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Environmental Impact of Autoclaved Aerated Concrete in Modern Construction: A Case Study from the New Egyptian Administrative Capital

Esraa A. Khalil, Mohamed N. AbouZeid

***Abstract*—**Building materials selection is critical for the sustainability of any project. The choice of building materials has a huge impact on the built environment and cost of projects. Building materials emit huge amount of carbon dioxide (CO_2) due to the use of cement as a basic component in the manufacturing process and as a binder, which harms our environment. Energy consumption from buildings has increased in the last few years; a huge amount of energy is being wasted from using unsustainable building and finishing materials, as well as from the process of heating and cooling of buildings. In addition, the construction sector in Egypt is taking a good portion of the economy; however, there is a lack of awareness of buildings environmental impacts on the built environment. Using advanced building materials and different wall systems can help in reducing heat consumption, the project's initial and long-term costs, and minimizing the environmental impacts. Red Bricks is one of the materials that are being used widely in Egypt. There are many other types of bricks such as Autoclaved Aerated Concrete (AAC); however, the use of Red Bricks is dominating the construction industry due to its affordability and availability. This research focuses on the New Egyptian Administrative Capital as a case study to investigate the potential of the influence of using different wall systems such as AAC on the project's cost and the environment. The aim of this research is to conduct a comparative analysis between the traditional and most commonly used bricks in Egypt, which is Red Bricks, and AAC wall systems. Through an economic and environmental study, the difference between the two wall systems will be justified to encourage the utilization of uncommon techniques in the construction industry to build more affordable, energy efficient and sustainable buildings. The significance of this research is to show the potential of using AAC in the construction industry and its positive influences. The study analyzes the factors associated with choosing suitable building materials for different projects according to the need and criteria of each project and its nature without harming the environment and wasting materials that could be saved or recycled. The New Egyptian Administrative Capital is considered as the country's new heart, where ideas regarding energy savings and environmental benefits are taken into consideration. Meaning that, Egypt is taking good steps to move towards more sustainable construction. According to the analysis and site visits, there is a potential in reducing the initial costs of buildings by 12.1% and saving energy by using different techniques up to 25%. Interviews with the mega structures project engineers and managers reveal that they are more open to introducing sustainable building materials that will help in saving the environment and moving towards green construction as well as to studying more effective techniques for energy conservation.

***Keywords*—**AAC blocks, building material, environmental impact, modern construction, New Egyptian Administrative Capital.

Esraa A. Khalil is with the Department of Construction Engineering, American University in Cairo, New Cairo, Cairo, Egypt (phone: +201004241652; e-mail: Esraamail@aucegypt.edu)

I. Introduction

THE Egyptian buildings are influenced by the Western ones not like the traditional architecture. A typical building in Egypt consists of a multi-story building of concrete skeleton, masonry walls, flat roofs and aluminum glassed windows and sometimes curtain walls are used as well as finishing materials for the exterior and the interior. This is a typical description of a building system in Egypt and it is constructed disregarding the main architectural aspects, environmental impacts, cost effectiveness, geography and others. Instead of using earth materials and simple finishing techniques, the use of concrete, bricks, and steel are widely employed, which have a great negative impact to the environment [1].

The interference of the human factor in the climate system is causing damage to the environment. The awareness to the global problem of climate change and the CO_2 footprint and their relation to the construction works and building materials are becoming widely spread. The global measurements stated that the share of the building sector is responsible for 36% of the greenhouse gas emissions worldwide [2]. According to the Annual Report for Solid Waste Management in Egypt, it shows that the generated quantities from the construction and demolition waste is 41,748,603 tons per year which is around 44% of the total solid waste, as shown in Fig. 1. This is a huge percentage that affects our environment [3].

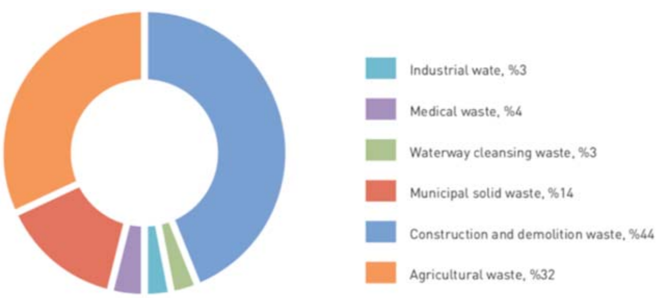


Fig. 1 Waste categorization in Egypt

The amount of CO_2 emissions from the manufacturing and construction process was 35 million tons in 2002, which is around 17.36%; however, this amount was estimated to be 403 million tons in 2014 or around 19.96% [4]. The recent cement production globally is estimated to increase by 3.27% in the year 2010 and it is expected to increase to 4.83% by the year 2030 [4].

Waste from the demolition of buildings in the construction sector is increasing since the lifespan of a building in developing countries is relatively short due to frequent remodeling. Moreover, the percentage of construction and demolition waste is an indicator on how much energy is consumed in this sector and how much materials are being wasted. In addition, according to the same report by the Ministry of State for Local Development (MoLD) states that, cement is the binder used for mostly all the building materials. This means that, 44% contains huge amounts of cement which is being wasted every year [3]. Furthermore, the Egyptian population is over 90 million and they are almost all concentrated around the Nile. This makes only 43% of the total area of Egypt's land urbanized, which is less than half the area of the country [5]. This made the spreading of the construction buildings to shift from horizontal single-story buildings to vertical multi-story which increased the materials used and the energy consumption per square meter.

The choice of building materials depends on many factors. One major factor is related to the cost of this material. Some studies show that building materials are considered as the largest input in the construction sector. In Ghana, it accounts for more than 60% of the total cost, in Tanzania around 76%, in Kenya around 68%, and in Nigeria around 65% [6]. However, other important factors must be taken in consideration such as the thermal conductivity, the sustainability, the maintenance and the long-term cost of these buildings.

Brick masonry is considered the most common traditional wall system in Egypt for the interior and exterior walls making it one of the oldest and common construction building material uses [7]. Additionally, bricks are produced in many sizes and types which vary from one place to the other. They are produced in huge quantities due to the high demand. There are two categories of red bricks either fired or non-fired bricks. Fired red bricks are the most commonly used types of bricks in Egypt due to the availability of the raw materials, the simplicity of the manufacturing process, and the strong properties due to burring [8]. Moreover, bricks are one of the main components of the waste generated from the construction and demolition waste in Egypt. Bricks on average constitute 9% of the demolition waste in Egypt and are one of the main components of the waste that is being dumped every day [9]. Brick masonry is bonded together by cement which is one of the components that affects the environment. Bricks are not only harmful to the environment due to the cement binder, but also due to the manufacturing process which depends on burning the raw materials. In addition, red bricks when demolished cannot be recycled or reused. These facts point to the need for a change in the choice of building materials. The need for new building materials which have less environmental impacts and long-term costs efficiency is significant [9].

A. Sustainable Construction

Green buildings are becoming more and more the new philosophy of buildings [10]. Sustainable development aims to reduce the energy crisis as well as the environmental pollutions, and could be traced back to the 1970s. Therefore, the need for energy efficient and environmentally friendly buildings is more desired. Moreover, there are many different aspects that affect the concept of sustainability in the architectural and urban design context.

AAC is one of the building materials that are available in the Egyptian market; however, it is not widely used [1]. AAC can be an alternative to the red bricks and which will reduce environmental impacts and global warming. AAC is a green building material which is in composition a foam like block. AAC was first invented in Sweden where the need for an alternative to wood, but with enhanced properties, was needed. Good thermal insulation, fire resistance, easy installation, long-term project savings, high strength, and high durability are all some properties of AAC [11].

The new Egyptian administrative capital is a mega project. It is planned to be Egypt's new heart. The layout of the city includes different building types such as residential districts, mixed use areas, universities, hotels, parks and government ministries [12]. Energy saving and environmentally friendly concepts are considered in the designing phase as well as the construction phase. Meaning that, Egypt is taking good steps to move towards more sustainable cities. According to the site visits and the interviews with the project manager, there is a potential in this new city to save in energy consumption up to 70% using different techniques such as sustainable building materials. Moreover, they are open to make some changes based on studying the effectiveness of the new approach regarding cost savings and environmental impacts.

Consequently, promoting the awareness of using more sustainable building materials, especially in modern constructions like the new Egyptian administrative capital contributes to the environment greatly since their use will reduce the energy demand of the building, reduce the amount of the waste generation, and reduce the toxicity, and thus health benefits are gained and there is an increase in the energy efficiency of the buildings. In addition, moving towards sustainable construction in the new Egyptian administrative capital required some factors to be taken in consideration such as the design strategy, the choice of materials, and the selection of the best techniques for construction without harming the environment or wasting materials, and saving not only in the initial cost but also in the long-term costs.

To sum up, the production process of sustainable building materials should be taken in consideration while assessing a building material. The two main categories that are in relation with the building materials being sustainable and have a great effect on the Egyptian context are the environmental, the cost and the socio-economic analysis.

II. Comparative Analysis

A. Environmental Analysis

1. CO_2 Emission

The increase in climate changes and people sensitivity to different temperatures in Egypt led to an increase in energy consumption to adapt to the needed cooling loads which then led to an increase of the carbon footprint. Assuming the outside temperature is 37°C, the normal red brick walls will maintain 33°C but AAC block walls will decrease this figure to 27°C. Additionally, the building sector consumes a total of 22% of the overall energy production in Egypt. Accordingly, one ft^2 of carpet area of red brick walls emits 17.6 kg of CO_2; however, the CO_2 emission of AAC walls for each one ft^2 of carpet area is 2.2 kg of CO_2.

The manufacturing method of fired clay bricks has shown some negative impacts on the environment in relation to many different aspects. These aspects include serious environmental contamination, energy consumption as well as depletion of raw materials. First, the manufacturing method of fired clay bricks leads to a lot of greenhouse gases emissions including CO_2 which affects the global climate and results in many changes in the climate such as global warming. In addition, human beings have suffered severely from the excessive amount of GHG which is known to causes heart diseases [13].

Second, the energy consumption of this process is huge. The use of energy such as fuel and electricity show extreme consumption levels due to the manufacturing process, which results to huge economic costs. These emissions are mainly due to the transportation of raw material and the finished bricks as well as from the firing phase of the manufacturing process [13]. On the other hand, the manufacturing process of AAC blocks has minimal environmental pollutions to the environment. The raw materials that are used in the production process of AAC are available in nature. They do not contain toxic gases, radioactive substances, or allergic materials.

AAC blocks are an eco-friendly, green and sustainable building material that reduces construction waste. The waste that is produced from AAC blocks is recyclable. Moreover, AAC blocks reduce energy consumption due to the autoclaving recycling process which decreases CO_2 emissions [8].

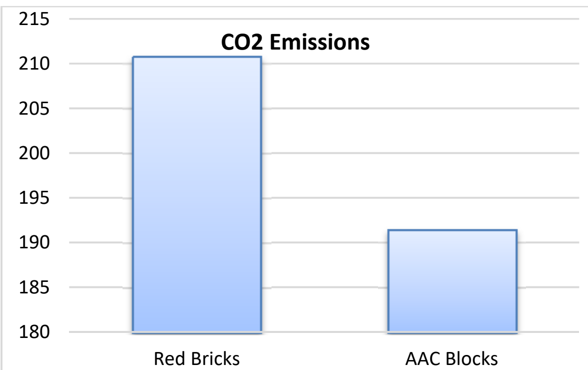


Fig. 2 Annual CO_2 emissions difference between both wall systems

2. Fuel Consumption

Conducting a life cycle assessment in the transportation phase, AAC blocks show a dramatic reduction in the cost of transportation. To give dimension to the savings, four full trucks of red bricks equals one full truck of AAC blocks. This shows that AAC blocks reduces the cost of transportation and the overall negative impacts of the transportation phase of AAC blocks; meaning, less CO_2 emissions from this phase and more savings. Comparing AAC walls to red brick walls regarding fuel consumption shows that one ft^2 of carpet area of red brick walls consumes 8 kg of coal, while AAC walls consume 0.9677 kg of coal [8].

The structure of AAC blocks provide maximum heat insulation for walls as well as building interiors and reduces heat losses in structures which assures energy efficient buildings. AAC blocks are an energy saving building material. Meaning that, one cubic meter of raw materials produces five cubic meters of AAC blocks [14].

3. Thermal Conductivity

The thermal transmittance of AAC blocks is 0.6 W/M.°C according to a test done to a block size of 15 cm at indoor air temperature of 20°C using the ASTM standard No. C236-89. The same test is done to a 25 cm AAC block wall and the thermal conductivity (K) is recorded to be 0.132 W/M.°C and the thermal transmittance is 0.43 W/M.°C at 20°C indoor temperature using the same ASTM standard, as in Fig. 3. The performance of AAC blocks with thickness 25 cm regarding thermal conductivity exceeds the traditional red perforated bricks with thickness of 24 cm brick and 2 cm mortar by 79% [14].

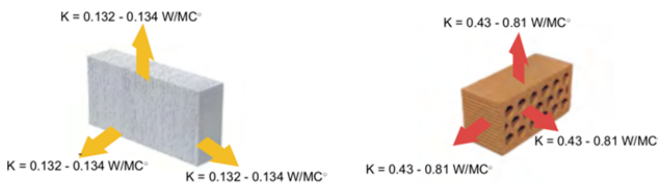


Fig. 3 Thermal conductivity difference between AAC and red bricks

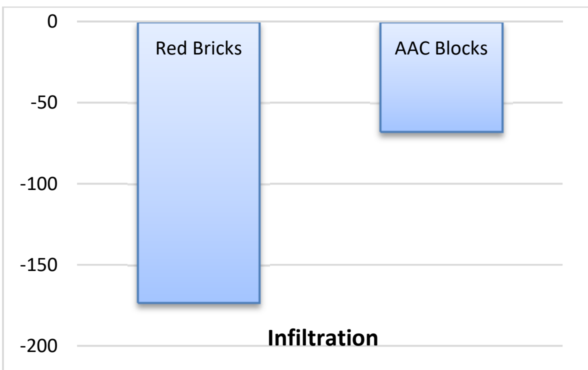
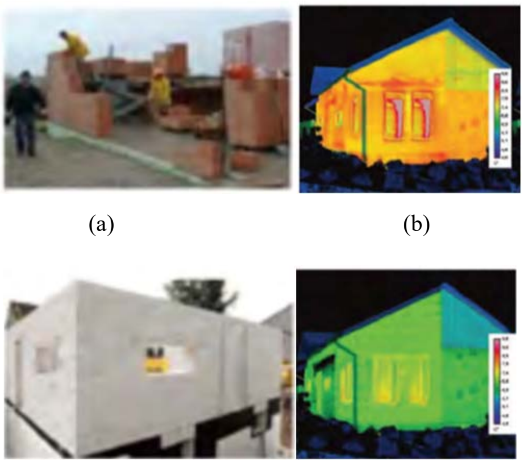


Fig. 4 Infiltration rate difference between both wall systems

The thermal resistance (R) of AAC blocks is affected by the different thickness of the blocks. In a 15 cm thickness block the thermal resistance is 1.667 W/M.°C; however, in a 25 cm thickness block the thermal resistance is 2.325 W/M.°C. In a demonstration to the difference between AAC blocks and red bricks [14], a test for both bricks is done under infrared rays to justify the difference in thermal conductivity between the red bricks and AAC blocks. Fig. 5 (b) is a simulation that represents the red brick wall system which is reddish and yellowish in color and in much darker colors, which is a strong indication to increased energy losses. Fig. 5 (d) is a simulation that represents the AAC block room under infrared which is almost green and blue in color and which indicates an energy saving wall system [14].



(a) (b)

(c) (d)

Fig. 5 (a) Simulation room form red brick walling material, (b) Thermal conductivity of red bricks under infrared, (c) Simulation room form AAC block walling material, (d) Thermal conductivity of AAC blocks under infrared

4. Soil Consumption

The consumption of raw materials such as clay and sand in the production process of red bricks causes resource depletion and environmental damages. The method of production of red bricks is done through the removal of the top soil causes waste to the virgin clay raw material. In addition, the top soil consumed by one red brick is 3.2 kg, while red brick walling consumes 25.5 kg of top soil for each one ft^2 . On the other hand, AAC blocks do not use top soil. Instead, AAC blocks use fly ash which is a waste product of power plants. Thus, AAC is a green building material that uses waste to be produced [8].

B. Cost Analysis

1. Cement, Mortar and Steel Savings

The most important factor that motivates investors to use a new material or product is the cost savings. There is a difference in sizes and shapes between red bricks and AAC blocks. In Egypt, red bricks are normally 25X12X6.5 cm while AAC blocks are normally 60X20X10-40 cm. These dimensions vary slightly, especially among red bricks. The number of units in a wall constructed from red bricks is around 100 brick per m^2; however, this number is 10 blocks per m^2 in an AAC wall with height of 10 cm. Meaning that, red bricks require six to 10 times the number of AAC blocks needed in 1 m^2; hence, the joints resulting from AAC blocks are 1/3rd less than that of red brick masonry. This reduction results in savings in the mortar cost. This saving can go up to 60% of mortar used in joints [8].

Furthermore, constructing walls using AAC blocks requires less time due to the modularity and uniformity of the blocks which is associated with less money. This means that, AAC blocks use a significant smaller number of laborers compared to red bricks which uses a larger number of laborers who are mostly children or non-skilled labor. The uniformity of the AAC blocks translates into uniform walls inside and outside, hence thinner plaster, means also less consumption of cement [8]. Combing all these factors leads to significant reduction in the total cost of the construction process in comparison with using traditional red bricks.

Model Definition

The analysis was done on a typical apartment in the new Egyptian capital having 210 m^3 bricks, and the savings of cement in mortar can reach 10 tons in this amount, which represents a total of 43% savings in the total cement in mortar. Fig.6 represents the floor plan of the prototype that was used in the analysis.

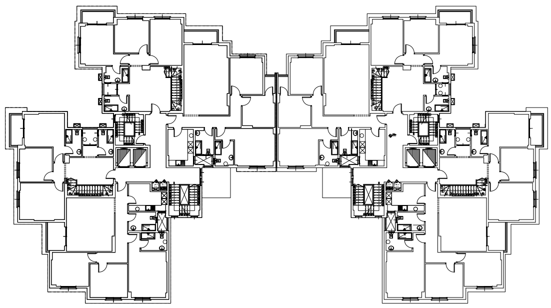


Fig. 6 Floor plan of the used prototype for financial analysis

Another advantage of the AAC blocks is their light weight which means that the dead load of the building decreases and leads to reduction in the total amounts of both steel and concrete used, and hence reduction in the consumption of cement. In the new Egyptian administrative capital, using AAC blocks can save in the total cost of steel from 16.9% to 23.2% according to the density of the block and the price of steel. Thus, using AAC blocks has many advantages over red bricks and will save in the total cost of the project.

2. Bricks Cost Savings

In the new Egyptian administrative capital, according to the observations and data collection from the field visits, there are different apartments with varying designs, uses and areas. The calculations of the initial costs of bricks in one apartment using AAC blocks of 650 kg/m^3 indicated that the initial cost of 210 m^3 AAC block walls is 168,000 Egyptian Pound (LE). Similarly, the initial cost of a 210 m^3 red brick walls is 92,400 LE. The total percentage of increase in the initial cost between the AAC bricks and the red bricks is 82% of the total cost of bricks. Taking into consideration all the savings in each item, the total initial cost savings in a given project is going to be 15.8 % (see Table I).

TABLE I
PERCENTAGE SAVINGS IN TOTAL COST

	Extra cost of AAC Blocks	Savings in Concrete	Savings in Steel	Savings in Cement	Total cost saved
Savings (L.E.)	-75,600	94,736	521,875	9,500	550,511
% savings in items cost	-82%	5.60%	16.90%	43%	--
% savings in Total Cost	-1.5%	1.9%	10.7%	1.0%	12.1%

Thus, taking into consideration the total savings in cement in mortar, concrete works, steel works, and the extra cost of the AAC blocks, there is a recognizable percentage of savings in the total cost. According to the cost analysis, the overall savings in the total cost is calculated to be 12.1% (see Table I). This percentage varies according to the density of the AAC blocks. Also, the total savings in the long-term costs will considerably decrease when adding the cost of the HVAC systems and risk factor costs. Fig. 7 represents a cost comparison between the different components of the wall systems and the saving amounts.

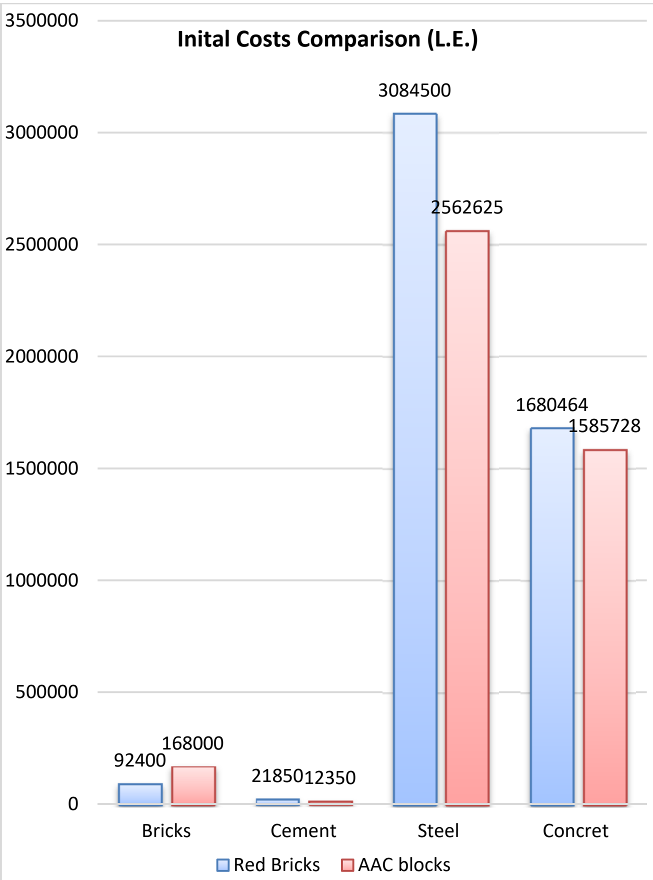


Fig. 7 Cost Comparison between different wall systems components

3. Energy Savings

One of the long-term benefits of using AAC blocks is its high thermal insulation which will save in the HVAC costs, as well as in electricity bills. The need for air conditioning units has increased in the past few years dramatically from 700,000 to 3 million units in the years 2006 to 2010, respectively. To illustrate, in Egypt, 12% of the capacity of the power stations is consumed by air conditioning units [8]. The HVAC analysis of a typical apartment of 150 m^2 in the new Egyptian administrative capital and using split air condition units, the total savings in energy consumption is around 23-25% and in electricity bills is around 2200-3000 LE, depending on the real consumption. Savings in the heating and cooling costs of the buildings will dramatically affect the lifetime cost of the building and the environmental costs as well.

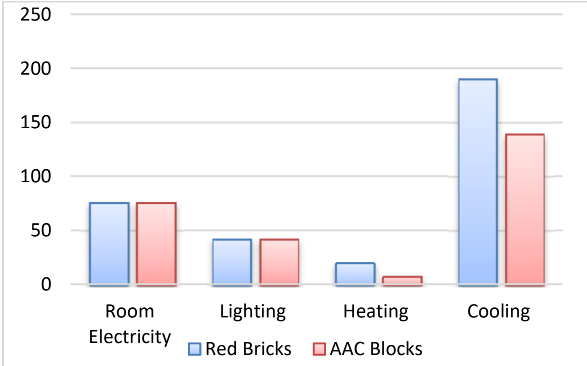
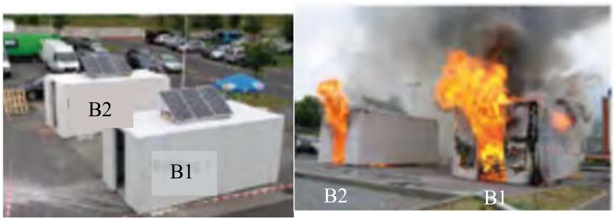


Fig. 8 A comparison between Red bricks and AAC blocks regarding heating and cooling loads

C. Fire Resistance Analysis

The ability of AAC blocks to resist fire is much higher than that of traditional red bricks, which is one of the main advantages of AAC blocks. The ability of AAC blocks to resist fire is due to the fact that its mix, which is homogenous, unlike traditional bricks where the mix design has coarse aggregates, which leads to cracking and different expansion rates. According to an experimental study, AAC blocks are extremely fire resistant; a typical 10 cm wall thickness can withstand fire for around 240 mins at a temperature of 1200°C. In addition, AAC blocks are classified as a non-combustible construction building material. AAC wall systems prevent fire from spreading to the building, and thus saves live and the environment. Additionally, smoke and toxic gases are not exerted when using AAC blocks, which is the main cause of death in the case of fire. AAC wall systems have around 46% higher heat insulation than traditional blocks [15]. A fire simulation case study was done in Egypt using two different wall systems. Building 1 (B1) is a steel sandwich wall system and building 2 (B2) is a reinforced AAC wall system. Figs. 9 10 represent two rooms from the exterior and interior during the fire simulation [14].



(a) (b)

Fig. 9 (a) The exteriors of the fire simulation rooms for Steel and AAC wall systems before fire, (b) After the fire

(a) (b)

Fig. 10 (a) The interior of the fire simulation for Steel room, (b) The interior of the fire simulation for AAC wall systems after the fire

III. Conclusion

To sum up, it is a challenge to replace an old traditional material like red bricks; however, the advantages of AAC blocks encourage their use. AAC blocks are environmentally friendly, cost saving and energy efficient material. Implementing new sustainable material in the new Egyptian administrative capital, which is considered as Egypt's new home, will encourage its use around the country and will save a lot in terms of resources and long-term costs, as well as reduce environmental impacts.

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