THE COST OF ACHIEVING THERMAL COMFORT VIA ALTERING EXTERNAL WALLS SPECIFICATIONS IN EGYPT; FROM CONSTRUCTION TO OPERATION THROUGH DIFFERENT CLIMATE CHANGE SCENARIOS

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ABSTRACT

In Egypt, the current widely used external walls are preferred in practice to minimize the project's initial cost, regardless of the negative impacts of the thermal comfort on the inhabitants, as well as the impact on the running cost of the energy consumption later. The objective of this research is to evaluate the effect of external walls with different specifications on the project's initial cost and running cost for achieving internal thermal comfort in the present time and under climate change. This work extends our earlier experiments on the same topic by running dynamic thermal simulations on three different climatic zones in Egypt, and for three current and predicted (future) weather data files. The recommendations resulting from the energy analysis suggest different types of walls according to location, to optimise for thermal comfort and financial benefits.

INTRODUCTION

External walls with large thickness have always been preferred in Egypt for the buildings' construction due to the nature of the hot-arid climate zone of the country. This is to reduce heat and delay its transfer from the harsh external conditions (Shafaq El-Wakeel 1989). At present, the most widely used external walls for residential sector is the half red-brick (12 cm thickness). The reason behind that is its relatively small initial cost compared with other external walls specifications. This ignores the negative impact of the half red-brick wall on indoor thermal comfort, energy consumption and associated running costs.

The objective of this paper is to evaluate the effect of using different external wall specifications on achieving internal thermal comfort, while evaluating their impact on the initial cost of the construction project as well as on the running cost of the energy consumption. Initial analysis conducted by the authors (Mohamed Mahdy, 2012) is extended for four different external wall specifications, to evaluate the effect of various specifications in three different climatic zones in Egypt, and under different climate change scenarios. The optimum specification case is then selected for each climatic zone, based on thermal comfort and the best economical solutions.

The simulations evaluate the use of four external walls: (1) the basic half red-brick (12 cm) most commonly used in Egypt, (2) the full red-brick (25++), (3) the double wall of half red-brick (Dair), and (4) the double wall of half red-brick with insulation (Dins).

The building tested is a typical residential building with Heating, Ventilation and Air conditioning (HVAC) installed. The building is simulated in three main Egyptian climatic zones defined in the Egyptian Residential Energy Code (EREC) (Centre, 2008). These include the Cairo and Delta, the North coast, and the Southern climatic zone. For the climate change scenarios of three different periods: 2002, 2020 and 2050.

EXTERNAL WALLS SPECIFICATIONS

The specifications for the four wall constructions evaluated are presented in Table 1. The thermal properties were obtained from EREC (Centre, 2008), and the Egyptian Specifications for Thermal Insulation Work Items (Centre, 2007).

The four external wall specifications are (1) the half red-brick wall, (2) the full red-brick wall with 2 cm of external expanded polystyrene thermal insulation layer, (3) the double wall of half red-brick with 5 cm air gap in between and (4) the double wall of half red-brick with 5 cm of internal expanded polystyrene thermal insulation layer. The first construction specification, the half red-brick wall, is one of the most commonly used external walls in practice in Egypt, since it has a relatively low initial construction cost. We aim to evaluate its cost-effectiveness, considering the energy consumption, in comparison with the three other specifications.

Table 1: External Walls main characteristics.

External Walls	**ABBRV.**	**Thick. (cm)**	**U-Value (W/m^{2}K)**
Half red-brick wall.	*12cm*	12	2.519
Full red-brick wall plus additional 2 cm of external expanded polystyrene thermal insulation layer.	*25++*	27	0.897
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 5 cm of expanded polystyrene thermal insulation layer.	*Dins*	29	0.503

CLIMATIC ZONES

The paper will focus on the main three (of the eight) Egyptian climatic zones (Figure 1) defined in the Egyptian Residential Energy Code (EREC) (Centre, 2008). These three climatic zones are:(1)Cairo and Delta zone (Cairo governorate), (2)North coast zone (Alexandria governorate), and (3) the Southern zone (Aswan governorate). About 50% of the construction projects carried out in Egypt are located in Cairo and Alexandria governorates (Joe Huang, 2003). While Aswan governorate considered very different zone in terms of the climatic aspects compared to the two other zones.

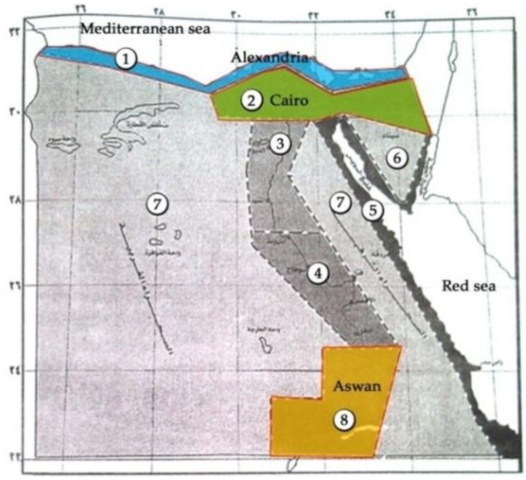

Figure 1: Egypt's climatic zones map(Centre, 2008).

SIMULATION METHODOLOGY

To carry out our experiments, a model of a typical residential building in Cairo was employed for the simulations, which is then tested in the three different climatic zones (see the pervious section), while keeping the same orientation of the building in each one of the various climatic regions. The following points define the main aspects of our experimental setup:

-The Model Definition: The building consists of six floors, where each has two residential flats with an approximate area of 70 m^2. The average number of occupants per flat is four. The building model and floor plan is shown in Figure 2 and 3 respectively.

-Building Performance Simulation Software (BPS): Modelling was carried out using dynamic thermal simulations for the different wall specifications, climate zones, and weather data files, using the DesignBuilder software (DB, 2012).

-Weather Data Files: Three different weather data files: 2002, 2020 and 2050 were used in the simulations for this research. This is according to the suggested 40-year period, which is the estimated half-life span of the buildings in Egypt, without any major retrofitting taking place. As 2012 was assumed to be the starting construction year, the weather data files for the test periods were divided as follows:

- 2002 weather data file to cover the period of 14 years, from 2012 to 2025,
- 2020 weather data file to cover the period of 14 years, from 2026 to 2039,
- 2050 weather data file to cover the period of 12 years, from 2040 to 2051.

The current weather data file (2002) was downloaded from the official site of the U.S Department of Energy (USDoE, 2012). The Climate Change World Weather File Generator (CCWorldWeatherGen) (Group, 2012a) was used to generate the future weather data files (for 2020 and 2050) required for the simulations. The 2020 and 2050 weather data files were developed to cover the periods 2010-2039 and 2040-2069 respectively and we have used them accordingly for our simulations (H Du, 2012).

CCWorldWeatherGen(Group, 2012a), is a Microsoft Excel based tool generating climate change weather data files. The files can be used in BPS programs by transforming current Energy Plus Weather files (EPW) into climate change EPW weather files that are compatible with the majority of BPS programs(Group, 2012b).

-Thermal Comfort Zone: previous research underpins the theory of Adaptive Comfort (Levermore, 2012). It has shown that people can adapt and can be comfortable at higher temperatures than those conventionally adopted. Based on that, the thermal comfort zone (20°C-29°C) was used in the simulations. This is a modification of the original comfort zone mentioned in the Egyptian residential energy code (EREC) (Centre, 2008) (22.2°C-25.6°C) calculated by including both the mean values of the slightly hot zone (25.6°C-34.5°C) and of the slightly cold zone (22.2°C-17.5°C). As we are working with the assumption that higher air temperatures are tolerated in this climatic context, we have not used PMV at all. We are only using air temperature as the indication.

-Activities and HVAC Systems: A fixed activity template, which defines the schedule for energy consumption based on the lifestyle in Egypt (holidays, working hours) was used. For each specification of the external walls, a simulation has been conducted to evaluate thermal comfort and to obtain the total energy consumption in kWh from house appliances and the HVAC systems. The HVAC specifications include the use of split air-conditioning units 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 is used. The assist of HVAC systems was the only focus in this experiments because, according to our previous study (Mohamed Mahdy, 2012) natural ventilation were not sufficient to achieve thermal comfort individually in the summer period; under the same experiment conditions in Cairo with different specifications. It should be noted that, in the cases where the internal temperature rises beyond the thermal comfort zone, comfort still can be obtained using higher HVAC units of higher cooling capacity, which will reflect on further increases in energy consumption. As our objective was to evaluate the effect of only the external walls, the HVAC equipments were kept fixed in all the simulations.

-Construction Material Costs: The Engineering Authority Indicative Guide (EAAF, 2012) was used for the price-list of the construction materials to calculate the initial cost of the external walls construction.

-Electric Energy Prices: For the financial analysis, the cost of the energy consumption per flat per year was calculated using the tariff of electricity declared by the Egyptian Ministry of Electricity and Energy for the residential sector (MOEE, 2012), which is referred to as operation cost.

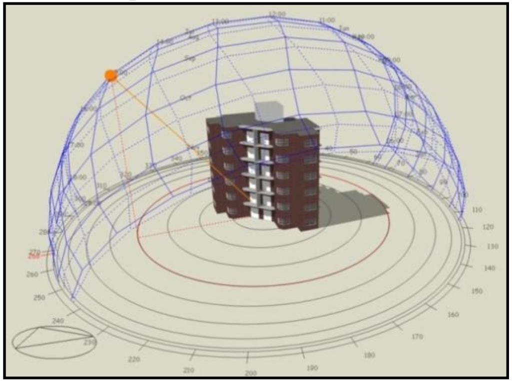

Figure 2:Solar analysis of the residential model used.

Figure 3: Typical plan of the Modeled flat.

RESULTS AND DISCUSSION

Simulation Results

The results obtained from the simulation of the four construction envelopes are divided in three separate graphs: Monthly Energy Consumption (kWh), Annual Energy Cost in Egyptian Pound (EGP) and Indoor/outdoor temperature (°C). These measures are plotted for the three climatic zones (Alexandria, Cairo and Aswan) in Figures 4, 5 and 6 respectively. Each graph divided into three different weather periods (2002, 2020 and 2050).

For each weather period, the upper left graph represents the monthly energy consumption for the four types of external wall. As expected, the energy consumption increases because of the temperature increase under climate change (Crawley, 2007) in all of the 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 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 type of construction for the external wall.

As shown, the simulation demonstrated that the double wall of half red-brick with additional internal 5 cm of expanded polystyrene thermal insulation (Dins) wall specification has achieved the best thermal performance amongst the three other specifications, and reduced the energy consumption for all the different simulations by at least 2% compared to the second best thermal performance wall specification. On the other hand, the most commonly used half red-brick (12cm) wall has the highest energy consumption. The financial implications for the results of the simulations are summarised in Table 2. These show the running costs for the energy consumed in each city for each period (sub total), as well as the average annual running cost obtained by dividing the running cost of the three periods added together (overall) by 40 years.

Financial Analysis

Using the results in Table 2, Figure 7 demonstrates the relationship between the initial cost of each external wall specification (reflects the U-value for each construction), and the average annual running cost for each specification in each of the climatic zones used in our experiments.

As expected, as the initial cost increases the average annual running cost decreases. At the beginning, the curves are very steep, as the intial cost increases (and the U-value decreases), the slope is smaller. This implies that the maximum benefit is obtained by replacing the use of the *12cm* specification (the first point on the *x* axis), which has the lowest intial cost and the highest running cost, by the double wall with air gap specification (the second point on the *x* axis), which has the second lowest initial cost and the second highest running cost. The marginal change in the running cost decreases as moving from one specification to another with higher initial cost. It seems to be more cost effective to use the double wall with air gap at initial cost of 6400 EGP, with average annual running costs of 1817.30 EGP in Aswan, 1008.30 EGP in Cairo and 657.60 EGP in Alexandria. Comparing the above by taking into account the long term financial benefits or investments provids further insight in the analysis of the results.

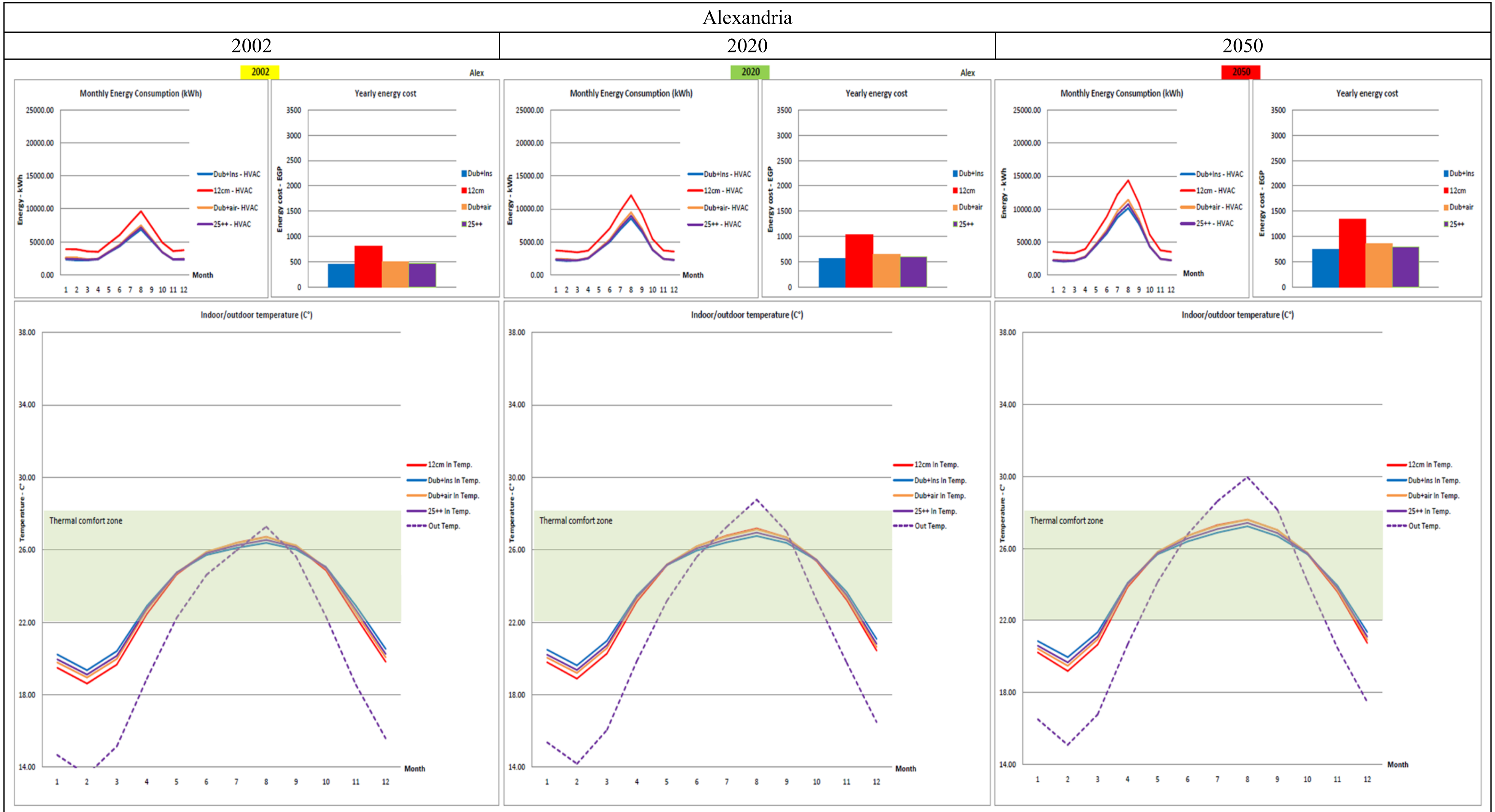

Figure 4: Simulation results for Alexandria city.

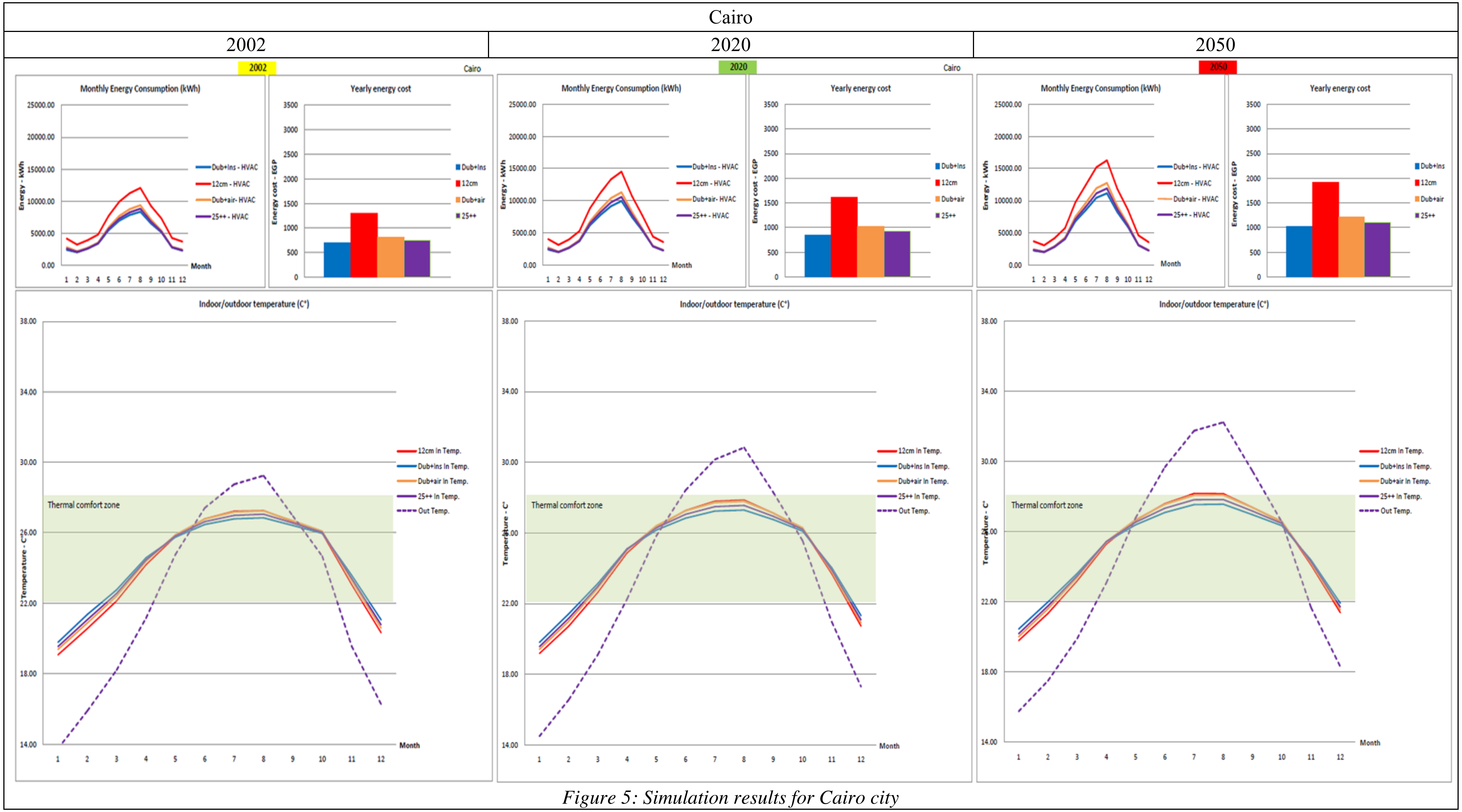

Figure 5: Simulation results for Cairo city

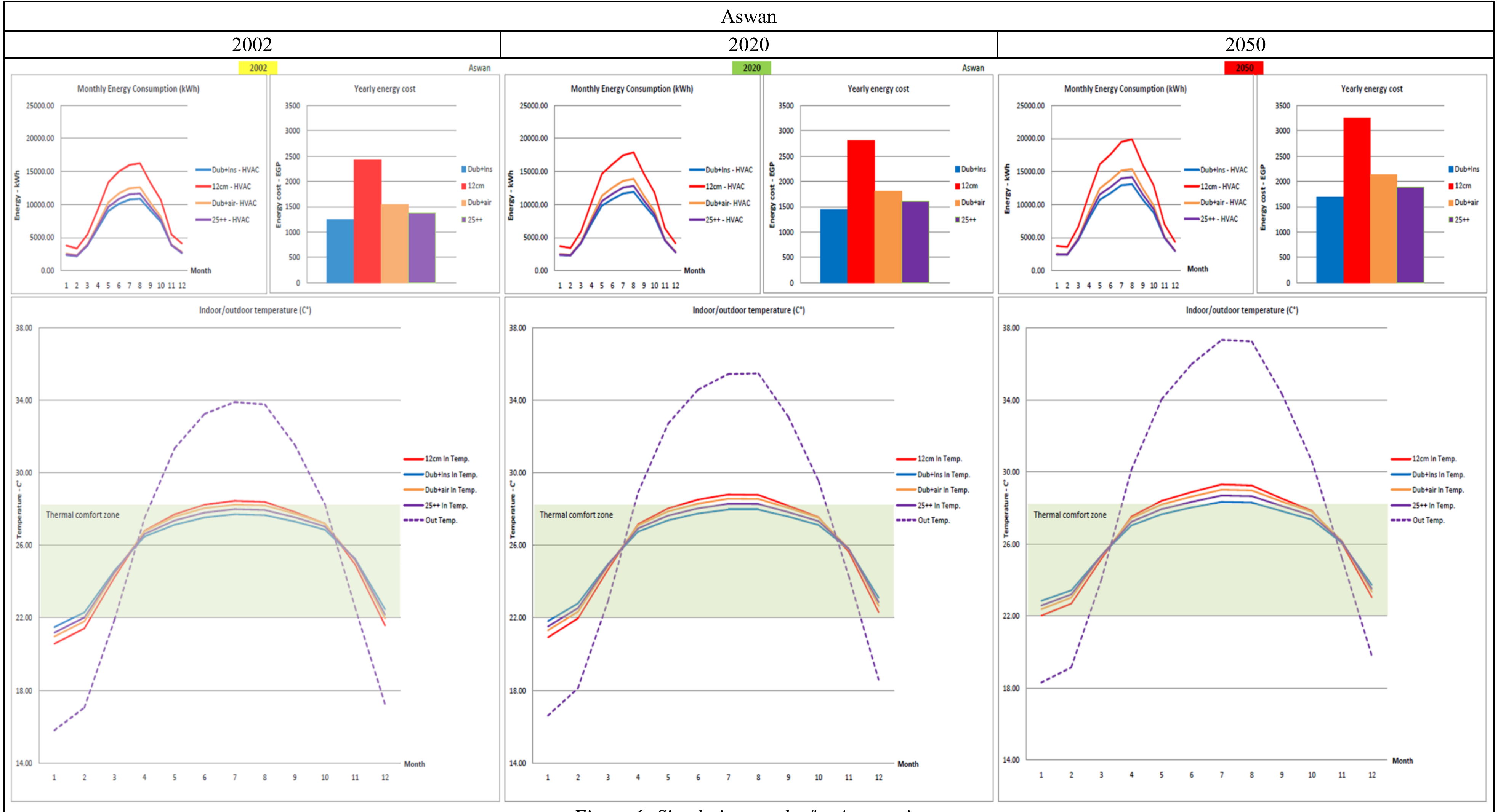

Figure 6: Simulation results for Aswan city

Table 2: Summary of the running costs, based on the thermal simulations for the different wall types, cities and weather periods(all costs shown in EGP).

Alex.	**Initial cost**	**2002 (2012-2025=14y)**		**2020 (2026-2039=14 y)**		**2050 (2040-2051=12 y)**		**Overall running cost**	**Average annual running cost**
		Running cost	Sub total	Running cost	Sub total	Running cost	Sub total		
12	3048	806	11284	1040	14560	1351	16212	42056	1051.4
25++	9406	471	6594	602	8428	796	9552	24574	614.35
Dair	6400	497	6958	643	9002	862	10344	26304	657.6
Dins	12590	447	6258	569	7966	738	8856	23080	577
Cairo									
12	3048	1300	18200	1608	22512	1911	22932	63644	1591.1
25++	9406	757	10598	925	12950	1106	13272	36820	920.5
Dair	6400	821	11494	1015	14210	1219	14628	40332	1008.3
Dins	12590	704	9856	850	11900	1016	12192	33948	848.7
Aswan									
12	3048	2435	34090	2809	39326	3255	39060	112476	2811.9
25++	9406	1384	19376	1608	22512	1894	22728	64616	1615.4
Dair	6400	1549	21686	1809	25326	2140	25680	72692	1817.3
Dins	12590	1253	17542	1445	20230	1689	20268	58040	1451

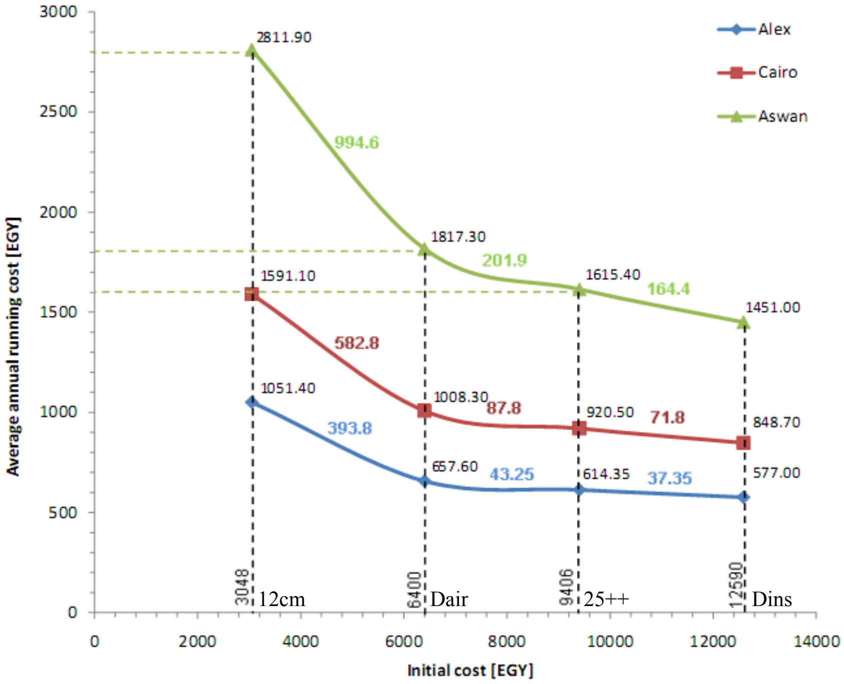

Figure 7: The relation of external walls initial cost and the average annual running cost.

Table 3: Initial and Running cost based comparison against the 12cm wall (EGP/flat).

Alex	**Different in initial cost**	**Accumulation after 40 yrs**	**Different in running costs**	**Accumulation after 40 yrs**	**Saving in initial cost vs. saving in running cost**	
12	-	-	-	-	-	
25++	6358	183212.01	437.05	147671.52	35,540.49	12 over 25++
Dair	3352	96591.17	393.8	133058.10	- 36,466.94	12 under Dair
Dins	9542	274962.09	474.4	160291.43	114,670.67	12 over Dins
Cairo						
12	-	-	-	-	-	
25++	6358	183212.01	670.6	226583.96	- 43,371.96	12 under 25++
Dair	3352	96591.17	582.8	196917.88	- 100,326.72	12 under Dair
Dins	9542	274962.09	742.4	250843.92	24,118.17	12 over Dins
Aswan						
12	-	-	-	-	-	
25++	6358	183212.01	1196.5	404276.34	- 221,064.33	12 under 25++
Dair	3352	96591.17	994.6	336057.87	- 239,466.71	12 under Dair
Dins	9542	274962.09	1360.9	459824.21	- 184,862.12	12 under Dins

* *The negative numbers indicates a financial gain against the 12cm wall.*

The assumption is that the buildings owners invest what they save from the initial cost, or what they save from the running cost in a bank savings account for the specified 40 years period, using the regular 9% interest rate in Egypt (NBE, 2012). Table 3 shows the difference in the initial and average annual running cost for every external wall, compared to the *12cm* wall, which provides the cheapest option and is the reason that is most commonly used across Egypt, along with the accumulated amount for each type after the 40 years investment. The comparison also presents the potential savings indicating that, there is a financial gain from using advanced construction instead of the basic *12cm* external wall.

From the analysis of the results listed in the table, it can be notice that:

-Alexandria: All construction specifications achieve thermal comfort. However, only the double wall with air gap is the one that gains financial benefits comparing to the *12cm* wall.

-Cairo: Both the *25++* wall and the double wall with air gap are beneficial constructions, where they both achieve thermal comfort. However, the financial gain of the double wall with air gap is higher than the *25++* wall by 57%. So it is more cost effective.

-Aswan: All construction specifications, except for the *12cm* wall, are more beneficial. However, when we compare with the thermal comfort graphs "Aswan" (Fig. 6), it is shown that only the double wall with insulation seems to maintain acceptable thermal comfort for the climate change scenarios, while also achieving the long term financial gains.

CONCLUSION

In this paper, the effect of using different material specifications for external walls on the cost of the energy consumption was compared, focusing on achieving internal thermal comfort with maximum financial benefits. Although we agree that the life cycle cost is important, it is beyond the focus of this paper. Four different types of external walls commonly used in Egypt were used (half red-brick wall, full red-brick wall with additional insulation layer, double wall with insulation and double wall with air gap), in the three dominant Egyptian climatic zones (Alexandria, Cairo and Aswan), using three sets of current and future weather data files (2002,2020 and 2050). The simulation results recommend the use of the double wall with insulation as the optimum external wall in Aswan, and the use of the double wall with air gap for Alexandria and Cairo climatic zones. These specifications have shown to achieve indoor thermal comfort, minimize the energy consumption, while attaining the maximum financial benefits, which would make them a more appealing option for occupants, justifying the higher initial cost.

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.

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