Appropriate use of Thermal Mass of Material and Insulation Technique

"As a passive solar legacy approach to reduce energy consumption of buildings in Egypt"

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Abstract :

The research doesn't present thermal mass of material or insulation passive solar technique as a new proposal. It's a legacy system has natural and historical roots in our culture, local environment, and in the world; but the research propose it as the most suitable, applicable, cheap and optimum solution, especially with the already existing urbanism, which comprises the majority of the current energy problem in Egypt, and has no noticeable or major effects on building architectural design, exteriors, and interior spaces, compared with other passive solar systems. The research follows descriptive analytical methodology. It aims to explain appropriate, efficiency, applicability of use this system in our local environment, especially with already existing unconformity buildings, at reasonable initial cost and low building running cost on the long term. It is an ideal step towards activate the Egyptian Energy Code, and sustainable criteria in the proposed Egyptian sustainable building rating system GPRS "Green Pyramid Rating System"; through simple commercial building model "case study", use insulation material has low thermal conductivity and high specific heat value, explains the difference in the thermal performance, initial and running cost, before and after development.

Keywords: Cultural Passive Systems; Legacy Environmental Systems; Thermal Behaviour; Traditional Thermal Comfort; Cultural Energy Saving.

1. INTRODUCTION

Egypt is searching now for radical solutions to energy problems, and to develop strategies and mechanisms to be implemented through two main directions:

i. Increase the capacity of energy production especially clean and renewable energy.
ii. Reduce energy consumption. Domestic and commercial sector consumption which represents 44%, followed by industrial sector = 34.5%, public utilities = 17.5%, and agriculture 4% (as depicted in Fig. 1).

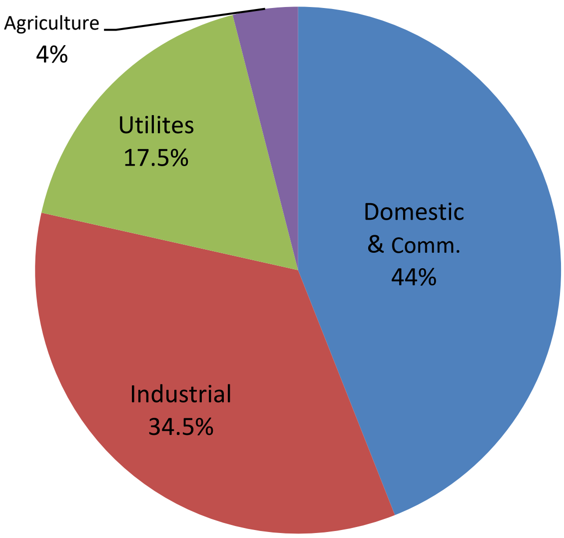


Fig. 1: Distribution of Energy consumption fields in Egypt, Source: (HBRC, 2009).

In order to reduce energy consumption in the residential and commercial activities, Egyptian Energy Code requirements must be followed during the design processes, finishing and construction material selection for new projects, or renovations of existing buildings. However, the main problem is in this large amount of existing buildings that do not meet energy code requirements, especially thermal requirements for construction materials, leading to significant energy consumption and losses.

This research aims to explain appropriate, efficiency, applicability of use thermal mass and insulation technique as a passive solar system in our local environment, especially with already existing urbanism, at reasonable initial cost and low building running cost on the long term. It could be considered an ideal step towards activate the Egyptian Energy Code, and sustainable criteria in the proposed Egyptian sustainable building rating system GPRS "Green Pyramid Rating System", issued in 2011 for public review.

It follows the descriptive analytical methodology, which explains this technique, reviewing natural, historical background of using this legacy system in the nature, vernacular, traditional and modern architecture. It explains characteristics, energy and money saving, through a case study on an existing simple commercial building. Highlight on energy saving and operating cost decrease.

Passive solar systems are classified as a perfect environmental solution in architecture to save energy. Cooling systems are used in warm climates, and heating systems are used in cold climates. But thermal mass and insulation, which are two different concepts, could be used separately or combined in both climates to minimize; heat lose in cold climate, and heat gain in cold climate; use insulation material has low thermal conductivity for optimum insulation and high specific heat value to optimize thermal capacity. Therefore, it is most appropriate for our region and climate where status changes between warm and cool during the year, and throughout the day, which is known as continental climate (as shown in Fig. 2)

Many research discussed thermal mass properties of some traditional materials used in building construction and explained their features, characteristics and thermal performance on building as a passive solar control tool in architecture. Such as Adobe or "mud bricks" and rammed earth, both are having large thermal capacity, as well as; heat-insulating materials, like; rock wool, polystyrene and foam. In addition to common materials currently in use: such as clay bricks and concrete bricks.

In addition, this paper addresses the cost of energy saving, focuses on the materials that can be used in our environment.

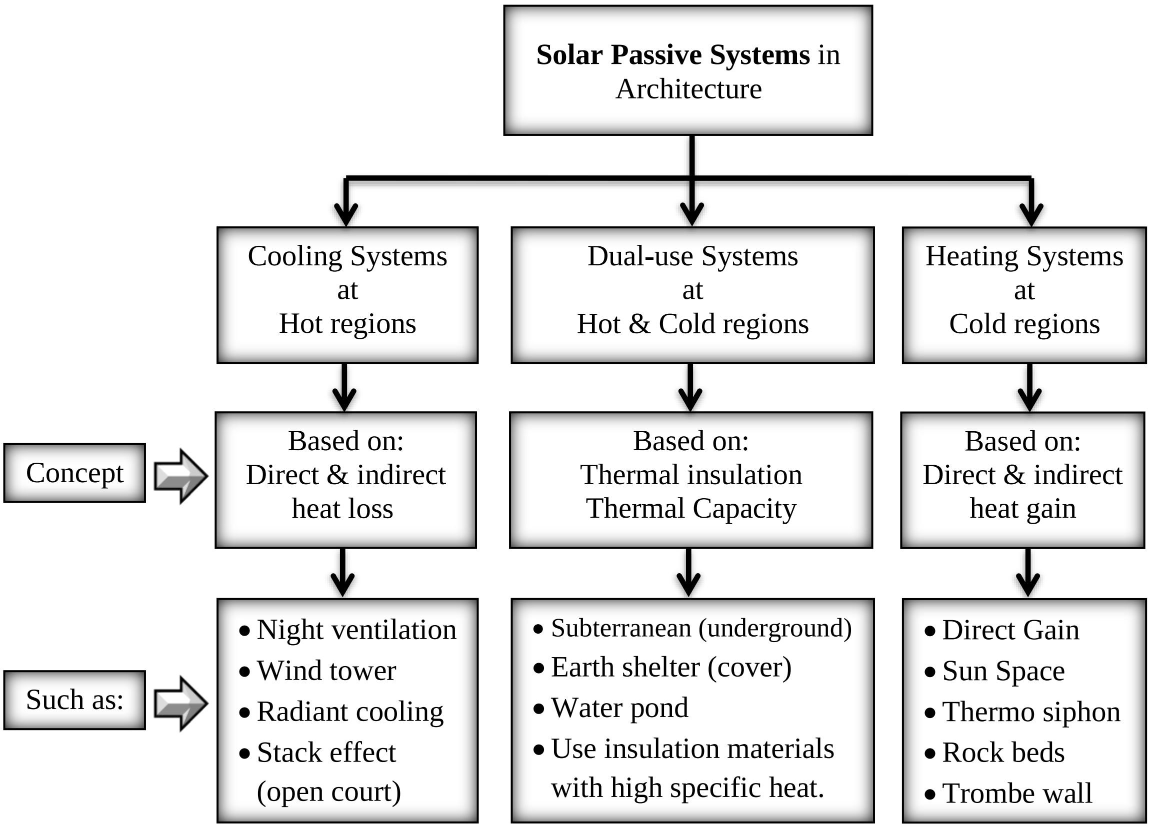


Fig. 2: Solar passive systems in Architecture and its working concept, Source: Author.

2. NATURAL AND HISTORICAL BACKGROUND

2.1. Natural Background:

Many animals use rammed earth to adapt to their natural habitats and to achieve thermal comfort, such as rodents, marmot and mole. Rodents excavate passage and chambers in the soil like badgers and marmots. Difference in temperature measurements taken in rodents burrows at the desert may be exceeding (35 °c). It reaches a depth of (3m) underground surface level (as shown in Fig. 3 and 4)

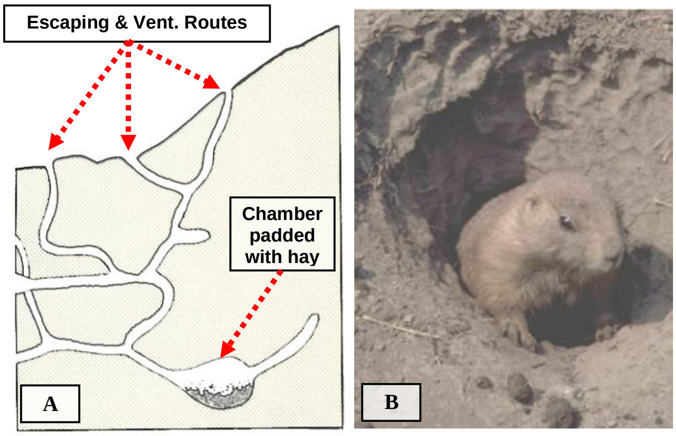


Fig. 3: Marmot use thermal mass of earth sheltered to isolate himself from desert heat and to achieve thermal comfort. Source: Farnham, (198-) and Frisch, (1975).

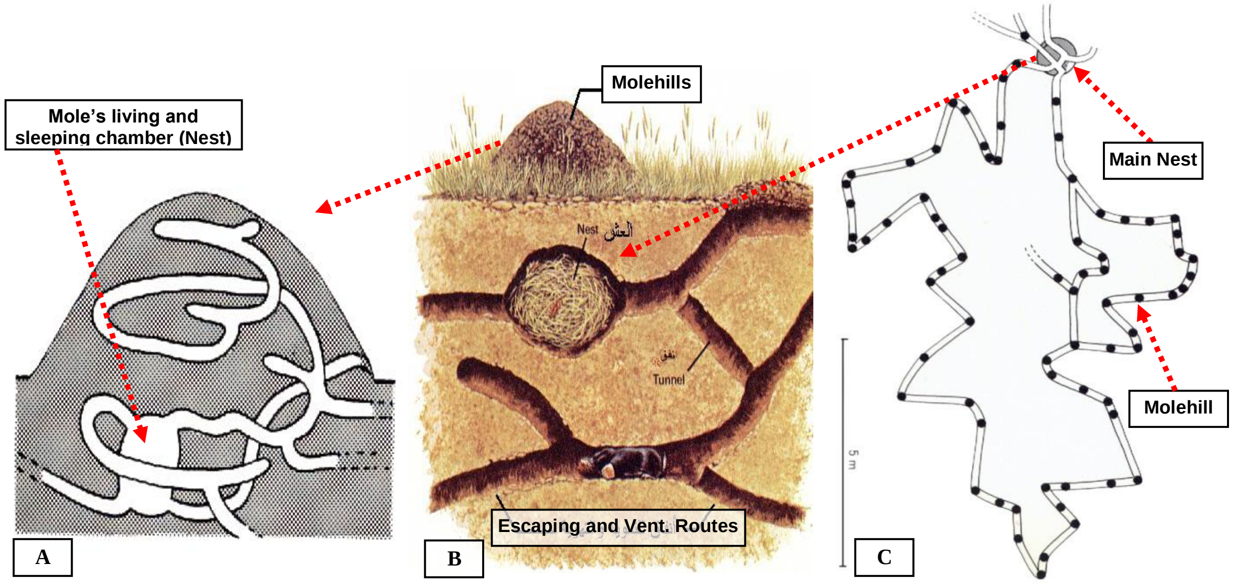


Fig. 4: Mole chamber digging at depth of about 0.1-0.3m, molehills serve as ventilators for the network of subterranean passages, it constitutes with earth cover thermal insulator. Source: Farnham, (198-) and Frisch, (1975).

2.2. Historical Background:

Many examples used this technique and environmental treatments dating back to the era of the old Egyptians, and are still used in many villages in Egypt, as is the case in many other countries

i. Such as using limestone blocks and adobe "mudbrick" wall that has a high thermal capacity. It stored heat at morning and radiated inside at night (see Fig. 5 and 6).

ii. Egyptians are still using corn, sugar cane, bagasse, straw, rice husk, rammed earth and dried animal waste tablets as an insulator above roofs as illustrated in (Fig. 7).

iii. They excavated many temples such as; Abu-simble, Hatshbsut, using limestone earth cover as an insulator with conductivity = 0.79 w/m. ◦c and Specific heat = 900 j/kg ◦c, (HBRC, 1998, p. 17) to optimize thermal comfort or to save their mummies in excavated tombs such as; Valley of the Kings and queens at Luxor, in addition to the security reasons.

Over the centuries, the Egyptians did not need the electro-mechanical means for cooling or heating their buildings. The Egyptian villages and until recently were using mudbrick since the era of old Egyptians over 5,000 years without energy crisis.

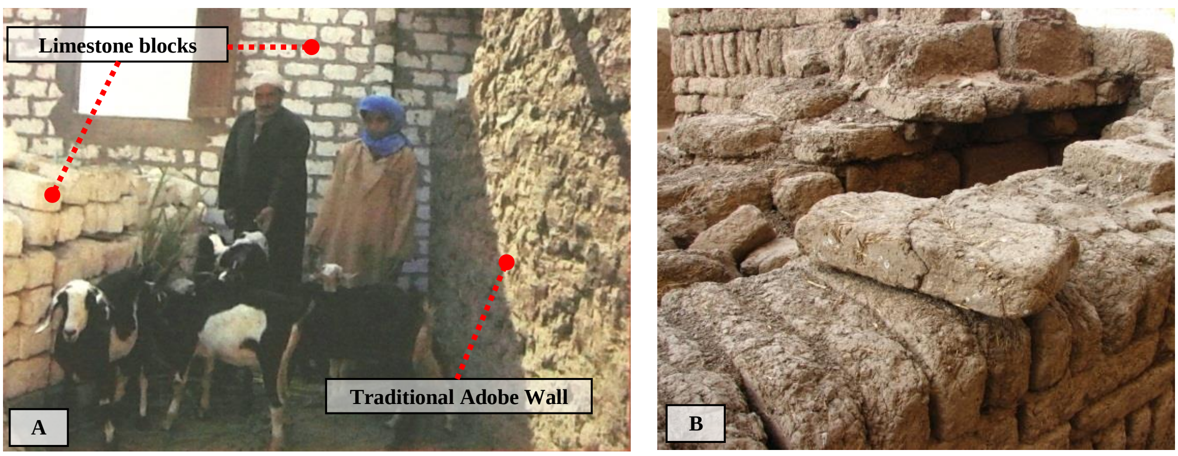
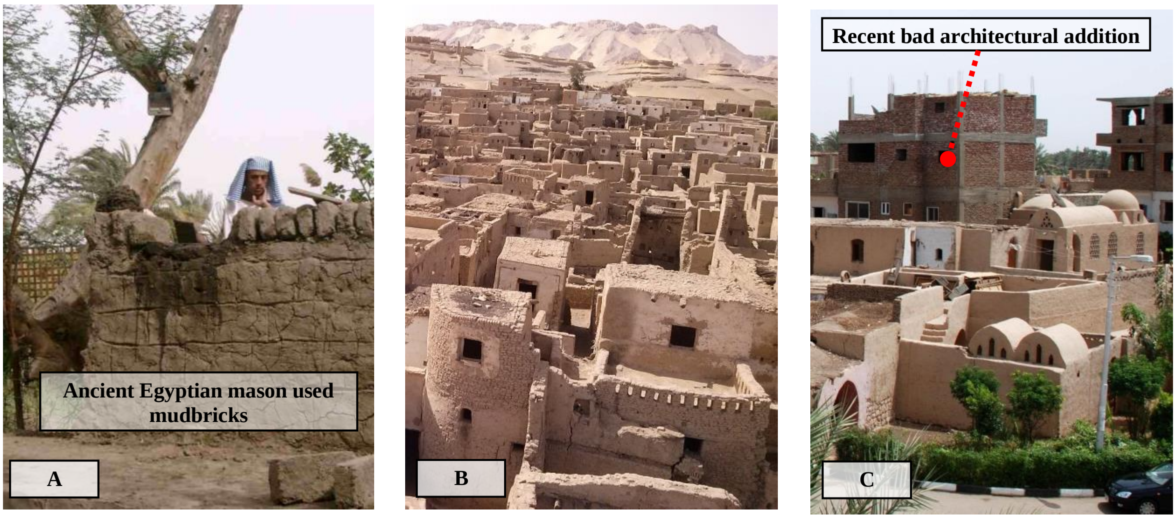


Fig. 5: Traditional Adobe, limestone blocks are traditional thermal mass technique and good insulators used in Egyptian village. Source: Author.



The Tourist Pharaonic Village, Giza El-Qasr city at Dakhla oasis New Gournah at Luxor

Fig. 6: Cultural Vernacular Architecture in Egypt. Source: Web Network.

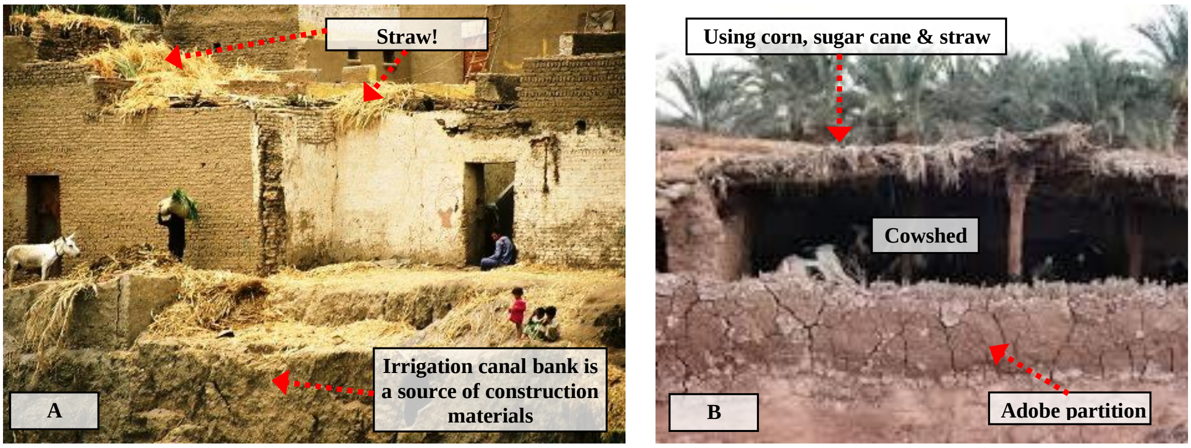


Fig. 7: Using bagasse, straw, rice husk and dried tablets of animal wastes as an insulator above roofs. Source: Author.

3. MATERIAL CHARACTERISTICS:

Four important values of material thermal properties help the architect to choose, and to trade-off between materials (Conductivity, Resistance, Heat capacity and Time Lag) as shown in (Tables 1 to 3 and Fig. 8).

Table 1: Density, Specific Heat and Thermal Mass Range of Materials, Source: Baggs, 2006.

Material	**Density** (Kg/m³)	**Specific Heat** (Kj/kg.K)	**Voumetric heat capacity thermal mass** (KJ/m³.K)
Water	1000	4.186	4186
Concrete	2240	0.920	2060
AAC	500	1.100	550
Brick	1700	0.920	1360
Stone (Sandstone)	2000	0.900	1800
FC Sheet (Compressed)	1700	0.900	1530
Earth Wall (Adobe)	1550	0.837	1300
Rammed Earth	2000	0.837	1673
Compressed Earth Blocks	2080	0.837	1740

Note: Figures are based on a number of sources and include estimations and interpolations

Table 2: Thermal Characteristics of most common Traditional Insulation Materials

Material	Thermal characteristics			
	Density (Kg/m³)	Conductivity (w/m. ◦c)	Specific heat (j/kg ◦c)	Time Lag (hour)
Extruded Polystyrene insulation Board	33	0.036	1500	4/0.04m
Gypsum Board	950	0.39	891→ 1017	3.23/0.12m
Rock wall Board	100-350	0.043→0.055	1400	4/0.04m
Rammed Earth	1540	1.25	837	10.3/0.25m
Adobe (mud bricks with straw)	1700	0.35 →0.57	837	9.2/0.25m

Note: Figures are based on a number of sources and include estimations and interpolations

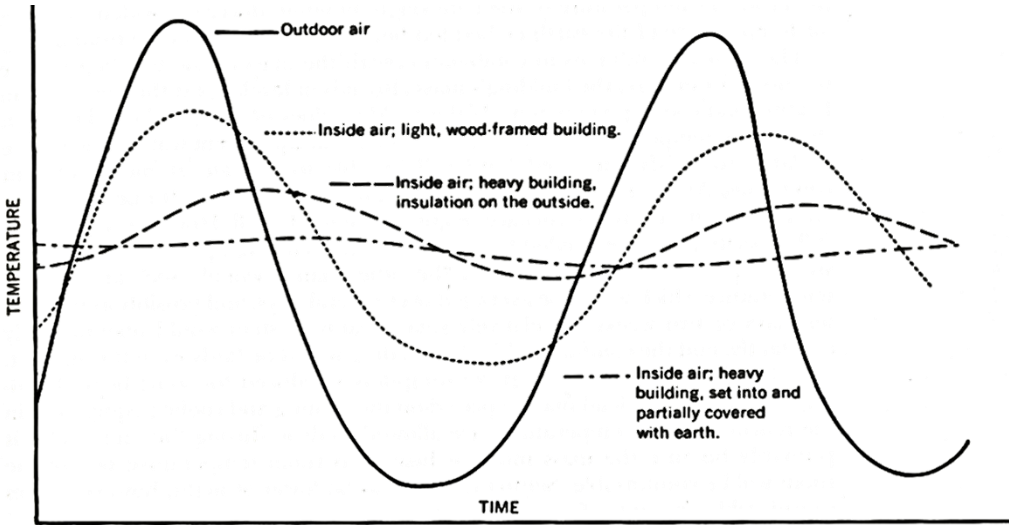


Fig. 8: Effect of fluctuations in outdoor temperature on indoor temperature for various construction types assuming no source of heating or cooling energy within the building, Source: Gollany, 1983.

Table 3: Main Advantages, disadvantages of using thermal mass and insulation as passive solar systems in Architecture, Source: Author.

Advantages	Disadvantages
1. Suitable to use in all climates; warm, cold and continental climate. 2. Can be used with the already existing buildings without need for costly engineering modifications in interior or exterior design of the building. 3. Materials are available in nature, local environment and relatively cheap for many other passive solar systems.	1. Increase the thickness of the walls and thus reduces the size of the internal spaces of the building. 2. Require external finishing or cladding materials. 3. Weight of thick walls and some other types of heavy materials add an additional load on building structure. 4. Reduces the direct contact surface (visual, auditory) with the external environment of the building

4. CASE STUDY

This study explains the appropriate, efficiency, applicability of use this technique in existing simple commercial building model, use insulation material has low thermal conductivity and high specific heat value. Illustrate how this traditional concept can be employed in a contemporary existing building to achieve thermal comfort and reduce the use of electromechanical energy-consuming means.

4.1. Building description and Chosen criteria

It is a shopping mall named "Five Stars Mall" at 6th of October City; Project lot size area = 5600m², constructed area = 1900m², with surrounded English court and internal open promenade = 3700m².
It was selected as a case study, because of the following criteria:

a) The second volume of Egyptian Code of Energy for Commercial Buildings, 2010, issued because of the importance and the increase of the energy consumption for this type of buildings.
b) It consumes with residential buildings more than 46.2% of the total electricity consumption in Egypt.
c) It presents a solution model of energy problem for an existing building, which is one of the research objectives.

4.2. Energy problem and proposed architectural solution

The lower ground floor "Basement" of this mall needs to be redesigned as an open hall "show room" for goods and other products, but the required power for air-conditioning machines with other loads is larger than the available capacity of the existing building transformer "500kw". Because of the huge amount of solar direct heat gain by radiation and conduction through the glass facades of this floor = 859m², thus increases the internal thermal loads and the required cooling capacity.

The proposed architectural solution use the extruded polystyrene boards 3cm thickness (Fig.10) between goods shelves and advertising poster behind the glass, just for external non-shaded facade = 355m² = 41.3% only of Total Area of

Fig. 9: Mall Glass Façade. Source: Author.

Fig. 10: Proposed Extruded Polystyrene Board with Internal Cladding Surface. Source: Author.

Glass Façade for this floor, which is used too as an advertising banners between polystyrene sheets and glass (Fig. 11, 12, 13) This material has low conductivity value 0.036 w/m. ◦c, so it provides good insulation. It has too a great specific heat value 1500 j/kg ◦c, (Table 2) which is optimizing the thermal capacity of this material, this considered the main concept of our legacy traditional thermal solutions.

This proposal reduced cooling capacity from 180ton to be 120ton as calculated by HVAC consultant" and thus reduces the initial cost of A/C machine and reduces running cost of its energy consumption as shown in (Fig. 9 to16) and (Table 4 and 5).

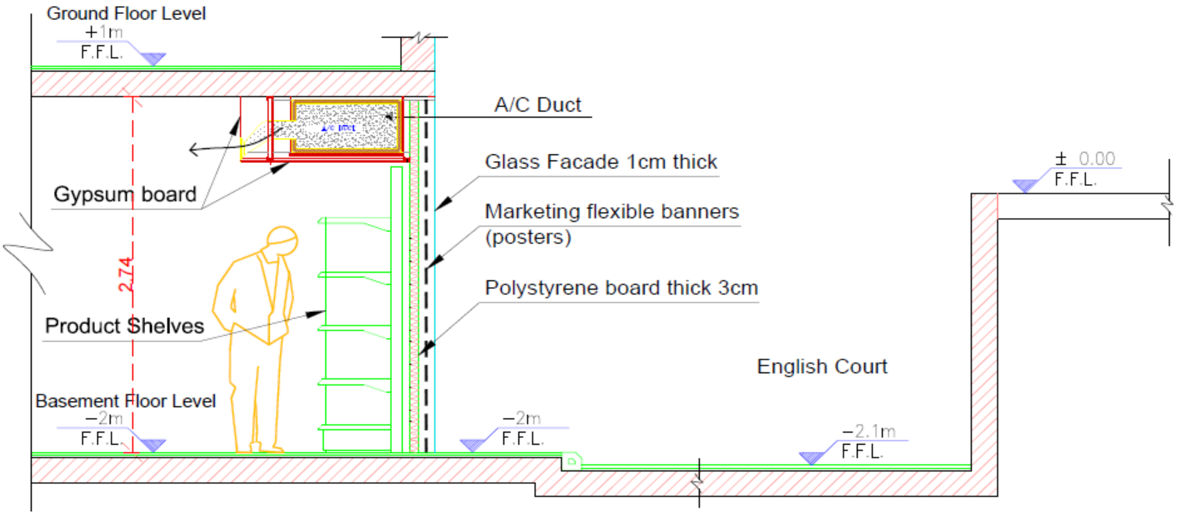


Fig. 11: Cross section passing through the façade showing the proposed solution. Source: Author.

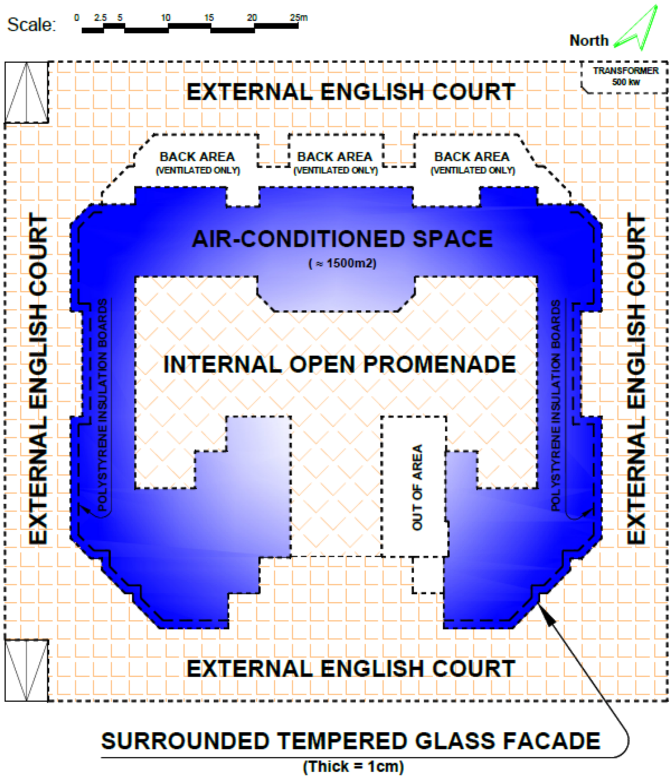


Fig. 12: Case study, lower ground floor plan. Source: Author.

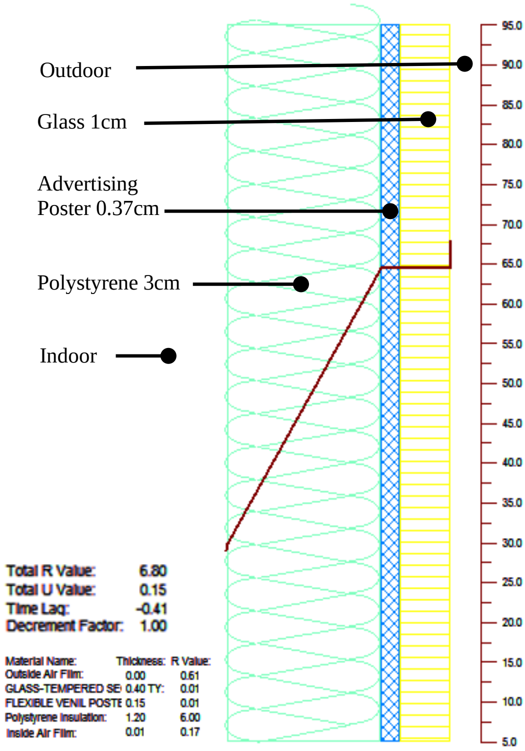


Fig. 13: Insulation cross section assembly view explain temp. drop between inside & outside. Source: Author, calculated by Opaque Program.

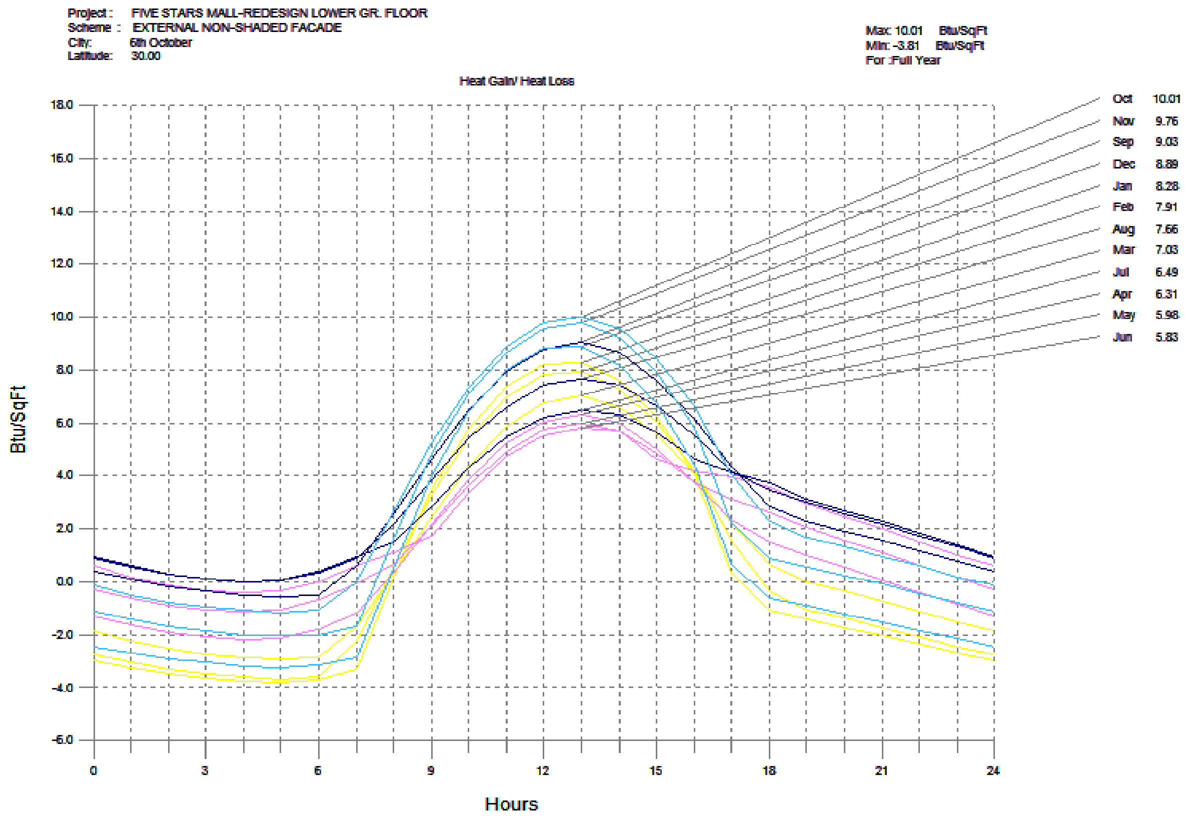


Fig. 14: Heat Gain / Heat Loss. Source: Author, calculated by Opaque Program.

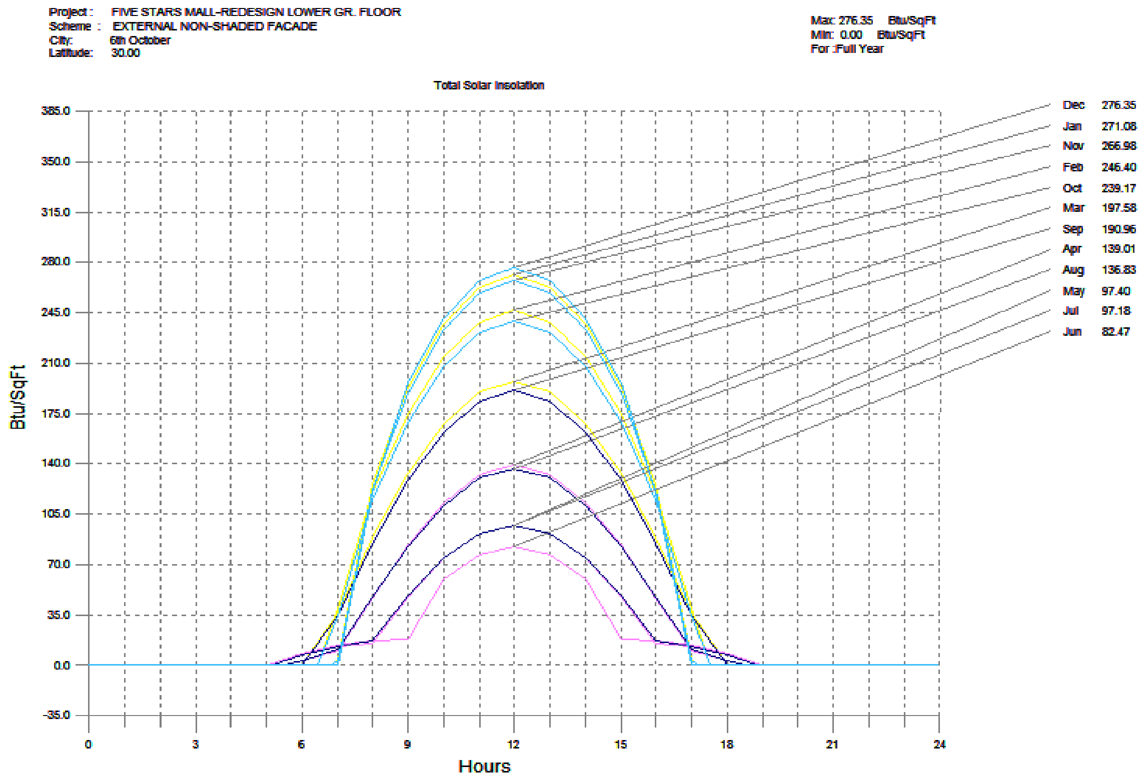


Fig. 15: Total Solar Insulation. Source: Author, calculated by Opaque Program.

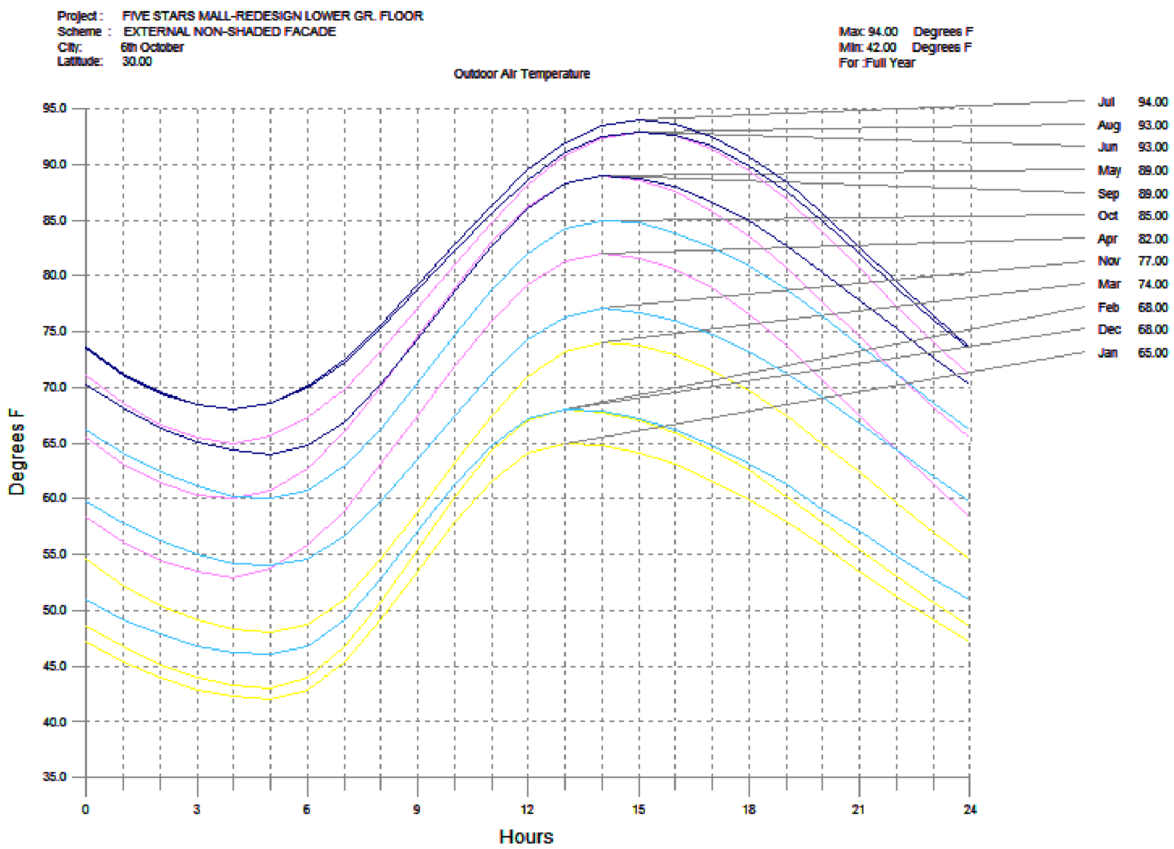


Fig. 16: Outdoor Air Temperature. Source: Author, calculated by Opaque Program.

Table 4: Total Initial Cost Saving by Insulation, Source: Author, Case Study.

	Existing Situation	**Proposed Solution**	**Saving**
HVAC price cost	Huge amount of solar direct heat gain resulting from surrounded glass facades. ==► Cooling Capacity ≈ 180ton ==► 9units DX carrier 240 (cost = 100,000 LE/unit "including ducts & accessories" x 9 units = 900,000 LE	Using extruded polystyrene boards for insulation. ==► Cooling Capacity ≈ 120ton ==► 6units DX carrier 240 (cost = 100,000 LE x 6 units = 600,000 LE	300,000 LE
Transformer upgrading cost	Electrical transformer upgrading cost from 500kw to 1000kw = 476,000 LE "required fees from local elec. Company"	Not needed	476,000 LE
Insulation Cost	Not Exist	Extruded polystyrene insulation board cost = insolated area x cost/m2 = 400m² x 26 LE/m² =10,400 LE	-10,400 LE
Total initial cost saving			**766,000 LE**

Table 5: Annually Running Cost Saving by Insulation, Source: Author, Case Study.

	Existing Situation	Proposed Solution	Saving
HVAC running cost	Annual energy consumption cost for two units = (energy consumption for each unit kw x 9units x running hours x 30day x unit working rate x electricity segment price/kw) x 7 months • Monthly energy consumption for 9 units = (35kw x 9units x 16hr x 0,55 x 30day) = 83,160kw • Annual energy consumption cost = 83160kw x 7months x 0.65LE 378,378 LE / year • Annual maintenance cost = 500LE x 9 = 4,500LE	Annual energy consumption cost for two units = (energy consumption for each unit kw x 6units x running hours x 30day x unit working rate x electricity segment price/kw) x 7 months • Monthly energy consumption for 6 units = (35kw x 6units x 16hr x 0,55 x 30day) = 55,440kw • Annual energy consumption cost = 83160kw x 7months x 0.65LE 252,252 LE / year • Annual maintenance cost = 500LE x 6 = 3,000LE	Annual energy consumption cost = 126,126 LE Annual maintenance cost = 1,500 LE
	Assuming: For A/C unit: • Cooling Capacity ≈ 180 ton Nominal cooling consumption = 35kw/unit • Device working rate ≈ 0.55% • Working hour/day ≈ 16 hr. • Annual A/C working months ≈ 7 months • electricity segment price/kw = 65 piaster/kw • annual maintenance cost per unit ≈ 500LE		
Annual running cost saving			**127,626 LE**

There are some local and foreign Architects present success architectural samples in Egypt using legacy traditional material has the same concept such as New-Gourna village at Luxor designed by Hassan Fathy. It was completely built with local mudbricks as the existing local material, (Fig. 17). And Ecolodge tourist resort at Siwa, designed by Laetitia Delubac and Christian Félix architects, Paris, France. (project's construction duration from 2004 to 2007), Local masons utilizing kershef, a locally found building material made out of mud, sand and sun-dried salt harvested from the Siwa's salt lakes, made this eco-home. With no provision for electricity, the green abode utilizes wastewater treatment and natural ventilation system using draughts, (Fig. 18).

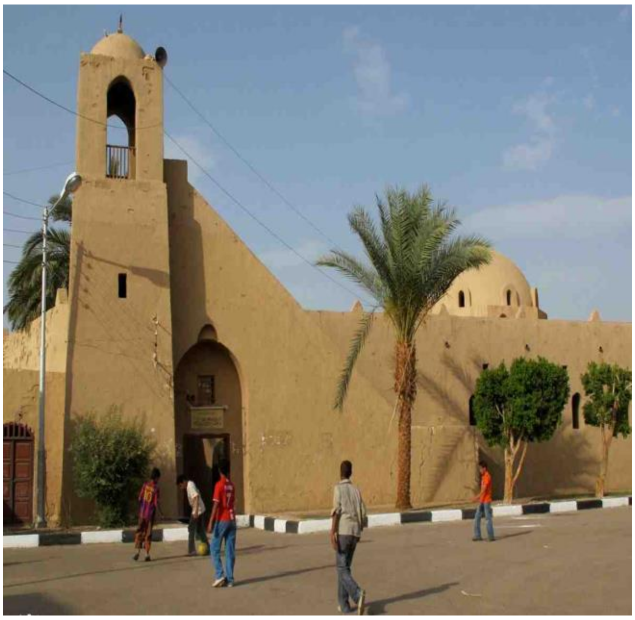
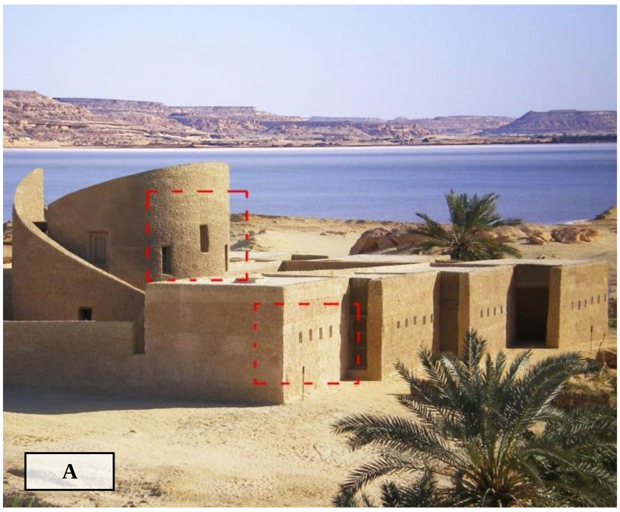


Fig. 17: Gourna Mosque, Luxor, built with mud bricks by Hassan Fathy Source: Web Network.



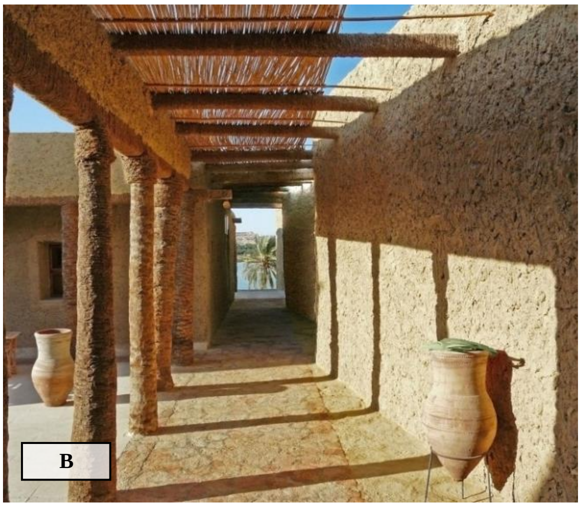


Fig. 18: Ecolodge tourist hotel at Siwa by Laetitia Delubac and Christian Félix architects, Paris, France, Pic. Source: Web Network.

5. CONCLUSIONS

The research presents thermal mass technique using insulation material with large heat capacity, which is a legacy traditional solution as; the **suitable, applicable and cheap** proposal could be used with the majority of existing non-conformity buildings. There are many architects used the local traditional materials in new buildings such as mudbricks and “kershef” to apply this concept, but it is difficult to be used with the existing buildings. Thermal-insulating Panels which have high specific heat could be used as an internal cladding for sun-exposed surfaces at existing buildings. The case study used these panels to explain that; this system saves about **(1/3)** of the required energy for air-conditioning system. **This achieved ratio** is sufficient to solve the electricity problem in Egypt on the short term, without need to more investments in power generation field, or need to expensive structural adjustments for existing constructions.

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طرح ملائمة استخدام الكتلة الحرارية للمادة وأسلوب العزل الحراري

"باعتباره أحد الأساليب التراثية الشمسية السالبة للحد من استهلاك المباني للطاقة في مصر"

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ملخص البحث باللغة العربية:

لا يطرح البحث استخدام الكتلة الحرارية للمادة وأسلوب العزل الحراري والتي تصنف من الأساليب الشمسية السالبة في العمارة، باعتباره حلا جديدا، فهو أسلوب تراثي وله جذور طبيعية وتاريخية في بيئتنا المحلية وفي العالم، ولكن يطرحه كحل أمثل أكثر ملائمة وأقل كلفة وقابل للتطبيق خاصة مع المباني والمنشآت الموجودة بالفعل، والتي تمثل النسبة الأكبر من المشكلة الحالية لأزمة الطاقة في مصر، كما أنه لا يؤثر جوهريا على التصميم المعماري للمبنى أو الفراغات الداخلية، مقارنة بغيره من الأساليب السالبة. للحد من تنامي استهلاك المباني للطاقة في مصر وبالتالي المساهمة بشكل فعال لحل أزمة الطاقة المزمنة والمتزايدة محليا وعالميا. ويتبع البحث المنهج التوصيفي التحليلي. ويهدف البحث إلى إثبات ملاءمة وكفاءة استخدام هذا الأسلوب في بيئتنا المحلية خاصة مع المباني القائمة بالفعل وقابليته للتطبيق بتكلفة مقبولة وبيان مردوده في خفض تكلفة تشغيل المبنى على المدى الطويل، كما يعد الخطوة الأكثر ملائمة نحو بداية تفعيل متطلبات الكود المصري لتحسين كفاءة الطاقة في المباني، ومتطلبات نظام الهرم الأخضر المقترح لتقييم الأداء البيئي للمباني في مصر "GPRS". من خلال دراسة نموذج مبسط لتطوير أحد المباني التجارية القائمة وتحليل الفرق في الأداء الحراري للمبنى، وتكلفة الإنشاء والتشغيل في كلا الحالتين قبل وبعد تطبيق هذا الأسلوب.

[١] تليفون محمول ٠٠٢٠١٢٢٣١٠١٠١٧