# The Effect of Using a Paraffin Wax-Aluminum Chip Compound As Thermal Storage Materials in a Solar Air Heater

**Khalil Ibrahim Abaas**

kh195814@yahoo.com

UOT - Machines & Equipment Engineering Department

Baghdad-Iraq

**Abstract:** *This paper presents an experimental investigation of a designed and fabricated air heater consisting of three cases. The first case used concrete as the main part of the air heater. The second case used paraffin wax as phase change material (PCM) accompanied with concrete as the main part of the air heater. In the third case aluminum chip was added to PCM and concrete. It was used as a thermal storage compound in a solar air heater. Results show that the exit air temperature was increased highly for the third case compared with the other cases and the efficiency of system was improved and the maximum storage efficiency achieved was 100% higher than the concrete case. The air heating gained was in its* *maximum value with the third case and the maximum increment achieved was 147.52% at Feb. also.*

***Keywords: Phase change material, solar heating system, air temperature, discharge process, aluminum chip.***

## 1. Introduction

Increasing energy consumption, shrinking resources and rising energy costs will have significant impact on our standard of living for future generations. In this situation, the development of alternative, cost effective sources of energy for residential housing has to be a priority [1]. Solar radiation, along with secondary solar resources such as wind and wave power, hydroelectricity and biomass, accounts for most of the available renewable energy on Earth. Only a minuscule fraction of the available solar energy is used. Solar energy is the radiant light and heat from the Sun that has been harnessed by humans since ancient times using a range of ever-evolving technologies [2].

Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute sunlight. Active solar techniques include the use of photovoltaic panels, solar thermal collectors, with electrical or mechanical equipment, to convert sunlight into useful outputs. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air [3].

Passive solar heating systems using air as the circulating fluid can be used effectively for space heating, particularly in small spaces such as field huts or refuges [4]. Air heating collectors have been occasionally used since World War II, mostly for low temperature space heating applications. In the 1960s, solar energy was developed in India as mean of cheap energy for crop drying. Gopta [5] tested several designs that used both corrected absorber surfaces as well as wire mesh backing over the absorber. A design by Close [6] was able to achieve temperature around 65oC with a collector efficiency of 50%. Whillier [7] was the first who used polymer material in his experiments, by using glazing made of Tedler, a polyvinylflouride film. It was found high heat losses from Tedler combined with transmittance improvement.

Many air heaters were penetrated after 1973 oil crisis, as a part of considerable interest in alternative energies. Stacunanathan [8] tested passing air between multiple glazing before heating it, and it was found that collector efficiency gained about 10 to 15%.

Modern heaters designs have focus mainly on improving convective heat transfer at the absorber. Mittal [9] investigated using wire mesh as a backing material, with air flowing between the absorber and second glazing through the mesh, achieving collector efficiency about 70%. Mohamad [10] found that a backing bed of porous media improved heat transfer as well as pre-worming the air by first running it between two glazing plates. This also helps in improving collector efficiency by reducing the overall heat losses. Efficiency achieved was about 75%. Ramadan [11] used double pass heating in addition to a limestone packing above the absorber plate and passing air through it to improve efficiency.

Latent heat thermal energy storage systems, using phase change materials (PCM) to store heat, have many applications. They are used in solar heating systems in houses and greenhouses to store heat collected during high isolation periods and subsequently liberate heat during the night or other periods, in air conditioning systems to shift peak heating and cooling loads to of-peak hours [12] and in space stations to bridge the eclipse period when no solar energy is available [13]. In comparison with other thermal energy storage systems, they potentially have less weight and volume. They also absorb and release heat at a suitable predetermined temperature [14].

Many authors [15 & 16] confirmed that the thermal energy storage systems using PCMs have been recognized as one of the most advanced energy technologies to enhance the energy efficiency and sustainability of buildings. An interesting feature of PCMs is that they can store latent energy as well as sensible energy. Their high latent heat storage capacity combined with friendly energy systems employing endogenous energies, such as solar thermal energy, can reduce the energy consumption of buildings in a passive and sustainable way [17]. The systems incorporating PCMs benefit also from the isothermal nature of the phase change process [18].

Many researchers have investigated experimentally and theoretically the transient behavior of the PCM encapsulated in different geometries, and PCM based LHS systems in different arrangements. Zalba, [19] have conducted a detailed review of PCM materials, heat transfer analysis and applications of TES systems.

Assis [20] experimentally studied the melting of the PCM in a spherical shell which includes the visualization of the process, and compared it with the transient numerical solution performed using the Fluent 6.0 software. A generalized correlation was suggested for the molten fraction, in terms of Fourier number, Stefan number and Grashof number.

Cho [21] experimentally investigated the thermal characteristics of paraffin in a spherical capsule packed inside a storage tank at different values of the Reynolds number and inlet temperatures. They concluded that the phase change period for the capsule at the edge of the storage tank was shorter than that at the center of the storage tank, because the porosity at the center was smaller than at the edge of the storage tank.

One of the main goals of the present work is to design a latent thermal energy storage system incorporating PCM, taking advantage of solar energy, which is an abundant resource in Iraq climates, for space heating during the winter season in Baghdad, Iraq. The present work carried out an experimental investigation to study the transient behavior of a cylindrical storage system, packed with a PCM, suitable for low temperature air heating applications. Commercially available paraffin was considered as the PCM.

## 2. Experimental Setup

Two air heaters boxes were designed and fabricated to carry out this study. The two air heaters consist of the following:

a- The wood box: the boxes were made of wood 1cm thickness to guarantee good thermal insulation. The boxes are opened from above where the glass is fitted. The boxes dimensions were (1 m length, 0.5 m width and 0.15 m height). The front and rear end converge to reduce air flow losses at these two points. Air drawing fan was fitted at the exit, its function was to draw air from the air heater and deliver it to conditioned space. The entrance was fabricated just as the exit with circular form of diameter size 10 cm. The perpendicular distances from the entrance and existence to the air heater (divergent zone for the entrance and convergent zone for the exit) were 35 cm.

b- The air heater: two air heaters were built. The first one was fabricated from concrete (sand, cement and pebbles) 12 cm thicknesses. Ten copper pipes (2.58 cm dai and 1 m long) were fixed inside the concrete block. These pipes were opened from its ends to allow air to pass through. The air gains transmitted heat from concrete to pipes while it is passing through it to the conditioned space. This crossing air was considered the base of comparison in the present study. Three essential parts form this air heating system, these parts are: a single transparent glass, isolated duct and the storage unit which is consist of a single row of cylinders. This unit works to satisfy two goals; absorb and storage the solar energy. The concrete block face was painted with an absorber painted black. The total mass of the concrete material is about 125 kg.

The second air heater was fabricated in the same dimensions of the first one. It was built from concrete also but three rows of copper pipes (each one consists of 10 pipes) were fitted inside it uniformly. The middle row pipes were open ends used for air passing. The higher and lower rows were closed ends filled with paraffin wax which is the PCM used in this study. **Table 1** represents the paraffin wax and concrete specifications. Wax weight used in this study was 9.72 kg. The design takes into consideration many concerns such as, the integration with PCM storage unit, the simplicity of construction, dismantlement, and handling the PCM unit. The experimental trials consist of two different processes, such as charging and discharging. The charging process is done by heating the PCM bed from concrete temperature (at constant temperature), until the PCM in the entire bed changes its phase completely. During the discharging process, heat is supplied through the heated PCM bed to concrete and air.

c- Aluminum chips: Aluminum chips (4.5 kg) contained in a mesh container was fitted in air entrance cone.

d- Glass: 2mm thickness glass was fixed at the top of the boxes to cover the concrete wall and the entrance cone. It was fixed by silcon material to prevent any air leakage 3 cm above the concrete wall. Exposing the aluminun chips for sun rays was the reason for covering the entrance cone with glass.

e- Thermocouples: six copper-constantant thermo-couples were fixed in six palces inside concrete block. Two were fixed at the block top, two at the middle and two at the bottom of the block. The avarage of these thermocouples was considered as the concrete temperature. Four thermocouples were fixed in each PCM layer. It was distributed in a way that its avarage can be considered as the higher and lower wax temperature. Two thermocouples were fixed in aluminum chips to measure it temperature each hour. Two mercury thermometers were fixed in the air entrance and exit to measure its temperature in each case.

f- Exit air velocity measuring device: Exit air velocity was measured by (Anometer). All the measuring devised were calibrated and there accuracy was found as will be seen in uncrtinaty paragaph.

g- Aluminum reflectors: two wooden sections were covered from one side with aluminum foils and used as reflectors. They were used to insure concentrating the sun rays on the air heater at the morning and noon periods. At the sunset these sections were used as covers for the air heaters to prevent any heat transfer by radiation or convection to the surrounding.

h- The Fan: A constant speed fan (10 cm dia. and 100 W powers) was used to maintain a laminar flow.

A schematic diagram of the experimental setup used in this study is given in **Fig's. 1 & 2**.

***Figure 1: Photograph for the air heater used in the study***

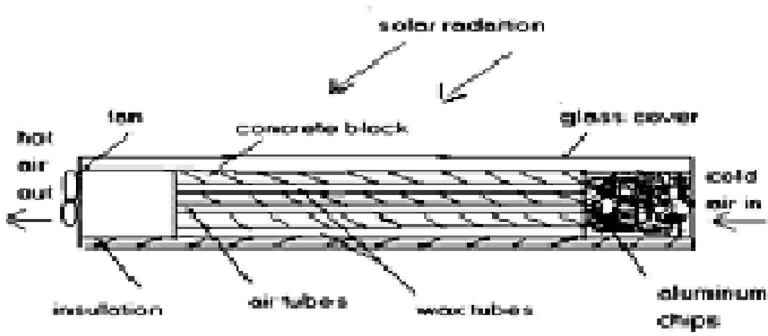



***Figure 2: A schematic diagram of the experimental setup used in this study***

***Table 1: Some of the studied materials specifications***

| Material | Density ($kg/m^3$) | | Specific heat (kj/kg k) | | Melting point ($^oC$) | Heat of fusion (kJ/kg) |
|---|---|---|---|---|---|---|
| | liquid | solid | liquid | solid | | |
| Paraffin wax | 786.1 | 833.1 | 2.44 | 2.35 | 45 | 173.6 |
| Concrete | 2300 | | 1.13 | | | |
| Aluminum | 2707 | | 0.896 | | | |

***Test Procedure***

Experimental measurments tests were conducted for the air heaters at the following cases:

1- First case: Concrete wall alone inside the air heater box.
2- Second case: Concrete wall with PCM pipes insde the air heater box.
3- Third case: Concrete wall with PCM pipes and aluminum chips insde the air heater box.

Teste were conducted from 1/ 1/ 2012 to 15/2/ 2012 in Baghdad city-Iraq winter weathers. The incident solar intensity for the former mentioned period was taken from the Iraq Metelorogy Organization. Measures were taken for the first and second cases at on day and followed by the third case acompanied with the first case at the following day. The temperatures were measured for several days in each month at a rate of two time per week. The avarage of these measured reading were considered as the hourly temperatures for each studied month. The measures started at 7.00 AM and continued untill the wall temperature reached intering air temperature.

The following equations were used to calculate storage energies and heating efficiency for each part of the used systems.

The stored energy in concrete wall:

$$Q_c = m_c \, c_{p_c} \, \Delta T_{h_c} \quad \text{(kJ)} \qquad (1)$$

The stored energy in paraffin wax

$$Q_w = m_w \, c_{p_w} \, \Delta T_{h_w} \quad \text{(kJ)} \qquad (2)$$

The stored energy in aluminum chips:

$$Q_{Al} = m_{Al} \, c_{p_{AL}} \, \Delta T_{h_{AL}} \quad \text{(kJ)} \qquad (3)$$

Air mass flow rate

$$m_a = \rho_a \, Q \qquad (4)$$

Air volume flow rate

$$Q = A \, V \qquad (5)$$

Heat transfer by air

$$Q_a = m_a \, c_{p_a} \, \Delta T_{h_a} \quad \text{(kW)} \qquad (6)$$

First case (Concrete) thermal storage efficiency (first case)

$$\eta_{storage} = \frac{Q_c}{I\ A} \quad (\%) \qquad (7)$$

Second case (Concrete+PCM)thermal storage efficiency

$$\eta_{storage} = \frac{Q_c + Q_w}{I\ A} \quad (\%) \qquad (8)$$

Third case (Concrete+PCM+aluminum chips) thermal storage efficiency

$$\eta_{storage} = \frac{Q_c + Q_w + Q_{Al}}{I\ A} \quad (\%) \qquad (9)$$

System heating efficiency

$$\eta_{heat} = \frac{Q_{air}}{I\ A} \quad (\%) \qquad (10)$$

***Error Analysis***

The error associated with experimental measurements of the temperature of various parts of the systems and air flow through air heaters are recorded in table 2. All measuring devices were calibrated before taking measures. The resulted uncertainties were less than 5% which confirm the high accuracy of the present study.
Table 2 Estimated values of uncertainties

***Table 2: Experimental Accuracies***

| Parameters | Error (%) |
|---|---|
| Temperature | 1.062 |
| Flow rate | 0.61 |

## 3. Results and Discussion

The test facility designed in order to carry out experimental measurements of heating process characteristics during charging consists of heating sections. The temperature histories are recorded continuously during the experiment. Several experiments are conducted for the repeatability of the readings.

**Fig. 3** shows the air heating process parts temperatures, inlet cold air, exit hot air and concrete wall temperature. Concrete wall temperature increases highly due to solar intensity starting from 8AM until 2 PM. After 2 PM the wall temperatures reduces due to solar intensity declines accompanied with cold air entering causing exit air temperatures to be reduced and declines. The air temperature increment rate at Jan. was 61.8% while at Feb. was 57.92%. These results indicate that the air heating system can be used for Baghdad City weathers efficiently.

**Fig. 4** represents temperatures details for the second case tested in this study where PCM was added to the concrete wall. Temperature increase and reduction still the same as fig.1, except for in this case worming time extended for about two to three hours. Concrete temperature relatively maintained the same temperatures as case one, putting in mind, that concrete mass in this case less than case one, whereas PCM pipes take place, on the account of concrete mass. At the time of worming (from 7 AM to 2 PM) concrete temperatures exceeded all other temperature. After 2 PM concrete sensible heat gained at the last period reduced faster than PCM. Wax temperature after 2 PM exceeded all other temperature depending on its stored sensible and latent heat. The air temperature increment rates were 78.92 and 65.08% for Jan. and Feb. respectively. It can be realized from figures 1 & 2 results that the increment rates at Jan. are higher than that at Feb. This is due to the higher inlet air temperatures introduced to the air heater at Baghdad Feb. days.

**Fig.5** clarifies the third studied case when aluminum chips were added to concrete-PCM system. The results indicates that aluminum chips gained temperatures higher than concrete and PCM. Aluminum chips temperatures exceeded all other temperature at the charging period (from 7 AM to 2 PM). At discharging period (from 2 PM and on) these temperature declined highly to become less than concrete and PCM temperatures. The high thermal conductivity for aluminum and the high surface area for its chips equipped this system with higher worming abilities causing higher outlet air temperatures at charging period. The air temperature increment rates were 83.88 & 108.29% for Jan. & Feb. respectively. The high increment rate at Feb. which exceeded 100% was due to the high aluminum chips temperatures gained, in addition to its high surface area which increased the heat transfer rate to air.

**Fig. 6** represents air stored energy for the three studied cases versus time. It is clear from the figure that the third case stored the highest energy in air. This case contains the effect of concrete sensible heat, wax sensible and latent heat and aluminum chips high thermal conductivity and large heat transfer surface area. For comparison purposes, the increments in air stored energy at Jan. were 54.59 and 89.74% for case 2 and case 3 respectively compared with case 1. At Feb. the increments were 52.97 and 97.08% for case 2 and case 3 respectively compared with case 1. It can be observed that higher heat was gained at Feb. due to fulfill two reasons. First higher solar intensity in Baghdad City region, in addition to aluminum chips high gaining and losing of heat due to its high thermal conductivity.

**Fig. 7** demonstrates the tested systems efficiencies versus time. It is clear that higher system efficiency can be achieved using the third case (concrete +wax+ aluminum chips). Increments in system efficiency percentages were 49.38 & 97.7% at Jan. and 54.13 & 92.31% at Feb. for cases 1 & 2 respectively compared with case 1.

**Fig. 8** illustrates the tested system thermal storage efficiency versus time. Case 3 still rank the highest thermal efficiency due to availability of concrete sensible heat storage added to wax sensible and latent heat storage in addition to aluminum chips heat storage. The increments in thermal storage efficiencies were 44.39 & 80.75% at Jan, while at Feb. it were 49.19 & 84.49% for cases 2 & 3 respectively compared with case 1.

**Fig. 9** shows the charging period of PCM. This period starts from the first daytime but it appears clearly starting from 11 AM and it expands till 2 PM. In this period PCM temperature increased to reach wax melting point, at which it settles until all the wax is melted. The liquid wax temperature starts to increase higher than melting point all the charging period. Wax phase changing in addition to sensible heat it stores after melting ensures high thermal energy storage. Adding aluminum chips (case 3) that wormed quickly due to aluminum high thermal conductivity will cause hot air to pass through pipes. This air will warm pipes and the surroundings (concrete and PCM). From the figure it is obvious that case 3 temperatures were higher all the charging period. Also, the figure clarify that wax melting in case 3 time was advanced compared with case 2, and because of higher gained temperatures melting period for case 3 was shorter about 10 minutes compared with case 2. All these differences effects will appears at discharge period as Fig. 8 clarifies.

**Fig. 10** represents the discharge period of PCM. This period starts around 2 PM and it expands until all the stored energy is used. PCM temperatures reduce in this period and paraffin wax starts to lose its sensible stored energy until it reaches melting point. At this point it settles until all wax changes its phase to solid phase. After all the wax is solidified its temperature reduces in high rate due to two reasons. The first one is the time of this operation takes place after 2:30 PM where the solar intensity starts to drop.

The second reason is the cold air passing through heater gaining stored energy.

The figure reveals the positive effect of adding aluminum chips (case 3). As a result of higher gained temperatures at charging period, case 3 temperatures lags after case 2. Also, PCM in case 3 reaches its melting point after case 2 with about 40 minutes. Adding aluminum chips gives higher air temperatures at charging time and makes the heater operates for longer periods.

## 4. Conclusions

Three cases were studied in the present paper, simple case of air heater made of concrete, in the second heater PCM was added to the system, and in the third case aluminum chip was added to the second system. The tests were conducted at Baghdad city winter days between 1-1-2012 to 15-2-2012. The results indicate the following:

1- Adding aluminum chips (case 3) improves the air heater system. Compared with case 1 (concrete heater) for Jan. and Feb. respectively the following is resulted: the gained temperatures increased with about 83 and 108%. The air stored energy was improved about 89 and 97%. The system efficiency was improved 97 and 92%.

2- Adding aluminum chips accelerates the system temperature rise at charging period. It also decelerates the system temperature lose at discharging period. This addition helps the system to worm air for longer time.

3- The results demonstrate that case 3 air heating system is adequate for air heating purposes in Iraqi winter weathers.

## References

1. Ahmed S T & Chaichan M T, "A study of free convection in a solar chimney sample", Engineering and Technology J, vol. 29, No. 14, pp: 2986-2997, 2011.
2. Chaichan M T & Abaas Kh I, "Practical investigation for measurement of concentrating solar power prototype for several target cases at Iraqi summertime weathers", 1st Scientific Conference for Energy & Renewable Energies Applications, UOT, Baghdad, Iraq, 2011.
3. Bendea C, Rosca M, Karitas K, "High solar fraction heating and cooling systems", Analele Universităţii din Oradea Fascicula de Energetică, vol. 15, 2009.
4. Szymocha K, "Advanced thermal solar system with heat storage for residential house space heating", SESCI 2005 Conference, British Columbia Institute of Technology, Burnaby, British Columbia, Canada, August 20 - 24, 2005.
5. Gopta G L & Grag H P, "Performance study on solar air heaters", Solar Energy, vol. 11, No. 1, 1967.
6. Close D J, "Solar air heaters for low and moderate temperatures applications, solar energy", vol. 5, No. 3, pp: 117-124, 1963.
7. Whillier A, "Plastic covers for solar collectors", solar energy, vol. 7, No. 3, pp: 148-155, 1963.
8. Stacunanathan S & Deonarine S, "A tow-pass solar air heater", Solar Energy, vol. 15, No. 1, pp: 41-49, 1973.
9. Mittal M &Varshney L, "Optimal thermo-hydraulic performance of a wire mesh packed solar air heater", Solar Energy, vol. 80, No. 9, pp: 1112-1120, 2006.
10. Mohamad A, "High efficiency solar heater", Solar Energy, vol. 60, No. 2, pp: 71-76, 1997.
11. Ramadan M, Al-Sebaii A, Aboul-Enein S & Al-Bialy E, "Thermal performance of a packed bed double-pass solar air heater", Energy, vol. 33, No. 8, pp: 1524-1535, 2007.

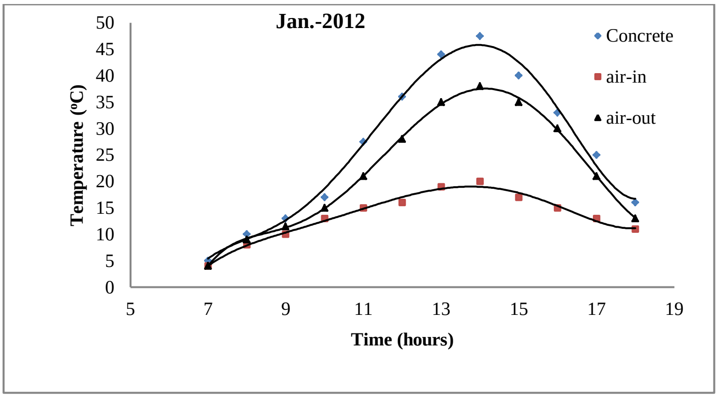
12. Zang Y P, Lin K P, Yang R, Di H F &Jiang Y, "Preparation, performance and thermal application of shape-stabilized PCM in energy efficient buildings", Energy and buildings, vol. 38, No. 10, pp: 1262-1269, 2006.
13. Regin F, Solanki F S C & Saini J S, "An analysis of a packed bed latent heat thermal energy storage system using PCM capsules: Numerical Investigation", Renewable energy, vol. 34, pp: 1765-1773, 2009.
14. Raj A & Velraj V R, "Heat transfer and pressure drop studies on a PCM-heat exchanger module for free cooling applications", Intl. Journal of thermal sciences, available online, 2011.
15. Regin F, Solanki A S C & Saini J S, "Heat transfer characteristics of thermal energy storage system using PCM capsules: A review", Renewable & Sustainable Energy Reviews, vol. 12, pp: 2438-2458, 2008.
16. Bilir L & Ilken Z, "Total solidification time of a liquid phase change material enclosed in cylindrical/Spherical containers", Applied Thermal Engineering, vol. 25, pp: 1488-1502, 2005.
17. Mahmud A, Sopian K, Alghoul M A & Sohif M, "Using a paraffin wax-aluminum compound as a thermal storage material in a solar air heaters", ARPN Journal of Engineering and Applied Sciences, vol. 4, No. 10, 2009.
18. Hazami M, Kooli S, Lazâar M, Farhat A & Belghith A, "Energy and exergy efficiency of a daily heat storage unit for buildings heating", Revue des Energies Renewable, vol. 12, No. 2, pp: 185 – 200, 2009.
19. Zalba B, MarinJ M, Luisa F & Mehling H, "Review on thermal energy storage with phase change: materials, heat transfer analysis and applications", Applied Thermal Engineering, vol. 23, pp: 251-283, 2003.
20. Assis E, Katsman L, Ziskind G & Letan R, "Numerical and experimental study of melting in a spherical shell", Intl.

Journal of Heat and Mass Transfer, vol. 50, pp:1790-1804, 2007.

21. Cho K & Choi S H, "Thermal characteristics of paraffin in a spherical capsule during freezing and melting processes", Intl. Journal of Heat and Mass Transfer, vol. 43, pp: 3183-3196, 2000.

## List of symbol

| | |
|---|---|
| **$m_c$** | **mass of the concrete in the wall (kg)** |
| **$m_w$** | **mass of the paraffin wax in the wall (kg)** |
| **$m_{al}$** | **mass of the aluminum chip in the wall (kg)** |
| **$cp_c$** | **specific heat of the concrete (kJ/kg k)** |
| **$cp_w$** | **specific heat of the paraffin wax (kJ/kg k)** |
| **$cp_{al}$** | **specific heat of the aluminum chip (kJ/kg k)** |
| **I** | **solar intensity (W/m2)** |
| **A** | **area (m2)** |

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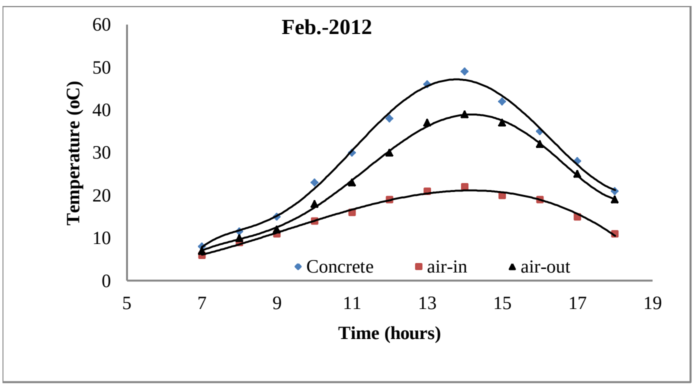


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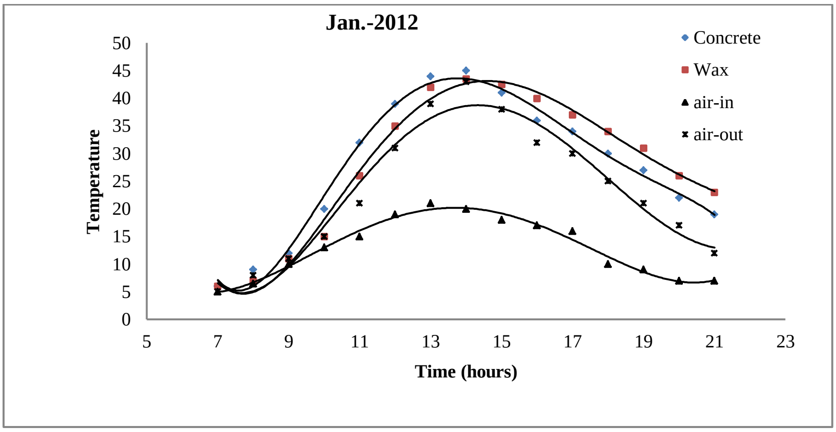
***Figure. 3, Temperatures of air heater parts for the first case***

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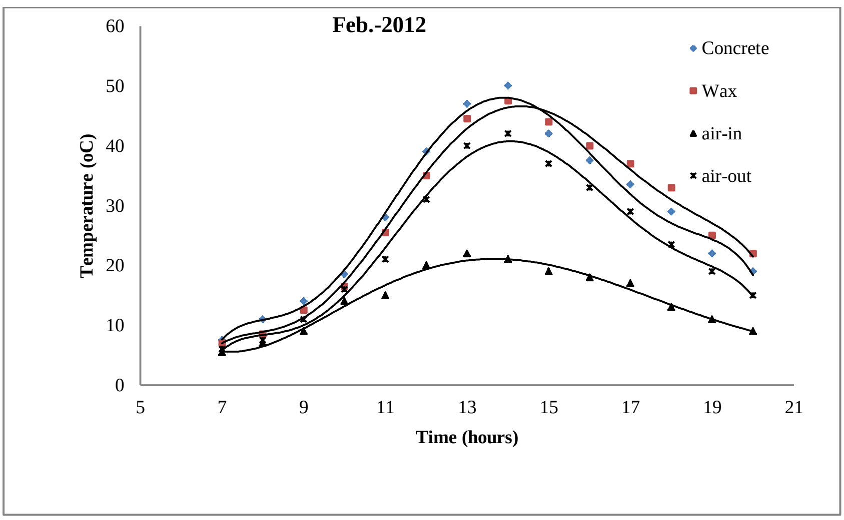


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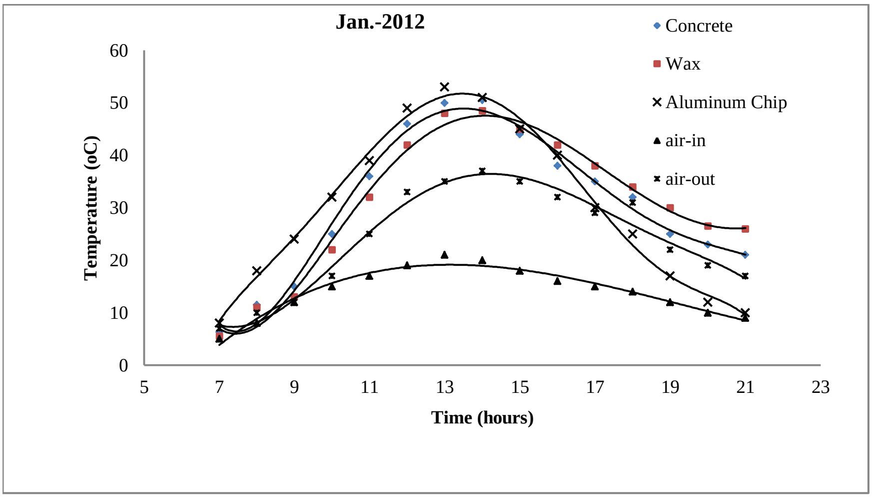
*Figure. 4, Temperatures of air heater parts for the 2nd case*

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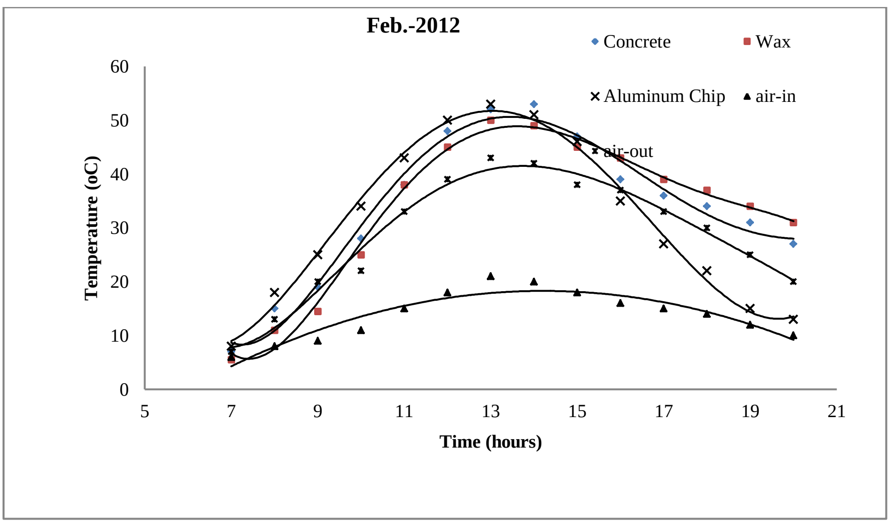


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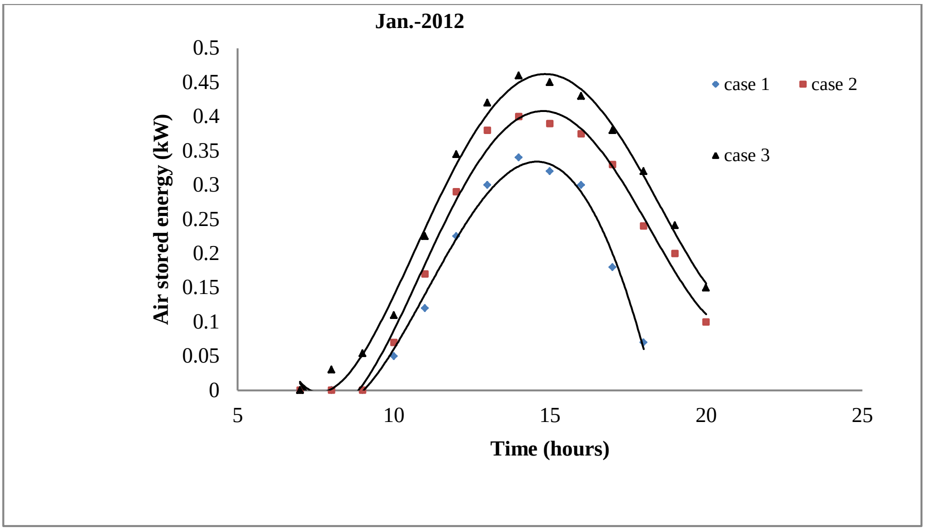
***Figure. 5, Temperatures of air heater parts for the 3rd case***

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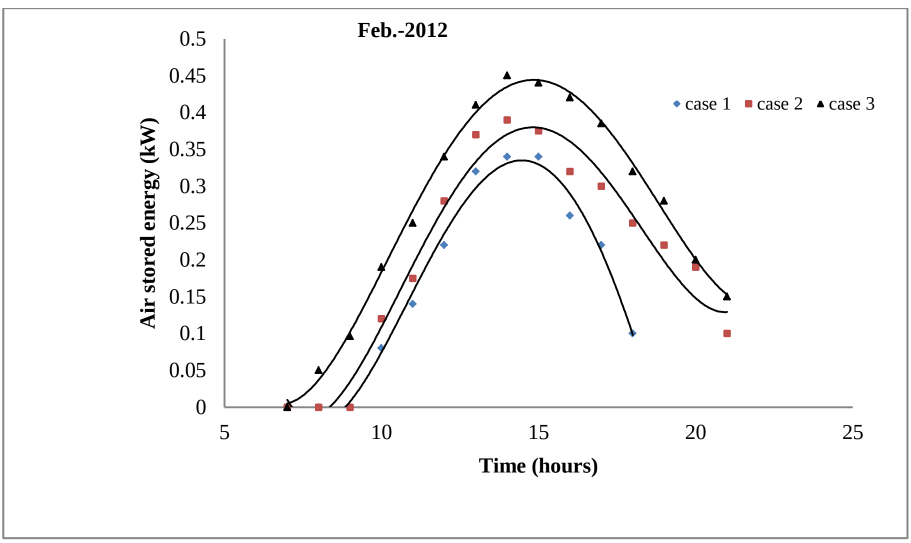


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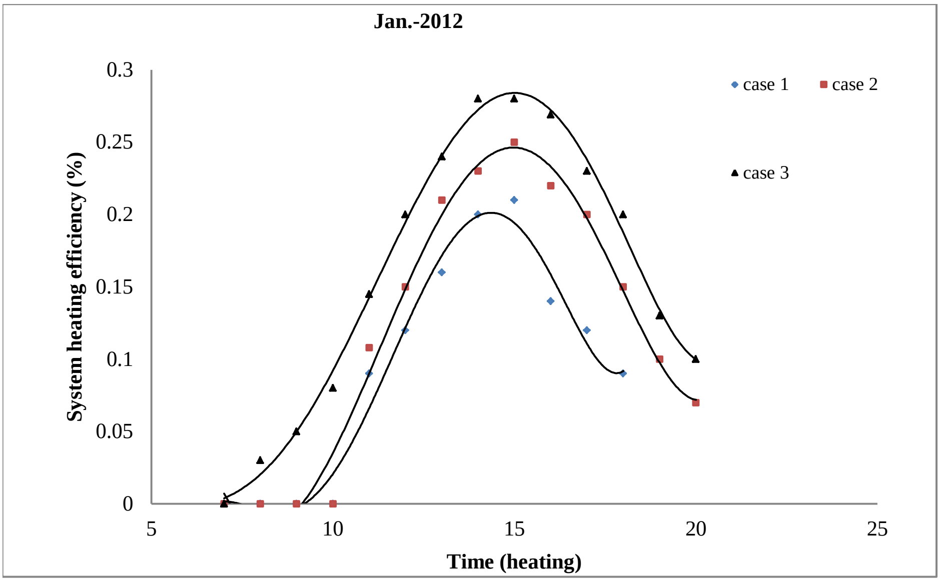
***Figure. 6, Air stored energy for the three studied cases***

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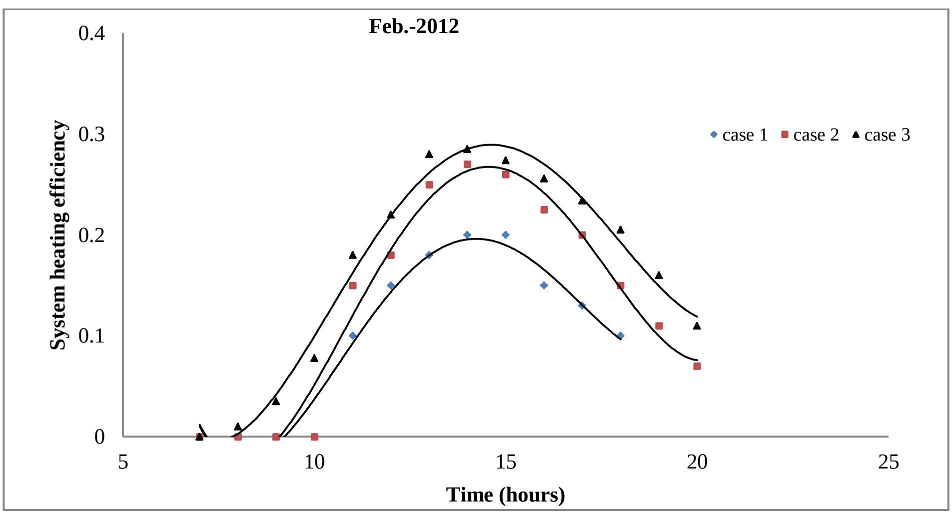
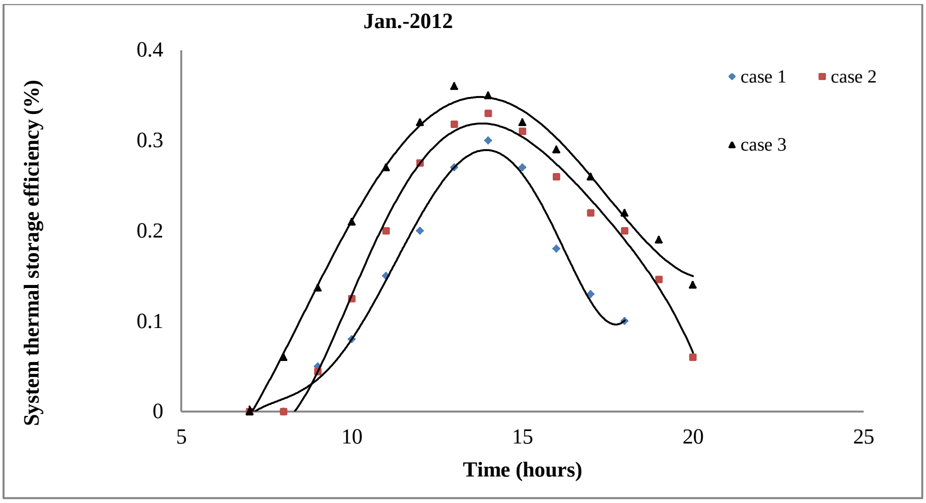



*(b)*

***Figure. 7, System heating efficiency for the three studied cases***

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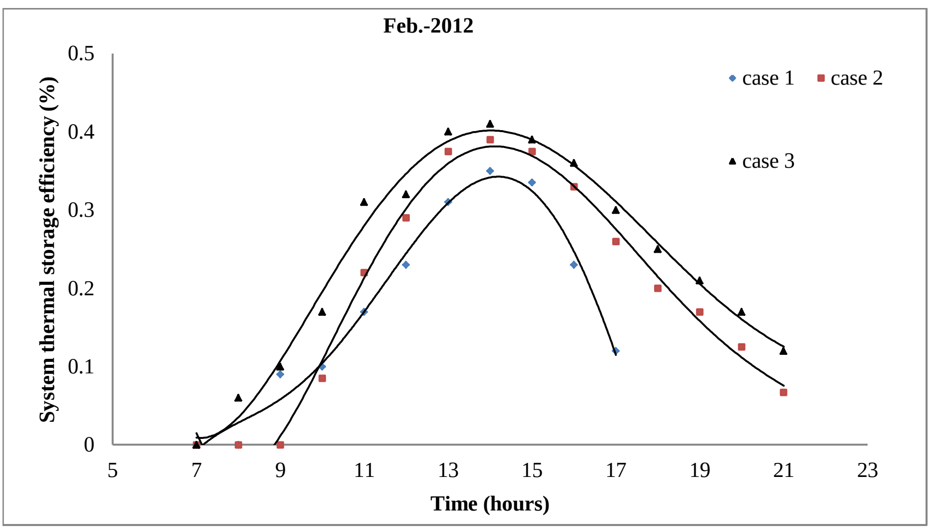


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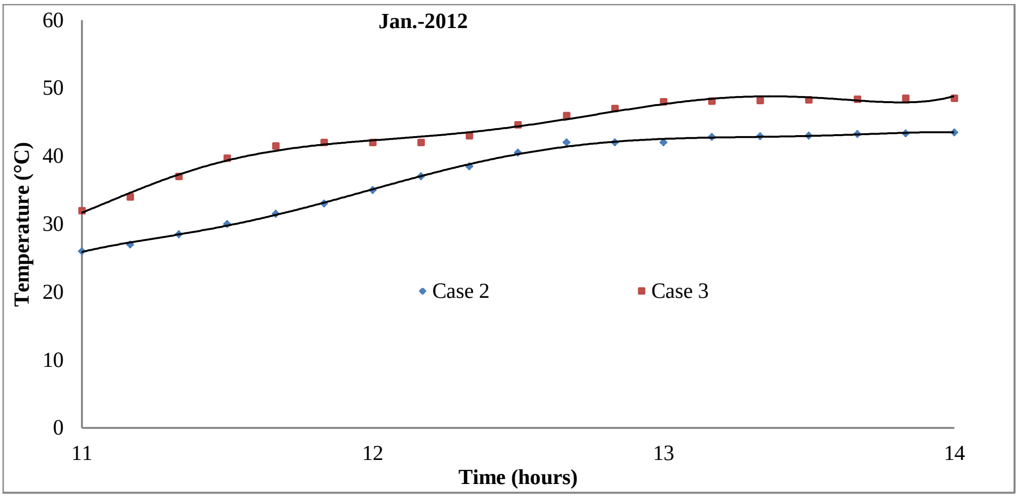
*Figure. 8, System heating efficiency for the three studied cases*

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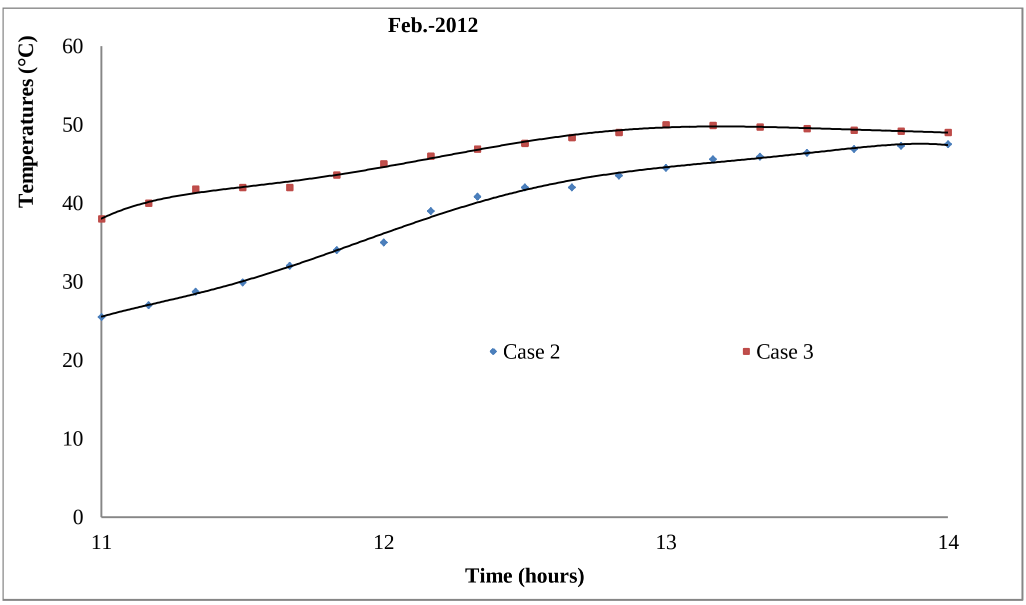


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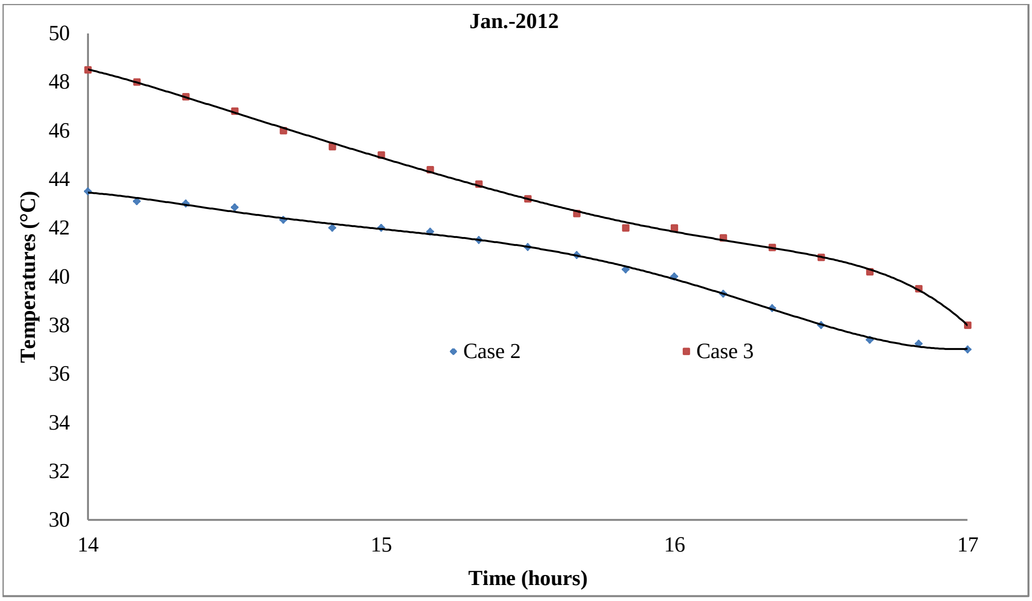
*Figure. 9, PCM charging behavior for cases 2&3*

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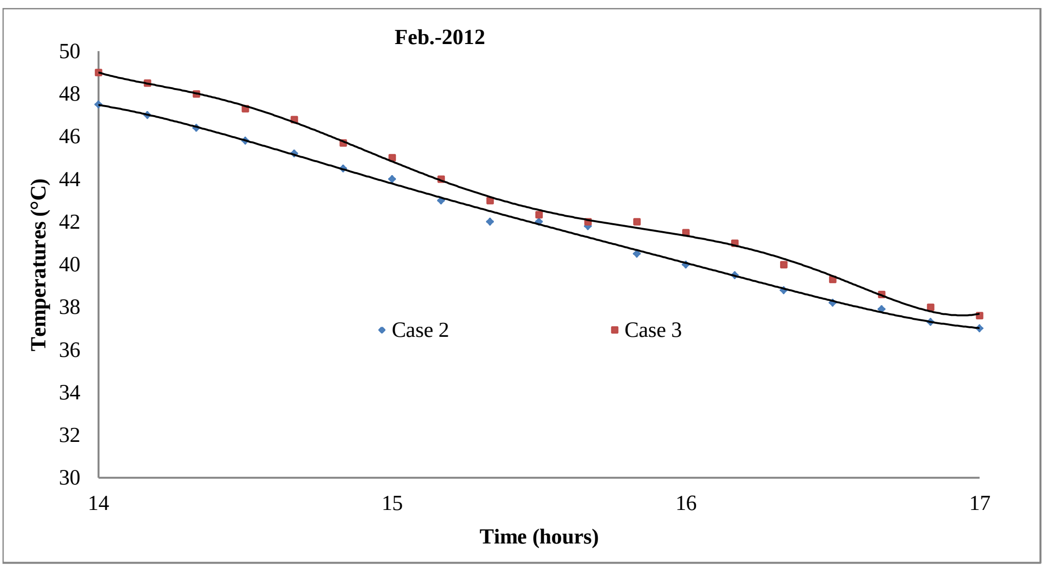


*(b)*

***Figure. 10, PCM discharging behavior for cases 2&3***

# تأثير استخدام مجموعة الشمع البرافيني- برادة الالمنيوم كمواد خازنة للحرارة في مسخن هواء شمسي

**م. خليل ابراهيم عباس**
kh195814@yahoo.com
الجامعة التكنولوجية - قسم هندسة المكائن والمعدات
بغداد- العراق

**المستخلص:**

تم في هذه الدراسة تصميم وصناعة مسخن هواء يتضمن ثلاث حالات، في الحالة الأولى استخدم الكونكريت كجزء اساسي من مسخن الهواء، وفي الحالة الثانية اضيف الشمع البرافيني كمادة متغيرة الطور الى الكونكريت، وفي الحالة الثالثة اضيف برادة الألمنيوم الى مجموعة الكونكريت والمادة متغيرة الطور. واستخدمت التركيبة كخازن حراري لمسخن الهواء الشمسي.

بينت النتائج ازدياد درجة حرارة الهواء الخارج بشكل كبير في الحالة الثالثة مقارنة بالحالتين الأخريين، كما تحسنت كفاءة النظام ووصلت قيمة كفاءة الخزن القصوى الى 100% أكثر من حالة استخدام الكونكريت بمفرده، كما كان الكسب الحراري للهواء المسخن في اعلى قيمه عند عمل المنظومة في الحالة الثالثة، وكانت اقصى زيادة تم الوصول لها 147.52% في شهر شباط.

**الكلمات الرئيسية: مادة متغيرة الطور، منظومة تسخين شمسية، درجة حرارة الهواء، عملية الكسب الحراري، برادة الومينيوم.**