International Journal of Advances in Applied Sciences (IJAAS)
Vol. 11, No. 3, September 2022, pp. 177~186
ISSN: 2252-8814, DOI: 10.11591/ijaas.v11.i3.pp177-186

Reducing the cost of energy used for adaptation by using different exterior wall covering materials in Iraq

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Article Info

Article history:

Received May 1, 2022
Revised May 19, 2022
Accepted Jul 5, 2022

Keywords:

Cooling capacity
Energy consumption
External walls
Heat transfer
Thermal insulation
Thermal plastic
Total heat transfer

ABSTRACT

This paper aimed to study how to reduce the amounts of heat transfer from or to the internal space of the building by covering its external walls with many locally available materials, thus reducing the rate of consumption of electrical energy used in adaptation, which leads to reducing energy consumption costs. The researcher built a model room with dimensions (1 x 1 x 2) m on the third floor of a building in Baghdad (L = 33.2 N), the dimensions of its walls (1 x 2 m) east for the installation of the sample, and the other surfaces are insulated with 200 mm polystyrene sheets. Use a 0.5 ton air conditioner to provide the room thermal comfort. The researcher found that the metal sheet with a thickness of 10 mm and covered with an insulating layer of thermoplastics is considered the best among the materials used in construction, as it saves 57% of the electrical energy consumed in air conditioning. While the use of marble, porcelain, helen stone, and fiberglass slabs with a thickness of 10 mm, comes last because it saves less than 30% of electrical energy.

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NOMENCLATURE

h	Heat transfer by free convection (W/m^2K)	T_i	The temperature of the inner surface of the wall (C)	U_t	The total coefficient of total heat transfer in the absence of an insulator (W/m^2K)
Cc	Cooling capacity (Ton/month cooling)	T_o	The temperature of the outer surface of the wall (C)	U_{tins}	The total coefficient of total heat transfer in the presence of the insulator (W/m^2K)
C_R	Reflectivity coefficient (%)	T_r	The temperature of the inner surface facing the room (C)	ΔE_c	Percentage change in energy consumed (kW. hr/ month)
E_c	Electricity Consumed energy, (kW–hr/monthl)	T_{Sh}	Shade temperature (C)	ΔT	Temperature difference (C)
E_{CE}	Amount of energy consumed east, (kW–hr/month)	T_w	The temperature of the inner surface of the wall (C)	ΔT_{i-o}	The difference between the external and internal temperature (C)
H_{cc}	Heat transfer coefficient by conduction and load (W/m^2K)	x_w	the thickness of the wall (mm)	ΔT_{i-r}	The difference between the temperature at the inner wall and the room temperature (C)
K	Heat transfer coefficient by conduction (W/mK)	U	Total heat transfer coefficient (W/m^2K)		

1. INTRODUCTION

It is known that the average building area in Iraq does not exceed 1000 m^2, and its height does not exceed three floors (9 m), so it consumes about 60% of its total energy consumption for air conditioning [1]–[3]. So, the effect of convection leaking from the walls ranges from 50% to 80% of the total thermal energy falling on the walls [4], [5]. Reducing heat leakage through the walls of the building directly affects the energy required to air-condition the buildings [6], [7]. Most of the population of Iraq uses traditional walls due to the abundance of their basic components and their low cost. The traditional walls are built of technical bricks with a thickness of 24 cm with two layers of gypsum powder, where the first layer is placed on the outer surface of the wall with a thickness of 2 cm, and the second layer is placed on the inner surface with a thickness of 2.5 cm [8]. The total heat transfer coefficient of conventional walls with finishing is up to 1.75 W/m^2 [9]. Although there are other patterns used in construction, the temperature difference on both sides of the walls for most materials does not exceed 20% [10]–[14].

Some stressed the need for afforestation around buildings using climbing plants, and others focused on the need to use building materials with thermal insulation with a thickness of (70-100) mm, depending on the type of material used and the direction of the wall [15]–[25]. Others suggested using a two-wall building system instead of a single wall, depending on the type of building materials used and tested [26]–[28]. Iraq is located in the subtropical region, a hot and dry desert climate, where the summer lasts for more than seven months, during which the sun shines for long periods (more than 12 hours/day), and the shade temperature during summer reaches more than 45 °C. Therefore, the outer envelope of the buildings is exposed to intense heat waves for periods, which causes a large difference between the air temperatures in contact with the outer and inner part of the building structure during daylight hours [Iraq]. The daily range of temperature changes (day and night), reaching more than 20 °C, as shown in Figure 1 [8], [29]. The maximum and minimum temperatures for each month, the maximum temperatures for six months for each day, and the maximum temperatures for five months and every hour of the day for 2020 in Baghdad are shown in Figures 1, 2, and 3, respectively. [30]–[32]. the intensity of solar radiation for four months, every hour of the day, is shown in Figure 4 [33].

The amount of heat gained for the outer shell of the building structure consists of the sum of the amounts of heat transferred in the steady-state (caused by the difference in air temperatures inside and outside the building) and the unstable state (caused by the difference in the intensity of solar radiation falling on the roofs of the building). And the value of the amount of heat gained depends on the amount of heat conduction, specific heat, and the density and thickness of the wall components [34]–[36]. It makes it stores part of the heat that is transmitted through it, as fluctuations in the temperature of the outer surface do not appear with similar fluctuations to the temperature of the inner surface, which means that the structural materials that make up the wall increase the amount of time delay of heat transfer, and cause the indoor air to remain cold [36]. The temperature of the building's internal walls rises after a short period, which raises the temperature of the building's internal air to higher levels [37]. To obtain thermal comfort levels appropriate to the nature of the materials used in the building, air conditioning is required most of the day [34]. The consumption of electrical energy as a result of operating air conditioners is related to the amount of heat transferred through the walls of the building. So, reducing this heat by using insulators will reduce the operating time of air conditioners, reduce the amount of electricity consumed for air conditioning, reduce the amounts of energy consumed in the residential sector, and reduce potential costs [35]. From the above, the importance of research in providing electrical energy in modern buildings by using some covering materials for walls in construction appears.

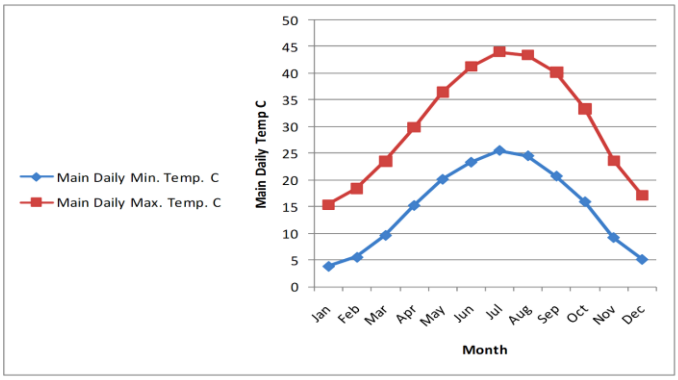

Figure1. The maximum and minimum temperatures for every month for the year 2020 in Baghdad

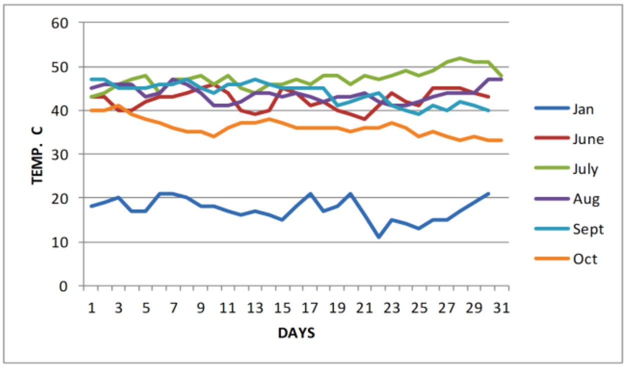

Figure 2. The amount of rising in temperatures for six months for each day in 2020 in Baghdad

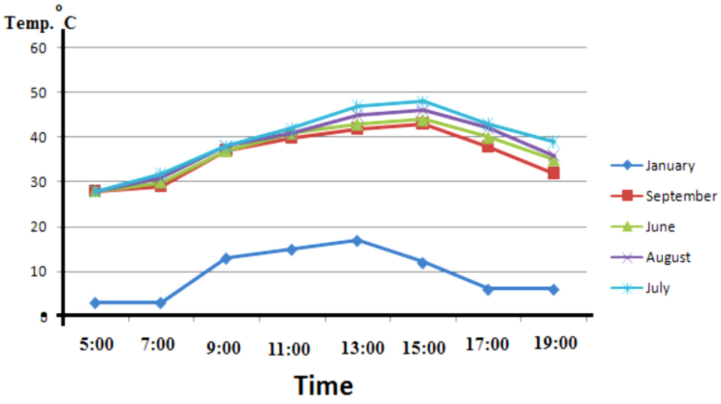

Figure 3. The maximum temperatures for five months for every hour of the day for the year 2020 in Baghdad

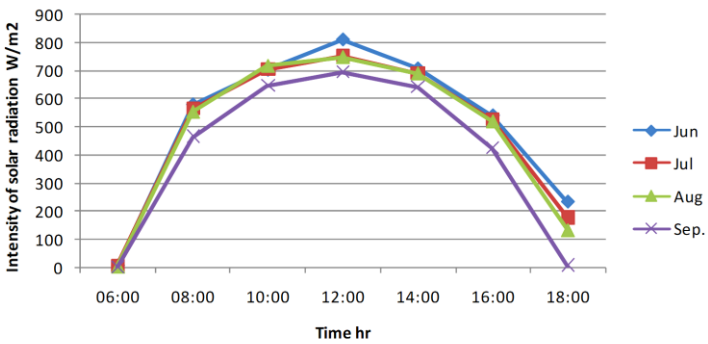

Figure 4. Intensity solar radiations for four months for every hour of the day

2. RESEARCH METHOD

To study the thermal behavior of wall covering materials the following have been adopted: i) The test area was chosen in the city of Baghdad-33.2 °N (average latitude across Iraq); ii) The location of the experiment room on the third floor of a residential building was chosen to avoid obstructing the access of sunlight to the building during daylight hours; iii) The direction of the test wall to the east was chosen. Table 1 shows the effect of changing the orientation of the building on thermal load and electrical energy consumption; and iv) To reduce heat transfer from other areas (exposed to the environment), use 20 cm thick polystyrene insulation to cover the sides, ceiling, and floor of the test chamber, to neutralize these areas as much as possible, and to generate heat through the front-end wall (alternate wall) only, as the main source affecting the level thermal comfort inside.

2.1. Test room and packaging materials

A test room was built to conduct the tests. Thermal insulation materials available locally were used to cover its walls. The room has dimensions (1 x 1 x 2 m) on the outside and is located on the third floor of a building in Baghdad as shown in Figure 5. One of its sides (1 x 2 m) is exposed to the outside (east facing). The chamber contains a movable cart on which the test sample is mounted for study purposes. One of its walls contains a window air conditioner with a capacity of 0.5 tons connected to an electrical conductor to supply it with electrical power, as well as a digital sensor to control the room temperature at a comfortable temperature (26 °C). The thermometer is connected to an electrical power source to measure the energy consumed in the air conditioning. Thermometers, which were attached to the test sample, were used at nine locations inside and outside the sample. In addition to the use of a thermometer, a thermometer was installed inside the room and another outside. Figure 6 shows a photo of the window-type air conditioner and thermometer used in the standards.

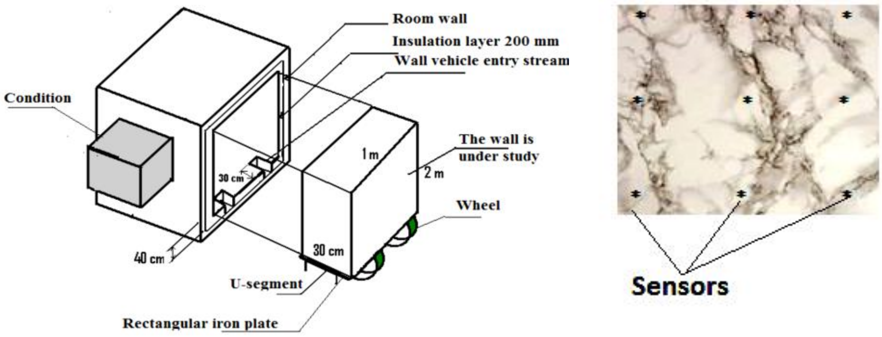

Figure 5. The test chamber and the locations of the sensors inside the wall

Figure 6. The thermometer and the air conditioner

Figure 7 showing some materials on which the tests were conducted. Figure 7(a) showing polystyrene, Figure 7(b) showing ceramic, Figure 7(c) showing building bricks, Figure 7(d) showing porcelain, Figure 7(e) showing asbestos, Figure 7(f) showing hellan stone, Figure 7(g) showing granite, Figure 7(h) showing decorative plastic panels, Figure 7(i) showing metallic sheet covered with plastic stain.

a. Polystyrene (Styropor): An organic material with high thermal insulation efficiency and high density. It is characterized by its high resistance to water vapor permeability, fire resistance, radiation.
b. Ceramic: An inorganic, non-metallic material prepared by heat and subsequent cooling. Ceramic materials may have a crystalline or semi-crystalline composition.
c. Building bricks: It is the basic building block for many buildings. They are made in the form of molds, often rectangular, of clay or other. Cement is used as a link between two adjacent bricks, where it is mixed with water and sand to form a cement mortar that secures the adhesion of the bricks to each other.
d. Porcelain: It is one of the most famous types of tiles in the world, and is characterized by its glossy and bright colors.
e. Asbestos: A group of natural fibrous minerals used for internal insulation purposes and in a variety of components for several products, such as roofing sheets, water supply pipes, fire extinguishing hoods, and plastic packaging.
f. Hellan stone (limestone): It is chemically referred to as ($CaCO_3$). It is a sedimentary stone that arose from the sediments of calcified aquatic organisms such as corals and mollusks, as well as inks and sea snails.

According to its geological nature, it contains varying amounts of silica in the form of inclusions, as well as varying amounts of pure limestone.

g. Reflective metallic sheet (metal foil): It is a laminate that combines thermal insulation, reflective, moisture, and vapor retention properties.
h. Fiberglass boards (glass wool): The advantage of glass wool is that it has a low conductivity coefficient and the conductivity modulus changes according to the density, the higher the density of glass wool, the lower the conductivity coefficient.
i. Granite: Igneous rocks underground formed under high temperatures. Granite is mainly composed of three minerals-quartz, alkaline a luminous silicate, and plagioclase.
j. Decorative plastic panels: It is a type of plastic whose scientific name is polyvinyl chloride (PVC). The composition of PVC includes chlorine (57%), carbon (42%), and hydrogen with impurities (about 1%). It is very rare, and lead is added to PVC as a stabilizing agent.
k. Metallic sheet covered with plastic stain: It is a sheet of metal, often made of aluminum, covered on its reflective surface with a plastic pigment.
l. Marble (natural alabaster): It is a metamorphic limestone, consisting of very pure calcareous (crystalline calcium carbonate) ($CaCO_3$) that is used in sculpture, as well as building materials.
m. Silver bituminous paints: There are heat-reflecting silver-colored bitumen paints that are used especially on the surface of the mantle, in poultry farms, and on the roofs of factories designed using the Saw Tooth method.
n. Sun reflective paints: There are several types of sun reflective paints with different commercial names.
o. Glass wool: Glass wool is characterized by a low conductivity coefficient and the conductivity coefficient changes according to the density. The higher density of glass wool, the lower the conductivity coefficient.

Figure 7. Some building and packaging materials used in the tests: (a) polystyrene, (b) ceramic, (c) building bricks, (d) porcelain, (e) asbestos, (f) hellan stone, (g) granite, (h) decorative plastic panels, and (i) metallic sheet covered with plastic stain

2.2. Method of measurement

Step 1. Measuring the effect of changing the direction of the construction of the wall on the average amount of energy consumed per square meter of the wall during July, which is shown in Table 1, and the finding of the thermal properties of the materials is shown in Table 2.

Table 1. The effect of changing the building's orientation to the wall on the average amount of energy consumed per square meter of the wall during July*

Wall guiding	To °C	Tr °C	ΔTr-w °C	Cc Ton/month	EckW-hr/month	ΔEc %*
N	34.31	35.53	9.03	21.4	16.1	- 20.8
NE	45.54	37.36	10.86	25.7	19.35	-4.8
E	46.2	37.9	11.4	27	20.33	0
SE	46.1	37.82	11.32	26.8	20.18	- 0.74
S	45.84	37.6	11.1	26.3	19.8	- 2.61
SW	47.02	38.5	12	28.44	21.4	+ 5.26
W	46.55	38.19	11.69	27.7	20.86	+ 2.61
NW	45.41	37.33	10.83	25.66	19.3	- 5.02

*Note: T_{sh} = 39.34 °C, T_w = 26.5 °C, U = 1.75, and A = 1.354 m^2

Table 2. The thermal properties of the respective materials

The material coated for the wall	xw mm	CR %	ρ Kg/m3	K W/mK	Hcc W/m²K	Ut	Utins
Decorative plastic panels	8	65	2752	0.85	-	1.509	0.86
Natural alabaster	20	20	2650	2.4	-	1.546	0.872
Granite	20	49	2688	2.1	-	1.54	0.87
Ceramics	6	50	2304	0.93	-	1.53	0.867
Porcelain	10	20	1990	2.4	-	1.546	0.872
Hellan stone	40	41	1680	1.13	-	1.485	0.852
Asbestos sheets	6	30	1500	0.6	-	1.543	0.871
Fiberglass panels	15	43	603	0.13	-	1.52	0.863
Hollow bricks	120	41	1200	0.56	0.2078	1.1	0.71
Brushed bricks	50	73	1350	0.49	0.49	1.351	0.807

Step 2. Since the thickness of the brick wall used in the test room is 240 mm with two layers of cement on the outside and white plaster on the inside, a total heat transfer coefficient of 1.75 W/m^2 is adopted.

Step 3. The level of thermal comfort required inside the residential building is 26.5 °C.

Step 4. The finishing material for the floor surrounding the test room is concrete slabs measuring (0.040 × 0.8 × 0.8) m-gray color-and the interior finishing material for the wall under-study–is plaster thickness of 25 mm.

Step 5. The (1) was used to estimate the convective heat transfer coefficient of the wall.

$$h = 1.31\ (\Delta T_{w-r})^{1/3} \tag{1}$$

Step 6. Use digital electronic meters, manufactured by Victor intelligent auto digital thermometer, to measure the air temperature in the outer and inners layer adjacent to the wall, as well as the ambient temperature (shade) and room air.

Step 7. To measure the amount of electrical energy consumed by the air conditioning to provide a standard level of thermal comfort conditions inside the room, use an electrical energy meter in units (kW. hr.).

Step 8. The (2) is used to find the total heat transfer coefficient per unit area (U).

$$U = \frac{1}{\left(\frac{1}{h_1} + \frac{x_w}{k} + \frac{1}{h_2}\right)} \tag{2}$$

Step 9. The cooling capacity C_c is calculated by using (3).

$$C_c = U.A.\Delta T_{w-r} \tag{3}$$

Step 10. Measure the electrical energy consumed directly from the meter connected to the air conditioning.

Step 11. The percentage change in energy consumed (ΔE_c) due to load to the energy consumed (E_c) in the eastern direction was calculated in (4).

$$\%\ \Delta E_c = \frac{E_c - E_{cE}}{E_{CE}}\ \% \quad (4)$$

The variables included in the study are: i) Using several locally available materials for wall covering (under-study) that is exposed to the environment are: Hollow plastic panels (decorative panels) thickness of 10 mm, the natural alabaster thickness of 20 mm, Chinese granite thickness of 20 mm, the ceramic thickness of 6 mm, porcelain thickness of 10 mm, hellan thickness of 40 mm, asbestos sheets thickness of 6 mm, fiberglass clamp thickness sheets 1.5 mm thick, brushed bricks 30 mm thick, hollow technical bricks for cladding façades thickness of 120 mm, and brushed bricks thickness of 50 mm, as shown in Table 2; ii) The use of a heat-insulating material 10 mm thick from polystyrene material with the materials; iii) Environment temperature (shade), air temperature in the adjacent outer layer (from the structural section of the wall under study (consisting of additive and original wall)), indoor air temperature, and room were measured during the first day of July (from 5:00 morning until 7:30 pm).

3. RESULTS AND DISCUSSION

3.1. Results

To facilitate determining the thermal performance (behavior) of the wall after covering it with one of the mentioned materials, the amount of change between the measured temperature of the external and internal surfaces of the wall (under-study) was calculated. Each material used for packaging compared to the electrical energy consumed in the case of a normal wall (before packing) built of bricks with a thickness of 240 mm. The following are the most important results of the research obtained from the average temperature recorded on the wall (external and internal surfaces) and the percentage of changes in the cooling load as it is shown in Table 3.

Table 3. The average temperatures recorded on the wall (external and internal surfaces) and the percentage change in the cooling load +

Packing mate-rail	Use a heat insulator	To °C	Ti °C	ΔTi-o °C	ΔTi-r °C	Cc Ton/month	Ec kW-hr/month	ΔEc %
Decorative PVC panels	-	40.5	39.2	1.3	13.2	30.9	23.3	17.5
	*	41.4	36.0	5.1	10.0	21.54	16.2	42.5
Natural alabaster	-	45.16	40.3	4.9	14.3	34.29	25.9	8.4
	*	47.74	38.27	9.5	12.27	28.19	21.3	24.7
Granite	-	47.74	39.74	8	13.74	33.0	24.8	13.05
	*	49.12	37.78	11.34	11.78	28.3	21.3	28.81
Ceramics	-	44.4	39.4	5.0	13.4	31.51	23.7	15.84
	*	45.8	37.0	8.8	11.0	24.38	18.36	31.9
Porcelain	-	45.7	40.4	5.3	14.4	34.6	26.0	7.6
	*	46.7	38.3	8.4	12.3	28.19	21.23	24.7
Hellan stone	-	44.8	38.5	6.3	12.5	28.79	21.68	23.1
	*	46.2	37.9	8.3	11.9	27.0	20.33	30.0
Asbestos sheets with epoxy coated	-	44.1	38.6	5.5	12.6	29.09	22.0	22.3
	*	46.3	37.2	9.1	11.2	24.96	18.8	33.4
Asbestos sheets coated in aluminum	-	43.9	37.0	6.9	11.0	24.38	18.4	34.0
Fiberglass panels	-	44.8	39.6	5.2	13.6	32.14	24.2	14.15
	*	45.5	38.2	7.3	12.2	27.89	21.0	30.0
Hollow bricks	-	44.06	37.8	6.3	11.3	26.68	20.1	32.6
	*	46.5	36.4	9.1	10.3	22.66	17.1	40.22
Brushed bricks	-	44.9	37.3	7.6	11.8	25.25	19.0	28.7
	*	46.0	36.3	9.7	10.3	22.38	16.9	39.5
Reflective metallic casing	-	38.8	37.9	0.9	11.9	27.00	20.3	27.9
	*	39.7	36.8	2.9	10.8	23.80	17.9	36.4
Metal housing coated with plastic pigment	+	45.8	35.5	10.3	9.5	20.15	15.2	46.2
	-	46.8	34.0	11.8	8.0	16.12	12.14	57.0
Hard red bricks	-	46.6	37.38	7.68	11.38	29.22	22.00	23.1
	*	47.64	37.72	9.92	11.72	25.46	19.17	33.0

-Without insulator * with insulator + with an air gap + Tsh = 39.34 °C, Tr=26 °C, and A = 1.354 m^2

3.2. Discussion

Table 3 shows the results of the study, the savings rate, and the percentage of electrical energy consumed for conditioning purposes, which is achieved by each material used for packaging compared to the electrical energy consumed in the case of a regular wall (before packing) built of bricks with a thickness of 240 mm. The following is a discussion of the main variables of the research.

3.2.1. Choosing the type of cladding (packaging)

The materials currently available in the local market and used in cladding (painting) walls of buildings are many and differ from each other in type, color and origin, so it is difficult to study the thermal behavior of all, and therefore the focus was on taking samples of what is commonly used.

3.2.2. The location of the cladding material within the building wall

Using one of the locally available materials and adding it to the structural section components of the building wall exposed to the environment will increase the thermal resistance value of that section and thus reduce the overall heat transfer coefficient of section U. The value of U is in W/m^2. As for the wall commonly used in Iraq, for several decades it is a wall constructed of technical bricks 240 mm thick with two outer layers of cement with a thickness of 20 mm and an inner layer of white plaster 25 mm thick. So that it provides a power factor of U = 1.74, and when covering the wall with alabaster the thickness of 20 mm will become the parameter U = 1.546, and when wrapped with hellan stone, the thickness of 40 mm becomes U = 1.485, and U = 1.10 when wrapping with hollow bricks is 120 mm thick. That is, the use of materials to cover the wall will lead to a decrease in coefficient U, and thus the amount of heat transferred by conduction and load will also decrease. In addition, the nature of the surface of the finishing material has a clear effect on changing the value of the reflection coefficient of solar energy from the surface of the wall, and the higher the value of the reflection coefficient, the less the amount of solar energy absorbed by the wall itself. The values of the reflection coefficient are variable with the change of color and the smoothness of the surface. We find that the average value of the reflection coefficient for the surface coated with medium roughness cement will be 21%, while it is 43% for yellow bricks, 41% for gum stone, and 49% for alabaster. Accordingly, the use of packaging materials for the structural section that consists of ficus with cement is an acceptable external finishing material, to increase the reflection coefficient and thus reduce the amount of energy absorbed by the wall itself, which means that the result of the packaging will lead to a decrease in heat, the first result of an increase The amount of the second reflection coefficient is the result of increasing the thermal resistance of the section.

3.2.3. The location of the insulation within the wall

The researcher can only find one location for placing the thermal insulation used, and it is behind the cladding material used to encapsulate the previously established wall, so this method led to an increase in the temperature of the additive for packaging purposes, as shown in Table 3, as the temperature of the outer surface of the wall increased in The limits are (2-5.6%) depending on the density and thickness of the additive, so we find that it takes the maximum limits when using alabaster, hollow bricks, and cement slabs, and the minimum limits are taken when using hollow plastic sheets, metal cladding, fiberglass, and porcelain sheets, while ceramic and polycrystalline materials take average values within those limits.

3.2.4. The effect of using a protective insulating material

The effect of using an insulating material with a thickness of 10 mm with the addition of the wall for packaging purposes will reduce the amount of energy consumed for air conditioning purposes by (15-30%) relative to the energy consumed, for air conditioning, with wall covering material and without the use of insulation.

3.2.5. The best packaging materials

By studying the thermal behavior of additives to the exterior wall of the building with the results shown in Table 3, it becomes clear that using coated aluminum as a metal cover achieves a percentage that reduces the energy required for air conditioning by 46.2% of the energy consumed, then the usual wall for conditioning purposes, followed by the use of asbestos sheets coated with aluminum paint the reflector, which achieved a reduction rate of 34%, and the use of 120 mm hollow bricks achieved a reduction of 32.6%, while a 28.7% achieved a reduction achieved by using the use of brush bricks with a thickness of 50 mm, and the reflective metallic casing with a 25 mm air gap achieved a saving of 27.9% while the 40% thickness achieved a 23.3% decrease. Asbestos sheets coated with epoxy achieved a saving of 22.3%, the presence of hollow plastic panels with a total thickness of 10 mm, achieved a saving of only 17.5%, and ceramics achieved a savings rate of about 16%, slightly different from that of granite, the thickness of 20%, while alabaster and porcelain achieved each has a savings rate of 8%.

3.2.6. The best packing material with insulator

Through the results shown in Table 3, it was found that the use of the metal coating coated with thermoplastic dyes achieved a savings of 57%, which was consumed by the usual wall without packaging and thermal insulation, while the use of the hollow plastic decorative panels achieved a reduction of 42.5%, The use of brushed bricks achieved a rate of close to 40%, while the use of coated aluminum cladding achieved 36.4%. The use of epoxy-coated asbestos sheets achieved 33.4% and ceramics achieved 32%, while the use of polystyrene, porcelain, and fiberglass sheets each achieved a reduction rate close to 25%.

4. CONCLUSION

From the foregoing, the researcher can confirm several conclusions, when a metal cover made of aluminum sheet and coated with thermoplastic pigments is used, as a less dense packing material and as a thermal insulator, the highest electrical energy savings can be obtained, for air conditioning purposes. While the use of hollow plastic decorative panels as thermal insulators results in energy savings that do not exceed 8%. It has been observed that the use of hollow bricks with heavyweight achieves a reasonable rate of reduction, although the cost of construction using it is not low, in addition, it requires saving space from the ground because its thickness is up to 120 mm. Hollow bricks can be replaced with metal plates painted with ordinary paint with little heat insulation and loss, and asbestos sheets can also be used with a reflective aluminum or ceramic coating.

REFERENCES

[1] Q. Al- Yasiri, M. A. Al- Furaiji, and A. K. Alshara, "Comparative study of building envelope cooling loads in Al-Amarah city, Iraq," *Journal of Engineering and Technological Sciences*, vol. 51, no. 5, pp. 632–648, Oct. 2019, doi: 10.5614/j.eng.technol.sci.2019.51.5.3.
[2] Y. M. M. Saleem, "Design of Horizontal Shading Devices for Baghdad city ' s Buildings," *The Iraqi Journal of Architecture and Planning*, vol. 10, no. 22, pp. 157–171, 2011.
[3] United Nations (ESCWA), "Addressing Energy Sustainability Issues in the Buildings Sector in the Arab Region," 2018.
[4] A. Ali, "The experimental study for heat transferred from building roofs and roof finishing system usage," *Iraqi Journal of Architecture and Planning*, vol. 12, no. 1, pp. 119–139, 2012.
[5] E. K. M. Abdelgadir, A. M. H. Adam, O. Younis, and A. K. Hussein, "Optimum thermal insulation thickness for building under different climate regions - a review," *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, vol. 59, no. 2, pp. 254–268, 2019.
[6] C. Caruana, C. Yousif, P. Bacher, S. Buhagiar, and C. Grima, "Determination of thermal characteristics of standard and improved hollow concrete blocks using different measurement techniques," *Journal of Building Engineering*, vol. 13, pp. 336–346, Sep. 2017, doi: 10.1016/j.jobe.2017.09.005.
[7] F. Benmoussa, A. Benzaoui, and H. Benmoussa, "Thermal behavior of latent thermal energy storage unit using two phase change materials: Effects of HTF inlet temperature," *Case Studies in Thermal Engineering*, vol. 10, pp. 475–483, Sep. 2017, doi: 10.1016/j.csite.2017.10.010.
[8] O. Al-Hafith, B. K. Satish, S. Bradbury, and P. De Wilde, "The Impact of Courtyard parameters on its shading level An experimental study in Baghdad, Iraq," *Energy Procedia*, vol. 134, pp. 99–109, Oct. 2017, doi: 10.1016/j.egypro.2017.09.539.
[9] S. L. Farhan, I. A. J. Hashim, and A. A. Naji, "The sustainable house: Comparative analysis of houses in Al Kut neighborhoods-Iraq," in *Proceedings - International Conference on Developments in eSystems Engineering, DeSE*, Oct. 2019, vol. October-2019, pp. 1031–1036. doi: 10.1109/DeSE.2019.00191.
[10] G. L. Bai, N. J. Du, Y. Z. Xu, and C. G. Qin, "Study on the Thermal Properties of Hollow Shale Blocks as Self-Insulating Wall Materials," *Advances in Materials Science and Engineering*, vol. 2017, pp. 1–12, 2017, doi: 10.1155/2017/9432145.
[11] L. Zhu, J. Dai, G. Bai, and F. Zhang, "Study on thermal properties of recycled aggregate concrete and recycled concrete blocks," *Construction and Building Materials*, vol. 94, pp. 620–628, 2015, doi: 10.1016/j.conbuildmat.2015.07.058.
[12] E. Sodupe-Ortega, E. Fraile-Garcia, J. Ferreiro-Cabello, and A. Sanz-Garcia, "Evaluation of crumb rubber as aggregate for automated manufacturing of rubberized long hollow blocks and bricks," *Construction and Building Materials*, vol. 106, pp. 305–316, 2016, doi: 10.1016/j.conbuildmat.2015.12.131.
[13] J. J. Del Coz Díaz *et al.*, "Hygrothermal study of lightweight concrete hollow bricks: A new proposed experimental-numerical method," *Energy and Buildings*, vol. 70, pp. 194–206, Feb. 2014, doi: 10.1016/j.enbuild.2013.11.060.
[14] J. Wu, G. L. Bai, H. Y. Zhao, and X. Li, "Mechanical and thermal tests of an innovative environment-friendly hollow block as self-insulation wall materials," *Construction and Building Materials*, vol. 93, pp. 342–349, Sep. 2015, doi: 10.1016/j.conbuildmat.2015.06.003.
[15] R. J. Issa, K. Leitch, and B. Chang, "Experimental Heat Transfer Study on Green Roofs in a Semiarid Climate during Summer," *Journal of Construction Engineering*, vol. 2015, pp. 1–15, Jan. 2015, doi: 10.1155/2015/960538.
[16] R. Fioretti, A. Palla, L. G. Lanza, and P. Principi, "Green roof energy and water related performance in the Mediterranean climate," *Building and Environment*, vol. 45, no. 8, pp. 1890–1904, Aug. 2010, doi: 10.1016/j.buildenv.2010.03.001.
[17] M. Razzaghmanesh, S. Beecham, and F. Kazemi, "The growth and survival of plants in urban green roofs in a dry climate," *Science of the Total Environment*, vol. 476–477, pp. 288–297, Apr. 2014, doi: 10.1016/j.scitotenv.2014.01.014.
[18] J. F. Li *et al.*, "Effect of green roof on ambient CO2 concentration," *Building and Environment*, vol. 45, no. 12, pp. 2644–2651, Dec. 2010, doi: 10.1016/j.buildenv.2010.05.025.
[19] T. Van Renterghem, M. Hornikx, J. Forssen, and D. Botteldooren, "The potential of building envelope greening to achieve

quietness," *Building and Environment*, vol. 61, pp. 34–44, Mar. 2013, doi: 10.1016/j.buildenv.2012.12.001.
[20] I. Jaffal, S. E. Ouldboukhitine, and R. Belarbi, "A comprehensive study of the impact of green roofs on building energy performance," *Renewable Energy*, vol. 43, pp. 157–164, Jul. 2012, doi: 10.1016/j.renene.2011.12.004.
[21] D. J. Sailor, "A green roof model for building energy simulation programs," *Energy and Buildings*, vol. 40, no. 8, pp. 1466–1478, Jan. 2008, doi: 10.1016/j.enbuild.2008.02.001.
[22] Y. J. Lin and H. Te Lin, "Thermal performance of different planting substrates and irrigation frequencies in extensive tropical rooftop greeneries," *Building and Environment*, vol. 46, no. 2, pp. 345–355, Feb. 2011, doi: 10.1016/j.buildenv.2010.07.027.
[23] H. F. Castleton, V. Stovin, S. B. M. Beck, and J. B. Davison, "Green roofs; Building energy savings and the potential for retrofit," *Energy and Buildings*, vol. 42, no. 10, pp. 1582–1591, Oct. 2010, doi: 10.1016/j.enbuild.2010.05.004.
[24] N. S. G. Williams, J. P. Rayner, and K. J. Raynor, "Green roofs for a wide brown land: Opportunities and barriers for rooftop greening in Australia," *Urban Forestry and Urban Greening*, vol. 9, no. 3, pp. 245–251, Jan. 2010, doi: 10.1016/j.ufug.2010.01.005.
[25] T. C. Liu, G. S. Shyu, W. T. Fang, S. Y. Liu, and B. Y. Cheng, "Drought tolerance and thermal effect measurements for plants suitable for extensive green roof planting in humid subtropical climates," *Energy and Buildings*, vol. 47, pp. 180–188, Apr. 2012, doi: 10.1016/j.enbuild.2011.11.043.
[26] S. Rastkar, M. Zahedi, I. Korolev, and A. Agarwal, "A meshfree approach for homogenization of mechanical properties of heterogeneous materials," *Engineering Analysis with Boundary Elements*, vol. 75, pp. 79–88, Feb. 2017, doi: 10.1016/j.enganabound.2016.12.004.
[27] O. Al-Hafith, B. K. Satish, S. Bradbury, and P. De Wilde, "The impact of courtyard compact urban fabric on its shading: Case study of Mosul city, Iraq," *Energy Procedia*, vol. 122, pp. 889–894, Sep. 2017, doi: 10.1016/j.egypro.2017.07.382.
[28] S. A. Hassan, "The effect of residential building fa ade design on energy consumption for hot desert climate," *IOP Conference Series: Materials Science and Engineering*, vol. 928, no. 2, p. 022029, Nov. 2020, doi: 10.1088/1757-899X/928/2/022029.
[29] T. Nikiforova, M. Savytskyi, K. Limam, W. Bosschaerts, and R. Belarbi, "Methods and results of experimental researches of thermal conductivity of soils," *Energy Procedia*, vol. 42, pp. 775–783, 2013, doi: 10.1016/j.egypro.2013.12.034.
[30] S. A. Hasan, "The impact of residential building's design on the energy consumption in hot desert climate (Baghdad city as an example)," *Journal of Urban and Environmental Engineering*, vol. 12, no. 1, pp. 88–92, 2018, doi: 10.4090/juee.2018.v12n1.088092.
[31] Nahlah Abbas, Saleh A Wasimi, and Nadhir Al-Ansari, "Impacts of Climate Change on Water Resources in Diyala River Basin, Iraq," *Journal of Civil Engineering and Architecture*, vol. 10, no. 9, Sep. 2016, doi: 10.17265/1934-7359/2016.09.009.
[32] M. A. Al-Doury, A. A. Hasan, R. K. Mohammed, and R. H. Al-Jawad, "Thermal Conductivity of Building Materials in Iraq," *Tikrit Journal of Engineering Sciences*, vol. 28, no. 4, pp. 37–49, Nov. 2021, doi: 10.25130/tjes.28.4.4.
[33] H. Varshney, "A Review Study on Different Properties of Hollow Concrete Blocks," vol. 4, no. 03, pp. 2015–2017, 2016.
[34] W. M. Rohsenow, J. P. Hernett, and Y. I. Cho, "Handbrook of Heat Transfe," Third Edit., New York: McGraw-Hill Company, 1997. [Online]. Available: https://www.researchgate.net/publication/206201081_Handbook_of_Heat_Transfer
[35] ASHRAE, "Table of contents 2021 ASHRAE Handbook–Fundamentals," *ASHRAE*, 2021. https://www.ashrae.org/technical-resources/ashrae-handbook/table-of-contents-2021-ashrae-handbook-fundamentals
[36] S. Abed Hassan, "The Environmental Criteria as a Strategy to Adapt Climate Changes in Iraq," *International Journal of Engineering & Technology*, vol. 7, no. 4.20, p. 496, Nov. 2018, doi: 10.14419/ijet.v7i4.20.26250.
[37] S. Pathirana, A. Rodrigo, and R. Halwatura, "Effect of building shape, orientation, window to wall ratios and zones on energy efficiency and thermal comfort of naturally ventilated houses in tropical climate," *International Journal of Energy and Environmental Engineering*, vol. 10, no. 1, pp. 107–120, Mar. 2019, doi: 10.1007/s40095-018-0295-3.

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