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Impact of wall material types on cooling and heating loads of a residential building at Sebha city conditions

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ABSTRACT

In the past few years, many countries have seen a significant increase in overall energy demand. Building energy consumption for air conditioning and electric heating represents a remarkably high percentage of total energy consumption in Libya. In addition, high temperatures in the summer lead to a significant increase in energy needs, which in turn depends on building materials used in the building walls. In this study, a simulation was carried out using MATLAB program for seven different types of wall materials available in Sebha city. The residential house with an area of 170 m^2 in is used as sample in this simulation. In MATLAB, the ASHRAE method is used for calculation of thermal load of house. The wall material used in our simulation includes hollow cement bricks, red bricks, sand bricks, expanded polystyrene (EPS), insulated or double bricks (with air gap), limestone brick, and clay bricks. Thermal loads were calculated using via the MATLAB program over four months, January and December for the heating load and July and August for the cooling load. The study showed that the wall of cement bricks has the highest load of (8.16 kw) at 7 a.m. and the sand has (1.95 kw) at the same time of the heating load in January. The highest cooling load in July was (10.1 kw) for cement bricks at 18 o'clock and at the same time (1.7 kw) for sand bricks. Since Sebha city has high solar radiation during the year, we recommend to use solar energy to supply residential buildings with the energy needed for cooling and heating processes to save energy consumption.

تأثير أنواع مواد الجدران على احمال التدفئة والتبريد لمبنى سكني عند ظروف مدينة سبها

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قسم الطاقات المتجددة، كلية الهندسة، جامعة سبها، ليبيا

الكلمات المفتاحية:
احمال التبريد والتدفئة
تقنيات الطاقات المتجددة
كفاءة الطاقة
مواد البناء

الملخص

في السنوات القليلة الماضية، شهدت العديد من البلدان زيادة كبيرة في الطلب الإجمالي على الطاقة. يمثل استهلاك الطاقة في المباني لأغراض التكييف والتدفئة (الكهرباء) نسبة عالية من اجمالي استهلاك الطاقة في ليبيا. بالإضافة إلى ذلك، تؤدي درجات الحرارة المرتفعة جدًا في فصل الصيف إلى زيادة كبيرة في احتياجات الطاقة الذي بدورها تعتمد مواد البناء المستخدمة في الجدران. في هذا الدراسة، اجريت محاكاة لسبعة انواع مختلفة من الجدران المتوفرة محليا منها الطوب الاسمنتي والطوب الآجر والطوب الرملي والطوب العازل بمادة البولسترين الموسع (EPS)والطوب الطيني، لمنزل سكني في مدينة سبها مساحته 170 م^2. تم حساب الاحمال الحرارية باستخدام طريقة ASHRAE عن طريق برنامج MATLAB على مدار 4 أشهر وهي يناير وديسمبر لحمل التدفئة ويوليو وأغسطس لحمل التبريد. خلصت الدراسة على ان الجدار المكون من الطوب الإسمنتي لدية أعلي حمل حراري حيث وصل إلى (8.16 kw) عند الساعة 7 صباحا وبالمقابل تحصل الطوب الرملي على (1.95 kw) في نفس الوقت من حمل التدفئة في شهر يناير. أعلى حمل حراري في شهر يوليو بقيمة (10.1 kw) للطوب الإسمنتي عند الساعة 18 وتحصل الطوب الرملي على (1.7 kw) في نفس التوقيت. نظرا لأن مدينة سبها تتمتع بإشعاع شمسي

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مرتفع خلال العام، فإننا نوصي باستخدام الطاقة الشمسية لتزويد المباني السكنية بالطاقة اللازمة لعمليات التبريد والتدفئة لتوفير استهلاك الطاقة.

Introduction

In the last few years, several countries experienced a dramatic increase of the overall energy demand. At the same time, greenhouse gas emissions are also increasing, causing several meteorological catastrophic events all over the world [1]. The energy consumption in Libyan buildings for air conditioning (electricity) represents a significantly high percentage of energy consumption. In addition, the very high summer temperature result in a drastic increase in energy needs. The problem is that the increase in energy consumption in the buildings for purposes of air conditioning in Libya has increased which dependence on traditional systems to provide thermal comfort [2]. Even though Libya is one of the richest countries in renewable energy resources such as solar energy and wind, the load of electricity in the country increases every year with the increasing demand for air conditioning [1]. In Libya, the improvement of living standard induced higher comfort requirements which translated into an increase in the use of heating and air conditioning equipment. In addition, no attention was paid to improve the thermal quality of the building envelope. As known, the effect the thermal properties (especially thermal conductivity) of the external building construction materials, significantly impact energy efficient [2]. The heat transfers through building envelope (walls, windows and roofs) are a key factor affecting the thermal comfort criterion and building energy consumption. Poor construction materials of building envelope cause larger heating and cooling loads. There are many studies on using some efficient technologies and sustainable materials to improve energy performance of building envelope (namely, the external wall [3]. Energy efficiency in buildings through the adoption of various insulation strategies is among the best practices for thermal comfort improvement and energy saving. Effective insulation conserves energy and requires less energy for space cooling in summer and less heating to keep the building warm in winter, thus, energy-efficient buildings with low negative environmental impact could significantly aid energy savings while improving occupants' comfort [4], [5].

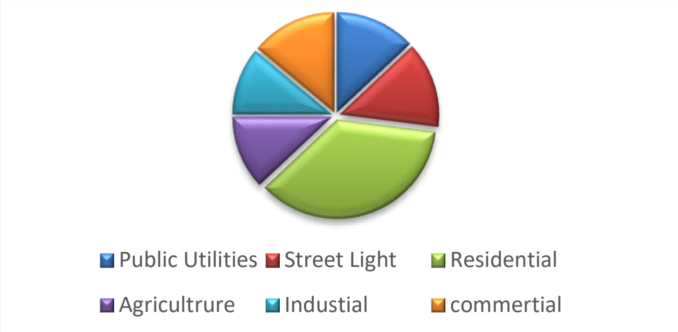

Fig. 1: The percentage of electricity consumption in Libya during 2012.

The electrical energy demand grows very rapidly with an annual growth of produced electricity of 8%. The total number of local electricity customers is of about 1,223,727 persons distributed among six categories. Residential sector represents the highest share in the local electrical energy demand with a contribution of about 36 % of the total consumption as shown in Figure (1) [6]. The efficient management of cooling and heating loads in buildings is of paramount importance in achieving energy efficiency and ensuring comfortable indoor environments. Building materials play a crucial role in the overall thermal performance of a structure, influencing the heat transfer between the interior and exterior environments [7]. The purpose of this paper is to investigate the effect of different building materials on the calculation of cooling and heating loads. By understanding how various materials impact energy needs for cooling and heating, better-informed decisions can be made during the design and construction phases, leading to enhanced energy- efficient practices. Overall, calculating cooling and heating loads is essential for designing energy-efficient systems, providing occupant comfort, and optimizing the overall performance of HVAC systems in residential, commercial, and industrial settings. This paper focus on a range of commonly used building materials. By accurately calculating cooling and heating loads, the building's HVAC (Heating, Ventilation, and Air Conditioning) system can be sized appropriately. This ensures the system operates efficiently, eliminating energy waste and reducing operational costs. measurements complemented by computer simulations, will be conducted to gather data on the thermal properties of these materials [8-9]. The study will concentrate on a residential building, with a consideration for different climate over the course of a year. In summary, this paper aims to contribute to the existing body of knowledge by providing valuable insights into the effect of building materials on calculating cooling and heating loads. The findings will help inform building design practices and promote energy-efficient measures in the construction sector [10].

Methodology

After reviewing previous studies that illustrate the effect of building material variables on energy efficiency in buildings and extracting some treatments used to achieve increased energy efficiency. Choosing a case study (a residential building in the city of Sabha) to study the effect of different types of walls, on increased energy efficiency. The building was simulated using MATLAB to calculate energy consumption, calculate the savings rate, evaluate processors, choose the best processors and apply them.

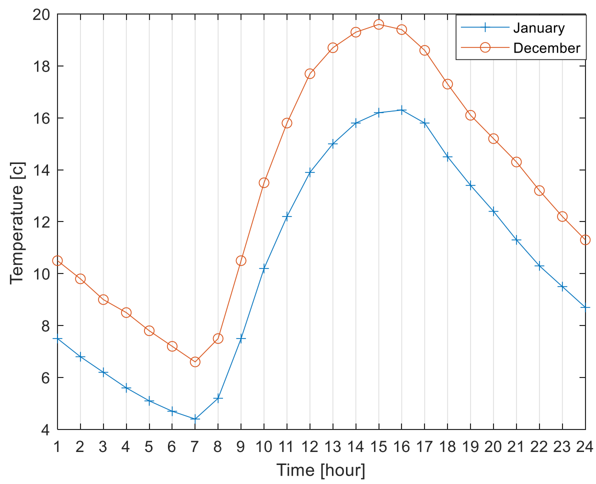

Fig. 2: Temperatures of Sebha at January and December

Figures 2,3 show temperature of Sebha during summer and winter times. From figures, the highest degree in summer (August) exceeds 38 ºC, while the lowest degree reaches 4 ºC during winter (January). It is clear that there is a difference over a 24-hour period during the months of winter and summer. It represents the average temperature for each hour of the months.

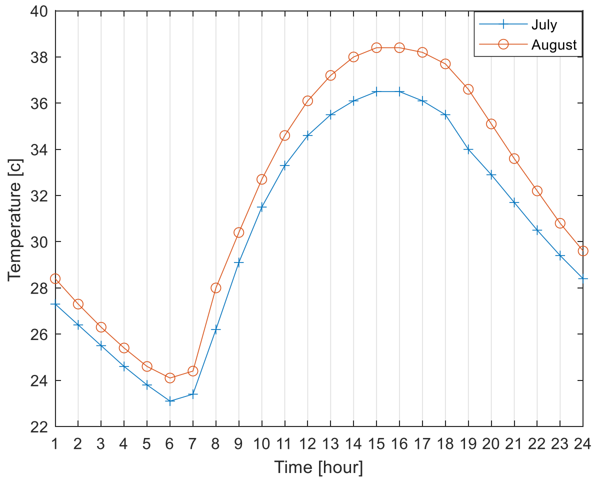

Fig. 3: Temperatures of Sebha at July and August

Thermal load calculation

Thermal load calculation refers to the process of determining the amount of heat energy that needs to be added to or remove from a certain space to maintain a desired room temperature. The heating load is the amount of thermal energy added while the cooling load referred to the amount of energy added. Table 1 shows the heat transfer coefficients for different wall materials. Figure 4 shows some type of bricks used in Sebha city [11-16].

Table 1: Heat transfer coefficients for some building materials

Types of Walls	Dimension in cm External Plaster	Block	Internal plaster	Heat transfer coeff. U= W/(m²·°C)
Hollow c Brick	1.2	20	1.2	2.44
Limestone Brick	2	20	2	2.02
Red Brick	1	20	1	1.72
Double Brick	1.2	15,10	air (5)	1.57
+air	2.5	60	2.5	0.755
Clay Brick	1.2	20	1.2	0.588
Polystyrene Brick	0.8	20	0.8	0.581
Light Sand Brick				

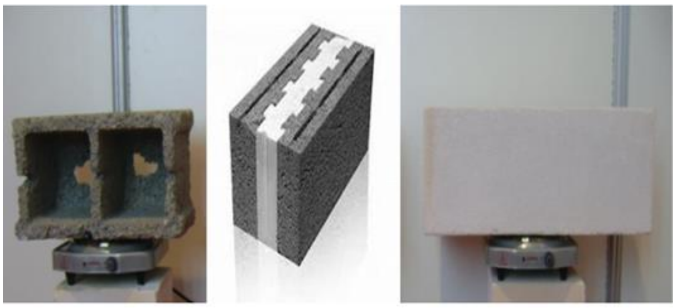

Fig. 4: Some types of bricks [from left to right, cement brick, polystyrene brick and light sand brick]

Heating load: -

The heating load is calculated using ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) [17].

$$Q_s = U\,A\,(T_i - T_o) \quad (1)$$

Where:

Qs = heating load in watt

U = overall heat transfer coefficient, W/(m²·°C)

A = area, m²

Ti = indoor temperature = 22°C

To = outdoor temperature, °C.

Cooling load: -

The cooling load is calculated according to the following formula [11].

$$Q_s = U\,A\,(CLTD) \quad (2)$$

Where,

CLTD = cooling Load Temperature Differences

It is corrected according to the type of building materials, direction and timing.

$$Q_s = U\,A\,(CLTD)_{Corr} \quad (3)$$

$$(CLTD)_{Corr} = [\,CLTD + LM\,] \times K + (25.5 - T_i) + (T_o - 29.4) \quad (4)$$

Where:

LM = Latitude month.

K = color correction factor = 0.85

Ti = indoor temperature = 25°C

Both heating and cooling load calculation are vital for the proper sizing and selection of HVAC (Heating, Refrigerating and Air-Conditioning) equipment, which can lead to cost savings and improved comfort [18].

Results and discussion

Simulation of cooling and heating loads is carried out using MATLAB. Seven types of wall materials are used in this simulation. All materials are available in Sebha city. Figures (5,6) show the heating loads for different types of walls during winter (December and January). It is noted that the highest heating load is for hollow cement bricks, as it reaches more than (7 kw) at 7 a.m during winter time. After that it begins to decrease until it reaches (3 kw) at 16 pm, then rises synchronous with the drop in temperature. Limestone bricks, red bricks, double walls with an air gap, and clay bricks have relatively low heating load compared with Hollow bricks. Finally polystyrene bricks and sand bricks constitute the lowest heating loads due to their low thermal conductivity.

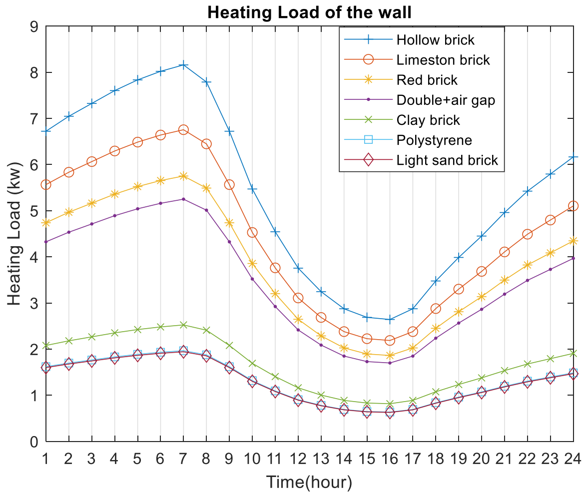

Fig. 5: Heating loads for January

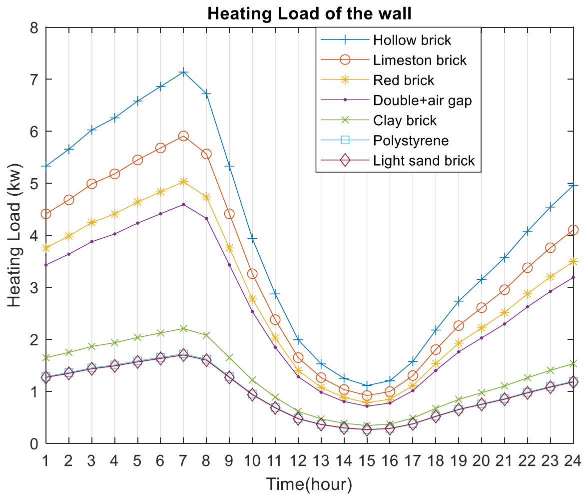

Fig. 6: Heating loads for December

Figures (7,8) show the cooling loads for different types of walls during summer time (July and August). It is noted that in July, the highest cooling load is for hollow bricks, as the load reaches (10 kw) at 16 o'clock. Followed by soft stone bricks, followed by double walls with air gap, followed by red bricks, then clay bricks, polystyrene bricks, and finally sand bricks, due to the low overall heat transfer. The thermal loads begin to rise simultaneously with the rise in temperatures in the early morning hours, and the thermal loads remain high at sunset at 18 p.m. and later. The thermal loads are close to each other, with the exception of clay, polystyrene and sand bricks because their thermal conductivity are low.

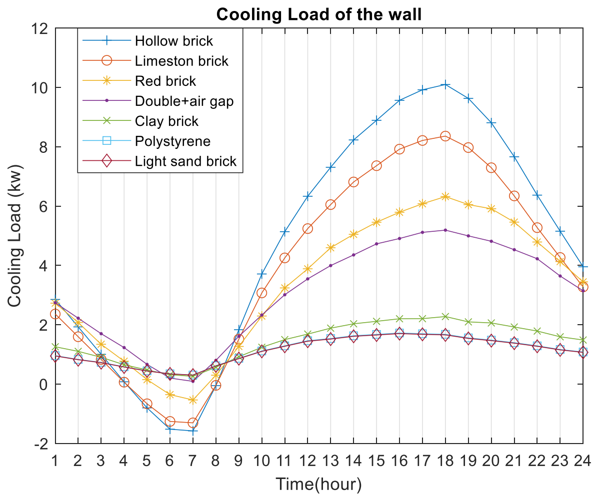

Fig. 7: Cooling loads for July

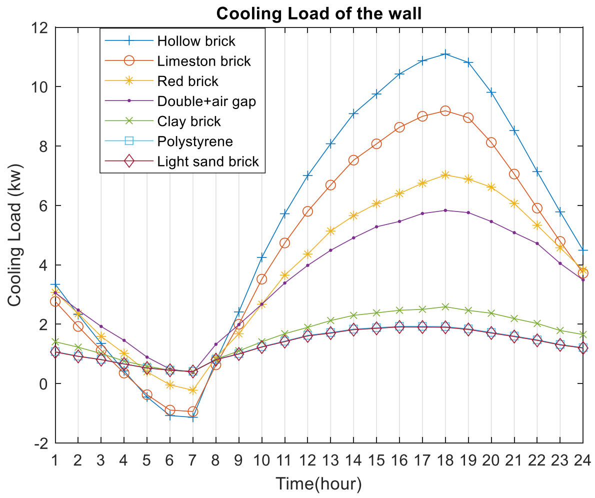

Fig. 8: Cooling loads for August

Conclusion

This paper aimed to know the thermal properties of local building materials to reduce the use of electrical energy for cooling and heating in residential homes. We found that there is a big difference in thermal properties for local building materials. Hollow cement brick has the highest heating load reaches 8 kw in January, while light sand bricks have the lowest value of (2 kW) at same time. Also, we found that the highest cooling load value for cement bricks exceeds 10 kW. The lowest cooling load is 1.75 kw for light sand bricks. From MATLAB simulations, the suitable wall materials for Sebha conditions are polystyrene bricks and light sand bricks. which they have identical loads.

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