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"Experimental Investigation of Heat Reduction through Walls Using Phase Change Material"

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ABSTRACT

The reducing of heat gain through the outer walls of the buildings in summer will contribute in reducing the air conditioning costs. This is one of the best features of design requirements nowadays. To achieve this, the phase change materials (PCM) can be used as an embedded material in the walls to reduce heat transfer. The paraffin wax is one of the common materials used as a PCM in the building walls. The paraffin wax is used in this study with (20%) volume percentage in the external layer of the treated wall. In the present work, the treated wall (with embedded wax in the wall) and non-treated walls have been experimentally investigated. Two Iraqi wall models were employed to run the experiments, whereby these models were exposed to an external heat source using (1000 W) projector for each model. The temperatures were recorded at different locations in the walls during the charging and discharging periods. The results showed that the temperature of the internal surface for the treated wall was lower than that of the non-treated wall at the end of the discharging period (6 hr) where the temperature difference between the treated and non-treated walls was reached (1.6°C).

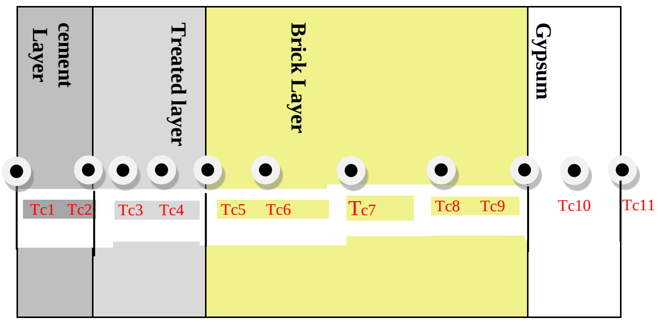
1. Introduction

In recent years, phase change materials PCM have played a vital role in saving thermal energy. Several reasons made PCMs important in conserving energy, they are environment friendly and of low cost compared especially with fossil fuels. There are different types of PCMs used in the building constructions to delay peak load and reduce electricity bills. The paraffin wax is used as PCM in this paper due to its low cost as being a side product from the refinement of crude oil. The most important consideration of the PCMs is the stable phase change temperature, which is fitted with the application temperature range, in addition to the low thermal conductivity. Many theoretical and empirical studies have been conducted in this field.

For instance, Farid and Husian [1] have devised a new idea to design storage heaters by replacing the ceramic bricks with a paraffin wax encapsulated in thin metal containers. The four individual storage units of the storage heaters were filled with paraffin wax that has a melting temperature of around (55°C). An electrical plate heater was fixed at the axis of each storage unit to supply a little heat flux but should be enough to melt all the wax within 8 hr. Using the phase change method of heat storage can lead to a significant reduction in weight in local storage heaters and reduce the cost of large units for these storage heaters.

In another study, Scalat, et al. [2] tested a small scale thermal-storage system by comparing the latent heat storage capacity of a room containing a wallboard lined with PCM to a room with a conventional untreated wallboard. The authers concluded that the treated wallboards can be considered suitable for heat storage and may help in shifting the peak load. Also, they concluded that the treated wallboards will enhance the operation efficiency of space cooling and heating equipment.

In addition, Hawlader, et al. [3] investigated the means of microencapsulation of paraffin wax in



adhesive polymeric films. They conducted through different scanning calorimeter tests that the capsulated paraffin wax has a high heat storage and high heat radiation capacities and it is suitable for energy storage applications. Taking an experimental approach, Zhang, et al. [4] studied the performance of microencapsulated PCMs by developing wall frames which mixed the encapsulated paraffin as a PCM in pipes through the walls. Two small scale test houses were constructed to compare the thermally improved walls in the first house to conventional walls in the other house. Peak heat fluxes in each house were measured at several typical summer days. The authers concluded that the average of the peak heat fluxes in the PCM improved frame walls were reduced up to 20% compared to the conventional frame walls depending on the concentration of PCM (10% to 20% by weight of the wallboard).

In a similar study, Zhang and King [5] used the same small-scale test houses to test the thermal performance of PCMs encapsulated in pipes in structural insulated panels. They found that the average of the peak heat flux was reduced up to 60% for the south facing walls being treated with paraffin-based PCMs. Moreover, Al-hadithi [6] has developed a numerical study using FORTRAN program in order to calculate the temperature distribution and latent heat storage (LHS) in a treated wall (TW) and non-treated wall (NTW). The novel idea of the study was to obtain physical validation of the numerical results for the two different walls. This validation was obtained through a comparison of the numerical solution of two wall compositions exposed to the same external and internal load conditions. The author used paraffin wax as a (PCM) with a volume percentage of (25%) of paraffin wax and (75%) of cement to form a treated layer. Al-hadithi, found that using the (TW) with (PCM) produces the lower surface and heat flux towards the cooling space compared to the (NTW).

In another study Al-hadithi and Saad M. [7] two laboratory experimental cement samples were tested using thermocouple junctions at the same external thermal load and outer ambient temperatures. The comparison of transient measured temperatures between the treated and non-treated cement samples with PCM have been investigated. The study indicates that the transient measured temperatures in the treated sample are lower than that in the non-treated sample with about (7.93% to 9.67%) at the same junction position for the two samples. The results have shown that the use of PCM in covering building has significant advantages for thermal storage component in wall structure. Moreover in an experimental study, Hasan et al. [8] the use of PCM as an insulation layer for walls and ceilings. The paraffin wax was used as a PCM in their work. Two model rooms are used at a latitude of (32.5)oN. The authors studied the effect of the PCM layer thickness and the wall orientation. They concluded that the use of PCM as a layer in buildings reduces the indoor temperature by 2.18 °C in all walls for 1cm thickness.

The goal of this study is to find out the possibility of use the capsulated paraffin wax incorporated with cement to form the external layer of wall model to reduce the heat gain through the external walls.

2. Expereimental Set up

Two wall models were constructed similar to the Iraqi conventional walls. The first model consists of an external layer of cement with a thickness of 0.5 cm, a sub treated layer of a mixture of (80% cement and 20% paraffin wax) by volume. The thickness of the treated layer is 2 cm, a common brick layer of 24 cm thickness and internal gypsum layer of 2 cm thickness, as shown in Fig.1 (a). The second model is a conventional wall model which consists of an external layer of cement of 2.5 cm thickness, brick layer with a thickness of 24 cm and internal gypsum layer with a thickness of 2 cm, as shown in Fig.1 (b). The bonding material is cement, where it is used and mixed with sand with a ratio of (1:3). Each of the two models contain (11) thermocouple k-types embedded and distributed within the walls along the center line through models construction, as shown in Fig.1 (a,b). Table (1) gives the position of the thermocouple probe along the center line from the external surface to the internal surface. A thermo tape is used to fix the thermocouple tips and protect them from corrosion when the thermocouple tips come in contact with wall materials. Table (2) gives the main properties of the wall materials which were experimentally measured.

(a)
(b)

Figure (1) thermocouples distribution along the models
(a) treated model, and **(b)** non-treated model.

Table (1) Thermocouple positions from outside to inside

Thermocouple	*Position(mm)*
Tc1	*0*
Tc2	*5*
Tc3	*12*
Tc4	*19*
Tc5	*26*
Tc6	*86*
Tc7	*146*
Tc8	*206*
Tc9	*266*
Tc10	*276*
Tc11	*285*

Table (2) Materials properties data for the models

Material	Density (kg/m^3)	Thermal Conductivity (W/m°C)
cement	1612	1.6
Brick	2000	0.812
Gypsum	1280	0.464
Paraffin wax	Solid: 819	0.18
	Liquid:780	0.19
Treated layer (20 % paraffin+80% cement)	1458.4	0.958

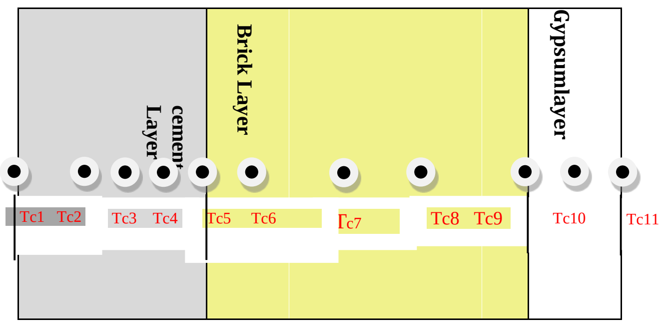


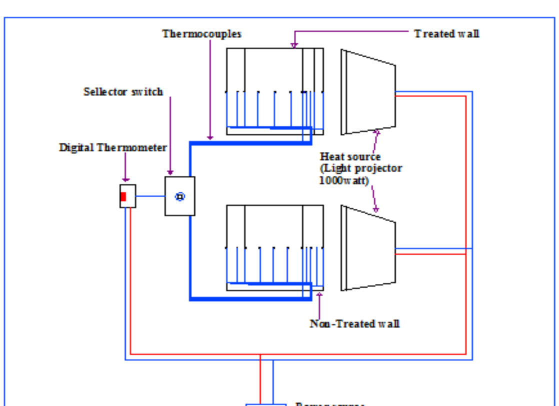
Figure (2) Schematic Diagram of the Experimental Rig.

2.2. Encapsulation of Paraffin Wax

Several attempts were carried out to form the capsulated paraffin wax by using an envelope of aluminum foil (k = 204 W/m.°C) with a thickness of (0.06 mm) [9]. Therefore, the thermal resistance of aluminum foil is very small compared with other building material layers. The foil formed as square pieces (0.8 cm x 0.8 cm) that give capsules with the same size which were filled with the same quantity of the melting wax. Finally, the capsules were immerged in an adhesive coating surrounding the wax capsules to prevent leakages. This coating was solidified as soon as it contacted with the surrounding air. The new capsules were tested for over (90°C) and no leakage of wax was observed from the enveloped capsules. Figure (3) shows a photograph of the used paraffin wax before and after capsulation. The capsules were mixed carefully with cement to get the proportion of mixing of 20% by volume to form the treated layer. The thermal resistance (R) of aluminum can be calculated by the equation :(R = Δx/k), where Δx≈0.05m and then, R=245x10^{-7} (m^2. °C/W), [9].

2.1. Temperature Measuring System

Thermocouple type k was calibrated with maximum errors (± 0.5°C) and then used to measure the temperature. The thermocouple probes were connected to two identical selector switches type (Tempcon). Each selector switch has (12) channels. The two selector switches are connected together by a two way selector switch connected with a digital thermometer type (Tempcon model 3750-K). The temperatures data are recorded by a digital camera with time and plotted. Figure (2) shows a schematic diagram of the Experimental Rig.



2.3. Assemblage of Test Walls

The walls are constructed inside the wall frames by building Iraqi bricks in two steps; the first step is building brick layers with dimensions of (240 mm x 300 mm x 300 mm) and fixing thermocouple probes along the center line of the brick layer. The second step was building the bricks with the same dimension to get optimal brick layer height. Then, the gypsum layer was constructed with dimensions of (20 mm x 300 mm x 300 mm) and the thermocouple probes were fixed along its center line for two walls. Then, the treated layer was constructed (for the treated wall) with dimensions of (20 mm x 300 mm x 300 mm) with a percentage volume of (80 % cement & 20 % paraffin wax) and the thermocouple probes were fixed along the center line. Then, a thin cement layer was constructed with dimensions of (5 mm x 300 mm x 300 mm) and the thermocouple node was fixed at its external surface. After that, the non-treated layer was constructed with dimensions of (25 mm x 300 mm x 300 mm) and the thermocouple probes were fixed along its center line (for non-treated wall). Finally, the two models were insulated from four sides (up, down and both sides) using a 50 mm a glass wool layer in order to keep the energy exchange in one direction and to reduce the heat losses.

2.4. Test Procedure

Since the experiment was done in winter, the two walls were exposed to an external heat source using two (1000 Watt) projectors. The projectors were put in front of both walls and the optimum space between the external surface and projector was (50 cm) for each one to achieve the same temperature of direct sun ray. The maximum heat flux at the peak period gained from sun in summer from 11:30 to 14:30, due to this reason the charging period was selected to be (3 hr). Test time was (6hr), the first (3hr) were the charging time, where all temperature data were marked from the reader every (5 minutes). After (3hr), the projectors were switched off and the data were marked for the last (3hr) every (5 minutes). The data were plotted to compare between the two walls results. It is notable that the two projectors were put outside the room and the two inner surfaces of the walls were inside the room to prevent the effect of projectors on the room temperature, as shown in Fig. (4).

Figure (3) photograph of the used paraffin wax
(A) Before capsulation and **(B)** After capsulation

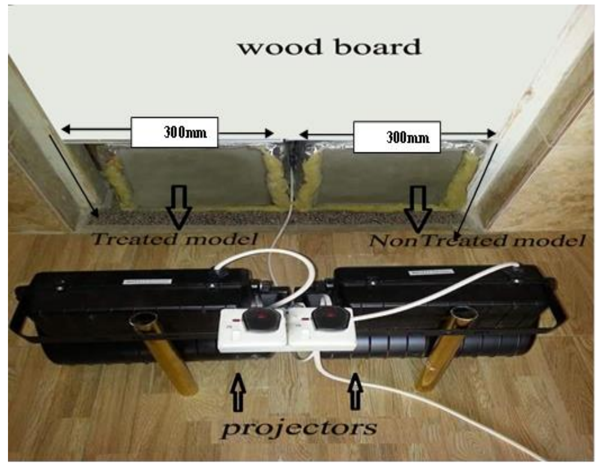
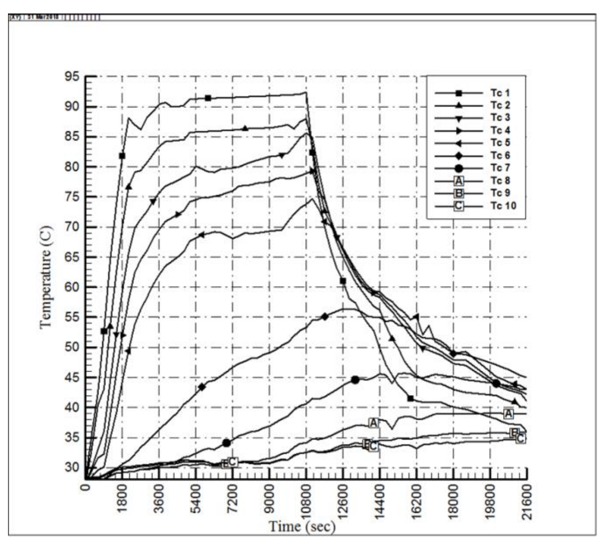


Figure (4) photograph of the projectors and the models

3. Results and Discutions

Figure (5) explains the behavior of the non-treated wall with time. The first thermocouple (Tc1) was planted on the external surface and its temperature expressed the ambient temperature (28.1°C). Thermocouples from (1 to 5) exhibit the same behavior; in the charging period, the temperature increases from set temperature (28.1°C) to reach a maximum temperature of (92.5°C) at (3 hours). This high temperature made the temperature exceed (50°C) in the treated layer, then the wax melts. In the charging period temperature of (Tc1) the higher temperature was obtained due to direct exposition to the heat source. This high temperature affects (Tc2 to Tc11) as previously mentioned and there is a temperature gradient from (Tc1 to Tc5). At the discharging period (10800 s), the temperature decreases gradually with a reverse behavior at (11000 s precisely) from (Tc5 to Tc1), respectively because the heat rejection increases when the thermocouples approach the external surface. As shown in figure (5), the temperatures of (Tc6 and Tc7) continue in the increases even after switching off the projector because of the continuous effect of the former wall layers due to the stored heat that reject to outside through the external layers, and it remains higher than (Tc1 to Tc5) to the end of the experiment time. The temperatures of (Tc8, Tc9 and Tc10) increase with time to mark (38.9°C, 35.9 °C and 34.8°C), respectively at (21600 s). Figure (6) shows the results of the treated wall with time. The first thermocouple (Tc1) behaves like Tc1 of the non-treated wall at the first (1800 Seconds) because the wax in the treated layer does not melt in this time. After (1800 Seconds), the temperature in the treated layer exceeds (50°C) then the temperature of (Tc1) of the treated wall will be less than (Tc1) of the non-treated wall. The sudden temperature decrease of the treated (Tc1) at (2700 Seconds) is attributed to the fast liquefying of the paraffin wax within its container in the treated layer. The maximum temperature of (89°C) at (3 hours) while the maximum temperature of the non-treated (Tc1) is (92.5°C) in the same time. (Tc2) also decreases at (3600 Seconds) from (75 °C to 72.5 °C) due to the continuous phase change of the wax with slow temperature raising to (9000 Seconds), while the non-treated (Tc2) continues increasing normally. After (9000 Seconds) in the treated wall, the thermocouple (Tc2) raises normally because of the complete melting of the wax, it remains less than the non-treated (Tc2). This is due to the fact that a part of the total input heat was changed to latent heat in the treated wall, while the total heat in the non-treated wall was a sensible heat. (Tc3, Tc4 and Tc5) rise from the set temperature to be less than the corresponding temperature in the non-treated (Tc) during the charging period. At the discharging period, after (18000 Seconds), the thermocouples (Tc1 to Tc4) in the treated wall are higher than the corresponding thermocouples in the non-treated wall. This is because the temperature at the treated layer is less than (50 °C) and the wax solidifies and then rejects the heat to the outside. Both the treated and the non-treated (Tc5) converge each other after (18000 second) and mark (40 °C) for the two at the end of the time. The temperatures of (Tc6 and Tc7) remain increasing in the discharge period because they gained heat from the previous layers and lose it slowly due to the low thermal conductivity of the brick as previously mentioned. (Tc8, Tc9 and Tc10) continue increasing from (28.1°C) to mark (37.4°C , 34.2 °C and 33.6°C), respectively on the internal surface at (21600 Seconds). Figure (7) shows a comparison between the treated and the non-treated walls with time. It is clear from the figure that (Tc2) for both models has the same behavior below the melting temperature (50°C). After (50 °C), the treated (Tc2) is less than the non-treated (Tc2). The maximum difference between the two curves is at (4000 Seconds). After the complete melting of the wax, the treated (Tc2) raises normally but does not reach the non-treated (Tc2) due to temperature reduction during the melting of the wax. This behavior continues after the discharging period and reverses after (18000 Seconds) to (21600 Seconds). The treated (Tc4) is less than the non-treated (Tc4). This behavior due to the (PCM) in treated layer starts for melting after 50°C, therefore, the heat is charged in this model with constant temperature at places where the paraffin wax was existed. After (1800 s), the non-treated (Tc4) raises normally to reach (79°C) while the treated (Tc4) is reduced to reach (74 °C) at (10800 Seconds). As previously mentioned, (Tc6) continues rising after (3hours), acquiring the heat from the previous layer and the slow loss of temperature due to the low thermal conductivity of the brick. The treated (Tc6) is less than the non-treated (Tc6) at the end of the time. The difference between the treated and the non-treated (Tc8 and Tc10) appears after (1800 Seconds) and it increases after (3600 Seconds) due to the resistance of wall layers, where (TC8) is located at the end of the brick layer and (Tc10) is located at the gypsum layer. After (3 hours), the difference between the treated and the non-treated curves increases to reach (1.5 °C and 1.2°C), respectively at the internal surface. Figure (8). It is considered the final component of the experimental results. The difference between the treated and the non-treated curves is considered the most important difference in this research because it directly affects the temperature of the room. It is clear from figure (8) that the difference between the two curves (Tc11) starts after (1800 s) and it increases with time to reach (1.6 °C) at the inner surface in the same conditions for the two curves. This profit in temperature reduction of the treated wall seems little but it can be reflected on the internal air-conditioning load and this load will be shifted away from the peak load of the national electricity grid.



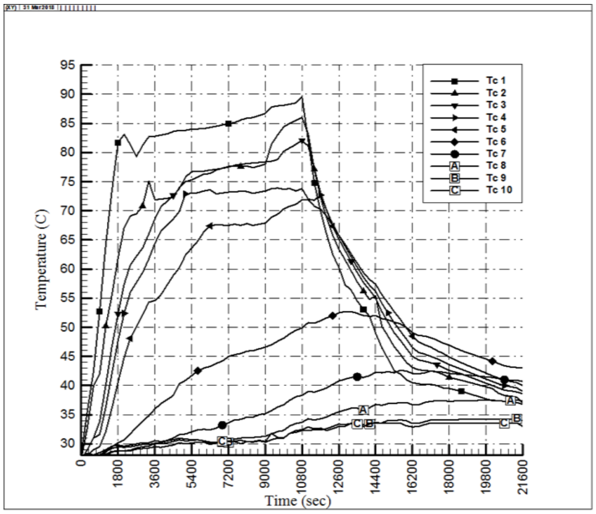


Figure (6) Temperature of the treated wall with time

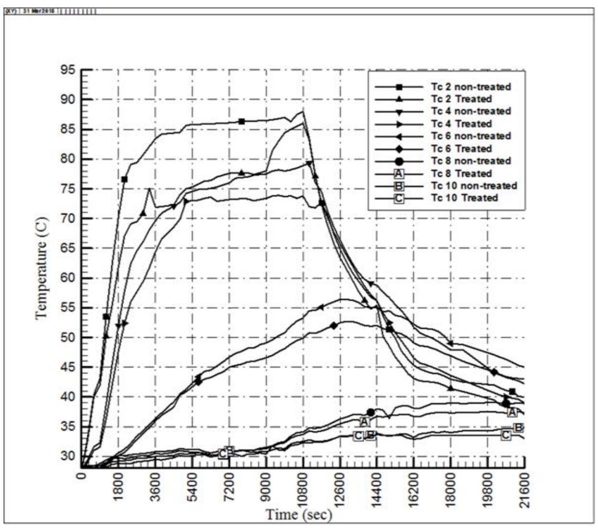


Figure (7) Comparison of temperature between the treated and non-treated walls with time

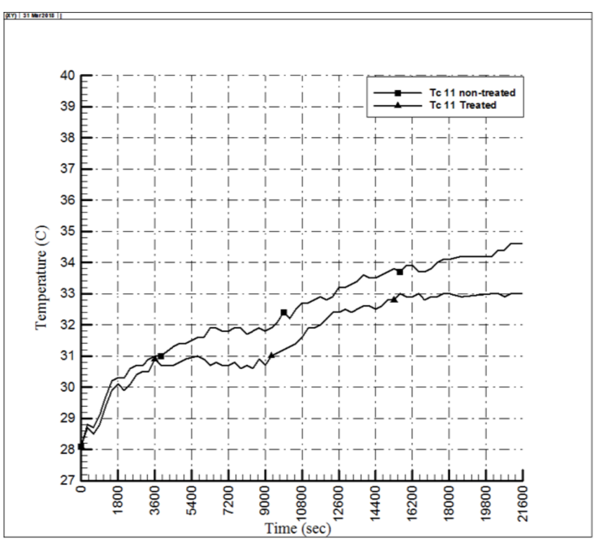


Figure (8) Comparison of internal surface temperature between the treated and non-treated walls with time

4. Conclusions

This paper describes the experimental results concerning the effect of paraffin wax which was mixed with cement layer on stored energy. The variation in the temperature of two walls models was studied. The internal surface temperature of the treated wall was lower than the internal surface temperature of the conventional wall after (1800 Seconds) and the difference increases with time to reach (1.6°C) at the end of the time of the experiment. The equivalent thermal conductivity of the treated layer was measured at the laboratory and found to be (0.958W/m.K) which was lower than that of the corresponding cement layer (1.16W/m.K), making the treated wall decreases the heat flow towards the internal surface. Also, the stored heat in the treated wall during the charging period was larger than that stored heat in the non-treated wall due to the effect of phase change. This state was concluded from the difference between the internal surface temperatures for both models.

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الخلاصة

إن تقليل الكسب الحراري من خلال الجدران الخارجية للأبنية صيفا سيساهم في تقليل نفقات تكييف الهواء وهو احد متطلبات التصميم في وقتنا الحاضر. المواد متغيرة الطور يمكن استخدامها ضمن جدار المبنى لتقليل انتقال الحرارة خلال الجدار. شمع البارافين هو احد المواد الشائعة الاستخدام كمادة متغيرة الطور في جدران الأبنية. استخدم شمع البارافين في هذه الدراسة بنسبة حجمية مقدارها (20%) لتكوين الطبقة الخارجة للجدار المعالج. الدراسة الحالية تتضمن اختبار نموذج جدارين (تقليدي ومعالج)عمليا. يتضمن الجانب العملي محاكاة الجدارين من خلال تعريضهما الى مصدر حرارة خارجي(كشاف ضوئي 1000 وات) وتسجيل درجات الحرارة خلال طبقات الجدار خلال فترتي الشحن والتفريغ الحراري. أظهرت الدراسة انخفاض في درجة حرارة السطح الداخلي للجدار المعالج بالمقارنة مع الجدار التقليدي(غير المعالج) حيث بلغ الفرق بين درجات الحرارة للسطوح الداخلية (1,6)°م للجانب العملي.