



**THE EFFECT OF USING INSULATION
MATERIALS ON THE THERMAL PERFORMANCE
OF RESIDENTIAL BUILDINGS IN CAIRO - EGYPT**

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ABSTRACT

Thermal comfort accompanied with low energy in architecture is a major target of building researchers and designers worldwide. Obviously, any portion of energy that can be saved in this respect means protection for environment and maintenance of its resources and may be able to be directed to any other activities, if any.

Building energy consumption can be reduced through various systems such as air conditioning (A/C is a major building energy consumer), lighting, equipment, etc. In regions where energy is limited or scarce, air conditioning would have to be replaced by natural ventilation for the removal of the building heat load for thermal comfort.

Also, energy conservation issues are being more important in hot arid regions, especially because building are consuming more than 60% of electric energy generated and about 65% of this energy is consumed for cooling. There is a set of complex factors, which determines energy needs in building, such as solar radiation, type of A/C systems, building operation, and thermal characteristics of the building envelope ...etc. The parameters, which have effects on the thermal performance of walls and roofs, are the color, general construction, insulation and ventilation.

In the present decade the aim is to discuss the meaning of thermal comfort and advantage of energy efficient building materials design or selection. There are several ways to reduce the energy consumed in the human comfort process, but what is the most energy efficient or more energy saving of these ways. One of these is the insulation, which can be used for insulating walls and roofs, which are subjected to a large amount of the solar heat gain. The insulation of walls (especially west walls) and roofs is intended to maximize resident's thermal comfort and minimize energy consumption in housing.

The present study presents the effect of west wall insulation on the indoor thermal performance in order to select the suitable insulation which gives maximum thermal comfort , minimum cost and maximum energy saving. This work was done using actual field temperature measurements on actual location. The results provide suggestions to improve the building construction and indicate the importance of using the insulation materials in the wall construction in order to achieve thermal comfort characteristics for the occupants and also to reduce the consumed energy.

Keywords: Thermal mass - Thermal comfort - Insulation materials - Energy conservation Energy consumption.

1. Introduction

Al-Karagholi et al. [1] investigated different energy conservation techniques to decrease the air-conditioning load. The first objective when designing a house - the first full scale project built in Iraq - was to minimize the air conditioning load. From analysis, it is found that during the summer season the most influencing factor in decreasing the cooling load is window shading. 100% shading will decrease the cooling load by 35% while using double glass will decrease the load by 23%. The wall insulation saves 22% to 31% of the consumed energy during the summer season.

Chang and Guo [2] developed Tianjin energy efficiency standard for rural residential buildings in order to reduce energy consumption and carbon emissions and to improve poor indoor thermal comfort in existing rural residential buildings, Natural materials and appropriate passive techniques should be used to achieve the human thermal comfort goal with minimum energy consumption and lowest percentage of carbon emissions. The insulation passive technique for building envelope, determination of heat transfer coefficient, principle of choosing insulation materials for building envelope, energy efficiency standards of walls, windows, and roofs are analyzed and described.

Chwieduk [3] describes the traditional methods that used to conserve energy in residential buildings according to the main reasons for high heat gains. A discussion of some ideas of modern methods for energy conservation was done and recommendations for application of renewable energy were concluded. Using analysis of climatic data for a period of thirty years using psychometric chart, effective temperature chart, and isotherm chart to define “over heated periods” which requires sun protection.

Hai-xiang and Frederic [4] designed statistical methods and artificial intelligence methods to study the effect of many factors, such as ambient weather conditions, building structure and characteristics, the operation of sub-level components like lighting and HVAC systems, occupancy and their behavior on the energy performance in buildings, accurately implement prediction of building energy consumption is very difficult. To solve this problem, developed models included elaborate and simplified engineering methods.

Hall [5] (2010) reviewed the building materials applicable to improve the built environment, materials for energy efficiency and thermal comfort in buildings. More than half of the total energy produced in the developed countries is used to improve inappropriate climate to reach thermal comfort levels for human beings. Usage of materials and passive technologies – strategies - in buildings would reduce the demand of energy consumption and carbon dioxide emissions in order to optimize the environmental behavior on built environment.

Jia Yin et al. [6] used various envelope insulation thicknesses to find out the optimal thickness. Also the optimal thickness for concrete exterior walls was carried out. Simulation of changing heat capacity proportion showed that the daily temperature difference decreased by 14 to 5.2°C. Optimizing design of integrated building environment plays an important role in reducing energy consumption and improving thermal comfort. A passive solar house was taken as an example. A simulation proposed optimization design principles for passive solar house.

Mohamed et al. [7] studied the effect of using different material specifications for the external walls on the cost of the energy consumption for achieving internal thermal comfort. In order to achieve indoor thermal comfort, a dynamic thermal simulation was carried out for four different types of external walls – commonly used in Egypt – in two different sets of cooling types: natural ventilation and mechanical means. Experiments recommend that using the Egyptian Residential Energy Code (EREC) to achieve inner thermal comfort with the minimum energy consumption (consequently the minimum CO₂ emissions) and the minimum running cost as well.

Saeed [8] presents an attempt to define the overheated period for Bahrain and determine shading requirements and shading angles. From the results a special solar chart was drawn which provides accurate sun angle to use.

Waewsak et al. [9] indicate that the indoor environment is basically affected by the outdoor climate conditions; therefore, all built environment has a great task to protect the human from either the thermal mass stress or unsuitable indoor thermal condition. They presented a method for designing an innovative Bio-Climatic Roof (**BCR**) particularly suitable for hot and tropical climate intending to maximize residents' thermal comfort and minimize energy consumption of housing. The results indicated that, the BCR design can provide three important benefits: high ventilation rate, high insulating efficiency and sufficient lighting during daytime.

2. Experimental work

The building envelope affects the heat transfer through walls into the indoor zones. More dense materials pass more heat and light weight materials with low thermal conductivity resist the thermal energy. The present study describes field measurements of temperature for different rooms in a residential flat. The three rooms have different external walls construction.

2.1. Case study description

A residential flat (in Maadi district - Cairo - Egypt) of total area 180 m² and height 3m , as shown in Fig. (1) consists of three bed rooms, living room, hall, kitchen, bath room and toilet was taken as a case study. The two bed rooms and the living room have the same area (19.5 m²) and same orientation façade (west direction). All of these rooms have the same brick wall construction with external finishes cement mortar. The three rooms differ in interior wall finishes.

The wall of the first room (living room) consist of hollow cement blocks of 20cm thickness plastered with cement thickness 3cm from outer side and 2cm from inner side and painted with plastic material (as shown in sections Fig. 2-A).

The second room (bed room) wall consists of hollow cement blocks with thickness 20cm plastered with cement plaster for thickness 3cm for outer side and 2cm for inner side and painted, gladded with high density blue foam with thickness 5cm inside wooden frame for 5cm thickness then a layer of MDF (Medium Density Fiber) panels with 8mm thickness fixed on the wooden frame and painted with plastic material (as shown in sections Fig. 2-B).

The third room (bed room) wall consists of hollow cement blocks with thickness 20 cm plastered cement plaster for thickness 3cm for outer side and gladded with natural stone (hashimi) with 4-5 cm thickness with 2cm mortar thickness. (as shown in sections Fig. 2-C).

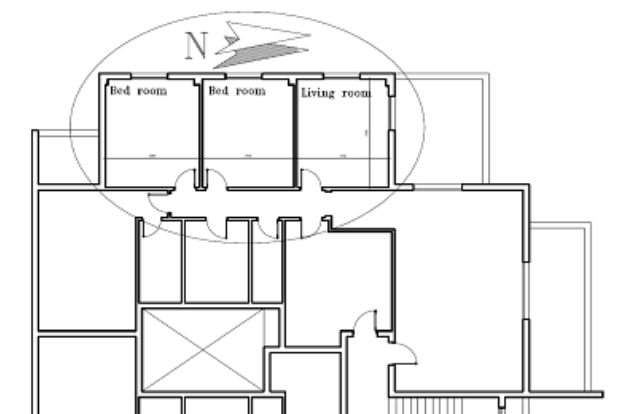


Fig. 1. Plan view of the tested flat

2. 2. Measuring techniques

To study the effect of wall construction on the heat transfer and the thermal performance of the tested rooms, twelve thermocouples were fixed at different locations of the tested rooms, as shown in Fig.3 and photos in Fig.4 (a, b, c and d).

Point No. 1 to measure the outdoor air temperature (T_{ao}).

point No. 2 to measure the external surface wall temperature (T_{so}).

Point No. 3 to measure the internal surface wall temperature (T_{si}).

Point No. 4 to measure the indoor air temperature (T_{ai}).

All of these 12 measuring points were taken at level +1.5m from floor level of the test area which is located on the fourth story in a five stories building, so the effect of the thermal mass produced from sun rays that affect on the roof is ignored because of the preservation of the above story from this thermal mass. The ceiling of the test flat is adiabatic.

In order to illustrate the heat performance through the temperature measurements which had been taken through 14 days (starting 24/7/2013, ending 6/8/2013) in the most hot months in Egypt (July & August), measurements of just two days, (Thursday 25/7/2013 & Thursday 1/8/2013) which were the hottest days in the test measurements period, had been recorded within tables (as shown in tables 1, 2, and 3). So that 6 diagrams were drawn to illustrate the thermal behavior using insulation materials. Fourteen-day measurements were taken in the test period to assure the similarity of temperature behavior.

2. 3. Instrumentation

All the thermocouples were connected to a scanning thermometer instrument to measure and record the temperature variation at different locations of the rooms during the tested days. Fig. 5 (a, b and c) shows photos of the scanning thermometer instrument.

3. Results and discussion

The temperature distributions of the tested rooms were measured and recorded during a period of time from 25 July until 6 of August, which characterized with high solar radiation intensity, reaching nearly 900W/m^2 and high outdoor air temperature.

Figure (6 a-b) shows the temperature distribution of room 1 during days 25-7-2013 and 1-8-2013. The outdoor temperature reaches its maximum value nearly 39C° at hour 2:00 P.M. and the indoor temperature reaches its maximum value nearly 38.5C° at hour 4:00 P.M. The time lag between the outdoor and indoor temperature is nearly 2 hours due to the high heat storage of the cement blocks. This increase in the indoor temperature is attributed to the increase of overall heat transfer coefficient (U-value) which nearly exceeds $1\text{m}^2\text{C}^\circ/\text{W}$. (OECP).

Figure (7 a-b) shows the temperature distribution of room 2 during days 25-7-2013 and 1-8-2013. The outdoor temperature reaches its maximum value nearly 39C° at hour 2:00 p.m. and the indoor temperature reaches its maximum value nearly 34C° at hour 5:00 P.M. The time lag between the outdoor and indoor temperature is nearly 3 hours. The maximum indoor temperature of room 2 is lower than room 1 due to the presence of wall insulation. The overall heat transfer coefficient (U-value) is nearly $0.8\text{m}^2\text{C}^\circ/\text{W}$ (OECP).

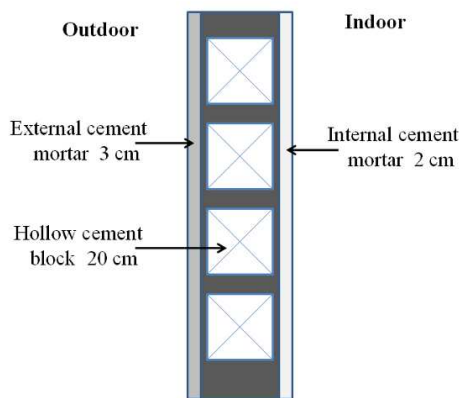
Figure (8 a-b) shows the temperature distribution of room 3 during days 25 July 2013 and 1st August 2013. The outdoor temperature reaches its maximum value nearly 39C° at hour 2.00 p.m. and the indoor temperature reaches its maximum value nearly 33C° at hour 5:30 P.M. The time lag between the outdoor and indoor temperature is nearly 3.5 hours. The indoor wall and air temperatures of room 3 give lower values during the day in comparison of room 1 and room 2 due to the lower magnitude of U-value nearly $0.7\text{m}^2\text{C}^\circ/\text{W}$.

Line no.1 (navy blue) illustrates the outdoor air temperature (T_{ao}).

Line no.2 (magenta) illustrates the outer side of the outdoor wall temperature (T_{so}).

Line no.3 (orange) illustrates the inner side of the outdoor wall temperature (T_{si}).

Line no.4 (green) illustrates the indoor air temperature (T_{ai}).



(a) External wall of room (1)

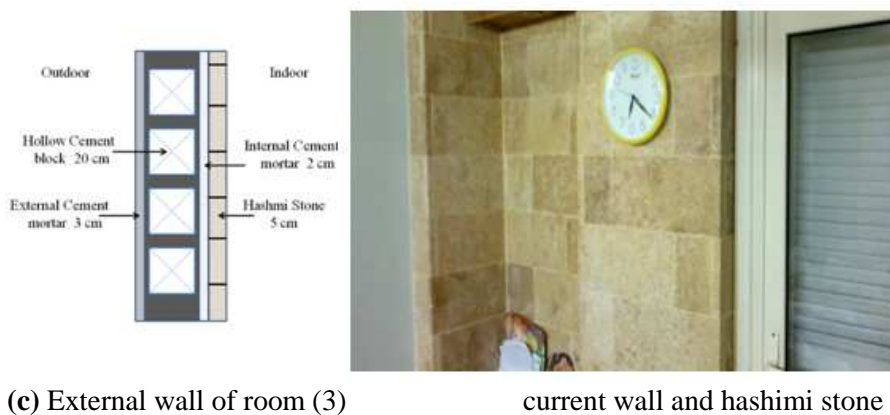
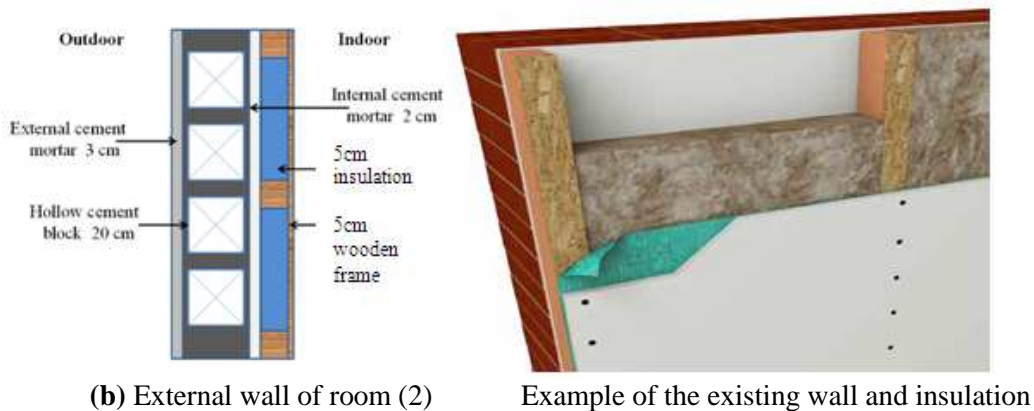


Fig. 2. (a, b, c) External wall construction for the three test rooms.

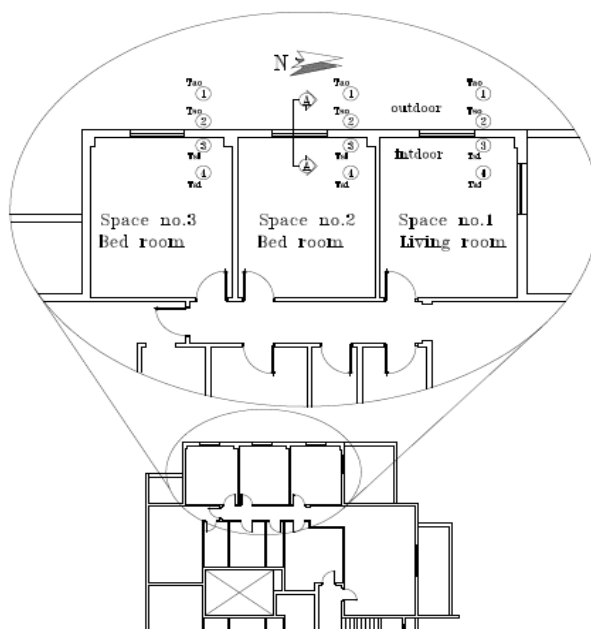
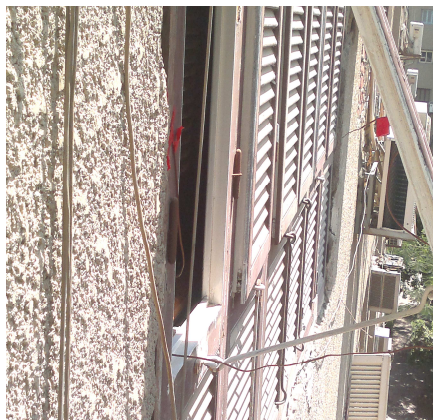


Fig. 3. Location of thermocouples for temperature measurements



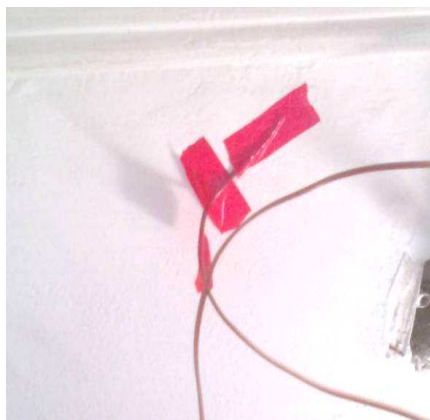
(a) Point No. 1



(b) Point No. 2

To measure the outdoor air temperature (T_{ao}). The thermocouple fixed to keep the end of it free in the outdoor air and keep it in shadow

To measure the outdoor air temperature The thermocouple fixed to keep the end of it contiguous to the external surface of the external wall and keep it in shadow



(c) Point No. 3



(d) Point No. 4

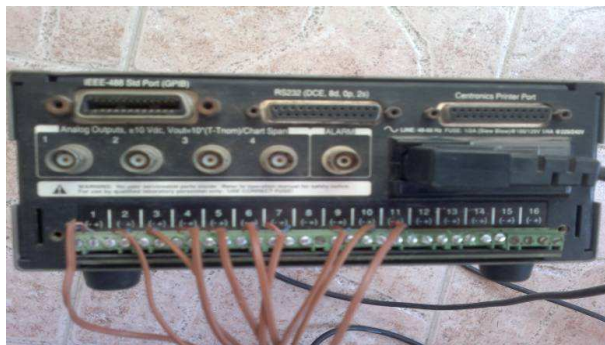
to measure the outdoor air temperature (T_{si}). The thermocouple fixed to keep the end of it contiguous to the internal surface of the external wall and keep it in shadow

to measure the outdoor air temperature (T_{ai}) The thermocouple fixed to keep the end of it free in the indoor air and keep it in shadow

Fig. 4. (a, b, c, d) Thermocouple locations at the tested rooms.



(a) The front façade of the scanning thermometer instrument



(b) The back façade of the scanning thermometer instrument illustrates the joint sockets



(c) The 12 thermocouples connected between the scanning thermometer instrument sockets and measuring points

Fig. 5. (a, b, c) Temperature scanning and recording instrument (16 channel)

Table 1.

Observation of temperature levels for room No. 1

Hour	Tao	Tso	Tsi	Tai
1	31.7	31.6	33.0	33.8
2	30.6	30.6	31.9	32.0
3	29.5	29.5	30.3	30.4
4	28.5	28.5	28.9	29.2
5	28.6	27.9	28.0	28.7
6	28.7	27.3	27.2	28.1
7	29.0	28.3	27.5	30.0
8	30.3	29.4	27.9	30.5
9	31.3	31.2	31.0	31.1
10	32.8	31.4	32.0	31.8
11	35.0	33.6	33.8	32.2
12	37.1	35.9	35.6	33.4
13	39.2	38.2	37.5	36.0
14	39.5	39.0	38.5	36.8
15	39.1	39.1	38.9	37.8
16	38.8	39.3	39.2	38.9
17	38.5	39.0	39.6	39.2
18	37.3	38.5	39.0	38.7

Hour	Tao	Tso	Tsi	Tai
19	35.6	38.0	37.7	37.1
20	34.1	37.4	37.3	35.8
21	33.2	36.5	37.1	35.8
22	32.3	34.8	36.8	35.7
23	32.5	33.0	36.4	35.5
24	32.1	32.3	34.9	34.7

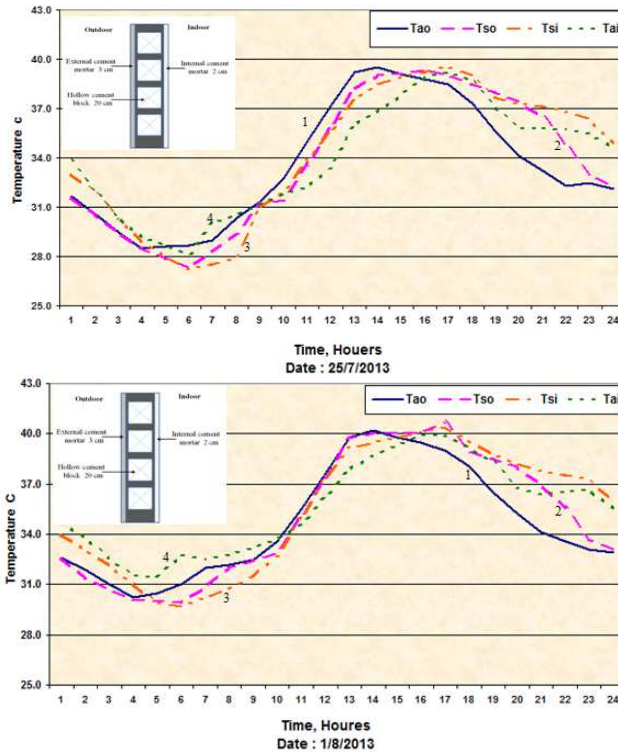


Fig. 6. Temperature distribution for room (1)

Table 2.

Observation of temperature levels for room No. 2

Hour	Tao	Tso	Tsi	Tai
1	31.7	32.7	31.4	31.5
2	30.6	31.6	30.8	30.5
3	29.5	29.6	30.4	29.8
4	28.5	28.7	30.0	29.1
5	28.6	28.0	29.7	29.1
6	28.7	27.4	29.2	29.1
7	29.0	28.4	29.4	30.0
8	30.3	29.4	29.7	31.0
9	31.3	31.2	31.5	31.5
10	32.8	31.4	31.5	31.5
11	35.9	33.6	32.0	32.0
12	37.1	35.9	32.5	32.5
13	39.2	38.2	33.1	33.0
14	39.5	39.0	33.2	33.0

Hour	Tao	Tso	Tsi	Tai
15	39.1	39.1	33.2	33.1
16	38.8	39.3	33.2	33.3
17	38.5	40.2	33.2	33.3
18	37.3	39.8	33.0	33.1
19	35.6	38.2	33.0	33.0
20	34.1	37.8	32.7	33.0
21	33.2	37.3	32.5	32.4
22	32.3	35.5	32.3	32.1
23	32.5	33.7	31.9	31.9
24	32.1	33.3	31.7	31.7

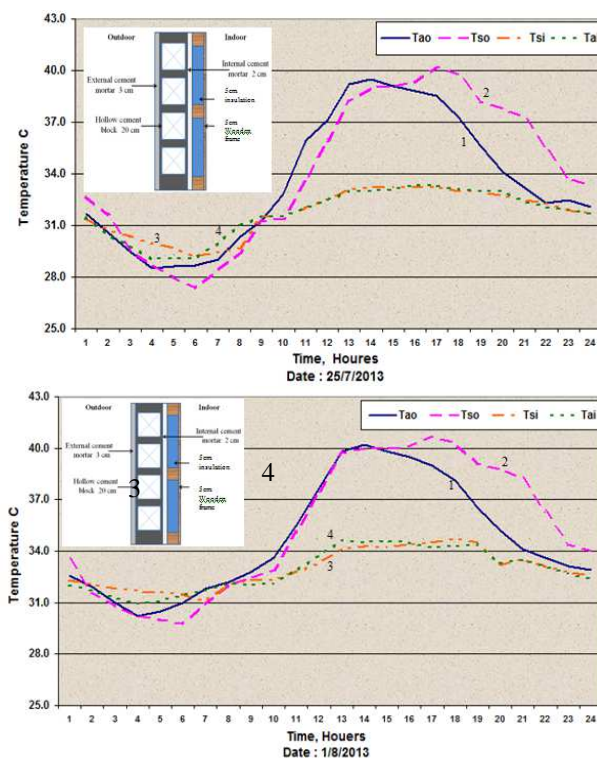


Fig. 7. Temperature distribution for room (1)

Table 3.

Observation of temperature levels for room No. 3

Hour	Tao	Tso	Tsi	Tai
1	31.7	32.3	31.3	31.3
2	30.6	31.2	30.5	30.4
3	29.5	29.4	29.8	29.7
4	28.5	28.7	29.2	29.0
5	28.6	28.1	28.7	29.1
6	28.7	27.8	28.2	29.2
7	29.0	28.5	28.2	29.3
8	30.3	29.4	28.3	29.7
9	31.3	31.3	30.6	30.7
10	32.8	31.4	30.6	30.7

11	35.9	33.6	31.5	31.6
12	37.1	35.9	32.4	32.4
13	39.2	38.2	33.3	33.3
14	39.5	39.0	33.4	33.3
15	39.1	39.1	33.4	33.3
16	38.8	39.3	33.4	33.4
17	38.5	40.1	33.4	33.4
18	37.3	39.2	33.3	33.2
19	35.6	38.0	33.2	33.1
20	34.1	37.4	32.8	32.9
21	33.2	37.0	32.3	32.4
22	32.3	35.6	32.0	32.1
23	32.5	34.0	31.7	31.8
24	32.1	33.2	31.5	31.6

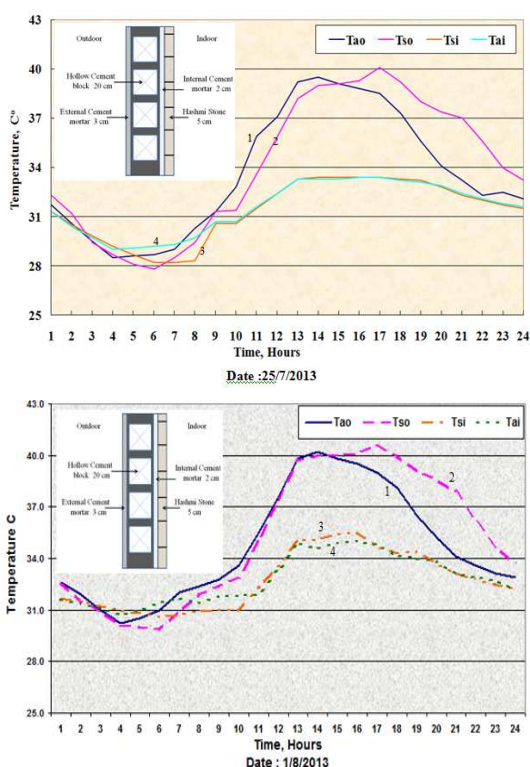


Fig. 8. Temperature distribution for room (3)

4. Conclusion

From previous results we can conclude that:

- 1) **Good building insulation** offers favorable and comfortable indoor environment natural condition without using of any mechanical devices (such as electric fans or A/C system). Therefore, the good insulation for roofs and sunny façades, to maintain acceptable level of the indoor thermal comfort is quite sufficient because they are the most important building elements continuously exposed to the sky dome. So, roofs and sunny walls insulation is very important in both design and construction processes of the building.

- 2) **Previous results** confirmed that sunny walls are major parts of building that must be carefully studied under the climatic conditions. The effect of the shading devices on the total energy consumption is small because the shading devices are used only for the openings (windows or balconies) but the solid parts of the building are still under the exposed to the direct and indirect solar radiation.
- 3) **Good type of Insulation** is the simplest and most common way to protect the indoors from uncomfortable weather and plays an important role in effective treatment, however, the wrong type of insulation can work against human thermal comfort by blocking heat when needed to retain it and vice-versa. Walls that are designed in response to the climate, with an appropriate thermal mass and the right kind of insulation will keep indoor space comfortable, lower heating and cooling costs and preserve natural resources.
- 4) **External walls** allow much heat exchange between the indoor envelope of a house and the outdoor. As well as acting as a primary insulation layer, the inner part of an external wall can also be used to store energy, but this can only be achieved with compound wall construction where the outside warm wall is separated from the inside cold wall by insulation. External walls fall into three basic categories: low thermal mass, medium thermal mass and high thermal mass.
- 5) **Although** the insulation for external side of the external wall with appropriate materials is more effective several times than the insulation for internal side for the same wall, this work concerned with the effect of the internal side insulation of the external wall on the thermal performance of the building envelope for some reasons:
 - When the external side is not accessible.
 - The insulating material in the internal position of the building has a great effects on reducing consumption of energy by preventing the leakage of high temperature or thermal mass from hot outer ambient to the inner spaces in insulated buildings in summer.
 - Vice versa, in winter to keep thermal mass inside buildings and prevent losing it through its leakage through non insulated walls.
- 6) **A cost analysis** has to be done in comparison between the cost of achieving thermal comfort for occupants by using mechanical means and between using insulation (cheep or expensive) materials taking in consideration the energy running cost and maintenance, advantages and disadvantages of using natural materials and consumption of natural resources (benefit and exploitation) for a long term.
- 7) **A healthy analysis** has to be done comparing two factors:
 - Emissions of using passive strategies – energy consumer means.
 - Side effects of using radiological (or non radiological) manufactured and artificial insulation materials for short and long terms.

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OECP: **O**rganization for **E**nergy **C**onservation and **P**lanning, architecture and energy guide

تأثير استخدام مواد العزل على الأداء الحرارى فى المباني دراسة حالة لمبنى سكنى بالقاهرة - مصر

المخلص العربى

تعتبر الراحة الحرارية التى تصاحب انخفاض استهلاك الطاقة فى المباني هو الهدف الرئيسى للباحثين و لمصممي المباني فى جميع أنحاء العالم ، حيث أن أي جزء من الطاقة التي يمكن حفظها في هذا الصدد يعني الحماية للبيئة وصيانة مواردها وربما يمكن أن توجه إلى أي أنشطة أخرى ، إن وجدت. ولذلك فإنه من الضروري خفض استهلاك الطاقة التى تستهلك من خلال أنظمة مختلفة مثل تكييف الهواء (المستهلك الرئيسى للطاقة فى المباني) ، الإضاءة ، المعدات وما إلى ذلك ، ففي المناطق ذات الطاقة المحدودة أو النادرة ، يجب أن تحل التهوية الطبيعية محل أنظمة تكييف الهواء الميكانيكية لإزالة الحمل الحرارى للمبنى لتوفير الراحة الحرارية . وتعتبر أيضاً قضايا الحفاظ على الطاقة أكثر أهمية فى المناطق الجافة والساخنة ، حيث تستهلك المباني أكثر من 60% من الطاقة الكهربائية المولدة وحوالي 65% من هذه الطاقة المستهلكة للتبريد.

هناك مجموعة من العوامل المعقدة ، التي تحدد احتياجات الطاقة فى المبنى ، مثل الإشعاع الشمسى ونوع أنظمة التكييف ، عملية الإنشاء ، والخصائص الحرارية لمحيط المبنى ، الخ . كما أن هناك عدة عوامل مثل اللون ، التكوين العام للمبنى ، أعمال العزل والتهوية الطبيعية التى يكون لها أكبر الأثر على الأداء الحرارى للجدران والأسقف .

تعتبر مناقشة معنى الراحة الحرارية وكفاءة الاستفادة فى استخدام الطاقة وتصميم مواد البناء من أهم الموضوعات التى تناقش فى العقد الحالى وسابقه على مستوى العالم . وهناك عدة وسائل للحد من استهلاك الطاقة لتوفير الراحة الحرارية للإنسان فى المباني ، ولكن ما هى أكثر الوسائل كفاءة فى استخدام الطاقة وتوفرها ؟ واحد من أهم هذه الوسائل هو العزل الحرارى والذي يمكن استخدامه لعزل الجدران الخارجية والأسقف ، والتي تتعرض لكمية كبيرة من الإشعاع الشمسى لتقليل استهلاك الطاقة فى عملية التبريد لتوفير الراحة الحرارية داخل الحيز الداخلى للمبنى .

وتوضح هذه الدراسة تأثير أنواع مختلفة من العزل والمستخدمة فى عزل الحوائط الخارجية للمبنى (خاصة الغربية منها) التى هى أكثر تعرض للإشعاع الشمسى والأحمال الحرارية) على السلوك الحرارى الداخلى من أجل الوصول لوسيلة لكيفية تحديد وسيلة العزل التى تعطي الحد الأدنى والحد الأقصى للتكلفة لتوفير أكبر قدر من درجات الحرارة المناسبة لخفض الطاقة المستخدمة فى عملية التبريد . وقد تم عمل الجزء التطبيقى لهذه الدراسة برصد قياسات درجة الحرارة الفعلية لحالة الدراسة ، ويعنى الهدف الرئيسى باستخدام المواد العازلة فى تكوين الجدران الخارجية من أجل تحقيق خصائص الراحة الحرارية لمستخدمى المبنى ، وكذلك للحد من الطاقة المستهلكة .

كلمات البحث : الكتلة الحرارية - الراحة الحرارية - مواد العزل - حفظ الطاقة - استهلاك الطاقة