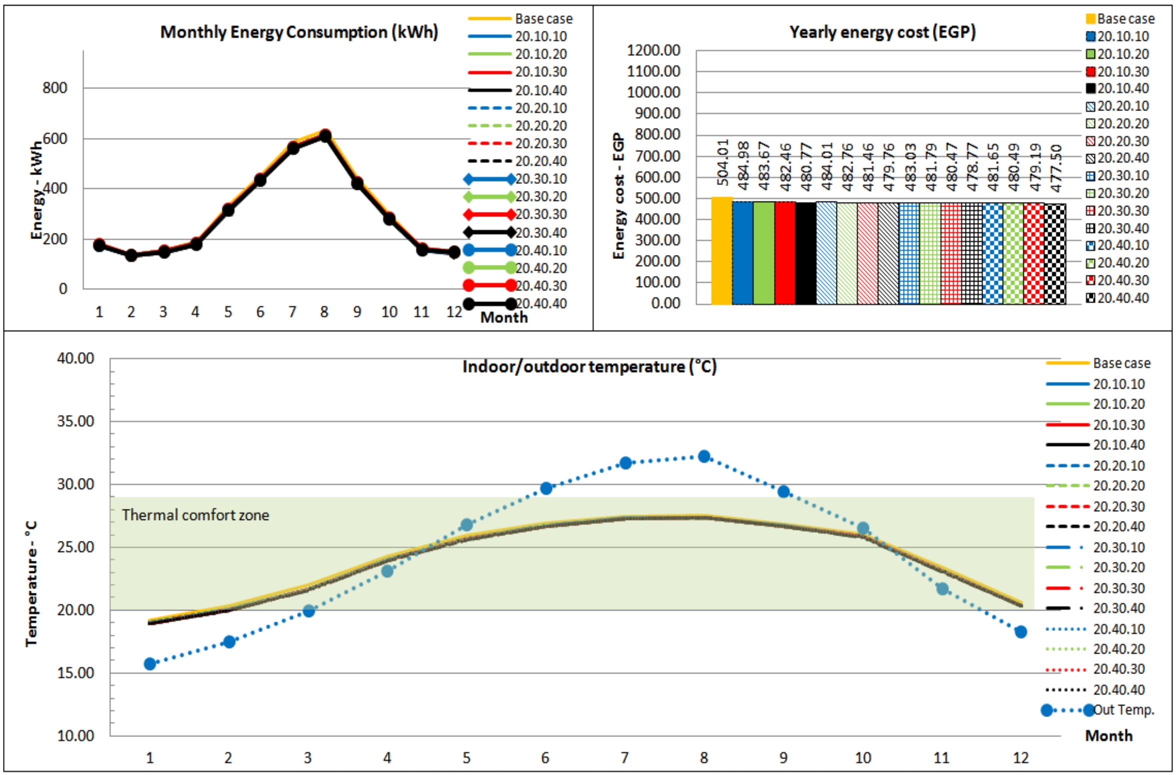

Figure 13: Simulation results for Cairo climatic zone - Southern Façade shading 20% - climatic period 2050

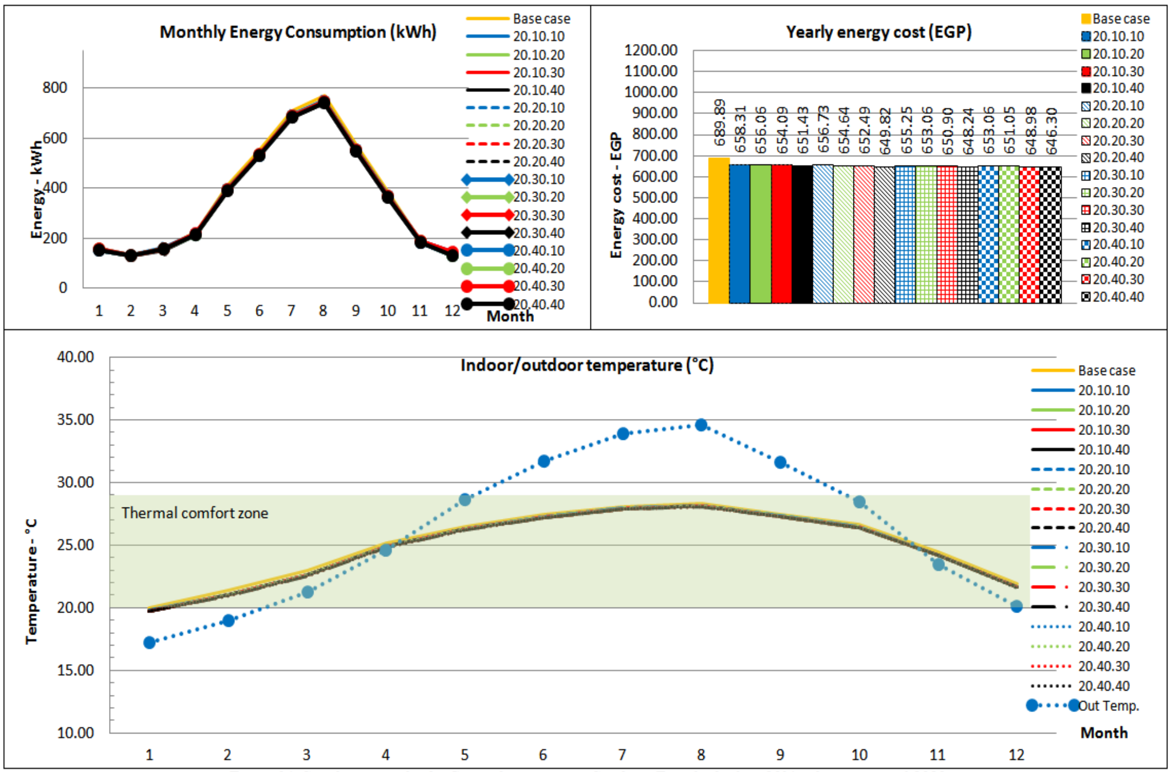

Figure 14: Simulation results for Cairo climatic zone - Southern Façade shading 20% - climatic period 2080

Table 6: Financial analysis for the simulation results of Cairo climatic zone.

	SS	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)	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
			Running cost	Sub total	Running cost	Sub total	Running cost	Sub total	Running cost	Sub total							
	Base B	EGP	352.18	4930.4943	421.22	5897.0748	504.01	15120.221	689.89	20696.5694	46644.36	530.05	0	0.00	0.00	0.00	
10%	10-10	6465.6	339.19	4748.6767	405.38	5675.375	486.44	14593.138	689.89	20696.5694	45713.76	519.47	6,465.60	11,660,418.93	- 10.58	- 230,860.32	11,429,558.62
	10-20	8236.8	338.25	4735.4831	404.22	5659.0949	485.15	14554.649	658.43	19752.9929	44702.22	507.98	8,236.80	14,854,698.51	- 22.07	- 481,799.38	14,372,899.13
	10-30	10008	337.34	4722.7081	403.09	5643.2086	483.91	14517.383	656.42	19692.5984	44575.90	506.54	10,008.00	18,048,978.08	- 23.51	- 513,136.86	17,535,841.22
	10-40	11779.2	336.05	4704.6516	401.53	5621.4381	482.23	14466.918	653.82	19614.6143	44407.62	504.63	11,779.20	21,243,257.65	- 25.42	- 554,882.24	20,688,375.42
	20-10	8236.8	338.46	4738.4411	404.48	5662.6949	485.44	14563.1	659.12	19773.5674	44737.80	508.38	8,236.80	14,854,698.51	- 21.67	- 472,971.92	14,381,726.59
	20-20	10008	337.55	4725.7581	403.36	5646.9871	484.20	14526.137	656.97	19709.0079	44607.89	506.91	10,008.00	18,048,978.08	- 23.14	- 505,200.40	17,543,777.68
	20-30	11779.2	336.63	4712.8417	402.20	5630.8554	482.93	14488.027	654.94	19648.0828	44479.81	505.45	11,779.20	21,243,257.65	- 24.60	- 536,974.83	20,706,282.82
	20-40	13550.4	335.33	4694.5651	400.63	5608.7662	481.22	14436.581	652.30	19569.0018	44308.91	503.51	13,550.40	24,437,537.23	- 26.54	- 579,369.26	23,858,167.97
	30-10	10008	337.80	4729.2617	403.62	5650.7321	484.48	14534.424	657.63	19728.9528	44643.37	507.31	10,008.00	18,048,978.08	- 22.74	- 496,398.55	17,552,579.53
	30-20	11779.2	336.86	4715.9973	402.44	5634.2035	483.17	14495.243	655.38	19661.4803	44506.92	505.76	11,779.20	21,243,257.65	- 24.29	- 530,247.55	20,713,010.11
	30-30	13550.4	335.93	4703.0344	401.29	5618.1081	481.91	14457.298	653.33	19599.7741	44378.22	504.30	13,550.40	24,437,537.23	- 25.75	- 562,177.30	23,875,359.93
	30-40	15321.6	334.65	4685.0323	399.74	5596.4114	480.23	14406.812	650.74	19522.2909	44210.55	502.39	15,321.60	27,631,816.80	- 27.66	- 603,771.79	27,028,045.01
	40-10	11779.2	336.83	4715.5935	402.35	5632.8343	483.12	14493.558	655.50	19665.0609	44507.05	505.76	11,779.20	21,243,257.65	- 24.29	- 530,217.13	20,713,040.52
	40-20	13550.4	335.92	4702.9087	401.22	5617.1446	481.91	14457.353	653.42	19602.4606	44379.87	504.32	13,550.40	24,437,537.23	- 25.73	- 561,767.49	23,875,769.73
	40-30	15321.6	334.99	4689.9199	400.07	5601.0484	480.63	14418.912	651.30	19539.0241	44248.90	502.83	15,321.60	27,631,816.80	- 27.22	- 594,256.13	27,037,560.67
	40-40	17092.8	333.66	4671.2998	398.47	5578.6029	478.88	14366.325	648.57	19457.1968	44073.42	500.83	17,092.80	30,826,096.38	- 29.22	- 637,788.65	30,188,307.73
20%	10-10	9388.8	338.49	4738.8303	404.20	5658.7435	484.98	14549.306	658.31	19749.262	44696.14	507.91	9,388.80	16,932,278.72	- 22.14	- 483,307.06	16,448,971.66
	10-20	11160	337.54	4725.617	403.05	5642.7459	483.67	14510.179	656.06	19681.754	44560.30	506.37	11,160.00	20,126,558.29	- 23.68	- 517,007.42	19,609,550.87
	10-30	12931.2	336.66	4713.1947	401.93	5626.9977	482.46	14473.749	654.09	19622.8228	44436.76	504.96	12,931.20	23,320,837.87	- 25.09	- 547,652.51	22,773,185.35
	10-40	14702.4	335.35	4694.8772	400.35	5604.9347	480.77	14423.223	651.43	19542.7924	44265.83	503.02	14,702.40	26,515,117.44	- 27.03	- 590,057.94	25,925,059.50
	20-10	11160	337.79	4729.0122	403.30	5646.2637	484.01	14520.408	656.73	19701.7957	44597.48	506.79	11,160.00	20,126,558.29	- 23.26	- 507,782.85	19,618,775.44
	20-20	12931.2	336.89	4716.4485	402.21	5630.9996	482.76	14482.73	654.64	19639.2653	44469.44	505.33	12,931.20	23,320,837.87	- 24.71	- 539,545.66	22,781,292.20
	20-30	14702.4	335.95	4703.3288	401.02	5614.342	481.46	14443.794	652.49	19574.7388	44336.20	503.82	14,702.40	26,515,117.44	- 26.23	- 572,599.47	25,942,517.97
	20-40	16473.6	334.61	4684.601	399.42	5591.9244	479.76	14392.801	649.82	19494.5592	44163.89	501.86	16,473.60	29,709,397.01	- 28.19	- 615,347.34	29,094,049.67
	30-10	12931.2	337.12	4719.6159	402.41	5633.7741	483.03	14490.949	655.25	19657.6373	44501.98	505.70	12,931.20	23,320,837.87	- 24.35	- 531,475.06	22,789,362.80
	30-20	14702.4	336.21	4706.8788	401.32	5618.4785	481.79	14453.844	653.06	19591.6511	44370.85	504.21	14,702.40	26,515,117.44	- 25.84	- 564,003.93	25,951,113.51
	30-30	16473.6	335.25	4693.4841	400.12	5601.6216	480.47	14414.228	650.90	19526.9828	44236.32	502.69	16,473.60	29,709,397.01	- 27.36	- 597,378.92	29,112,018.10
	30-40	18244.8	333.92	4674.9376	398.52	5579.3402	478.77	14363.042	648.24	19447.2663	44064.59	500.73	18,244.80	32,903,676.59	- 29.32	- 639,981.30	32,263,695.28
	40-10	14702.4	336.12	4705.7021	401.14	5615.9643	481.65	14449.462	653.06	19591.7511	44362.88	504.12	14,702.40	26,515,117.44	- 25.93	- 565,981.68	25,949,135.76
	40-20	16473.6	335.27	4693.7653	400.11	5601.5141	480.49	14414.645	651.05	19531.6098	44241.53	502.74	16,473.60	29,709,397.01	- 27.30	- 596,084.72	29,113,312.29
	40-30	18244.8	334.35	4680.9332	398.96	5585.4905	479.19	14375.759	648.98	19469.4217	44111.60	501.27	18,244.80	32,903,676.59	- 28.78	- 628,317.28	32,275,359.31
	40-40	20016	333.02	4662.3304	397.36	5563.0672	477.50	14324.976	646.30	19388.9276	43939.30	499.31	20,016.00	36,097,956.16	- 30.74	- 671,061.37	35,426,894.79
30%	10-10	12312	337.71	4727.9922	402.90	5640.5664	483.40	14501.968	655.68	19670.2753	44540.80	506.15	12,312.00	22,204,138.50	- 23.90	- 521,843.33	21,682,295.17
	10-20	14083.2	336.77	4714.8218	401.75	5624.5201	482.09	14462.842	653.44	19603.3319	44405.52	504.61	14,083.20	25,398,418.08	- 25.44	- 555,404.72	24,843,013.36
	10-30	15854.4	335.92	4702.8423	400.69	5609.6618	480.96	14428.724	651.60	19548.1189	44289.35	503.29	15,854.40	28,592,697.65	- 26.76	- 584,223.49	28,008,474.16
	10-40	17625.6	334.58	4684.1111	399.08	5587.0784	479.19	14375.847	648.83	19464.7668	44111.80	501.27	17,625.60	31,786,977.22	- 28.78	- 628,267.76	31,158,709.47
	20-10	14083.2	337.05	4718.6659	402.06	5628.8136	482.46	14473.769	654.17	19625.0959	44446.34	505.07	14,083.20	25,398,418.08	- 24.98	- 545,276.00	24,853,142.07
	20-20	15854.4	336.10	4705.4045	400.90	5612.5559	481.16	14434.91	651.94	19558.0901	44310.96	503.53	15,854.40	28,592,697.65	- 26.52	- 578,861.64	28,013,836.01
	20-30	17625.6	335.17	4692.4373	399.75	5596.4439	479.91	14397.413	649.88	19496.3643	44182.66	502.08	17,625.60	31,786,977.22	- 27.97	- 610,690.33	31,176,286.90
	20-40	19396.8	333.89	4674.4372	398.20	5574.7918	478.24	14347.255	647.29	19418.7295	44015.21	500.17	19,396.80	34,981,256.80	- 29.88	- 652,229.43	34,329,027.37
	30-10	15854.4	336.38	4709.3275	401.19	5616.6055	481.51	14445.26	652.69	19580.5631	44351.76	504.00	15,854.40	28,592,697.65	- 26.05	- 568,741.10	28,023,956.55
	30-20	17625.6	335.46	4696.4255	400.05	5600.7686	480.22	14406.622	650.53	19515.8381	44219.65	502.50	17,625.60	31,786,977.22	- 27.55	- 601,512.55	31,185,464.67
	30-30	19396.8	334.52	4683.2334	398.88	5584.2776	478.96	14368.906	648.45	19453.5454	44089.96	501.02	19,396.80	34,981,256.80	- 29.03	- 633,685.99	34,347,570.80
	30-40	21168	333.22	4665.0514	397.32	5562.4247	477.26	14317.67	645.81	19374.4151	43919.56	499.09	21,168.00	38,175,536.37	- 30.96	- 675,958.65	37,499,577.73
	40-10	17625.6	335.39	4695.4147	399.89	5598.3958	480.12	14403.478	650.49	19514.8454	44212.13	502.41	17,625.60	31,786,977.22	- 27.64	- 603,378.17	31,183,599.06
	40-20	19396.8	334.54	4683.5325	398.88	5584.2833	478.99	14369.733	648.50	19454.961	44092.51	501.05	19,396.80	34,981,256.80	- 29.00	- 633,053.98	34,348,202.82
	40-30	21168	333.61	4670.5119	397.71	5567.9391	477.70	14330.877	646.43	19392.9126	43962.24	499.57	21,168.00	38,175,536.37	- 30.48	- 665,370.90	37,510,165.48
	40-40	22939.2	332.31	4652.272	396.15	5546.0447	475.98	14279.356	643.76	19312.9182	43790.59	497.62	22,939.20	41,369,815.95	- 32.43	- 707,953.06	40,661,862.88
40%	10-10	15235.2	336.83	4715.5939	401.33	5618.6574	481.41	14442.408	652.34	19570.2363	44346.90	503.94	15,235.20	27,475,998.29	- 26.11	- 569,946.82	26,906,051.47
	10-20	17006.4	335.88	4702.3476	400.16	5602.2398	480.09	14402.74	650.01	19500.4425	44207.77	502.36	17,006.40	30,670,277.86	- 27.69	- 604,460.78	30,065,817.08
	10-30	18777.6	335.00	4690.0375	399.05	5586.6796	478.89	14366.73	648.06	19441.6638	44085.11	500.97	18,777.60	33,864,557.44	- 29.08	- 634,889.69	33,229,667.75
	10-40	20548.8	333.72	4672.1191	397.51	5565.0838	477.21	14316.45	645.47	19363.99	43917.64	499.06	20,548.80	37,058,837.01	- 30.99	- 676,434.45	36,382,402.56
	20-10	17006.4	336.12	4705.7144	400.44	5606.104	480.43	14412.933	650.81	19524.3797	44249.13	502.83	17,006.40	30,670,277.86	- 27.22	- 594,200.10	30,076,077.76
	20-20	18777.6	335.28	4693.8927	399.40	5591.6422	479.27	14377.999	648.81	19464.1536	44127.69	501.45	18,777.60	33,864,557.44	- 28.60	- 624,327.34	33,240,230.10
	20-30	20548.8	334.28	4679.9858	398.14	5573.9333	477.90	14336.88	646.56	19396.707	43987.51	499.86	20,548.80	37,058,837.01	- 30.19	- 659,103.12	36,399,733.89
	20-40	22320	332.99	4661.9211	396.58	5552.0962	476.20	14285.942	643.93	19318.0042	43817.96	497.93	22,320.00	40,253,116.58	- 32.12	- 701,162.57	39,551,954.01
	30-10	18777.6	335.48	4696.7518	399.58	5594.0933	479.49	14384.673	649.31	19479.3891	44154.91	501.76	18,777.60	33,864,557.44	- 28.29	- 617,574.83	33,246,982.61
	30-20	20548.8	334.55	4683.7152	398.43	5578.0184	478.19	14345.752	647.07	19412.0348	44019.52	500.22	20,548.80	37,058,837.01	- 29.83	- 651,160.90	36,407,676.11
	30-30	22320	333.65	4671.0456	397.29	5562.0743	476.98	14309.305	645.06	19351.94	43894.36	498.80	22,320.00	40,253,116.58	- 31.25	- 682,209.19	39,570,907.40
	30-40	24091.2	332.49	4654.8027	396.08	5545.1877	475.75	14272.475	643.25	19297.4146	43769.88	497.38	24,091.20	43,447,396.16	- 32.66	- 713,090.96	42,734,305.20
	40-10	20548.8	334.61	4684.5381	398.64	5580.8958	478.55	14356.561	647.90	19436.8881	44058.88	500.67	20,548.80	37,058,837.01	- 29.38	- 641,396.18	36,417,440.83
	40-20	22320	333.61	4670.5074	397.22	5561.1163	476.89	14306.81	644.99	19349.6397	43888.07	498.73	22,320.00	40,253,116.58	- 31.32	- 683,769.86	39,569,346.72
	40-30	24091.2	332.71	4657.9368	396.08	5545.1028	475.61	14268.356	642.92	19287.5498	43758.95	497.26	24,091.20	43,447,396.16	- 32.79	- 715,803.60	42,731,592.56
	40-40	25862.4	331.41	4639.749	394.52	5523.2165	473.91	14217.178	640.27	19208.0998	43588.24	495.32	25,862.40	46,641,675.73	- 34.73	- 758,150.74	45,883,524.99

* Only negative numbers in the last column "saving in initial cost vs. saving in running cost" indicates financial gains against the base case.