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Comparison of the Quality of Building Bricks in Terms of Thermal Insulation and Energy Saving Using Building Information Modeling

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ABSTRACT

This study attempts to uncover the causes of the inefficient thermal performance of buildings in southern Libya. It conducted virtual tests (simulations) on some types of building bricks used in buildings in the study area. The simulations were performed using ARCHICAD, which uses Building Information Modeling (BIM) technology. An operational simulation was conducted for a single-story residential building in the city of Sebha, southern Libya. The results showed that the use of lightweight sandstone bricks in the construction of external walls provides 15.5% better thermal comfort per 100 m2 compared to construction using hollow cement bricks. Meanwhile, thermal comfort inside buildings constructed using lightweight sandstone bricks is 7.4% better per 100 m2 compared to construction using red bricks. When using electrical heating and cooling methods for a building constructed using lightweight sandstone bricks, the building will save 11.4% less annual operating costs per 100 m² compared to a building constructed using hollow cement bricks. Furthermore, the use of sandstone bricks will save 11% less annual operating costs per 100 m² compared to red bricks. It was also found that lightweight sandstone bricks prevent heat transfer into the buildings constructed from them by 343% compared to hollow cement bricks. Furthermore, buildings constructed using sandstone bricks prevent heat transfer by 226% compared to buildings constructed using red bricks. This indicates that lightweight sandstone bricks are the best construction option for building walls in the study area, thus addressing the thermal comfort problems within these buildings.

Keywords: ARCHICAD, building bricks, thermal conductivity, BIM.

مقارنة جودة طوب البناء من حيث العزل الحراري وتوفير الطاقة باستخدام نمذجة معلومات البناء

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ملخـــــــص البحـــــــث

تحاول هذه الدراسة الكشف عن أسباب الأداء الحراري غير الكفء للمباني في جنوب ليبيا. وقد أجرت اختبارات افتراضية (محاكاة) على بعض أنواع طوب البناء المستخدم في المباني في منطقة الدراسة. وأُجريت عمليات المحاكاة باستخدام برنامج **ARCHICAD**، الذي يستخدم تقنية نمذجة معلومات البناء (**BIM**). وأُجريت محاكاة تشغيلية لمبنى سكني من طابق واحد في مدينة سبها، جنوب ليبيا.

وأظهرت النتائج أن استخدام طوب الحجر الرملي خفيف الوزن في بناء الجدران الخارجية يوفر راحة حرارية أفضل بنسبة 15.5٪ لكل 100 متر مربع مقارنة بالبناء باستخدام طوب الإسمنت المجوف. وفي الوقت نفسه، فإن الراحة الحرارية داخل المباني المبنية باستخدام طوب الحجر الرملي خفيف الوزن أفضل بنسبة 7.4٪ لكل 100 متر مربع مقارنة بالبناء باستخدام الطوب الأحمر. وعند استخدام طرق التدفئة والتبريد الكهربائية لمبنى مبني باستخدام طوب الحجر الرملي خفيف الوزن، سيوفر المبنى تكاليف تشغيل سنوية أقل بنسبة 11.4٪ لكل 100 متر مربع مقارنة بمبنى مبني باستخدام طوب الإسمنت المجوف. علاوة على ذلك، يُقلل استخدام طوب الحجر الرملي من تكاليف التشغيل السنوية بنسبة 11% لكل 100 متر مربع مقارنةً بالطوب الأحمر. كما وُجد أن طوب الحجر الرملي خفيف الوزن يمنع انتقال الحرارة إلى المباني المُشيدة منه بنسبة 343% مقارنةً بالطوب الإسمنتي المجوف. علاوة على ذلك، تمنع المباني المُشيدة باستخدام طوب الحجر الرملي انتقال الحرارة بنسبة 226% مقارنةً بالمباني المُشيدة باستخدام الطوب الأحمر. هذا يُشير إلى أن طوب الحجر الرملي خفيف الوزن هو الخيار الأمثل لبناء الجدران في منطقة الدراسة، مما يُعالج مشاكل الراحة الحرارية داخل هذه المباني.

الكلمات المفتاحية: أركيكاد، طوب البناء، التوصيل الحراري، نمذجة معلومات البناء (**BIM**).

1. INTRODUCTION

Southern Libya is considered a hot, dry desert region with harsh climatic conditions, characterized by extremely high temperatures in the summer and low temperatures in the winter. In addition to the hot seasonal winds and the scarcity of rainfall throughout the year, ancient inhabitants sought out building materials for their homes, such as brick, clay, and stone. These materials were naturally heat-resistant, and they were used to construct buildings to withstand these climatic conditions. They also used construction methods that were highly thermally insulated. The urban and social development in Libya in general, and southern Libya in particular, resulted in an increase in the number of buildings and the necessary complementary facilities to keep pace with the development and progress of humanity in our contemporary world. The majority of these buildings were designed largely without consideration for the principles of rationalizing the energy consumption used in cooling and heating these buildings. This resulted in the construction of buildings characterized by qualitative and technical deficiencies in terms of natural thermal insulation, given the harsh climatic conditions of southern Libya. This deficiency can be observed in the citizens' struggle to provide the energy needed to heat and cool their homes, which has increased the cost of building investment and their household expenses most days of the year. On the other hand, this type of building has been reflected in the worst conditions in light of future climate change. In addition, these burdens do not stop at the citizen alone, but extend to the state level, represented by urgent maintenance and restructuring of the infrastructure of electrical devices and equipment, and the provision of specialized technical personnel to provide the huge quantities of expensive electrical energy; and the resulting expenses for operating, generating and distributing this electrical energy, which all residents of southern Libya depend on primarily to power their homes and provide thermal comfort within these buildings.

2. THERMAL TRANSFER

Heat is generally considered a form of energy that is transferred from one body to another. It is transferred between bodies with different temperatures. This transfer occurs from bodies with a higher temperature (hot) to bodies with a lower temperature (cold), as shown in the figure (1).

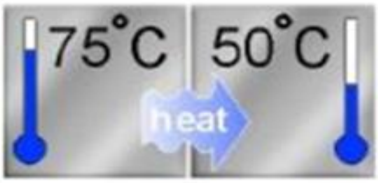

Fig 1. Heat transfer from the hotter part to the lower temperature (9).

This transition continues until these bodies reach a state of stability, and the temperature between them becomes equal in the absence of a continuous source of this heat, as in Figure (2).

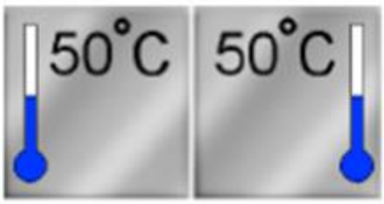

Fig 2. The occurrence of thermal equilibrium between parts of the substance(9).

However, in the case of the presence of a continuous source of heat, these bodies will take on the temperature of this source according to the strength and time they are exposed to from this source. Heat transfer is also known by other names, including (heat flow - heat exchange) (5). Heat transfer occurs in three general ways. The first type is convection, which is the heat transfer that occurs in liquids and gases, as a result of the natural movement of less dense and hotter molecules, such that these molecules rise upwards and are replaced by others of higher density and lower temperature. The second type is thermal radiation, where thermal energy is transmitted in the form of electromagnetic waves that reach the speed of light, transmitting heat to the body that absorbs this heat. It is not necessary for the environment in which these waves are transmitted to be heated, unless this environment absorbs part of these waves and then its temperature changes. The third type is thermal conduction, where heat is transferred in the walls and ceilings of buildings that are mainly made of building materials, by thermal conduction. This type of thermal transfer occurs when objects are in direct contact with each other. (5)

3. BUILDING INFORMATION MODELING

The emergence of Building Information Modeling (BIM) technology has revolutionized the engineering and construction industries, providing a means for documenting and managing design throughout a building's entire life cycle, from the initial conception of the project, its design and drawings, to the construction phase, and then the operation and management of the building. The development of BIM technology has been a reason for a large group of universities around the world to develop their educational curricula according to the requirements of BIM technology, with more than 103 universities; in order to provide students with the necessary experience and skills to deal with the tools of this relatively new technology. Also, global companies have greatly accepted the use of BIM technology in their work and designs, as projects have become more difficult and complex to be designed and managed by a single designer using traditional methods and techniques (2). The term BIM technology is an abbreviation for the phrase: (Building Information Modeling), where Building is specific to buildings and facilities such as schools, factories, houses, and cities. The word: Information refers to the information that is useful in the construction process, not just a model or structure, while the word: Modeling refers to a model and a visual representation of information; as if you see a three-dimensional model in front of you with its real specifications that are completely identical to reality. In this technology, each element has all the information that the user needs. Theoretically, BIM technology has existed since 1970 AD, but the reason for its lack of spread is that computers at that time were not advanced and had low speed; It was not possible to represent the building's characteristics in a single digital model. With the development of computers, the first implementation of this technology was in the ARCHICAD program, by the GRAPHISOFT company, at the beginning of 1987 (6). It is worth noting that the BIM technology is not a single program, but rather a group of different techniques and working methods. Therefore, any program that can draw a model of the building with all the required information for all of its composing elements, and can resolve conflicts and inventory work in a second, is included in the BIM list. Therefore, when the correct data is entered into the computer, there is no limit to what you can obtain from this technology (6).

4. PRACTICAL PROGRAM

A virtual reality study was conducted on some local building materials available in the Libyan market to demonstrate their total heat transfer. Three types of building bricks used in building the buildings in the study area were selected, namely (hollow cement bricks, red bricks, and light sand bricks). This was done to determine the total amount of heat transferred through these materials to the buildings, and to determine the different effects resulting from this heat transfer. This was done by assuming seven different case studies of a hypothetical residential building in the study area. These case studies were tested using simulations using a computer program that relies on Building Information Modeling (BIM) technology in its calculations.

4.1 The Program Used in The Study

The study tool here is the ARCHICAD program, which was designed and developed by GRAPHISOFT, which produced the first version of it in 1982 (12). In general, this program is compatible with computer operating systems (Windows & Mac), as this program was designed to work according to BIM technology, to become the first program specialized in this technology. The program is characterized by an easy and clear user interface, as in Figure (3).

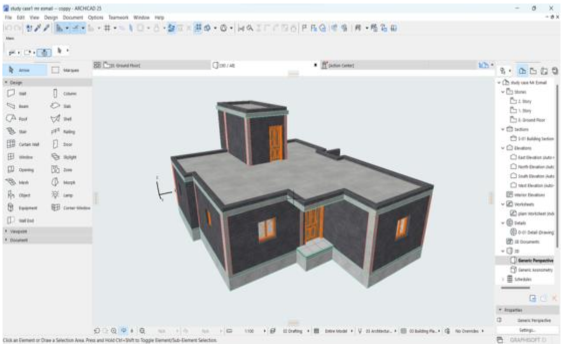

Fig 3. the ARCHICAD interface.

BIM software programs rely on drawing buildings and dealing with them in their real-life situation, and this software is the same. The software contains a large library of materials that the user needs to draw and represent his study building within the software. These materials were entered into the software with their real specifications according to what exists in reality. Therefore, when the software draws any wall, it treats it as a real wall that is completely similar to reality, taking into account the type and shape of the bricks used in building this wall, as well as the dimensions of the openings in it, such as doors and windows, and the material from which the door or window was made. It is worth noting that the software relies in its calculations on tables issued by ASHRAE (the American Society of Heating, Refrigerating and Air-Conditioning Engineers), which are added by the company that owns the software.

4.2 The Study Sample

This study was conducted on a hypothetical residential building in the southern Libyan city of Sabha, specifically in the Al-Jadid area. The horizontal projection of the study building is shown in Figure (4).

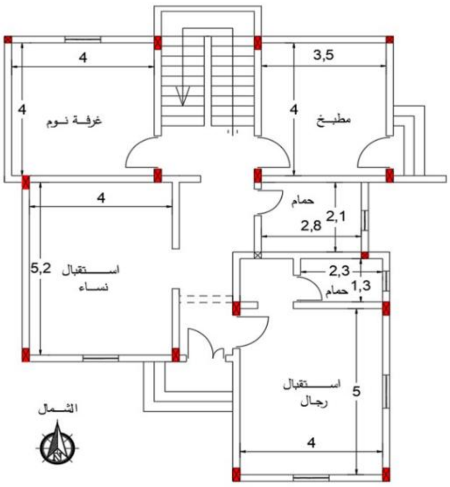

Fig 4. The Horizontal Plan of The Study Building.

Regarding the general data for the study building that was entered into the program, it is shown in Figure (5).

General Project Data		
Project Name:	study case Mr Esmail	
City Location:		
Latitude:	12 '3 27°" N	
Longitude:	51 '24 14°" E	
Altitude:	419.00	m
Climate Data Source:	LBY_SB_Sab...7-2021.epw	
Evaluation Date:	م 09:38 13/08/2023	
Building Geometry Data		
Gross Floor Area:	**24.44**	m²
Treated Floor Area:	**20.50**	m²
External Envelope Area:	**63.57**	m²
Ventilated Volume:	**53.91**	m³
Glazing Ratio:	**2**	%

Fig 5. General data for the study building.

4.3 Climate Data for The Study Area

The study area climate file for the year 2021 (27) was approved and uploaded to the program, and Figures (6, 7, 8, 9) show some values for the general data for the study area climate:

Fig 6. Air temperature of the study area.

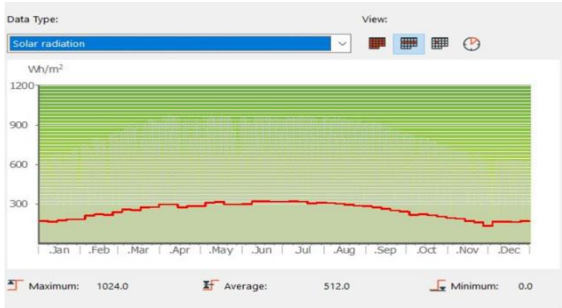

Fig 7. Solar radiation of the study area.

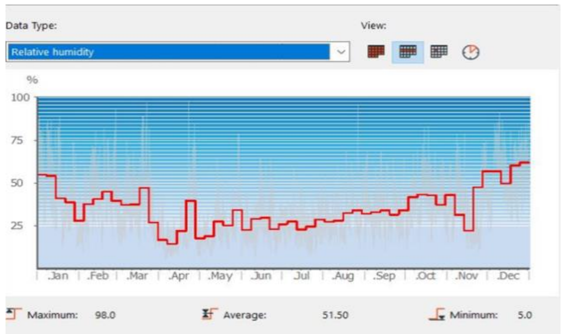

Fig 8.. Relative humidity of the study area.

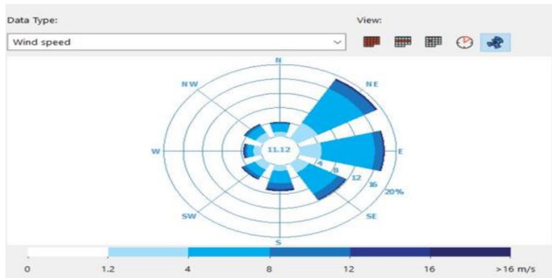

Fig 9. Wind speed in the study area.

It was also considered that in each case study the space under study would be cooled by a two-piece wall-mounted air conditioner, both indoor and outdoor, and the room cooling data was as entered into the program as shown in Figure (10):

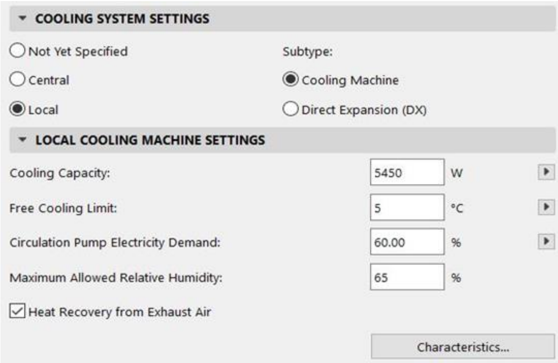

Fig 10. Cooling data of the studied room.

As for the heating process, the room was considered to be heated by an electric radiant heater, and the data for this heater that was entered into the program was as in Figure (11):

Fig 11. Heating data of the studied room.

To calculate the annual operating cost resulting from heating and cooling operations for the study sample, the cost of electricity was considered to be 40 Libyan dirhams per kilowatt per hour, which is the electricity price in Libya.

4.4 The cases of study

1. Wall Built of Hollow Cement Bricks with Internal Cement Plastering Only, This case is a wall built of hollow concrete blocks with dimensions of 40×20×20 cm, as shown in Figure (12).

Fig 12. Hollow cement bricks.

This wall was plastered with cement from the inside (inside the room) only with a thickness of 1.5 cm, so that the implementation detail entered into the program was as in Figure (13)

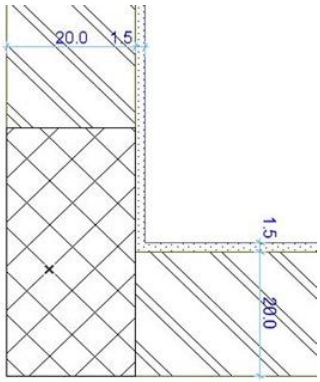

Fig 13. The implementation details of the first case study.

2. A wall built of hollow concrete blocks with internal and external cement plaster, This case is completely similar to the previous case, except that an external cement plaster of 1.5 cm thickness was added to the wall, so that the implementation detail entered into the program was as in Figure (14).

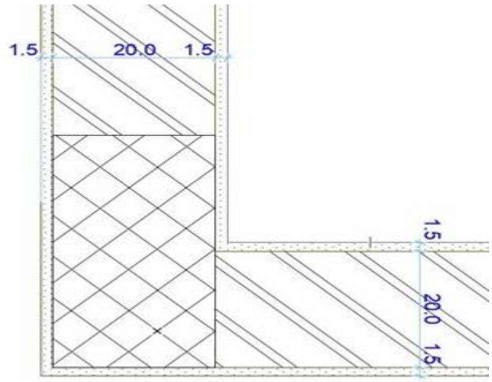

Fig 14. Executive detail of the second case study.

3. Wall Built of Red Brick with Internal Cement Plastering Only, In this case study, red bricks were used to construct the wall, measuring 40×20×20 cm, as shown in Figure (15)

Fig 15. Red brick.

This wall was considered to have been plastered internally with only the same thickness imposed for the previous cases, which is 1.5 cm, so the implementation details entered into the program were as in Figure (16).

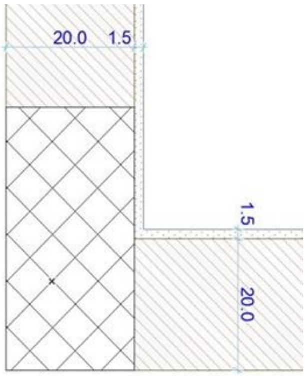

Fig 16. Executive detail of the third case study.

4. Wall Built of Red Brick with Internal and External Cement Plastering, This case is completely similar to the previous case in terms of the wall construction material, except that an external cement plaster of 1.5 cm thickness was added to the wall, so that the implementation detail entered into the program was as in Figure (17).

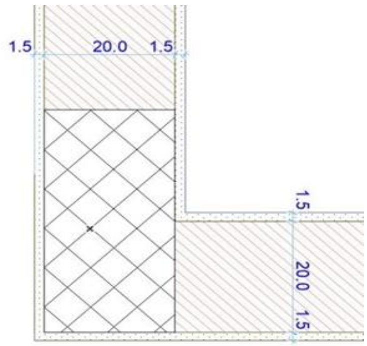

Fig 17. Executive detail of the fourth case study.

5. Double Hollow Cement Brick Wall with Internal and External Cement Plastering, In this case, a double wall was built, leaving a space between each of the two walls. The dimensions of the bricks used to construct the wall are 40 x 8 x 20 cm. The internal and external cement plastering of the wall was made with a thickness of 1.5 cm for each. The implementation details entered into the program were as in Figure (18).

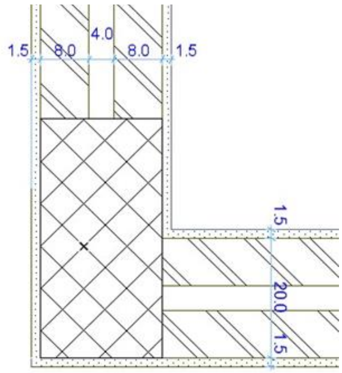

Fig 18. shows the implementation details for the fifth case study.

6. Wall Built of Sand Bricks with Internal Cement Plastering Only, The material from which the wall was constructed was changed, which is sand brick, which is a type of building brick that is somewhat not popular locally. It is also called light sand brick because of its light weight compared to others. It was called sand because its basic composition is sand in addition to some other materials (quicklime, gypsum, cement, and aluminum powder). This type is considered one of the best types of building bricks and has many features that make it environmentally friendly. Figure (19) shows a sample of the sand brick used.

Fig 19. lightweight sand bricks.

The wall under study was constructed from sand bricks with dimensions of 40×20×20 cm, with only an internal cement plaster of 1.5 cm thickness. It should be noted here that the plaster layer for this brick is around 8 mm (31) and may not need external plaster if it is built accurately and artistically. However, the thickness of the plaster layer was considered to be 1.5 cm so that there would be no difference between the study cases in terms of the general thickness of the wall. The implementation detail entered into the program was as in Figure (20).

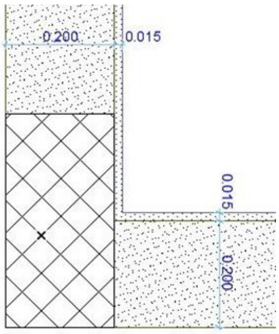

Fig 20. the implementation details for the sixth case study.

7. Wall Built of Sand Bricks with Internal and External Cement Plastering, In this case, an external cement plastering of the wall with a thickness of 1.5 cm was imposed, and the implementation details entered into the program were as in Figure (21).

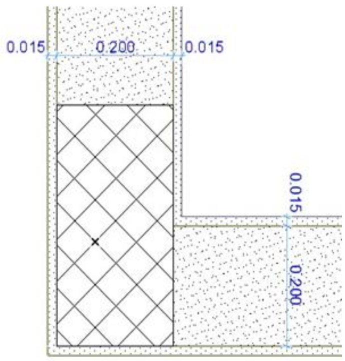

Fig 21. the implementation details of the seventh case study.

4.5 Properties of Materials Used in The Case Studies

Table 1. properties of materials considered as constants for all study cases

Material	Thickness m	thermal conductivity W/mk	Density Kg/m3	heat capacity J/kg, K
Hollow Cement Bricks	0.20	0.91	1400	880
Red Brick	0.20	0.58	1500	840
Sand Bricks	0.20	0.13	500	840
Cement plaster	0.015	1	1800	1000
double wall air gap	0.04	0.15	1.2	1008

5. RESULTS AND DISCUSSION

5.1 Internal Temperature Values for The Case Studies

After conducting the simulation process for the study cases, it became clear that the worst results regarding the internal temperature came from the first study case, and Figures (22, 23, 24, 25) show the daily temperatures inside the space for the first study case during the months (March - June - September - December).

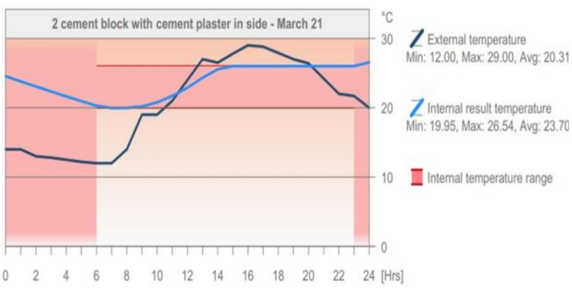

Fig. 22

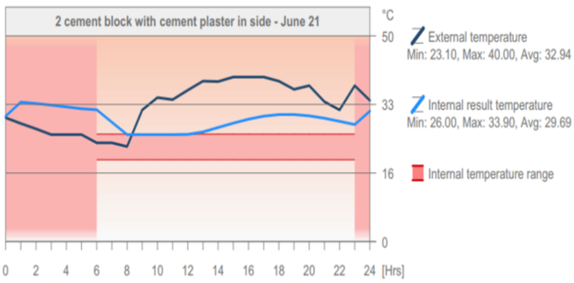

Fig 23

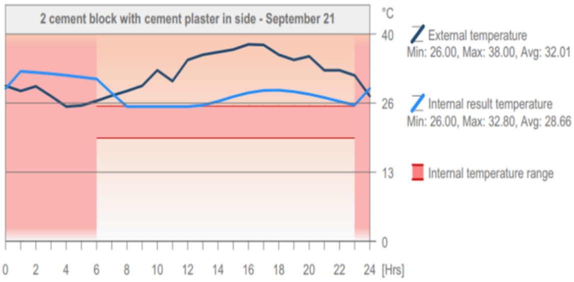

Fig 24

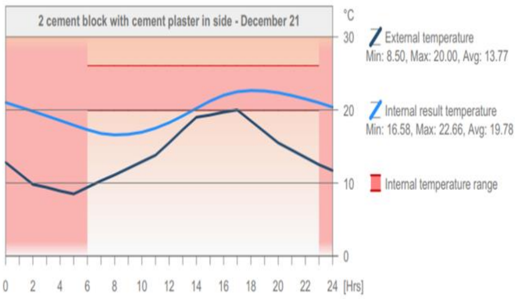

Fig. 25Fig (22, 23, 24, 25) show the internal temperature for the first case study.

The wavy line represents the temperature outside the building resulting from the weather conditions in the study area. The curved line shows the temperature inside the room resulting from the flow of external heat or part of it into the room, in addition to the temperature resulting from the previously imposed heating and cooling device. The two straight parallel lines represent the limits of thermal comfort inside the room that the program assumes according to the ASHRAE tables. The value of the limits of this thermal comfort is (from 20 to 26 0C). The best study cases in terms of temperature inside the room came from the seventh study case, and figures (26, 27, 28, 29) show these values. It is worth noting here that the temperature values inside the room can be displayed for any day of any month during the year, and here the internal temperature values were displayed for 21 days of the months (March - June - September - December).

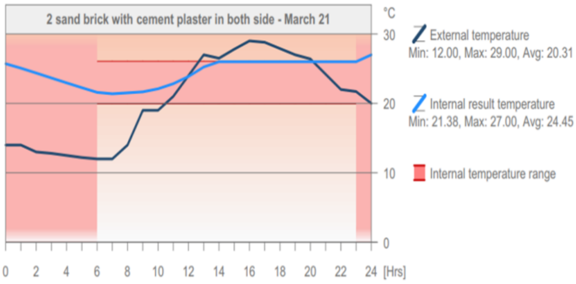

Fig. 26

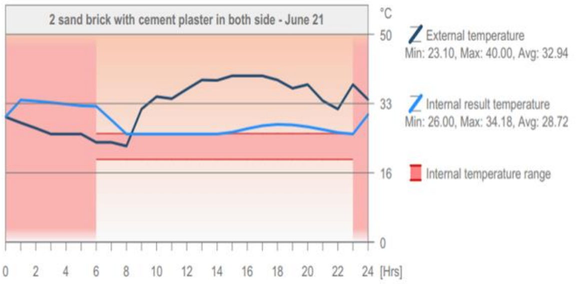

Fig. 27

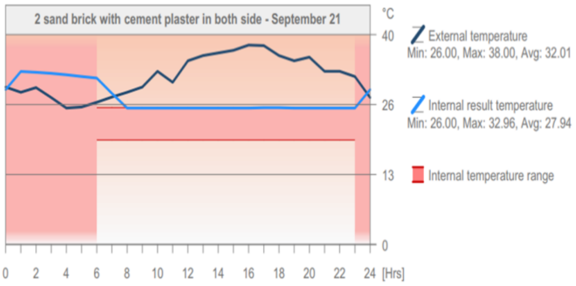

Fig. 28

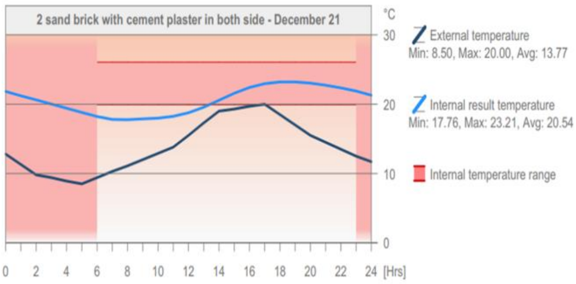

Fig. 29

Fig (26, 27, 28, 29) show the internal temperature for the seventh case study.

By reviewing the remaining results of the daily internal temperatures of the studied room, which were obtained as a result of the study cases, and taking the arithmetic mean, it became clear that all the obtained values were somewhat close, as shown in Table 2.

Table 2. properties of materials considered as constants for all study cases.

Case study	Average indoor temperature during the months			
	march	June	September	December
First	23.7	29.69	28.66	19.78
Second	23.78	29.6	28.59	19.8
Third	24.13	29.32	28.3	20.15
Forth	24.18	29.27	28.27	20.16
Fifth	24.14	29.23	28.2	20.14
Sixth	24.44	28.72	27.93	20.53
seventh	24.45	28.72	27.94	20.54

The reason for the similarity of these results is that during the calculations, the ARCHICAD program tries to keep the internal room temperature within the limits of its approved thermal comfort temperatures, which are from 20 0 C to 26 0 C, by operating the heating and cooling devices during times when the internal temperature drops or rises. To express these results more clearly and facilitate comparison between them, they were calculated as a percentage relative to the worst value obtained from all the study cases, which are the values that came from the first study case.

Table 3. shows the percentage difference between the indoor temperatures of the studied room compared to the worst-case outcome (first case).

Case study	Percentage difference between the average indoor temperatures compared to the first case over the months.			
	march	June	September	December
First	0%	0%	0%	0%
Second	0.336%	0.304%	0.245%	0.101%
Third	1.782%	1.262%	1.272%	1.836%
Fourth	1.985%	1.435%	1.380%	1.885%
Fifth	1.823%	1.574%	1.631%	1.787%
Sixth	3.028%	3.377%	2.614%	3.653%
seventh	3.067%	3.377%	2.577%	3.700%

5.2 Total Heat Transfer Values for The Study Cases

As for the total heat transfer value of the wall that was studied in each study case, it was different in a varying way, with large differences between the results obtained, and the table shows these values.

Table 4 the total heat transfer through the room wall for each study case.

Case study	First	Second	Third	Fourth	Fifth	Sixth	seventh
Total heat transfer W/m²k	2.57	2.47	1.94	1.89	1.59	0.59	0.58

The lowest heat transfer value was achieved when sand bricks were used in the seventh and best case study, making sand bricks one of the best types of bricks used in wall construction in terms of thermal insulation. The case that yielded the highest heat transfer value was the first case in which hollow cement bricks were used. A thermal bridge will be created across the wall in this case, as illustrated in Figure (30) , which represents the heat transfer across the wall of the worst case study, the first case.

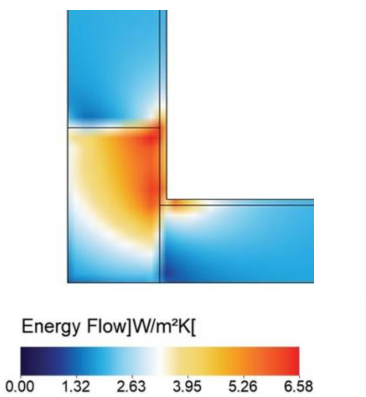

Fig 30. The Heat Flow Through The Wall Of The First Case Study

The shape of the thermal bridge resulting from heat transfer through the wall of the seventh case study is shown in Figure (31) which represents the heat transfer through the wall of the best case study.

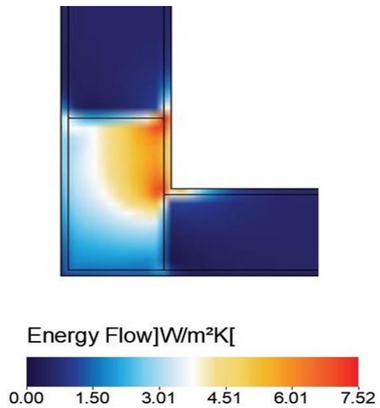

Fig 31. Shows The Heat Flow Through The Wall Of Seventh Case Study.

From Figures (30, 31), we notice that the heat generated by the column is considered large compared to the heat generated by the walls. In this study, the wall that was studied is the southern wall, while the effect of the heat generated by the column comes from the western wall in which the column extension is located. Therefore, the heat generated by the columns was considered to be a constant value for all study cases, such as the heat generated by the ceilings, windows, and other constants imposed in this study. Therefore, the values of the heat generated by the columns were not mentioned. In the same way as discussing the previous results and comparing them, a table was created representing the percentage difference between the values of heat transfer across the wall of the room that was studied for the study cases relative to the worst study case, as in Table 5.

Table 5 shows the percentage difference between the heat transfer values across the study room wall for each study case relative to the worst case.

Case study	1	2	3	4	5	6	7
The percentage difference between the heat transfer values relative to the first case	0	4	32.5	36	51.6	336	343

5.3 Estimate the annual operating costs resulting from heating and cooling operations

As for the annual operating costs of the space studied, resulting from the internal heat of the study cases, they differed from one case to another depending on the requirements of each case and what it needed in terms of heating or cooling. Figure (32) shows the values obtained for these costs.

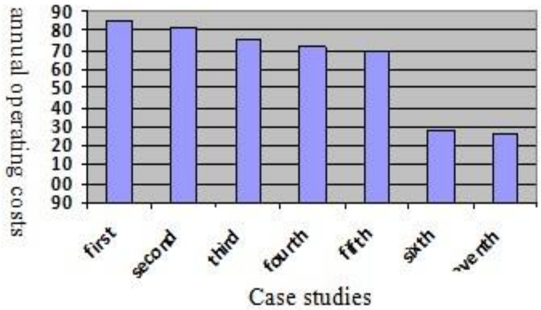

Fig 32. The annual operating costs resulting from heating and cooling operations for the case studies.

It was noted from the previous chart that the lowest operating cost was also when using light sand bricks, in both the sixth and seventh cases, with a value of (428 - 427 Libyan dinars/year) respectively, while the highest value was for the first case in which hollow cement bricks were used with only internal plaster. In the table vi, the percentage difference between the operating values resulting from the heating and cooling operations for the study cases relative to the worst study case.

Table 6 showing the percentage difference between the annual operating costs resulting from heating and cooling for the study cases relative to the worst case.

Case study	1	2	3	4	5	6	7
The percentage difference between the operating cost values relative to the first case	0	0.6	1.9	2.3	3.2	13.3	13.6

6. CONCLUSIONS

• When constructing external building walls, attention must be paid to the point where the column meets the wall, as well as the inner surface of the column from inside the room. It has been shown that this area is a major source of heat leakage into the building. Therefore, it is recommended to insulate this area well to prevent heat leakage into the building. Studies on this issue should continue and expand.

• Using lightweight sandstone bricks to construct external walls 20 cm thick for a given building provides 15.5% better thermal comfort per 100 m² than using hollow cement bricks. Lightweight sandstone bricks also provide 7.4% better thermal comfort per 100 m² than using red bricks.

• When constructing a double wall, leaving a small air gap between the walls does not significantly improve thermal insulation. Therefore, it is recommended to fill this gap with an insulating material suitable for the building's wall construction, or to increase the thickness of the wall to increase the space between the walls and increase the volume of air trapped between the walls. • Using building materials with good thermal insulation properties in the construction of building exterior walls reduces the electrical energy consumption required for heating and cooling these buildings.

• Lightweight sand bricks used in the construction of the exterior walls of a particular building reduce heat transfer through these walls by 343% compared to building them using hollow cement bricks, while these lightweight sand bricks reduce heat transfer through walls constructed from them by 226% compared to red bricks.

• Using sand bricks in the construction of 20 cm thick exterior walls of a particular building saves annual operating costs resulting from heating and cooling operations for that building by 11.4% per 100 m2 compared to building the same building using hollow cement bricks. Furthermore, the annual operating costs resulting from the use of air conditioning and cooling equipment in buildings constructed from lightweight sand bricks are 11% per 100 m2 lower than the costs resulting from buildings constructed using red bricks.

7. RECOMMENDATIONS

• Adopting Building Information Modeling (BIM) technology in higher education at all levels will raise the standard of undergraduate and graduate education, thus filling the current shortage of skilled personnel in this field.

• Lightweight sandstone bricks have excellent insulation properties and good thermal performance, making them recommended for use in the construction of external walls of residential and service buildings.

• Focusing on the lightweight sandstone brick industry in Libya in general, and in the south in particular, given the southern region's abundant sandstone brick-making raw materials. Researching the reasons for the failure to commence operations of the existing factory in the southern region and subsequently contributing to its operation.

• Expanding and increasing research into the conductivity and thermal transfer of building materials to increase the efficiency and quality of local building materials. The results obtained will then be used to create a database that can be referenced when designing and constructing buildings.

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