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ORIGINAL RESEARCH PAPER

Improving the building's thermal performance by using untraditional building blocks

H. Obaidi[1], Atif A. Hasan[2], Omer Adil Zainal Al-Bayati[3] and Mahmood H. Khaleel[4*]

[1] Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq

[2] Department of Mechanical Power Technical, Institute of Technology/ Baghdad, Middle Technical University, Iraq

[3] Mechanical Engineering Department, College of Engineering, University of Kirkuk, Kirkuk, Iraq

[4] Department of Mechanical Power Technical, Kirkuk Technical Institute, Northern Technical University, Iraq

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ABSTRACT

Iraqi buildings consume high-level electrical energy for air conditioning purposes to provide the standard human comfort condition. This paper adopted an experimental study by using Styrofoam adhesive or white cement as an alternative to ordinary Portland cement to manufacture building blocks with dimensions of 200 × 200 × 200 mm containing an internal core with dimensions of 90 × 130 × 130 mm, which were filled by using corrugated scratch-up or closed air gap. The samples were divided into two sets: the first had an aluminium foil layer applied to the external surface of the samples (reflective surface), while the second was without any layer (ordinary surface). The samples were tested under the climatic conditions of Baghdad city during the summer months (May to September) of 2021. These blocks were also evaluated by different structural tests. It can be seen from the test results that the use of Styrofoam adhesive with a reflective surface with panels of corrugated scratch-up increased the thermal insulation of the wall. It leads to reduce thermal leakage and the electrical energy consumed to provide comfortable thermal conditions by 52.7%, in addition to decreasing the mass density by 14.1% while compressive strength decreased by 21%.

KEYWORDS

building blocks, closed air gap, corrugated scratch-up, reflective surface, white cement, styrofoam adhesive, thermal properties

1. INTRODUCTION

The use of electrical energy in Iraq has escalated to a concerning level, reaching its highest point in recent years. The majority of this energy is used in residential, commercial, and governmental buildings, which make up 85% of the total yearly production [1]. The primary contributor to this energy consumption in buildings is the use of air-conditioning systems, due to the fact that Iraq's climate is hot and dry in the summer for about six months, when the temperature in the shade exceeds 50 °C, and the sun shines for a period of about 12 hours/day with an intensity of around 750 W/m^2 [2]. Consequently, a considerable quantity of thermal energy penetrates the buildings. Nevertheless, the buildings' external structure has a limited number of layers, resulting in high temperatures within the internal space. Consequently, air conditioning systems must operate continuously to dissipate a substantial amount of thermal energy and maintain the desired human comfort conditions of 26 °C and 60% relative humidity [2, 3].

*Corresponding author.
E-mail: mahmood.aboretag.husain@gmail.com, mahmood.aboretag.husain@ntu.edu.iq

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Various raw materials are used in the building of Iraqi towns, with clay brick being the most renowned. Hasan (2012) used bricks with a thickness of 240 mm which are famous for their satisfactory density and thermal insulation, surpassing other materials like concrete blocks. The walls were externally finished with an exterior finish of cement mortar, which is about 20 mm thick. Internally, a layer of white gypsum with a thickness of about 12 mm was set up. The configuration of the wall layers resulted in an overall heat transfer coefficient (U) of 1.54 W/m^2 C that causes a cooling load of 10.5 ton/m^2 [4]. Increasing the value of the overall heat transfer coefficient U of the structural section and wall components will cause an increase in a rapid flow of heat transfer from the environment to the building space thus raising the design temperature of the building. Therefore, it requires operating air conditioning units for a longer period of time to absorb this transferred heat, so the amount of energy consumption for that wall increases [4].

Therefore, significant efforts are underway to boost the thermal resistance of the structural section's components in order to lower the wall's electrical energy consumption. Other researchers have focused on investigating methods and procedures that reduce the environmental effect of buildings by enhancing the thermal efficiency of walls. This enables us to decrease the energy consumption required for human comfort. For instance, several researchers used materials with thermal insulation and low density for construction or finishing purposes. The building's exterior was constructed using thermal stone, which had a thickness of 200 mm, in addition to lightweight concrete [5] Another option was to utilize blown concrete [6] or include thermal insulation panels, ranging from 40 to 140 mm in thickness, among the layers of the external wall [7, 8] The objective of this is to decrease thermal transfer into the conditioned space.

It is important to highlight that the wall thickness has a beneficial impact on thermal performance. Increasing the thickness of the wall enhances its thermal resistance, hence positively impacting the wall's thermal performance. However, considering the relation between the wall thickness, cost, and weight density, it becomes unfavorable to increase the thickness. Consequently, the researchers discovered a technique to marginally enhance the thickness of the wall by employing materials that augment its thermal resistance, resulting in a slight elevation in the weight density and cost of the wall. This can be achieved by utilizing concrete blocks with high porosity, incorporating them with cement [8–10] or by applying thin layers of environmentally recycled materials like plastic and chicken feathers. To form sustainable building blocks, recycled materials are produced from industrial waste such as plastic [11], chicken feathers [12, 13], crushed sunflower seed husks [14], milled eucalyptus bark [15], and paper [16, 17]. Additionally, some researchers have implemented a technique of aerating the wall by including certain layers or venting the gap between the wall and the external cladding with fresh air [18]. Another approach involves humidifying the expelled air and capitalizing on it, or using packing materials in order to enhance thermal insulation and the passage of air on it [19–21]. This is done by increasing the ability of building materials to increase thermal insulation by using two-phase materials [22, 23] or by incorporating two-phase materials [24], or utilizing cold and lightweight substances like white cement. Another option is to employ a highly reflective surface or orient buildings in a way that increases thermal efficiency [25–27].

Since the production of blasted clay brick caused so many environmental issues, its use was minimized and alternatively, hollow concrete blocks were used in construction. This also led to consume a higher electrical energy for the building's air conditioning where the hollow concrete blocks have a heat transfer coefficient of 2.613 W/m^2 C and a consumption rate of 12.5 ton/m^2 [14]. It is also evident from the information provided that there is a shortage of technological infrastructure in Iraq to support the majority of these solutions. In order to lower consumption rates, new materials need to be developed. Consequently, researchers had to create construction materials that were easily accessible in the area and included uncomplicated steps of manufacture, preparation, and processing. At the same time, there is severely limited research in the previous studies that assesses the performance of concrete in terms of mechanical and thermal properties by the creation of sustainable building blocks using white cement or Styrofoam adhesive. As a result, this research has two objectives: first, to develop the production of building blocks using white cement or Styrofoam adhesive material contained in a hollow filled with a closed air gap or corrugated scratch-up; and second, to improve thermal insulation, reduce electrical energy consumption, and thus increase energy savings rates.

2. MATERIALS AND METHODS

2.1. Material used

In order to achieve the objective of developing building blocks with improved insulation and reduced density compared with conventional construction materials, ordinary Portland cement was replaced with Styrofoam adhesive and white cement. The models A, B, and C were building blocks that were investigated for their hollow structure with closed air gap or corrugated scratch-up, and solid structure, respectively. Table 1 displays the characteristics of Styrofoam adhesive and white cement.

This research used fine aggregates (sand) and coarse aggregates (gravel) with specific gravities of 2.6 and 2.63, respectively. The maximum size of sand and gravel was 4.75 and 10 mm, respectively. Tables 2 and 3 show the classification of sand and gravel based on their size.

2.2. Methods

2.2.1. Experimental procedure. The mixing proportions were (1:1.5:3) (Cement:Sand:Gravel) by weight, with a water/cement ratio of 0.5. The sample preparation process adhered to the British standard (BS EN 12390-2:2019) [29].

Table 1. Properties and specification of Styrofoam adhesive and white cement

Product data	Properties of Styrofoam adhesive	Properties of white cement
Specification	ANSI A1184 and A11811 Standards	ASTM C150, AASHTO M85, CSA. A3001
Base materials	Quartz sand, modifying supplements, polymers, micro-fibres, Portland cement	Limestone (high carbonate, low iron), Clay (high alumina, low iron), oil, pet coke, rubber, gypsum
Color	White (Dries clear), brightness 0.74	White, brightness 0.89
Bulk density	1,003–1,007 kg m^{-3}	1,100 kg m^{-3}
PH	7–9	–
Compressive strength	19 MPa	21 MPa

Table 2. The gradation of gravel

Sieve diameter (mm)	Passing (%)	British specification limits B.S. 882 (1992) [28]
37.00	100	100
20.00	100	100
9.500	78	(50–85)
4.75	6	(0–10)

Table 3. The gradation of sand

Sieve diameter (mm)	Passing %	British specification limits B.S. 882 (1992) [28]
10	100	100
5	95	(89–100)
2.36	82.15	(60–100)
1.18	66.3	(30–100)
0.6	44.55	(15–100)
0.3	14.6	(5–70)
0.15	3.55	(0–15)

The building blocks were produced using iron moulds measuring 200 × 200 × 200 mm. They featured an internal core in the shape of a hollow measuring 90 × 130 × 130 mm. This core was filled either with corrugated scratch-up material, which had a density of 113.6 kg m^{-3}, or with a closed air gap which had a density of 25 kg m^{-3}, see Fig. 1. Furthermore, the samples were categorized into two groups: the first group had an aluminium foil layer placed as a reflective surface on the outer side of the samples, whereas the second group lacked an exterior layer and had an ordinary surface.

2.2.2. Experimental sets. A thermal experiment was conducted at a testing site situated on the second level of a building in Baghdad. The location had internal dimensions of 1 × 1 × 2 m. Figure 2 shows the setup of the measurements of isolating all surfaces in the test room (except the test wall) using micro-fiber glass insulation materials that are 200 mm in thickness. The test wall with dimensions of 1 × 2 m in the direction of the east was constructed by building blocks and coated with 25 mm thick gypsum board around all the interior surfaces of the room, including the test wall. The test room has been equipped with a window-type air conditioner that has a cooling capacity of 3.5 kW (12000 BTUH). The room's design conditions were measured at 26 °C and a 60% humidity percentage [3].

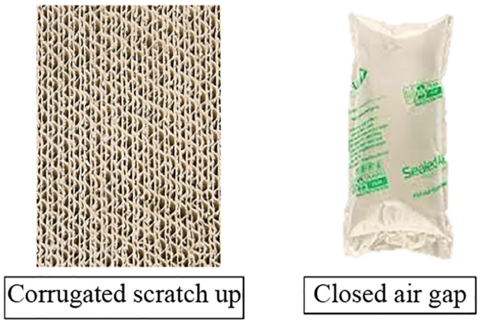

Fig. 1. The types in filling hollow of the studied building blocks '*Source*: Author'

Additionally, it has been equipped with a cumulative electric energy device that is linked to the network and provides power to the air conditioner. The intelligent self-thermometer was used for measuring the ambient temperatures as followed: the shaded area is that area partially darkened when the sun's light has been blocked by anything (T_{SH}) and the temperatures of the exterior surfaces of the construction blocks (T_o) that are exposed to the surroundings. Furthermore, the pre-calibrated thermocouple was used for measuring the temperatures of the interior layer of the building block that is exposed to the room (T_i) and the temperatures of the air inside the test room (T_r). The experimental measurements were conducted between 6 a.m. and 6 p.m. on the 21st day of each month during the summer season of 2021, namely from May to September. To determine the total amount of heat (Q) that the air conditioning system needed to remove from the room, equations (1) and (2) [23] were used,

$$Q = A.h.(\Delta T_{i\text{-}r}) \quad (1)$$

$$h = 1.31.(\Delta T_{i\text{-}r}) \quad (2)$$

where the coefficient of heat transfer with forced convection is represented by the symbol h (W m^{-2} K), the $\Delta T_{i\text{-}r}$ represents the disparity in temperature between the inner surface and the air in the room, A specifies the surface area of the wall measured in m^2. In order to evaluate the thermal and structural behavior of these building blocks and determine the potential energy savings from switching them, measurements were taken of the base material quality, the composition of the block's inner core, and the type of surface exposed to the environment (either normal or reflective). The bulk density of the solidified construction blocks was determined using the guidelines of BS 12390, Part 7 (2000) [30] for supplementary specimen analysis. The water absorption of the building blocks was evaluated using the B.S.

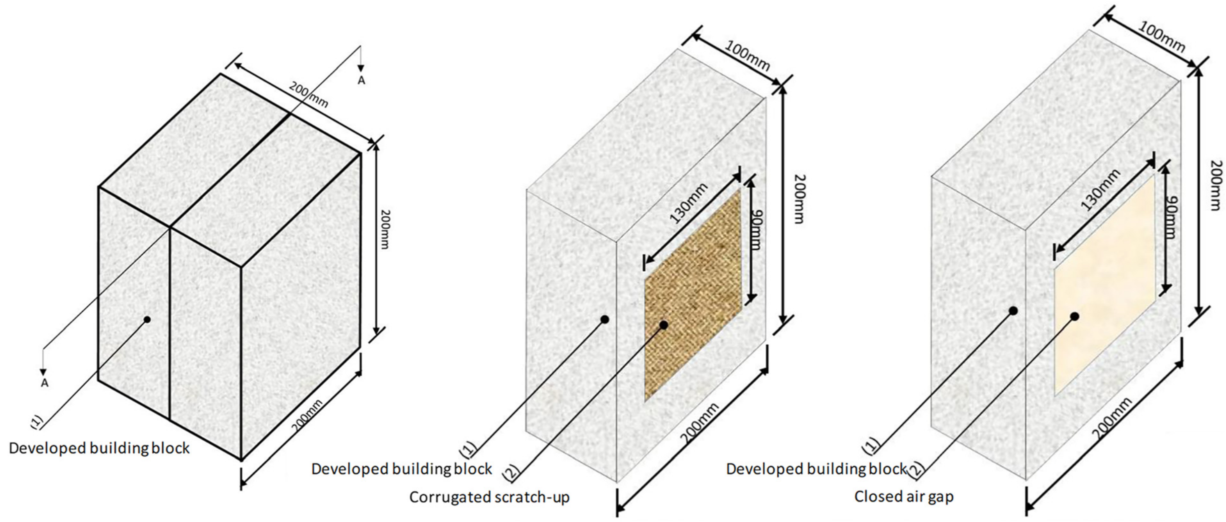

Fig. 2. Diagram of the test room '*Source*: Author'

1881: Part 122 (1983) [31]. The compressive strength test was conducted using an E.L.E. International 2007/UK/A.D.R. 2000 standard machine instrument. The performance was carried out in accordance with B.S. 1881: Part 116 (1989) [32].

Regarding the methodology for calculating the energy consumptions, a cumulative electrical energy meter, which is an analogue electrical energy meter type measured in kWh was used and installed on the air conditioner supply line in the test room. This meter records the electrical energy consumption by the same air conditioner to absorb the thermal loads transmitted through the test wall into the test room space. When the room temperature reaches the design values, the air conditioner stops working due to the temperature regulator, which interrupts the electrical circuit supplying the air conditioner. When the temperature of the room space changes from the design values, the temperature regulator will switch on and close the electrical circuit so that the air conditioner returns to work and absorbs the heat load that has accumulated inside the space. The energy currently consumed will be added to what was recorded by the energy meter in the first period. The temperature of the wall surfaces continues to be recorded from 6 a.m. to 6 p.m. At the end of the reading range, the total electrical energy is recorded by the energy meter. After that, the meter is zeroed and prepared for the next day. The total energy recorded by the meter, which shows the total energy consumed throughout the air conditioner's operation within the limits of recording readings for each case examined, was compared to the total energy recorded by the meter.

3. RESULTS AND DISCUSSION

3.1. The physical properties of the building blocks

The physical characteristics of the building blocks under investigation as determined by their structural analysis are shown in Table 4.

3.1.1. The bulk density of building blocks. Table 4 shows that the bulk density of solid building blocks (model C) manufactured using Styrofoam adhesive was 1,442 kg m^{-3}, but the bulk density of solid building blocks constructed using white cement as the basic material was 1,482 kg m^{-3}. The density increases for model C utilizing Styrofoam adhesive and white cement was approximately 13% and 16%,

Table 4. The physical properties of studied building blocks

Studied building block		Mass density (kg m^{-3})	Compressive strength MPa after 28 days	Absorbability (%)	Settlement (mm)
Conventional building block		1,280	27.8	1.2	1.3
Styrofoam adhesive	A	920	20	1.4	1.4
	B	1,100	22	1.4	1.3
	C	1,442	24	1.4	1.3
White cement	A	1,032	21	1.5	1.3
	B	1,200	23	1.5	1.3
	C	1,482	26	1.5	1.3

A-Hollow studied building block with closed air gap.
B-Hollow studied building block with corrugated scratch-up.
C-Solid studied building block.

respectively, in comparison with conventional building blocks that have hollow cavities. The hollow construction blocks constructed of white cement with an insulating core made of corrugated scratch-up (model B) had a bulk density of 1,200 kg m^{-3}, but the blocks manufactured from Styrofoam adhesive (model B) had a recorded bulk density of 1,100 kg m^{-3}. The density decreases percentages for model B, while utilizing Styrofoam adhesive and white cement, were approximately 14% and 6.3%, respectively, in comparison with conventional building blocks.

For model A, the bulk density of building blocks constructed with Styrofoam adhesive with an insulating core (closed air gap) was 920 kg m^{-3}. In comparison, the bulk density of building blocks constructed using white cement was 1,032 kg m^{-3}. The density decreases percentages for blocks with Styrofoam adhesive and white cement, respectively, were 28% and 19% in comparison to conventional construction blocks. This is because the closed air gap has a lower density than the corrugated scratch-up.

3.1.2. Absorbability and settlement of building blocks. Table 4 shows that the absorbability of building blocks for models A, B, and C, while using Styrofoam adhesive, was 1.4%, indicating an increase of about 17% in comparison with conventional building blocks. In addition, the settlement of blocks utilizing model A was evaluated at 1.4 mm, but the settlement of building blocks using models B and C was virtually the same, at 1.3 mm, which was comparable to the settlement value of conventional building blocks. The absorbability characteristic of building blocks manufactured from white cement was continuous at 1.5% throughout all models, exhibiting an increase of 25% in comparison with conventional building blocks.

3.1.3. The compressive strength of building blocks. The compression strength results for all studies of building blocks are presented in Table 4. The conventional constituent components were evaluated at a pressure of 27.8 MPa. The reduction percentage in compressive strength after 28 days for models A, B, and C was 28%, 21%, and 14%, respectively, with Styrofoam adhesive. In the case of using white cement, the reduction values of building blocks for models A, B, and C were recorded at about 24%, 17%, and 6%, respectively, compared to conventional building blocks. It was found that building blocks made of white cement had a greater compressive strength value than those made of Styrofoam adhesive. The compressive strength of building blocks made from Styrofoam adhesive dropped more when closed air gaps and corrugated scratch-up were used as inner cores. It reached 20 and 22 MPa, compared to 24 MPa for the solid building block that was being studied. The compressive strengths of building blocks made from white cement using closed air gaps and the corrugated scratch-up approach are 21 and 23 MPa, respectively, when compared to the strengths of solidly researched building blocks. Despite the fact that both kinds of building blocks' compressive strengths for all models were lower than those of conventional blocks, those building blocks can still be used in structural structures in the same way according to ASTM (C 567/C 567 M-19) [33].

3.2. Thermal properties

3.2.1. Hourly temperatures reading of building blocks. The thermal behavior of the building blocks with dimensions of 200 × 200 × 200 mm that are made of white cement or Styrofoam adhesive on the two types of surfaces under study is shown in Figs 3 and 4. The obtained results represent the hourly temperature readings that were carried out during the summer months, especially in July. It can be observed that there is an increment in the exterior temperatures (T_o), interior temperatures (T_i) and shaded temperatures (T_{SH}) until 10 or 11 a.m. Moreover, Fig. 3 shows that temperatures began to decrease gradually after 11 a.m. The temperatures at 11 a.m. for the building blocks exposed to the environment (T_o) were reached for models A, B and C at 46 °C which were formed from Styrofoam adhesive with reflective surfaces. The T_o recorded a significant increase in white cement blocks until 10 a.m., with a temperature value of 51 °C for model A and around 52 °C for models B and C. These readings were for a reflective surface. The T_o values of 46, 48, and 47 °C were recorded for models A, B, and C, respectively, for white cement blocks with ordinary surfaces until 11 a.m. (see Fig. 4). It also shows that the temperatures after 11 a.m. started reducing gradually, but T_i at 6 p.m. recorded values higher than T_o and T_{SH}. In the case of a reflective surface (Fig. 3), the T_i at 6 p.m. for Styrofoam adhesive block models A, B, and C was approximately 42.9 °C, 43.4 °C, and 44.4 °C, respectively. The T_i of the blocks formed on white cement was approximately 43.4 °C, 43.5 °C, and 43.9 °C, respectively, compared to the T_{SH} of 42.5 °C. In the case of ordinary surface (Fig. 4), the values of T_i for the studied building blocks formed by Styrofoam adhesive were in comparison to the T_{SH} of 43 °C, the T_i for the white cement building blocks studied was 44.4 °C, 44.2 °C, and 45.3 °C, respectively.

Figure 5 shows the hourly average temperature value for conventional building blocks. It can be illustrated that the T_o was significantly increased until it reached 60 °C at 10 a.m. and 43 °C at 6 p.m. compared with the T_o for building blocks made of Styrofoam adhesive using corrugated scratch-up (model B) with a reflective surface that reached 48 °C at 10 a.m. and 42 °C at 6 p.m.

3.2.2. Temperatures reading of building blocks during July. The thermal characteristics of the construction blocks were analyzed from May to September but July was specially identified as the hottest month in Iraq, as seen in Table 5.

3.2.2.1 Interior surface temperature (T_i). The interior's temperature refers to the temperature of the internal surface of a construction block that faces the room. Two different cases were used in the manufacturing of the building components. Each case study comprises three models, dependent upon the characteristics of the surface of the building component. Table 5 shows that the temperatures

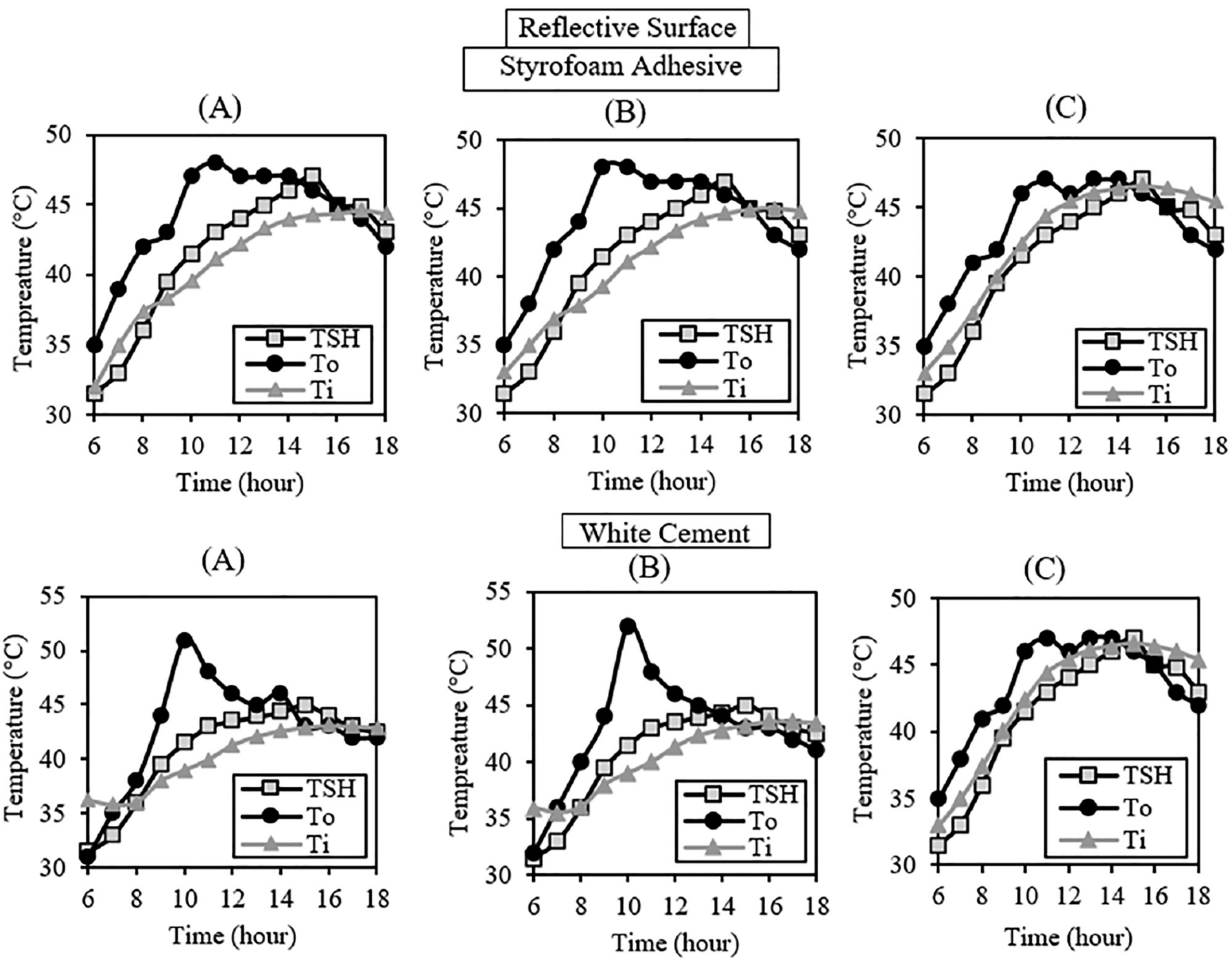

Fig. 3. Hourly thermal behavior for studied building blocks with reflective surface ‘*Source*: Author’

of the building components under study, consisting of white cement with ordinary and reflecting surfaces of Model A, were recorded at 37.5 and 36.25 °C, respectively. The temperatures of Model B’s ordinary and reflecting surfaces were 36.4 and 35 °C, respectively. The increase in T_i percentage for model A, with ordinary and reflecting surfaces, was 2.2% and 2.4%, respectively, compared to model C for each type of surface. The decrease in T_i for model B with ordinary and reflective surfaces was approximately 0.8% and 1.1%, respectively, in comparison to model C. Concerning the Styrofoam adhesive, according to Table 5, the temperature of model A was 37.2 °C for ordinary surfaces and 36.17 °C for reflecting surfaces. The temperature of model B ranged from 35.7 to 34.9 °C for each surface. It is important to point out that model A showed an increase in T_i (thermal insulation) of about 3% and 3.1% for ordinary and reflecting surfaces, respectively, compared to model C. On the other hand, model B showed a decrease in T_i compared to model C, with reductions of about 1.1% and 1.5% for every type of surface.

3.2.2.2 Exterior surface temperature (T_o). The temperature of building components that are exposed to the environment has directly influenced the surrounding air temperature. Table 5 shows the mean exterior surface temperatures for the summer season. The temperatures recorded for model A on the ordinary and reflective surfaces of white cement building blocks were 47.2 and 45.9 °C, respectively. In a comparable manner for model B, the temperatures recorded on the ordinary and reflective surfaces were 47 and 45.9 °C, respectively. Furthermore, there was an increase in surface temperature for the tested building blocks. Models A and B, with ordinary and reflecting surfaces, respectively, had an increase of 0%, 0.2%, and 0.4% compared to model C. The Styrofoam adhesive blocks indicate that the temperatures for models A and B on ordinary and reflective surfaces were 47.6, 45.6, 47.10, and 45.3 °C, respectively. The temperature increases for model A compared to model C was 0.6% while decreases for model B about 0.4% for ordinary surfaces. On the other hand, the increment in temperature for model A was 0.3% while the reduction in temperature for model B about 0.4% compared to model C for reflecting surfaces. In summary, the results indicate that the use of a reflecting surface in the construction materials, whether it be white cement or Styrofoam adhesive material, led to a decrease in the rate of heat transfer.

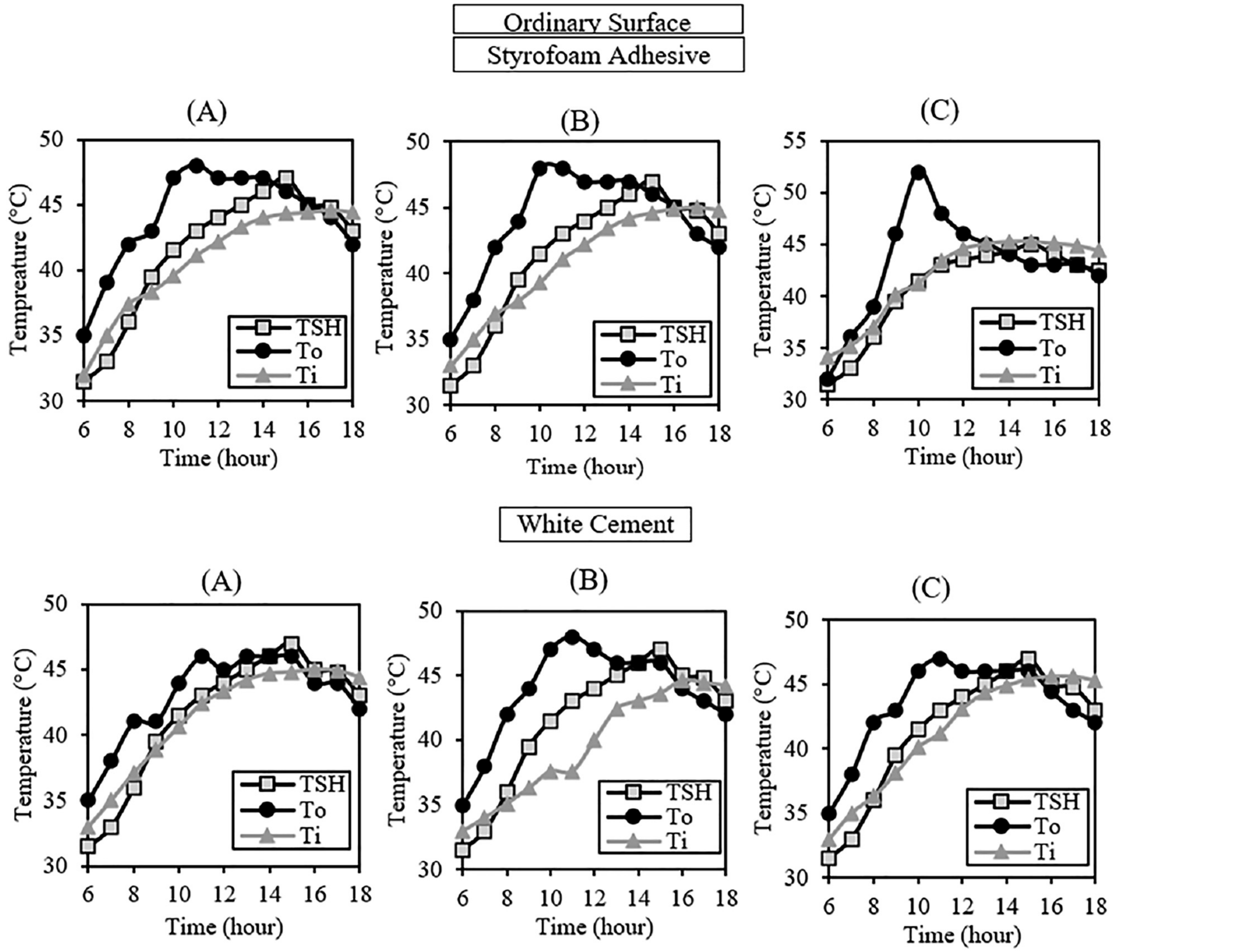

Fig. 4. Hourly thermal behavior for studied building blocks with ordinary surface '*Source*: Author'

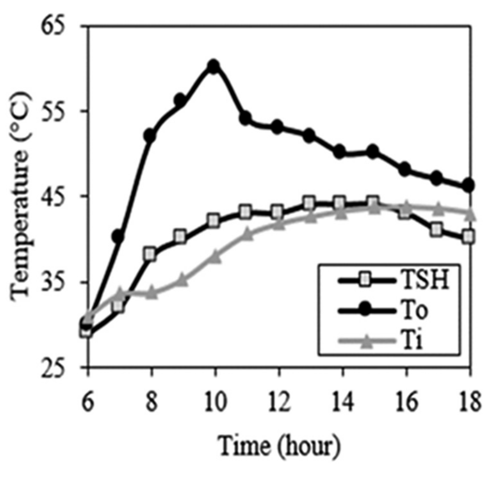

Fig. 5. Thermal behavior of conventional building blocks '*Source*: Author'

3.2.3. Temperature difference (ΔT_o–T_i), (ΔT_i–T_r). Table 6 shows the use of white cement for manufacturing building blocks for models A and B of ordinary surfaces is higher than that of reflective surfaces for the two types of temperature difference. It is clear that the same behaviour can be seen with the building blocks that use Styrofoam adhesive material, where the percentage increase in the difference of temperature values (ΔT_o–T_i) was about 48 and 12 % for models A and B with ordinary surfaces compared to model C. Otherwise, there was a decrease of about 24% in model A and an increase of about 14% of model B with a reflective surface compared to model C when using white cement. The decreasing percentage of temperature difference (ΔT_o–T_i) with building blocks made of Styrofoam adhesive was 11.7% for model A while it became a 17% increment for model B compared to model C with an ordinary surface. While the building blocks with reflective surfaces have decreased by 55 and 28%, respectively, in models A and B compared to model C.

In terms of the temperature difference (ΔT_i–T_r), it is observed that the temperature difference was recorded as an increase in percentage for building blocks manufactured from white cement of about 5.2% for model A and a

Table 5. Thermal behavior for studied building blocks in July 2021

Studied building block	Type of surface	Surfaces temperatures (°C) A T_o	A T_i	B T_o	B T_i	C T_o	C T_i	TSH (°C)
Styrofoam adhesive	Ordinary surface	47.60	37.20	47.10	35.70	47.30	36.10	40.80
	Reflective surface	45.60	36.17	45.30	34.90	45.47	35.44	
White cement	Ordinary surface	47.20	37.50	47.00	36.40	47.10	36.70	
	Reflective surface	45.90	36.25	45.9	35.00	46.10	35.40	

Table 6. Exterior and interior temperatures and temperature difference of studied building blocks

Parameters calculated			T_o	T_i	ΔT_i–T_o	ΔT_i–T_r
Styrofoam adhesive	Ordinary surface	A	43.74	39.50	4.24	13
		B	43.78	38.15	5.63	11.65
		C	43.66	38.86	4.80	12.36
	Reflective surface	A	41.29	38.58	2.70	12.09
		B	41.12	36.76	4.36	10.26
		C	43.20	37.17	6.03	10.67
White cement	Ordinary surface	A	43.06	40.05	3.01	13.55
		B	42.93	38.56	4.37	12.06
		C	41.20	39.17	2.04	12.67
	Reflective surface	A	41.46	38.71	2.75	12.21
		B	41.44	37.29	4.15	10.79
		C	41.44	37.81	3.63	11.31
Conventional surface			47.4	43	4.4	16.50

decrease in percentage of about 5.7% for model B compared to model C. While it can be seen with an increasing percentage of 13% for model A and a decreasing percentage of 3.8% for the building blocks built of Styrofoam adhesive material compared to model C.

For comparison between Styrofoam adhesive and white cement in manufacturing the building blocks of each model and each type of surface, it is noted that the comparison of the difference percentage of ordinary surface for building between Styrofoam adhesive and white cement was 1.6, −1.37, 40.9 and −4.1% for model A, 1.97, −1.1, 28.8 and −3.4% for model B, 5.97, −0.78, 136 and −2.4% for model C for T_o, T_i, ΔT_i–T_o and ΔT_i–T_r respectively.

Otherwise, for T_o, T_i, T_i–T_o, and T_i–T_r, the difference values between Styrofoam adhesive and white cement in manufacturing the building blocks with reflective surfaces were −0.43, −0.34, −1.75, and 1.03% for model A, −0.53, −1.41, 4.82, and −4.91% for model B, and 4.24, −1.7, 66.1, and −5.66% for model C.

3.3. Building cooling load and energy saving

It is clear from Table 7 that the test wall 2 × 1 m, which is constructed of building blocks with corrugated scratch-up (model B) either white cement or Styrofoam adhesive has a low load capacity compared to models A and C. The building blocks that use reflective surfaces made of either white cement or Styrofoam adhesive have cooling load values lower than the ordinary surface. The building blocks built on white cement with corrugated scratch-up (model B) have caused a seasonal cooling load with a capacity of 73.65 and 63.5 kW with ordinary and reflective surfaces respectively. While it became 70.33 and 59.4 kW when using blocks manufactured from Styrofoam adhesive material with ordinary and reflective surfaces respectively. The percentage of reducing the cooling load during the summer was about 1.4 and 6.5% when comparing the building blocks with Styrofoam adhesive and white cement for models A and B, both of which had reflective surfaces. When compared the cooling load of the conventional blocks was about 125.6 kW,

Table 7. Building cooling load, saving percentage and electrical consumption of studied building blocks

Parameters calculated			Building cooling load (kW)	Saving percentage %	Electrical energy consumption (kW h)
Styrofoam adhesive	Ordinary surface	A	35.2	81.33	51.10
		B	44.0	70.33	45.60
		C	39.4	76.10	48.40
	Reflective surface	A	41.22	73.82	46.80
		B	52.70	59.4	37.70
		C	50.1	62.57	39.70
White cement	Ordinary surface	A	31.5	86.03	54.60
		B	41.40	73.65	46.80
		C	33.9	83.00	52.60
	Reflective surface	A	40.4	74.90	47.50
		B	49.4	63.50	40.40
		C	46.2	67.61	43.00
Conventional surface			125.60		80.00

while the building blocks made of Styrofoam adhesive or white cement of model B with reflective surface were about 59.4 and 63.5 kW. The percentage of loading saved was approximately 52.7 and 49.5% respectively thus providing more energy compared to conventional blocks.

$$\text{Saving percentage} = \frac{\text{variable value-original value}}{\text{original value}} \quad (3)$$

3.4. Electrical energy consumption

The effect of the reflective surface is evident in Table 7. The presence of an aluminum layer as a reflective surface on the outer surface (facing the environment) of the building block made of Styrofoam adhesive or white cement used in corrugated scratch-up (model B) to form the test wall has lower electrical energy consumption and a higher saving percentage compared to the wall formed by a closed air gap (model A) and solid building block (model C). The percentage reduction in the consumption of electrical energy was 17% and 14% with building blocks formed with Styrofoam adhesive or white cement for Model B when comparing reflective and ordinary surfaces respectively.

The electrical energy consumption was reduced for the building blocks made of Styrofoam adhesive or white cement for model B with a reflective surface, which were about 37.7 and 40.4 kW h, respectively. That leads to providing energy within the limits of 53 and 50% respectively when compared with the conventional building block, whose energy consumption was about 80 kW h.

4. CONCLUSIONS

Overall, the results of the laboratory experiments can be summarized as follows:

1. The values of T_o were generally higher than those of T_i and T_{SH}, either with blocks made of Styrofoam adhesive or white cement.
2. The maximum temperature values reached for building blocks with Styrofoam adhesive were 47–48 °C, while blocks with white cement reached 51–52 °C, and with conventional blocks, they reached 60 °C at 10–11 a.m.
3. The temperature readings generally for July were lower with blocks made of Styrofoam adhesive compared with blocks made of white cement.
4. The use of building blocks made of Styrofoam adhesive with a reflective surface that uses corrugated scratch-up (model B) is the best in thermal insulation, where the difference values of T_o, T_i, ΔT_i–T_o, and ΔT_i–T_r between Styrofoam adhesive and white cement in manufacturing the building blocks with a reflective surface were −0.53%, −1.41%, 4.82%, and −4.91% for model B compared with model A of −0.43%, −0.34%, −1.75%, and 1.03%, and model C of 4.24%, −1.7%, 66.1%, and 5.66%.
5. The building cooling load was about 59.4 kW with Styrofoam adhesive building blocks using corrugated scratch-up with a reflective surface compared to conventional blocks, which were about 125.6 kW. The percentage of loading saved was approximately 52.7%, thus providing more energy compared to conventional blocks.
6. The presence of the reflective surface on the outer face of the solid building block using corrugated scratched-up provides electrical energy consumption of about 53% compared to the conventional blocks.
7. The reduction in bulk density of the building blocks under study leads to a reduction in the weight of the wall compared with conventional building blocks.
8. Although the hollow blocks under study had a lower compressive strength than conventional blocks, but hollow blocks can still be used in structural buildings in the same way as conventional buildings.

So, the use of Styrofoam adhesive with a reflective surface and panels of corrugated scratch-up (model B) was a good option to improve the thermal insulation, increase the energy savings rate and reduce electrical energy consumption. Finally, it can be recommended that the findings from this research assist future researchers in understanding the current and future directions in the field production of sustainable concrete into market-ready products using waste materials as a corrugated scratch-up.

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