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LIFE CYCLE COST REDUCTION OF A SOCIAL HOUSING BUILDING BY USING POLYURETHANE LIGHTWEIGHT BRICKS

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ABSTRACT: This study examines the ability to reduce the cost of constructing low-income housing buildings by modifying wall material properties. A new clay brick mixed with polyurethane foam was prepared. Different types of tests were conducted – compression strength, water absorption, thermal conductivity. Three types of studies were conducted literature review, experimental study to prepare samples of the different, and comparative study, to compare the construction costs using ordinary clay bricks and light bricks using the ETAB program. The test results showed that adding foam to the bricks in different proportions weakened the compressive strength of the bricks. The optimum percentage of polyurethane additive to the regular brick mixture is 30% by volume. The use of polyurethane foam bricks on building the social housing project showed a 4.15 % reduction of the total cost. It can be said that reducing the cost of the building will be higher than the calculated percentage in reducing the initial cost based on thermal conductivity tests, which will reduce the cost of the building's life cycle by reducing the cost of energy used in conditioning the building.

Keywords: Red clay brick – Polyurethane– Thermal Conductivity – Low-Cost Housing- Life cycle cost

1. INTRODUCTION

The housing projects are one of the leading prime concerns in Egypt [1]. Egypt has the highest demand for affordable housing in the MENA region due to its large population and relatively low-income levels [2]. Governments have many attempts to provide suitable accommodation for low-income people at the lowest possible cost [3], such as the Egypt's national social housing project

Walls are the most significant building component in a housing unit. Walls materials can affect the total cost of the building and the entire life cycle cost of a housing unit related to thermal conductivity and energy consumption in providing thermal comfort for user's [4]. The cost of wall construction equals 15% of the total cost of the building in general [5]. Traditional masonry walls still the appropriate construction material for low and medium-rise buildings, affording weather protection, sound insulation, and long life with little maintenance [6].

Power, water, and soil are the main ingredients that contributed to brick making [7]. The technical specifications of mud bricks in Egypt, which are the main component of walls, and are comparatively the most sustainable walling material for building affordable housing [4]. The technical specifications such as components, type, dimensions, density, and the ability to heat insulation affect the architectural and the structural design of buildings in many ways:

1. First, the weight of the bricks affects the structural elements, so lowering brick's weight leads to a reduction in the cost of the structural elements.
2. Second, the more remarkable ability to thermal insulation leads to a decrease in heat consumption by the air conditioning loads of the building, which leads to a reduction of both the life cycle and initial cost of a building.

Many studies discussed the recycling alternatives of several industrial wastes that have become a widespread practice in the industry. The recycling process aims to reduce industrial waste disposal costs and protect the environment [8]. One of the most common waste materials is polyurethane. Polyurethane foams are one of the most widely used plastic materials in the world [9]. Polyurethane has a thermal conductivity coefficient of 0.02 w/m k, making polyurethane foam one of the best insulators [10]. According to that, one of the essential applications of polyurethane in the building is thermal insulation. Indeed, heat insulation plays a fundamental role in reducing energy consumption in creating a healthy and comfortable living space [9].

This research aims to reduce the cost of constructing low-income housing buildings by different walling materials modified by the researchers. A theoretical, experimental, comparative, and applied studies were implemented in this research. The comparison will be between ordinary clay brick and modified clay bricks mixed with polyurethane foam. According to the Egyptian codes and standards, different types of tests will be conducted – compression strength, water absorption, thermal conductivity - All this, according to the Egyptian codes and standards. Moreover, the result will be applied to a residential building model, six –floor social housing building, about six floors. This study would benefit the decision-makers, and the public understands the real value when selecting walling materials for their affordable houses and choosing the best suitable material considering the embedded energy and total life cycle cost. Finally, this research gives a suitable building unit for construction that is safe and economically valued.

2. RESEARCH SIGNIFICANCE

Examine the possibility of minimizing the construction cost of a building and the life cycle cost of low-income housing by modifying the properties of red brick material used to build the walls in Egypt. The modification of clay brick properties will affect the structural system properties and the lifecycle cost by reducing the weight of the brick and reducing the heat conductivity. The modification will be done by modifying the properties of the red brick manufacturing mixture by adding Polyurethane material to the original mixture of mud bricks with different ratios by volume.

3. LITERATURE REVIEW

The total demand for low-cost housing is forecasted to increase ahead of the supply achieved [11]; resource scarcity, shortage due to urgent demand, and waste caused by inefficiency are regarded among the critical challenges of affordable housing [2].

The building materials that affected buildings' cost, especially the brick wall, were investigated in many works. Many researchers studied the performance of alternate methods of manufacturing masonry units [12]. The results, when compared to the conventional clay bricks, the various combinations of mud bricks, mud bricks with slag, mud bricks with quarry waste, and fly ash bricks with quarry waste all gave better performance. Therefore it can be cleanly recommended for cost-effective construction for low-cost housing. A study also experimented and compared three materials burnt clay brick, Autoclaved Aerated Concrete Block, and fly ash bricks [13]. They have concluded that the AAC blocks will cost 1.55% lesser than burnt clay brick and 9.8% lesser compare to fly ash brick. A research focused on studying the laterite block to reduce the average block production costs [14]. The laterite soil mixed with fine and coarse aggregates stabilized with Cement and Lime with four different mix ratios (5-10-15%). These ratios maintain the laterite level up to 50% to explore the most suitable sustainable strength. The compressive strength result shows that the cement stabilized sample had higher compressive strength than the lime stabilized and that the strength increased as the curing age increases, also compressive strength increases as the content of the stabilizer increased. Another study discussed the possible reuse of bio-solids in fired clay bricks and the effect of incorporating bio-solids on the compressive strength, density, and other physical and mechanical properties of bricks. In this study, bio-solids from the stockpiles. It was used to assess their suitability as a partial replacement material for clay in the formulation of fired clay bricks. The significant research outcome in this research is establishing a process for manufacturing fired clay bricks incorporating bio-solids [15].

Also, the polyurethane foam material and its effect on improving brick properties have been studied in many previous researches. For example, a study experiment reinforced polyurethane materials with recycled or organic materials to reduce costs. Then the laboratory results showed that an increase of 32.6% occurred for the compressive strength for the glass sample—overall improvements of the mechanical properties for other additive materials [16]. A study also investigates the behavior of polyurethane foams, used as gummy for the construction of joints brick masonry walls. The foam-brick walls with traditional mortar masonry were performed, as the type of joints varies and the arrangement of the holes of the bricks varies concerning the direction of the applied load. It was providing indications on which adhesive must be adopted for masonry buildings [17].

The thermal performance of walls has been investigated in many works by using additives. And the brick was also investigated separately as a building material to better understand its thermal performance [6] A study measured the thermal properties of clay used in building materials using transient and steady-state hot-plate and flash methods [18]. A research also studied the thermo physical properties of Alveolar earth bricks through experimental investigation. The research found that the alveolar brick construction system presents higher thermal inertia than the insulated one, justifying the low measured energy consumption [19]. A study in Australia suggests adding crushed waste glass to the bricks to reduce firing temperature and keeping compressive strength. Results show that increasing the glass ratio improves the physical and mechanical properties of the clay bricks [20]. Another study in Thailand also investigates the effects of adding sawdust waste with different ratios (2.5%, 5%, 7.5%, and 10%) to the fired clay bricks. Many properties were tested, such as bulk density, water absorption, compressive strength, thermal conductivity, and apparent porosity. Results show that adding sawdust to the clay bricks reduced the compressive strength and the bulk density of the bricks. The thermal conductivity of clay bricks with sawdust additives also decreased compared to clay brick without additive [21]. Many researchers have studied the importance of improving the properties of clay bricks by adding waste or some materials to it or adding it to other building materials to improve materials properties. Red clay brick was used as an additive material to develop refractory bricks in Bangladesh. It is found that refractory bricks with 60% red clay bricks have the highest compressive strength value [22].

A study investigated strengthen the Clay brick to increase its performance against earthquakes by preparing specimens of RC frame infilled with brick masonry. This method was described as an effective and inexpensive method [23]. A study also investigated the need to check the effectiveness of using waste materials such as iron filings because it affects the environment negatively [24].

4. MATERIAL AND METHODS

The research Implemented through three methodological stages to reach the research goal as follows:

1. Literature Study of the nature of waste materials in Egypt, which can be added to clay bricks to reduce weight and reduce the cost of the construction structure and foundations of the social housing project in Egypt. With the benefit of increasing the insulation property of the brick, reducing the heat load of the building, and reducing the life cycle costs for the building.
2. Experimental Work by preparing samples of the different ratios by adding polyurethane to the clay bricks and conducting the necessary tests to reach the optimal sample according to the Egyptian standard specifications.
3. Comparative study, to compare between the construction costs using both ordinary clay bricks and light bricks using the ETAB program, and this required a field survey of the local market prices of different building materials to calculate the final cost of the residential unit using the two samples of bricks. As well as make a comparison with life cycle cost before and after modification

4.1 Experimental Work

The experimental study evaluated the efficiency of using in-house manufactured bricks made from different ratios of polyurethane's additive to the brick to determine the best and suitable ratio according to the Egyptian code for clay bricks, especially from compression Strength & water absorption. After that test, the thermal conductive for the best sample. Fig. 1 clarifies the polyurethane's additive preparation.

(a) Preparing the polyurethane foam sieve No. 2.76 (b) Final shape of the polyurethane foam

Fig.1 Polyurethane's additive preparation

Fig. 2 clarifies the stages of manufacturing samples of bricks with different ratios of polyurethane additive by size.

(a) Prototypes pressing machine (b) Brick production process

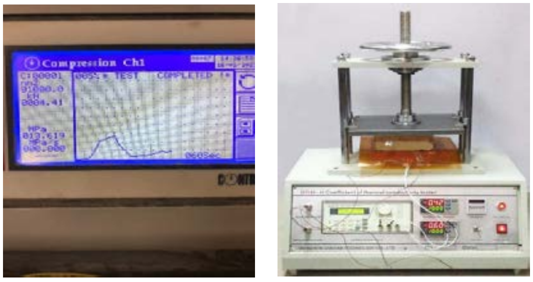
(c) Wet prototypes (d)Prototypes after drying from 20-24 hours

Fig.2 The stages of manufacturing bricks samples

Fig. 3 clarifies the testes conducted on the prepared bricks

(a) Absorption test (b) Compression strength test

Fig. 3(a) Absorption test, (b) Compression test



(c) The shape of the pressure strain curve

(d) Thermal conductivity test

Fig.3(c) Pressure strain, (d) Thermal conductivity

5. RESULTS AND DISCUSSION

Five sets of samples were prepared with different ratios of polyurethane, adding to the regular brick of the total volume (10% - 20% - 30% - 40%). Subject to re-adjusting the compressive strength of the piston and not burning the bricks during manufacture. Then, each of the compression strength, absorption, and thermal conductivity tests were performed on samples, and each group consisted of five samples, compared with the standard bricks and the results of the average tests, as shown in Table 1.

Table 1 Results of tests conducted on manufactures bricks

Average of (5 pieces) Size/cm 2.5X2.7X5.2	Polyurethane ratios by volume				
	0%	10 %	20 %	30 %	40 %
Average weight/ gram	29.5	26.5	24	18	15
Water absorption %	8.4±.5	8.1±.7	7.8±.6	6.9±.4	6.4±.3
Average comp. strength (kN/mm^2)	4.5	2.5	2.3	2	1.7
Average Thermal conductivity Walt per $Wm^{-1}K^{-1}$	0.6	0.45	0.35	0.18	0.0992
Average density kg/m^3	1040	920	830	630	510

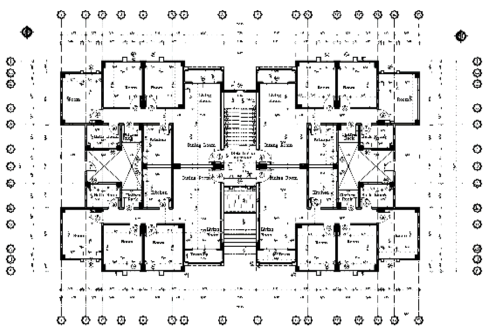
The typical case of bricks consists of 78% clay and 22% sand. The clay ratio is 11% from the Al-Hiba region and 89% silt clay. The polyurethane is added to the mixture with four different ratios by volume to produce the final samples. The polyurethane passed through sieve no. 2.76. Noting that the burning stage in preparing polyurethane bricks has been canceled. According to the Egyptian standard specifications (1756 / 1989) [25], the Average comp. Strength should not be less than 2 kN/mm. Therefore, the sample with 30 % by volume of polyurethane is shown in Table 1, which achieves the lowest available density and weight.

5.1 Applying the Prepared Samples to the Case Study

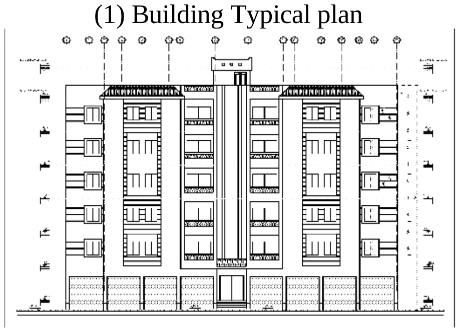
The study is carried out on a social housing model building, a six-stories building with a total area of 292-meter square, the primary structural information related to the building are clarified below (These quantities are depending on the final calculated quantities of the construction sites under the study, and it was matched with the quantities calculated from the ETAB software program):

- The live load of residential buildings is 250 kg / m^2.
- The external walls of the building are 25 cm thick and the interior is 12 cm thick, the bathroom walls and the stairs are cement bricks, and the rest of the walls are clay brick - the subject of comparison - and The total amount of clay bricks used in single residential buildings = 118.75m^3 + 162.5 m^2 (size 25 X 12 X 13cm) = 31.074 thousand brick units
- The cost per square meter for clay bricks, including supply and installation = 1250 EGP per m^3 and 220 EGP per m^2 that cost is the average item price for the sites under study (79 buildings) [26].
- The cost of a cubic meter of clay bricks by adding 30% by volume of polyurethane = 1050 EGP per m^3 and 170 EGP per m^2 (The researchers analyzed the item cost according to the local market prices at the time of the study, considering that the used bricks did not pass the firing phase in the factory).
- The density of normal case of clay bricks = 1040 kg/cm^2 and the density of clay bricks by adding polyurethane 30% by volume = 630 kg / cm^2.

The structural system used is separated foundations, columns, beams, and concrete ceilings. Fig. 4 clarifies the building drawings. The cost study is carried out in two stages that mainly depend on studying using the prepared bricks in constructing the typical building on cost reduction. The first stage is to study the effect of the load variation of prepared bricks on the building's structural elements (assuming that the rest of the structural elements in the building will not be changed). The second stage analyzes the effect of using prepared bricks on the thermal insulation and air conditioning loads inside the building and the effect on the life cycle cost of the building. The cost data is as follows: The cost of the typical residential building used in this study (24 apartments) using standard clay bricks is 5547884 Egyptian pounds (including taxes, insurances, and value-added tax).



(1) Building Typical plan



(2) Building main elevation

Fig.4 The case study typical plan & main elevation

This price was an average of four sites from the Social Housing Project - 79 buildings - the third phase in the Beni Suef Governorate, which took place from 2018 - 2020. These prices were obtained from the records of the Housing Directorate in Beni Suef government and the Consulting Unit at the Faculty of Engineering, Beni Suef University, according to Table 2; we also conclude that the cost of the apartment or housing unit is equal to 231161 EGP. Moreover, this cost does not include the price of the land [26].

Table 2 The average cost of the typical building for the Social Housing Project

Site (in Beny Suef)	Bny Solman	Seds	Al-Noira	Wana-Alkas
Buildings # /site	30	13	18	18
The cost of all site units in EGP [26]	146408 450	6510 8102	1204554 32	106310 832
The cost the unit in EGP	488028 2	5008 316	6691968	590615 7.3
The cost of structural system	409943 66	1953 2431	3734118 4	308301 41
Average cost of the structural system	28%	30%	31%	29%
Average cost of the structural system,	29%			
Average cost per unit in EGP = 5547884				
The average cost per apartment in EGP = 231161				

Note 1: The exchange rate of the US dollar at this time = 16 Egyptian pounds
Note 2: The listed prices and quantities are the average contractual prices according to the bill of quantities
Note 3: The structural system (columns, foundations, and beams)

As shown in previous table, the average cost of the structural system (columns, foundations, beams, and beams) to the total cost for each site in the case of standard clay bricks is 1942314 EGP, which is equal to 29% of the total construction cost of the building.

Table 3 clarifies the cost of the bricks used in construction concerning the total cost of the building

Table. 3 The cost of the bricks used concerning the total cost of the building

	Standard clay brick		Clay bricks with 30% polyurethane	
The amount of bricks	118.75 m^3	162.5 m^2	118.75 m^3	162.5 m^2
Cost in EGP	1250 EGP	220 EGP	1050 EGP	170 EGP
Total cost in EGP	148438 EGP	35750 EGP	124688 EGP	27625 EGP
	184188 EGP		152313 EGP	
Average total cost per building in EGP	5547884 EGP			
The percentage of the cost of a brick to the total cost	3.32%		2.74%	
The cost comparison in EGP	+31875 EGP		-31875 EGP	

The percentage of the standard clay brick cost to the total building cost is 3.32%. And the percentage of the prepared clay brick with 30% polyurethane cost to the total building cost is 2.74%.

As shown in the previous table, the prepared bricks cost ratio by adding polyurethane to the clay bricks equals 2.74% of the total building cost. The difference in the cost of the bricks by adding polyurethane to the clay bricks is 31875 EGP and is equal to 0.5% of the total cost of the building.

5.2 The Structural Study Using the Prepared Bricks Samples

A comparison was made between the use of normal clay bricks with a density of 1040 kg / cm^3 to construct the walls and bricks with 30% polyurethane with a density of 630 kg / cm^3. The structural analysis and the design of the residential building model were performed using the soft were program called ETAP, as shown in Fig. 5.

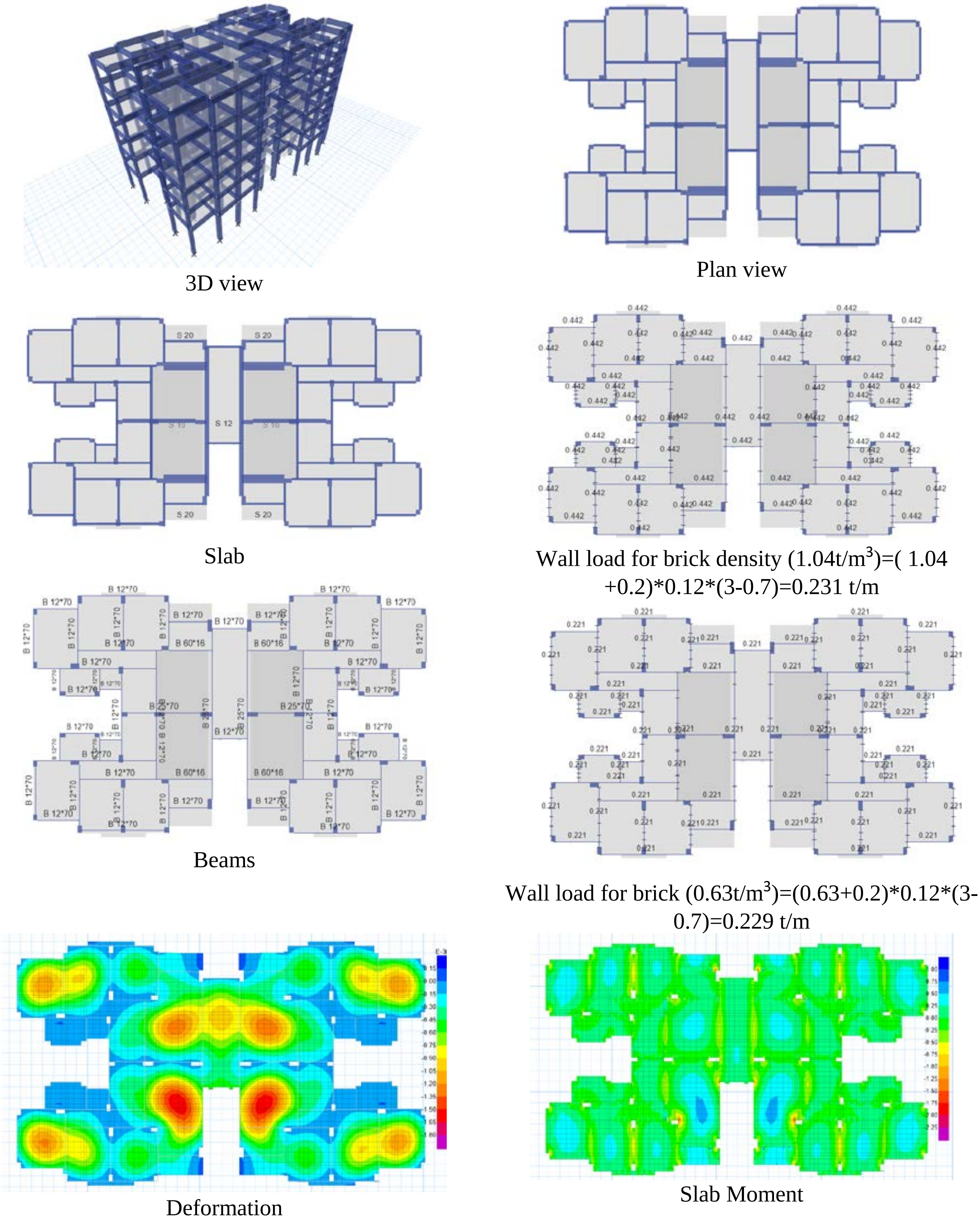


Fig.5 Structural analysis and design of the residential building model using the ETAP software program

The foundations and the structural elements were designed using standard bricks and prepared Clay bricks with 30% polyurethane.

The results show that the total reduction of the total cost, after using foam in bricks by 30% by volume, which equal the summation of (the reduction in the cost of the brick itself + the reduction of the structural system) and equal (0.005% + 4.14%) = 4.145% of the total cost of building which equals 9581 EGP from the total cost of the apartment unit (221580EGP instead of 231161 EGP for standard brick).

The calculated numbers related to cost after and before modifications would have led to a reduction in the total cost of constructing a building with 79 apartments equals 18166823 EGP. The total cost for each unit using both types of bricks is shown in Table 4.

Table. 4 The structural system cost comparison between the two cases

Object	Concrete Quantity m^3	Cost / m^3 by EGP	Total cost EGP.
Normal Clay Brick			
Columns	170	3300	561000
Ground beams	155	3200	496000
Rein. Concrete foundation	160	2600	416000
Plain concrete foundation	165	150	24750
Ground beams	20.5	2800	57400
Total cost of original case of clay brick			1555150
Brick with the addition of 30% by volume of polyurethane			
Columns	142	3300	468600
Ground beams	139.5	3200	446400
Rein. Concrete foundation	133	2600	345800
Plain concrete foundation	140	150	21000
Ground beams	16,65	2800	43290
Total cost for brick with the addition of 30% by volume of polyurethane			1325090
Decreases of cost			230060
% Decreases of total cost			4.14 %

5.3 The Effect of Thermal Insulation

Lee's Disk device was used to measure the thermal conductivity, as a Corselli experiment was made to measure the thermal conductivity coefficient. The next Table 5 clarifies the a comparison between the two case (standard and modified bricks)

Table. 5 A comparison between the standard and the modified bricks

Normal brick		Polyurethane foam brick	
Advantage	Weakness	Advantage	Weakness
Rarely cracked	Water absorbency is high enough	Waterproof	Less strength resistance
Better endurance quality	The cost is higher	The cost is cheaper	Quality endurance is less
Suitable for bearing walls	Heavier	Loads lighter	Suitable for non- bearing walls only
Easily formed and worked	Less heat insulation	Better heat insulation	Somewhat difficult to form
	The manufacturing capacity is greater	The manufacturi ng capacity is less	

6. CONCLUSION

Many conclusions are reached, these are:

1. Adding polyurethane foam to ordinary bricks showed a decrease in compressive strength compared to the standard bricks. The maximum compressive strength test results reached was that were conducted on five specimens of the modified bricks were 2.5 kN/mm2 for 10% polyurethane foam additive by volume— which is more than the Egyptian standards (The minimum compressive strength for bricks used for partitions is 2.0 kN/mm2). The results indicate that adding polyurethane to the bricks in different ratios weakened the compressive strength of the bricks but still meet the standards except for bricks 40% polyurethane additive by volume and needs to improve to raise the strength to meet the standards.
2. The results of the water absorption test showed a decrease in the absorption value when adding different polyurethane materials ratios by volume in bricks compared to ordinary bricks. The water absorption test results also show that the absorption decrease with the increase of the percentage of foam added to bricks.
3. The heat conductivity test results show that the heat conductivity values decrease with the increase of the percentage of polyurethane added to bricks. The results of heat conductivity tests are less than ordinary brick, which indicated that an improvement in the thermal insulation of the brick
4. The optimum percentage of polyurethane additive to the regular brick mixture is 30% by volume. This percentage achieves the minimum required compressive strength specifications and density according to the Egyptian standard specifications for Bricks No. (1756 / 1989)
5. Polyurethane bricks are suitable for non-load-bearing walls (partitions and curtain walls).
6. Using polyurethane bricks in constructing building portions will increase the cost. The study sample consisted of 79 social housing buildings: The use of polyurethane foam bricks on building the social housing project showed a 4.145 % reduction of the total cost. This cost reduction is related to brick cost and the modification in structural elements due to the lightweight and density of polyurethane foam brick comparing with an ordinary brick.
7. It can be concluded that reducing the cost of the building will be higher than the calculated percentage in reducing the initial cost based on thermal conductivity tests, which will reduce the cost of the building's life cycle by reducing the cost of energy used in conditioning the building.

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