BAU Journal - Creative Sustainable Development

Volume 1 | Issue 1
ISSN: 2664-9446

Article 2

November 2019

THE APPROPRIATE BUILDING MATERIALS FOR ENERGY SAVING IN DIFFERENT CLIMATE ZONES IN EGYPT

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Energy-efficient; Building materials; Climate zones; Energy saving; Thermal comfort zone

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Abstract

Nowadays, reducing energy consumption is globally considered a matter of high priority on the different levels of community and economic interest, especially in the developing countries, due to the growing shortage of traditional energy resources with the rapidly increasing energy prices and its impact on the natural environment through the consumption of various energy resources such as fossil fuels. The residential building sector is responsible for consuming a large percentage of energy, especially that used in heating and cooling, which could be reduced through using different passive design strategies, such as designing the building shape, setting the optimum orientation and selecting the most appropriate building materials for the specific climate zones. Therefore, this paper focuses on reducing the energy consumption in the residential building sector in Egypt by evaluating four different non-structural filling wall materials, including red bricks, cement bricks, stone and curtain walls located in different climate zones. Simulation analysis techniques are used to measure the related energy consumption parameters for cooling and/or heating to achieve the thermal comfort zone for building users. These results will aid architects in the pre-design stage to choose the most appropriate material for their designs, depending on the location concerned.

Keywords

Energy-efficient; Building materials; Climate zones; Energy saving; Thermal comfort zone

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ABSTRACT: Nowadays, reducing energy consumption is globally considered a matter of high priority on the different levels of community and economic interest, especially in the developing countries, due to the growing shortage of traditional energy resources with the rapidly increasing energy prices and its impact on the natural environment through the consumption of various energy resources such as fossil fuels. The residential building sector is responsible for consuming a large percentage of energy, especially that used in heating and cooling, which could be reduced through using different passive design strategies, such as designing the building shape, setting the optimum orientation and selecting the most appropriate building materials for the specific climate zones. Therefore, this paper focuses on reducing the energy consumption in the residential building sector in Egypt by evaluating four different non-structural filling wall materials, including red bricks, cement bricks, stone and curtain walls located in different climate zones. Simulation analysis techniques are used to measure the related energy consumption parameters for cooling and/or heating to achieve the thermal comfort zone for building users. These results will aid architects in the pre-design stage to choose the most appropriate material for their designs, depending on the location concerned.

KEYWORDS: Energy-efficient; Building materials; Climate zones; Energy saving; Thermal comfort zone

1. INTRODUCTION

Climate change is considered to be the most important issue facing the earth in recent years, as it is a global challenge facing humankind with major impacts on human health and the environment. Many scientific studies have indicated that one of the causes of this problem is the high percentage of carbon produced by fossil fuel combustion to generate energy. In the last few decades, many countries have begun to reduce their demand for energy consumption, especially in the building sector, which is responsible for approximately 40% of the total primary energy consumption and 36% of CO2 emissions into the atmosphere in the European Union (Carpio, García-Maraver, Ruiz, Martínez, & Zamorano, 2014; Ionescu, Baracu, Vlad, Necula, & Badea, 2015). Furthermore, in the United States, according to the U.S. Energy Information Administration (EIA), about 40% of total U.S. energy consumption was consumed by the residential and commercial sectors in 2016 ((EIA), January 2018; Conti et al., 2016).

Meanwhile, in Egypt, according to the Egyptian electricity holding company's annual report of 2015/2016, energy consumption in the residential sector is 54.90% of total Energy Sold by Distribution Companies (on medium and low voltage) related to the Purpose of Usage (Energy, 2016).

There are many aspects that affect energy consumption in the residential building sector, including HVAC systems, lighting, artificial ventilation and consumer equipment. The climate conditions are considered the most influential aspect on the energy demand for space heating and/or space cooling, related to the following factors (Outlook, 2013):

- Building conditions through its location, orientation, construction materials, and design;
- Energy cost which varies between countries in relation to the user income level and behavior;
- Equipment efficiency which plays a main role in energy saving in reference to culture and the awareness of society.

This paper focuses on residential buildings as the most energy-consuming sector, taking into consideration the space cooling and heating used to achieve user thermal comfort in different climate zones in Egypt. It will study the non-structural filling wall materials and their role in reducing energy consumption through using simulation programs to identify the most suitable material.

2. THEORETICAL BACKGROUND

Green design has become the focus of many researches, with the aim of reducing the negative environmental effects. Building green buildings emerged as an environmental solution by using suitable design strategies. Using passive design strategies is considered the most sustainable solution, requiring skilled architects and active users. These solutions are created by maximizing the benefit of utilizing natural resources in building design in order to fulfil the user's need for thermal comfort while simultaneously reducing the energy consumption.

There are many passive design strategies, such as building orientation, building shape, landscaping, daylighting, and choice of building material, which is the main research focus. Various materials may be used in building construction. They are divided into visible and invisible materials. The visible materials are seen as finishing materials, while the invisible materials are either structural or non-structural components (Conti et al., 2016). The process of selecting suitable building materials, especially the filling materials between the support columns, involves several constraints depending on the climate zone where the building is located, availability, cost and characteristics such as dimensions, weight, density, durability and thermal conductivity.

As a building envelope, the filling construction materials play a major role in controlling the heat transfer between indoors and outdoors. Heat loss in winter occurs when the indoor temperature being maintained exceeds the outdoor temperature, whereas heat gain happens in summer when the indoor temperature being maintained falls below the outdoor temperature (Tam, 2011) .

Recently, achieving the maximum energy saving and energy efficiency of building performance has become one of the most important building designer decisions during the design and construction stages, especially related to the process of choosing building materials by using relative values to compare the differences between them, such as the cost over the building's life cycle.

According to this, the efficiency of using different outer wall construction materials has been the recent research focus to achieve thermal comfort in various climatic zones. According to the study by Felix and Elsamahy (2017), the total energy consumption of the building may be affected by the selection of the wall construction materials in the same skeletal system under identical circumstances.

3. THE CLIMATE ZONES IN EGYPT

Egypt is a major country located in northern Africa, covering an area of approximately 1.000.000 km2. Its climate varies from extremely hot, especially in the Western Desert, to extremely cold in the high Sinai mountains (M. M. Mahdy & Nikolopoulou, 2014). According to the Egyptian Residential Energy Code (EREC) (Centre, 2006), the climate in Egypt is divided into eight climate zones (M. Mahdy, Fahmy, Barakat, & Abdelalim, 2017; Mahmoud, 2011) as shown in figure (1) and Table (1).

The first climate zone is the Northern Coast zone which is located next to the Mediterranean Sea in the north of Egypt. It is approximately 10 km wide and includes Alexandria, Mersa-Matruh and port-Said as its main cities. The operative temperatures in this zone range between 33-37°C maximum and 18-23°C minimum in summer as well as 25-28°C maximum and 7-9°C minimum in winter.

The second climate zone is the Cairo and Delta Zone, which is located between a latitude of 26° 50" N and 30° 45" N. It includes Cairo, Tanta and Al-Mansurah as its main cities. The operative temperatures within this zone range between 37-46°C maximum and 13-21°C minimum in summer, and 25-28°C maximum and 6-9°C minimum in winter.

The third climate zone is the Northern Upper Egypt zone, located on the banks of the Nile River between a latitude of 26° 50" N and a latitude of 29° 42" N. It includes El-Minya, Bani Suwayf and Al-Fayyum as its main cities. The operative temperatures in this zone range

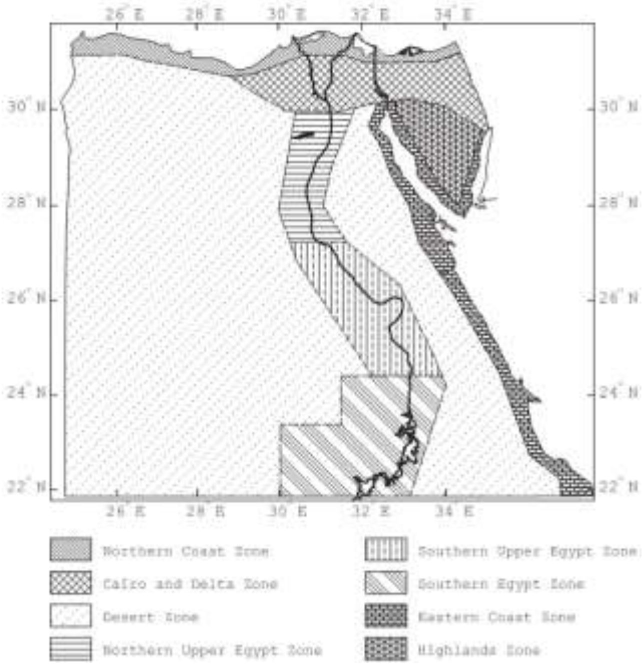


Fig.1 Egypt's climatic zones classification map according to EREC (Centre 2006, Mahdy, Fahmy et al. 2017)

between 40-47°C maximum and 10-22°C minimum in summer, and 27-31°C maximum and 2-6°C minimum in winter.

The fourth climate zone is the Southern Upper Egypt zone. This zone is located on the banks of the Nile River between a latitude of 26° 50” N and 25° 00” N. It includes Qina, Suhaj and Asyut as its main cities. The operative temperatures in this zone range between 41-46°C maximum and 16-21°C minimum in summer and 30-36 °C maximum and 3-9°C minimum in winter.

The fifth climate zone is the Eastern Coast zone. This narrow strip is located on the Red Sea coastline. The zone includes Hurgada, Sharm El Sheikh and Suez as its main cities. The operative temperatures in this zone range between 39-42°C maximum and 19-22°C minimum in summer and 28-31°C maximum and 8-11°C minimum in winter.

The sixth climate zone is the Highlands zone. The Mountains and Highlands in South Sinai range between 400 and 2000 meter above sea level. It includes Sant Catherine and El-Tur as its main cities. The operative temperatures in this zone range between 37-39°C maximum and 12-16°C minimum in summer and 22-29°C maximum and 0-5°C minimum in winter.

The seventh climate zone is the Desert zone, which includes western and eastern desert areas of Egypt, including Al-Farafirah and Siwa as its main cities. The operative temperatures in this zone range between 42-48°C maximum and 19-22°C minimum in summer and between 28-31°C maximum and 3-10°C minimum in winter.

Finally, the eighth zone is the Southern Egypt zone, which is located on the banks of the Nile River between a latitude of 22° 00” N and 25° 00” N. Aswan is the main city in this zone. The operative temperatures in this zone range between 43-48°C maximum and 18-2°C minimum in summer and between 29-34°C maximum and 5-10°C minimum in winter.

Table 1: Egypt’s climate zones according to the Egyptian Residential Energy Code
Reference: (Centre, 2006), (Mahmoud, 2011)

Bioclimatic zone	Summer Temp (°C)		Winter Temp (°C)	
	Max	Min	Max	Min
Northern coast zone	33-37	18-23	25-28	7-9
Cairo and Delta Zone	37-46	13-21	25-28	6-9
Northern Upper Egypt zone	40-47	10-22	27-31	2-6
Southern Upper Egypt zone	41-46	16-21	30-36	3-9
Eastern coast zone	39-42	19-22	28-31	8-11
Highlands zone	37-39	12-16	22-29	0-5
Desert zone	42-48	19-22	28-31	3-10
Southern Egypt zone	43-48	18-2	29-34	5-10

4. WALL BUILDING MATERIALS EMPLOYED IN EGYPT

Based on the natural availability of clay along the banks of the Nile River and stone, especially in southern Egypt, ancient Egyptian builders used these local materials in their construction process as the main raw materials. This led to the creation of a special architectural identity (Klemm & Klemm, 2001). Recently, with the development of the construction industry, many construction materials are frequently used as non-structural filling wall materials, such as red bricks, cement bricks, stone and glass, as the main components in curtain wall systems as an outer building cover.

These building materials play a main role in controlling the indoor environment quality through their characteristics.

5. RESEARCH METHODOLOGY

This paper is based on an experimental methodology involving simulation and comparative analysis of the simulation outcome, aiming to test the effect of wall building materials on energy consumption in the space heating and cooling process to accommodate the comfort zone of each climate zone in Egypt.

The case study is a hypothetical building model that include several constraints. First, the same model design will be used and analyzed across several climate zones. This model is a residential building with seven floors, where each floor consists of four apartments with an area of 108 square meters per apartment, as shown in figure 2.

The occupancy of each apartment is five persons. Second, the same building construction materials are considered. The building structure is designed as a concrete skeletal building which consists of reinforced concrete slabs and columns. Third, the same building orientation is considered. The building is oriented toward the four cardinal directions. Fourth, the same wall thickness and HVAC systems are used for heating and cooling. The other forces are neutralized, such as the surrounding buildings, wind direction or landscape.

As previously indicated in the theoretical part, the most popular materials for wall construction in Egypt nowadays are red bricks, cement bricks, stone and curtain walls. The case study will involve a comparative analysis of these four materials in terms of energy consumption during heating and cooling to identify the human thermal comfort zone for each climate area.

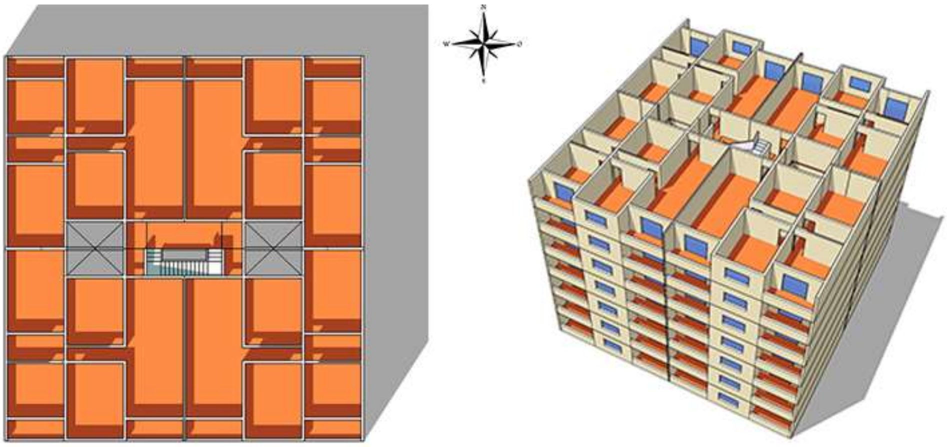


Fig.2 Case study model (Reference: Authors)

By using red bricks, stone and cement bricks, the model is designed using the same wall materials for both the internal and external walls. The thickness of the outer walls is 25 cm and that of the inner walls is 12 cm. However, the model for the curtain wall is based on using an inner wall thickness of 12 cm of red brick and curtain walls for the outer shell for four sides of the building.

The eight climate zones in Egypt are studied through employing one city as being representative of each climate zone. Alexandria represents the Northern coast zone, Cairo the Cairo and Delta zone, Al-Minya the Northern Upper Egypt zone, Qina the Southern Upper Egypt zone, Hurgada the Eastern coast zone, St Catherine the Highlands zone, Al-Farafirah the Desert zone and Aswan the Southern Egypt zone. These eight cities are analyzed using simulation tools in three main phases:

a) First, the comfort thermal zone charts are documented to identify the percentage of indoor comfort for a normal situation in each city.

b) Second, by using simulation tools, the model is analyzed regarding four different material situations to fulfill the comfort zone through the HVAC system.

c) Third, the results are compared and criticized to find the most appropriate construction material for saving energy in each climate zone.

Of the two simulations tools employed, the first is the Autodesk Green Building Studio, which is a building performance analysis platform used as a simulation tool to provide energy use for the residential building model. This simulation tool depends on Revit 2017 for the modeling and input data. The second is Climate Consultant V6.0, that provides comfort thermal zone diagrams for each city in different climate zones, based on each city's weather data.

5.1 Documentation and analysis of the comfort thermal zone charts

The eight selected cities in the different climate zones of Egypt have different comfort levels for indoor spaces in a basic situation (without using heating or cooling systems). As shown in figure 3, the comfort zone chart consists of two axes. The temperatures in degrees celsius are represented on the horizontal axis and the humidity ratio is represented on the vertical axis.

The points in red show the cooling and heating of the environment by adding dehumidification or humidification. The points in green show the adaptive comfort ventilation in the indoor areas. The adaptive comfort ventilation range is presented by the percentage of thermal comfort of the indoor areas without the use of HVAC systems for heating or cooling.

The range of comfortable indoor climate percentages in the eight selected cities is between 19% in St. Catherine, which represents the Highlands climate zone, and 31% in Hurgada, which represents the Eastern coast climate zone. On the other hand, the uncomfortable indoor percentages, which are between 69% and 81%, need a heating or cooling process to make the indoor spaces more comfortable for humans. The heating and cooling processes consume energy. The research, therefore, will analyze the different construction materials in each zone to find a more economical wall material that can save energy expenditure on heating and cooling.

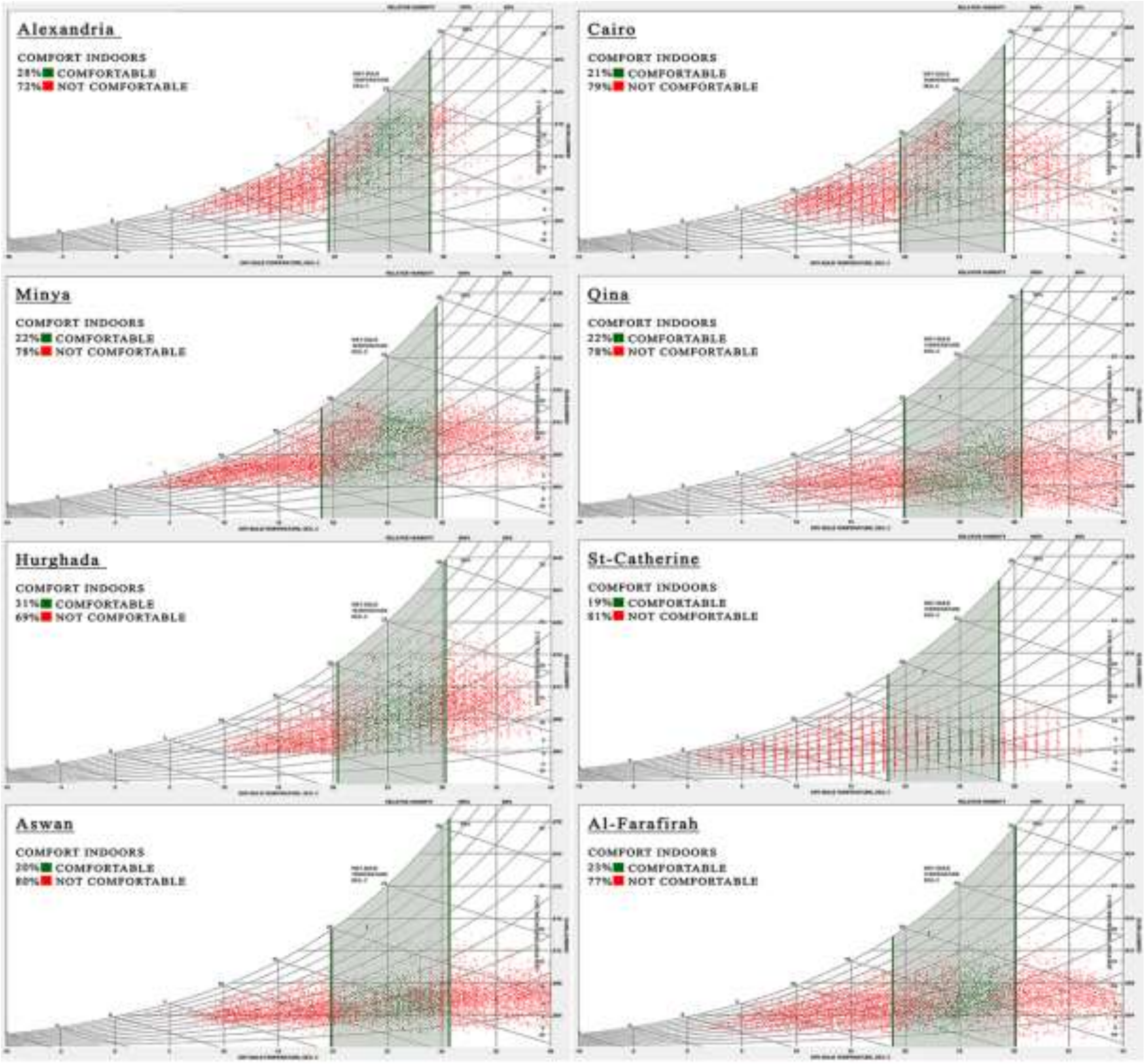


Fig.3 The comfort zone - Analytical charts for each city
Reference: Authors by using the 'Climate consultant 6.0' simulation tool, based on the cities' weather data

5.2 The efficiency of energy saving by using different building materials in the eight climate zones of Egypt.

By using the simulation tool Autodesk Green Building Studio as a building performance analysis platform, the model is analyzed in the four material situations of red bricks, stone, cement bricks and curtain walls. The simulation for each material in each climate zone aims to fulfill the comfort thermal zone by using the HVAC system. The following part represents a comparison between the different construction wall materials' performance in terms of energy consumption for the selected cities in each climate zone of Egypt by using simulation results analysis.

The analysis represents the efficiency of energy saving in four situations: energy consumption in space cooling, energy consumption in space heating, heating plus cooling energy consumption and total energy consumption, which reflects other aspects of energy consumption, such as lighting, vent fans, water heating, etc. in addition to heating and cooling energy consumption, as shown in Tables 2 & 3. These tables present the simulation data charts for energy consumption for the eight climate zones of Egypt.

5.3 Energy consumption related to space cooling

The simulation analysis shows that the curtain glass wall is the material that consumes the most energy for space cooling in the eight climate zones of Egypt through every month of the year. In the months of July, August and September, the simulation of the four materials represents the same ranking in terms of space cooling energy consumption—curtain wall, cement brick, red brick and stone, respectively. Stone is the most economical material for space cooling energy consumption in August for all climate zones except for St. Catherine city, which represents the Highlands climate zone. The results for St. Catherine city show that red brick is the material that consumes the lowest amount of energy, followed by cement brick, then stone and finally curtain walls. In the months of January to April and October to December, the results of the simulation show that red bricks and cement bricks are more efficient in terms of saving energy for space cooling in comparison to stone and curtain walls in the eight climate zones of Egypt. The total energy consumption by space cooling throughout the year shows that red brick is the most economical and efficient material, that saves space cooling energy in all eight of the climate zones of Egypt.

5.4 Energy consumption related to space heating

The simulation analysis of the eight climate zones of Egypt shows the same results in the months that need space heating as for the total energy consumption for space heating throughout the year. The results show that stone is the most appropriate and efficient material for saving space heating energy. The second and third most energy conserving materials with regard to space heating are curtain walls and red bricks. The material that consumes the most energy for space heating is cement brick.

5.5 Energy consumption related to space heating and cooling throughout the year

The simulation of energy consumption related to space heating and space cooling throughout the year produced the following results. First, stone is the most energy efficient material among the eight climate zones of Egypt and the other three materials (red bricks, cement and curtain walls) show far higher results related to energy consumption. Second, in all of the climate zones except for Hurgada city, which represents the Eastern coast zone, and Aswan city, which represents the Southern Egypt zone, the material that consumes the most energy is cement brick. Third, in Hurgada city and Aswan city, the material that leads to the highest energy consumption is the curtain wall.

Table 2: The total space cooling, space heating, and space cooling plus heating and total energy in k/Wh by using four different materials, cement, curtain, stone and redbrick walls, in the eight climate zones of Egypt. (Reference: Authors)

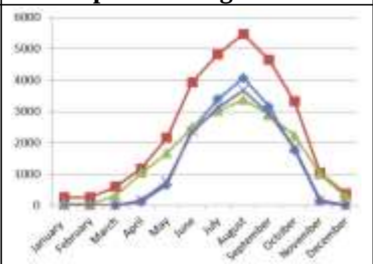
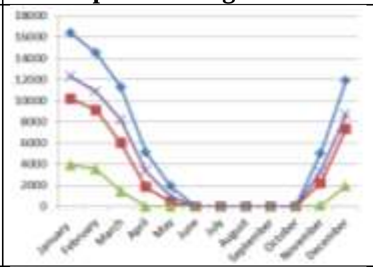
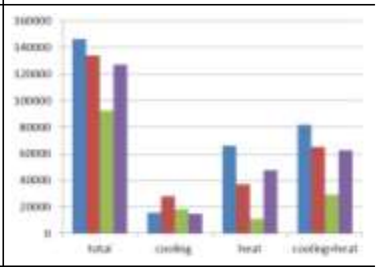
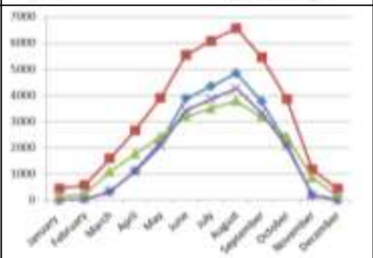
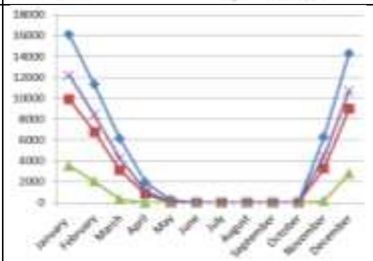
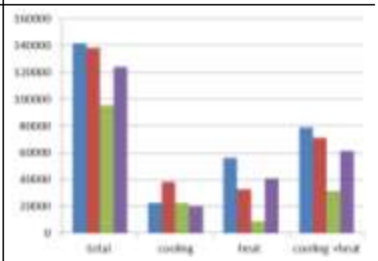
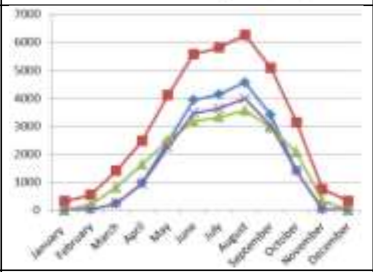
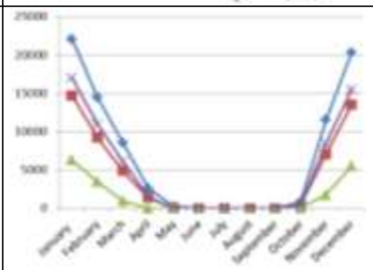
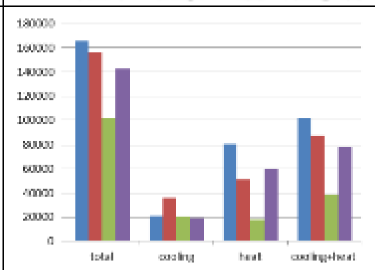
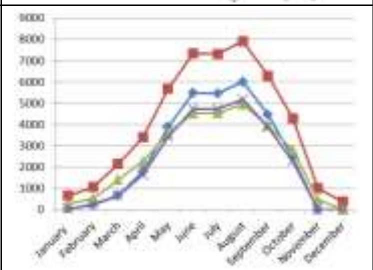
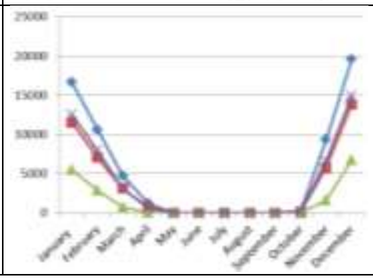
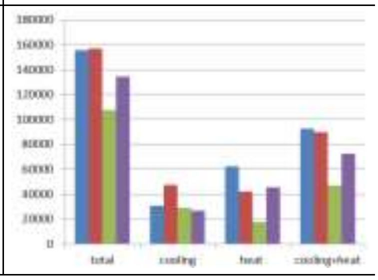
City		Alexandria	Cairo	Al-Minya	Qina	Hurgada	St. Catherine	Aswan	Al-Farafirah
Total Space cooling k/Wh	Cement	15662	22705	21133	30515	30554	7136	36307	22268
	Curtain	28024 ▲	38165 ▲	35804 ▲	47492 ▲	45722 ▲	16922 ▲	53042 ▲	37186 ▲
	Stone	18363	22614	20534	29356	30588	10397	32913	21178
	Redbrick	14962 ▼	20544 ▼	18988 ▼	26845 ▼	27457 ▼	7036 ▼	31735 ▼	19866 ▼
Total Space heating k/Wh	Cement	66041 ▲	56229 ▲	80472 ▲	62320 ▲	25623 ▲	157895 ▲	50450 ▲	83515 ▲
	Curtain	37096	32880	51127	42195	14037	105229	34560	52696
	Stone	10884 ▼	8807 ▼	17846 ▼	17497 ▼	4724 ▼	44209 ▼	14680 ▼	18306 ▼
	Redbrick	29247	41040	59826	45745	17004	116881	36512	61497
Cooling + heating energy k/Wh	Cement	81703 ▲	78934 ▲	101605 ▲	92835 ▲	56177	165031 ▲	86757	105783 ▲
	Curtain	65120	71045	86931	89687	59759 ▲	122151	87602 ▲	89882
	Stone	29247 ▼	31421 ▼	38380 ▼	46853 ▼	35312 ▼	54606 ▼	47593 ▼	39484 ▼
	Redbrick	62584	61584	78814	72590	44461	123917	68247	81363
Total ene	Cement	146460 ▲	141899 ▲	165790 ▲	155368	117354	234845 ▲	147979	169895 ▲

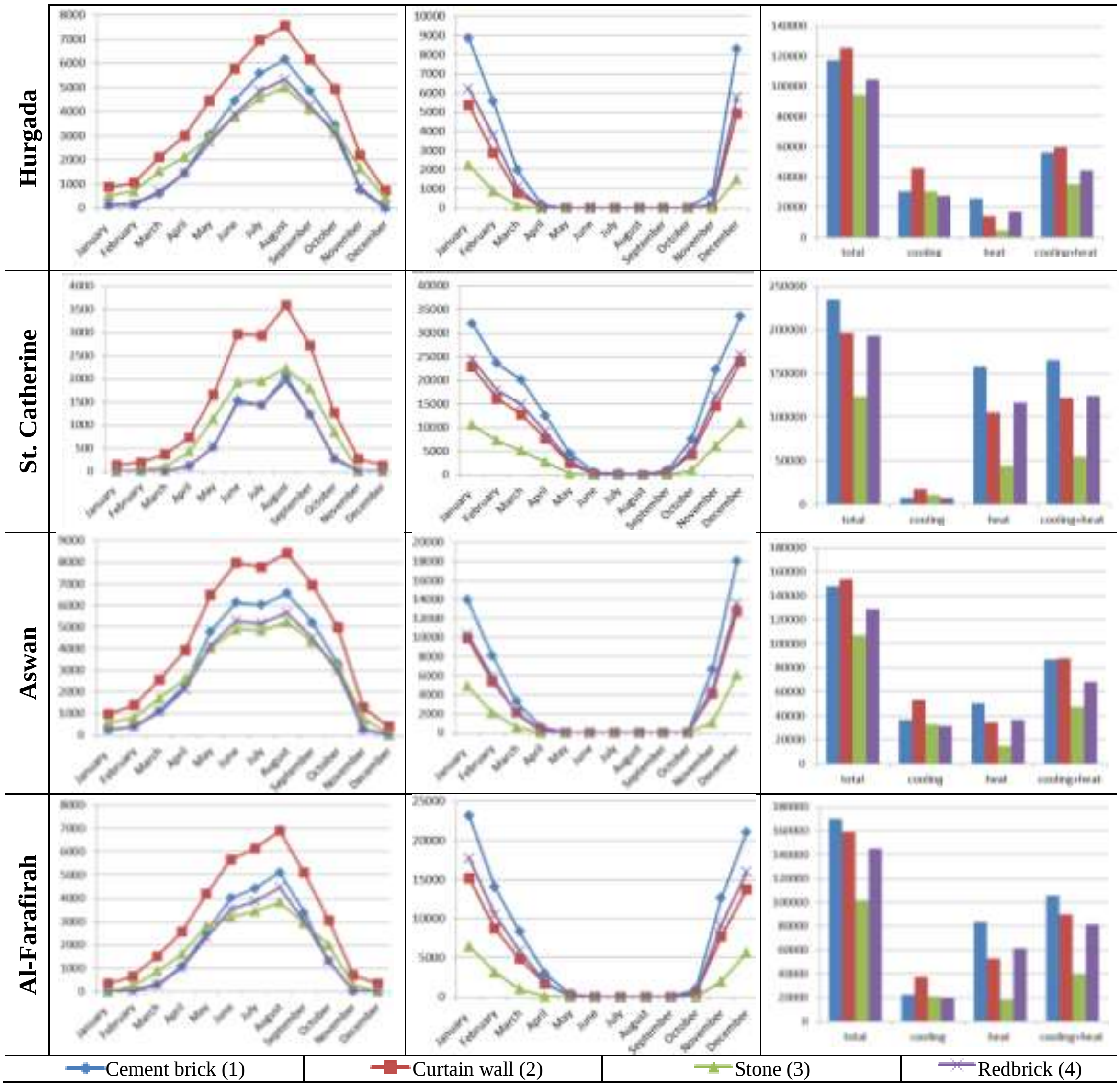
	Curtain	133829	138450	156011	157233▲	125413▲	196862	153756▲	158859
	Stone	92415▼	95399▼	101086▼	107391▼	94566▼	123065▼	106811▼	101669▼
	Redbrick	127070	124082	142598	134195	104607	193333	128499	145090

5.6 Total Energy consumption throughout the year

A huge amount of the total energy consumption which reflects other aspects of energy use besides heating and cooling energy consumption is mainly related to space heating and space cooling. This is primarly affected by the change in construction material. However, other factors, such as lighting, vent fans and water heating, consume energy in constant values, which are marginally affected by a change in the building material, producing other results. In Cairo, Alexandria, Al-Minya, Al-Farafirah and St. Catharine, the building materials are sorted in terms of their total energy efficiency, beginning with stone followed by red bricks, curtain glass walls and, finally, cement bricks. In Qina, Hurgada and Aswan, building materials are sorted in terms of the total energy saved, beginning with stone then red bricks, cement bricks and finally curtain glass walls.

Table 3: The charts for energy consumption simulation for total space cooling, space heating and cumulative results in k/Wh by using four different materials (cement, curtain, stone and red brick walls) in the eight climate zones of Egypt. Reference: Authors

	Space cooling kw/h	Space heating kw/h	Cumulative results kw/h
Alexandria			
Cairo			
Al-Minya			
Qina			



6. A CRITICAL COMPARISON OF THE RESULTS

By comparing energy consumption by means of different building materials in the different climate zones in Egypt, the simulation demonstrates several results, which are presented as follows:

In the low temperature months, between October and April, across all of Egypt's climate zones, the most appropriate energy saving material for space heating is stone, and the highest energy consuming material is cement bricks. In contrast, in the high temperature months, between May and September, across all of Egypt's climate zones, the most appropriate energy saving material for space heating is red bricks, and the highest energy consuming material is curtain wall. In the category of total energy consumption around the year in all climate zones in Egypt, stone is considered the most effective energy saving material. The material that consumes the most energy is cement bricks in Cairo, Alexandrea, Al-Minya, Al-Farafrah and St. Catherine while, in Qina, Aswan and Hurgada, curtain walls represent the highest total energy consuming material. As a critique of the above comparison to aid architects in the design and construction stages, stone, as a natural material, is considered the most appropriate material for energy saving, and it is unnecessary to use energy to achieve thermal comfort for building users using HVAC systems due to the low thermal transmittance co-efficient factor (U.Value). Therefore, stone was the most widely used material in traditional architecture in Egypt. In other senses, the use of the curtain wall in high temperature cities or climate zones, like those in Egypt, is not preferable, due to the high thermal transmittance co-efficient factor (U.Value), as there are several constrains related to its use, such as the type of glass and its specifications, using architectural solutions such as louvers or shading devices and building orientation. As future research, it may be helpful to investigate the integration between the different building materials to identify the best energy saving material for use in the different climate zones.

7. CONCLUSION

A. Based on the research aim to evaluate four different non-structural filling wall materials located in different climate zones as an energy saving strategy in the residential building sector in Egypt, the results confirm the importance of selecting appropriate building materials in order to reduce energy consumption, especially for HVAC systems, to achieve the user's thermal comfort through space cooling and heating throughout the year.

B. In Egypt, there is a large climate diversity, ranging from a hot to a cold, a dry to a humid, and a rainy to a snowy climate. This led to the division of Egypt into eight climate zones. This climate diversity makes it difficult for the designer to identify the most appropriate building materials in relation to energy efficiency from among the most widely-used non-structural filling wall materials, including red bricks, cement bricks, stone and curtain walls.

C. The current research found that stone is the most suitable material to employ in in all climate zones to minimize the total energy consumption for space cooling plus heating throughout the year, through using HVAC systems, to achieve the user thermal comfort zone due to the low heat transfer factor between indoors and outdoors. Also, red bricks are considered the most appropriate building material in relation to energy conservation for space cooling in all climate zones. Using curtain wall systems in all climate zones increases the energy consumption in relation to space cooling and using cement bricks also increases the energy consumption in relation to space heating.

D. The use of HVAC systems for space cooling to reach the thermal comfort zone is used predominantly in every climate zone, while HVAC systems for space heating are used less except in the cold climate zone in St. Catherine, which represents the Highlands zone. Therefore, red bricks are the most appropriate building material to use in terms of energy saving across the different climate zones in Egypt while curtain wall systems and cement bricks are the materials that increase energy consumption across all of the climate zones in Egypt.

E. For architects, there are a chance to reduce the high energy consumption in the local environmant by returning to traditional or vernacular architecture to study and take advantage of both: the traditional architectural treatments and using local materials.

ACKNOWLEDGEMENT

The authors thank Mr. Usama Youssef for his assistance in simulating the results using the Revit Program and Autodesk Green Building Studio.

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