Effect of Building Material and Wall Construction on the Energy Consumption

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Abstract: Architects consider an important link in the design of efficient buildings. Therefore, energy-efficient design strategies require architects and engineers to work together in optimizing the building envelope. The building sector represents a large proportion of final energy consumption in developed countries. This paper investigate the effect of the different element of the building such as building materials type, wall construction and wall insulation, roof construction and roof insulation, insulation type and its thickness, and finally the effect of the building orientation on the yearly total power consumption. The simulation were done using a computer software called “Visual DOE”, in which the building was constructed as a base case and each of any modified case can be compared with the base case.

Keywords: Building, Materials, Wall, Energy,

1.1. Introduction

The building sector in Egypt is a major consumer of generated electrical power, estimated at 54% of the national electricity [1]. Increase in sales of air conditioning systems to attain thermal indoor comfort contribute to the rising annual energy consumption of 7-8% [1]. The function of the building envelope in hot arid zones is to withstand the onslaught of solar radiation and high daytime outdoor temperatures, and to control the inward flow of both heat and hot air for most of the day during summer [2]. Virgone and kuznik [3] presents the results issuing from full-scale test room 3.1 m x 3.1 m x 2.5 m height. the temperature the climatic chamber is imposed dynamically to create a triangular temperature profile. A lighting system allows simulating the sun radiation effects. The results concern a summer day without air conditioning system and a comparison is made between the case with phase change materials (PCM) and the case without PCM. Passe [4] discusses how spatial design theory can contribute to and enrich the development of sustainability and the reduction of energy consumption in architecture and building. The results from the CFD programs propose the development of a design guide for healthy buildings through architectural design and spatial composition. Tavares and Martins [5] presents a methodological proposal in which computer-based simulation plays a central role, nevertheless demanding only a moderate effect of designers to adapt themselves to the systematic use of simulation tools. Several preliminary decisions were taken, regarding walls types, fenestration solutions (including frames and glazing types), active systems, and conditioned areas. Varfalvi and etal [6] investigated and recording using the monitoring system the key energy and thermal comfort parameters of a room has 2.6 x 5 x 2.6 height of a building was built at 1960s. The results show that that it should include a 6 or 8 thick layer of thermal insulation.

Karlsson and Moshfegh [7] reported a comprehensive investigation of low-energy building insweden. The total area is 120 m^2. The results showed that, a set point temperature of 23 ^oC gives the greatest numbers of occupants satisfied, which is also in agreement with the outcome of the temperature measurements in all buildings. Also, the economical comparison shows further that the low-energy buildings are less affected by higher electricity prices and the pay-back period is within reasonable limits.

Schiavon and Melikov [8] quantified the potential saving of cooling energy by elevated air speed which can offset the impact of increased room temperature on occupants' comfort by means of simulations with Energy Plus software. Fifty-four cases covering six cities (Helsinki, Berlin, Bordeaux, Rome, Jerusalem, and Athens), three air velocities (less than 0.2, 0.5, and 0.8 m/s) were simulated. The results obtained that, a cooling energy saving between 17-48% and a reduction of the maximum cooling power in the range 10-28%. Also, the results reveal that, the required power input of the fans is a critical factor for achieving energy saving at elevated room temperature.

Wang, et al [9], discussed possible solution for zero energy building design in UK. Simulation software Energy plus and TRNSYS 16 were used in the study, where Energy Plus simulation are applied to enable façade design studies considering building materials, window size and orientations. TRNSYS is used for the investigation of the feasibility of zero energy houses with renewable electricity, solar hot water system and energy efficient heating systems under Cardiff weather conditions. Various designed methods were compared and optimal design for typical homes and energy systems are provided.

Virtal, [10] presented energy simulation of office buildings located in France. It takes into account the energy consumption of different HVAC systems. Two different kinds of buildings were used. The reference building has external structures of typical new buildings in Paris today. In the advanced building the external walls and windows have lower U-value and improved tightness. Windows have also better shading coefficient and external overhang of 500 mm for solar shading. Results show that with right HVAC system and building design can reduce energy consumption nearly 75%.

Nabil [11] evaluated the energy efficiency of a single flat residential building of area 200 m^2 using the Visual DOE. The effect of the wall construction and the roof insulation were investigated. The results indicated that the roof was needs more thick insulation than the wall especially in hot arid zones.

1.2. Methodology

Computational investigation was carried out using computer software for the energy calculation and energy estimation called “Visual DOE” [12]. A single story flat as shown in Fig. 1, which were consists of two bed rooms, hall, bath room, and kitchen. The total flat area was 120 m^2. The light power density (LPD) and equipment power density (EPD) were fixed at 21.53 W/m^2 and 8.07 W/m^2 respectively. The floor was adiabatic floor with U-factor is 0.18 W/m ^oC. The different types of building brick which were used in this study were shown in Table 1.

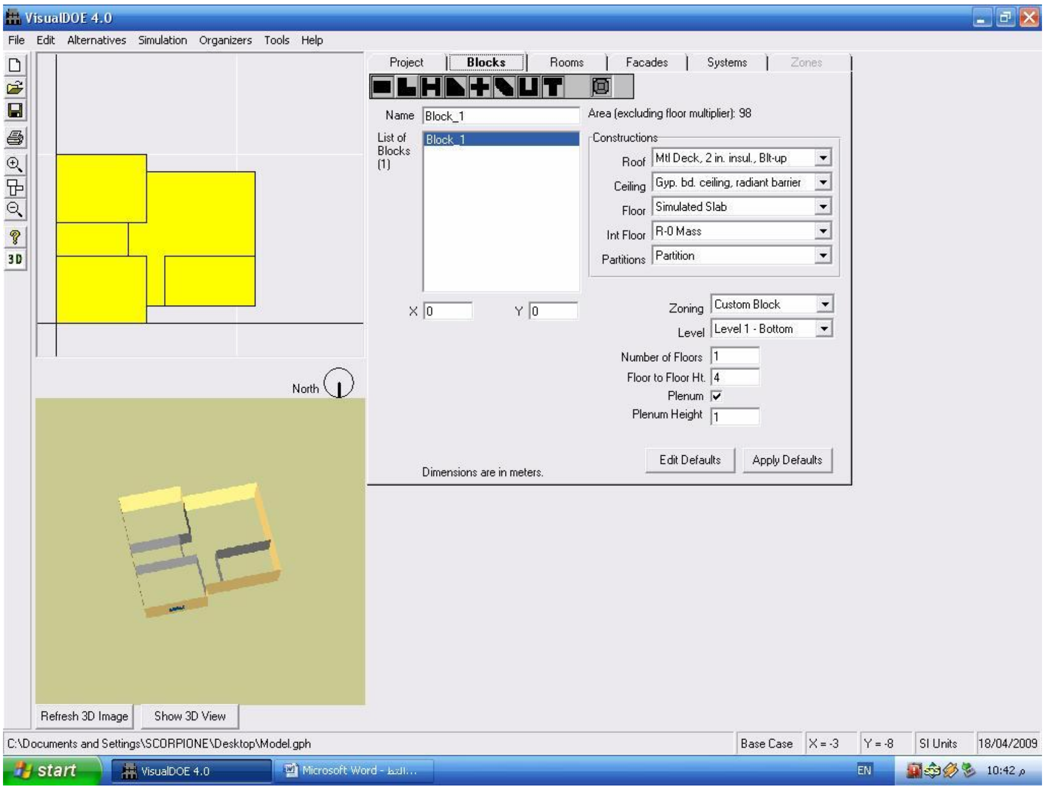

Figure 1: A Single Story Flat

Table 1: Physical Characteristic of the Different Building Materials Types

	Thickness cm	Density Kg/m^3	Thermal Conductivity W/m °C	U-factor W/m^2 °C
Solid clay brick	12.5	1950	1	3.07
Solid cement brick	12.5	1800	1.25	3.30
Hollow cement brick	25	1140	1.6	2.80
Solid concrete brick	25	2000	1.4	2.64
Light white brick	12.5	985	0.33	1.04
Solid sand brick	12.5	1800	1.59	3.59
Hollow clay brick	12.5	1500	1.39	2.54

The simulation was carried out for three different environmental regions in order to know the effect of the environmental climate on the electrical power consumption. The three environmental regions are Cairo, Alexandria, and Aswan.

1.3. Results

The effect of the building materials type on the heat and cooling power consumption are shown in Table 2. As shown in Table 2 for Cairo, the suitable building materials type is light white brick 12.5 cm in which the lowest electrical power consumption for the two purpose heating and cooling. The same behavior was occurred for the two environmental climatically regions Alex and Aswan. These because of the light white brick 12.5 cm have the lowest physical properties; 0.33 W/m ^oC thermal conductivity, and U-factor 1.04 W/m^2 ^oC. It is mean that, the architecture or planners must take into consideration the suitable type of building materials for each environmental region.

Table 2: effect of building material type on heat and cooling power consumption

	U-factor	Cairo		Alex		Aswan	
	W/m^2 ^oC	heating	cooling	heating	cooling	heating	cooling
Hollow cement 25 cm	2.8	5582	2797	4881	1888	3949	5133
Hollow clay brick 12.5 cm	2.45	5438	2764	4740	1903	3783	4986
Light white brick 12.5 cm	1.04	3771	2468	3408	1758	2263	4259
Solid concrete 25 cm	2.64	5043	2644	4540	1808	3443	4946
Solid cement 12.5 cm	3.3	6408	2851	5644	1925	4794	5384
Solid clay brick 12.5 cm	3.07	6100	2836	5348	1920	4467	5279
Solid sand brick 12.5 cm	3.59	6805	2807	6009	1899	5196	5414

1.3.1. Effect of insulation thickness

Table 3 illustrates the effect of the insulating thickness with the light white brick on the heating, cooling and total power consumption for the three different climatic regions Cairo, Alex, and Aswan. In order to know the effect of the insulation thickness with the case of using light white brick 12.5 cm Table 3 shows there are an optimum insulating thickness for cooling process which is 10 cm thick but in case of heating process the optimum insulating thick is 20 cm. therefore according the goal of the user or the designer and also according the economical comparison between the cost of the increasing of the insulating thickness from 10 cm to 20 cm and the saving of the decreasing of the electrical power from 3011 to 2895 {116 kW) and the time of recovery the insulating cost.

For Alex, also there are two optimum insulating thicknesses one for cooling process which is 10 cm and the other for cooling process is 20.5 cm. The saving in the electrical power consumption in the heating process was 3115-2841=274 kW/h.

Because of the hot arid environmental in Aswan therefore the thickness of the insulating material was larger than the two regions Cairo and Alex and was 17.5 cm.

Table 3: effect of the insulating thickness with the light white brick on the heating and cooling power consumption for the three different climatic regions.

	U-factor	Cairo		Alex		Aswan	
	W/m^2 ^{o}C	heating	cooling	heating	cooling	heating	cooling
Light white brick + ins 2.5 cm	0.56	3364	2391	3115	1716	1902	4079
Light white brick + ins 5 cm	0.38	3178	2385	2970	1731	1755	4025
Light white brick + ins 7.5 cm	0.29	3076	2384	2891	1741	1674	3997
Light white brick + ins 10 cm	0.23	3011	2332	2841	1747	1623	3979
Light white brick + ins 12.5 cm	0.20	2969	2333	2808	1751	1587	3967
Light white brick + ins 15 cm	0.17	2937	2333	2784	1754	1563	3958
Light white brick + ins 17.5 cm	0.15	2914	2334	2766	1756	1544	3952
Light white brick + ins 20 cm	0.13	2895	2334	2751	1758	1531	3868

1.3.2. Effect of the azimuth angel

As shown in Table 4 the effect of the azimuth angle for the light white brick for the three climatically regions Cairo, Alex, and Aswan. Table 4 illustrate there are an optimum azimuth angle for each of the three climatically regions; for example: the azimuth angle facing north which means that, the front façade of the flat facing the north direction. This behavior was happened for the other two climatically regions. Also, the results in Table 4 illustrated that, the bad azimuth angle for Cairo was happened when the front façade facing the east direction.

1.3.3 Effect of roof insulation and the use of exterior shading

As shown in Table 5 the effect of the roof insulation on the heating, cooling and the total power consumption for the three climatically regions Cairo, Alex, and Aswan. Also the table illustrates the use of the exterior shading with the case of the roof insulation 10 cm thickness.

As shown in Table 5 the suitable insulating thickness was 15 cm for all three climate regions. In case of using an external shading there are a decreasing in the electrical power consumption for heating and cooling comparing with the case of no roof insulation for Cairo and Alex. But the value of the electrical power consumption for heating process was still higher than comparing with the case of roof insulation. The value for Cairo was increased from 2861 Kw/h to 4199 kw/h (1338 Kw/h), the reason was the shading the solar radiation to enter the building in the winter and the owner was used the electrical heating devices to make a warm comfort condition in their occupants spaces. Therefore it is important to know what do you needs and what is the effect of your modification on the electrical power consumption for the two processes heating and cooling. Also, the same behavior was occurred for the two remaining environmental regions Alex and Aswan.

Finally for the case of roof insulation and using external shading the electrical power consumption for cooling was the lowest one compared with the case of roof insulation with 10 cm insulation which is saved 352 kw/h. but the electrical power consumption for heating process was increased by 579 Kw/h. for Alex the saved in the electrical power consumption for the two process cooling and heating were 264 Kw/h and 452 Kw/h respectively. The reason of decreasing the electrical power consumption for heating in Alex in winter season was the insulation and the shading not permit the heat to transfer out side the building.

Table 4 : effect of azimuth angle for light white brick for the three climatically regions

Light white brick	Cairo			Alex			Aswan		
	heating	cooling	total	heating	cooling	total	heating	cooling	total
Angel 0	3142	2416	11531	2880	1722	10555	1720	4066	12015
Angel 45	3154	2632	11996	2787	1849	10753	1716	4414	12789
Angel 90	3158	2854	12500	2727	2030	11021	1502	4552	12838
Angel 135	2744	2534	11229	2247	1767	9589	1369	4131	11995
Angel 180	2700	2400	10915	2280	1695	9499	1362	3862	11419
Angel 225	2993	2472	11446	2651	1769	10162	1658	4050	12079
Angel 270	3231	2559	11871	3182	1908	11298	1829	4059	12329
Angel 315	3272	2513	11709	3102	1845	10854	1971	4037	12329
Angel 360	3142	2416	11531	2880	1722	10555	1720	4066	12015

Table 5: effect of the roof insulation on the heating and cooling power consumption for three climatically regions

	U-factor	Cairo		Alex		Aswan	
	$W/m^2\ ^oC$	heating	cooling	heating	cooling	heating	cooling
Roof no insulation	1	4634	2821	4060	1986	2812	5163
Roof + ins 2.5 cm	0.80	3422	2319	3134	1640	1976	4174
Roof + ins 5 cm	0.48	3135	2220	2938	1585	1783	3955
Roof + ins 7.5 cm	0.34	3010	2177	2850	1563	1694	5859
Roof + ins 10 cm	0.27	2940	2153	2800	1550	1646	3805
Roof + ins 12.5 cm	0.22	2893	2136	2766	1542	1614	3767
Roof + ins 15 cm	0.18	2861	2125	2744	1536	1594	3744
Exterior shading	1	4199	1734	3762	1166	3085	3884
Roof + ins 10 cm + Exterior shading	0.27	3519	1801	2536	1103	2404	3783

1.4. CONCLUSION

1.4.1. For Cairo

Light white brick 12.5 cm is the more suitable, polystyrene 10 cm is the most effective thickness, north direction is the optimum azimuth angle, roof insulation with a thickness 10 cm insulating materials are the best selection for heating, the use of exterior shading is the more effective for cooling process. Finally for the total power consumption the case of polystyrene 10 cm thickness with external shading is the best solution.

1.4.2. For Alex

The light white brick 12.5 cm is the most suitable building materials for this climate region, a thickness of 5 cm polystyrene is the effective thickness for saving the electrical power consumption. As Cairo the north direction was the optimum azimuth angle for building, polystyrene 5 cm thickness with external shading is the best and economic solution.

1.4.3. For Aswan

The light white brick 12.5 cm is the most suitable building materials, a thickness of 12.5 cm polystyrene is the effective thickness for saving the electrical power consumption. As Cairo the north direction was the optimum azimuth angle for building, roof insulation with a thickness 12.5 cm insulating materials are the more effective selection. polystyrene 12.5 cm thickness with external shading is the best solution.

Finally it is important to compromise between the effect of the each modification on the electrical power consumption for the two processes heating and cooling and must select the most economical modification.

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