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Experimental Study of Cooling System for Energy Saving and Shifting Using Phase Change Materials.

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Abstract—Energy saving and shifting study to space cooling of a resident conventional test room situated in Iraq with dimensions of 3 x 2.5 x 3 m. A water evaporative cooler is used to produce cold water that is circulated inside the roof core by a pump. The air delivered from the evaporative cooler is directed to the outdoor A/C unit to minimize condenser temperature for COP enhancement. The Thermal Energy Storage (TES) is filled with Phase Change Material (PCM) paraffin. TES exchanges the heat (charging and discharging) with air forced by a fan through channels. An electric solar system operates evaporative cooling and the TES fan while the A/C is off. The solar panels are cooled by another air stream supplied by the evaporative cooler. Experimental work was carried out in the dry summer, from April, May, June, July, August, September, and October. The experimental results showed that the reduction in the percentage of heat gained through the ceiling using water was 3.44%,4.78%, 7.67%, 15.87%, 11.45%, 10.21%, and 6.23% respectively. The results also showed a reduction of power consumption by using paraffin for the summer months 3.8%, 6.65%, 7.34%, 8.57%, 5.85%, 4.77%, and 3.53% respectively as well as enhancing A/C COP, but only 9.01% of energy was saved due to the effect of improving A/C COP alone. Maximum heat gain participation was through the roof at 43% without operating the systems, and water circulation was minimized to 21%.

Index Terms--Cooling System, Thermal Energy Storage, PCM, Energy.

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1 INTRODUCTION

Recent and current research has focused on improving energy efficiency by boosting renewable energy usage, regulating energy consumption, and lowering heating and cooling expenses. This is owing to a considerable increase in global energy consumption as a result of the world's rapid population and economic development, both of which have severe environmental consequences [1–8]. Economic expansion, the intensity of energy consumption, population growth, and the intensity of carbon emissions, according to Kaya and Yokoburi [9], all have an influence on total carbon emissions, which contribute to global warming. Researchers and policymakers, on the other hand, have connected high carbon emissions intensity to increasing energy consumption as a result of rapid economic growth and greater usage of fossil fuels [10–12]. The aim of this paper is to energy save and shift the study to space cooling of a conventional test room using PCM, which also improves the COP of A/C also reduction power consumption.

2 TEST ROOM SPECIFICATION

A test room was constructed and situated in Kirkuk (33.3°N and 44.4°E) above a resident's 2 floors by external dimensions (length 3 x width 2.5 x height3) m. The roof was created from a reinforced concrete slab with a thickness of 15 cm. For slab cooling by water circulation, aluminum pipes with a 1 cm diameter were installed in a U shape for three passages (forward and returned) on the longitudinal side of the roof at the reinforcement level. The conventional evaporative cooler was selected to use for system enhancement purposes by producing water at a temperature close to that of the wet bulb to be pumped into the roof piping network. In addition, air will be blown to the A/C and PV solar panels. Current research will adopt the conventional air cooler, which contains 80 L of water and produces air at (1700 m3/hr) by a fan connected to an air diverter. The overall electrical load is 180W. The air cooler external dimension is (0.9*0.9*1.1) m. The wet pads are made of wood fiber gird. The water is sucked from the water sump and pimped directly to the roof piping network and back to the experimental rig by dripping on wet pads to cool it down

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by evaporation. The experimental rig with all parts is shown in fig. (1).

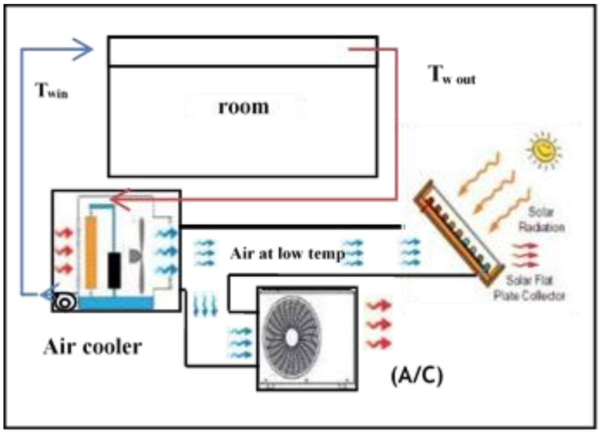

Fig (1): The experimental rig with all parts.

3 PARAFFIN WAX PREPARATION.

Soft paraffin wax was used as a PCM, this wax resulted from a process of segregation from national crude oil components, the thermos- physical properties of the current PCM specification were provided by the mentioned manufacturer and are listed in table (1).

Table (1): Soft Paraffin Wax Specification

Property	Measure
Melting Point	48°C
Oil Content	1.5%
Color	Cay bolt (min)
Specific Heat	2.1kJ/kg °C
Thermal Conductivity	0.2W/m k
Density	880kg/m3
Enthalpy of Fusion	210kJ/kg

lowering melt-solid temp. in this research Kerosene is used to be mixed with melted paraffin liquid, the process attempting several Kerosene fractions (10%, 20%, and 35%) of volume mixed very well with 100% of melted paraffin and examining the melt-solid temp. for each separately, figure (2) is discharging process in an environment of multiple mixtures of one type of PCM with different Kerosene concentrations, with 35% of Kerosene showing about 29°C of phase change temperature.

Fig (2): The mixing of paraffin wax with paraffin oil.

4 EXPERIMENTAL CALCULATIONS ENTHALPY.

Using the energy balance method, 0.2 kg of modified wax was slowly heated until 100% liquid at 31°C, then quickly poured into 0.6 kg of water initially at 19.5°C placed in an adiabatic buckle. The melted modified PCM will solidify quickly within a few seconds, giving off a final balanced temperature of 24.5°C by applying the following formula [13]:

$$Q = (Q_{sen} + Q_{Lat})_{PCM} . \dot{m}_{w.} Cp_{w} . (Ti - Tf)_{W} \tag{1}$$

5 HEAT TRANSFER FROM ROOF

The heat added or removed from roof is evaluated from following famous equation [14]:

$$Q_{roof} = \dot{m}_{w.} Cp_{w} (T_{w,out} - T_{w,in}) \tag{2}$$

6 EVALUATING AND ENHANCING COEFFICIENT OF PERFORMANCE OF A/C UNIT.

The concept is that the cooled air from evaporative cooling is orientated by flexible ducts to hit the A/C condenser front to minimize the condenser temperature and proportional pressure by maximizing heat rejection, which will increase the sub-cooling region. From the concept of the refrigeration cycle the COP is evaluated as the following equation [15]:

$$Cop = \frac{\text{Refrigerant effect}}{\text{Compresor work}} = \frac{(h_1 - h_4)}{(h_2 - h_1)} \tag{3}$$

7 THERMAL ENERGY STORAGE.

It is supported by a frame and metallic bar. The TES is placed in a position facing to A/C indoor split unit downstream, where there is an electric fan blowing cold air from A/C into TES circular air passages the exit to the test room indoor space. The heat capacity of TES is evaluated by contained

PCM, to heat up or cool down PCM from temperature level to another undergoing phase transition point, the energy is equal to the summation of sensible prior and after transition point plus the latent heat as per the following formula [16]:

$$Q_S = [Cp_S(T_m - T_S) + H + Cp_l(T_l - T_m)] \qquad (4)$$

$$\text{Reduction heat\%} = \left|\frac{Q_{without} - Q_{with}}{Q_{with}}\right| \times 100 \qquad (5)$$

$$\text{Reduction Power\%} = \left|\frac{P_{without} - P_{with}}{P_{with}}\right| \times 100 \qquad (6)$$

8 RESULT AND DISCUSSION

8.1 Effect of Water-Cooled Roof on Average Roof Temperature

The effect of cold water circulating inside the slab core will surely alter the roof's overall temperature; the reason is that the water will remove heat through direct contact. Figure (3) shows a stabilized temperature difference of 3.28 °C (With and without water) across the months with sine wave as absolute values, indicating that the average roof temperature is directly proportional to ambient parameters (Solar Radiation and Ambient Temperature). Figure 3 also shows the effect of a phase-changing material on reducing and stabilizing the temperature distribution, which gives a comfortable environment for the space.

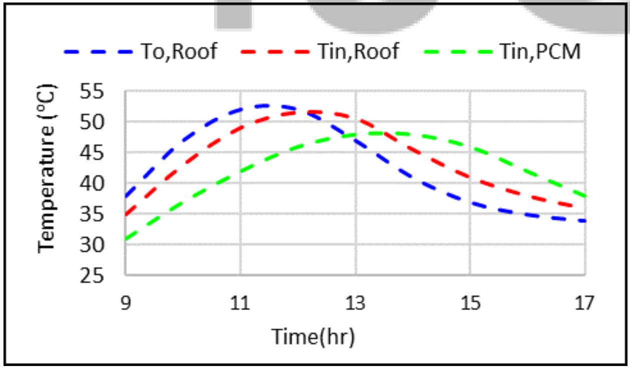

Fig (3): Effect of Water-Circulation and PCM on

Average Roof Temperature per Day.

8.2 Effect of Water-Cooled Roof on Average Heat Gain

Heat accumulation and the effect of circulating water in a roofing sheet is other important factor to consider. When testing with cooling water circulation, overheating during summer should be avoided. Heat gain was calculated using CLTD technology, and was calculated for both indoor and outdoor water circulation scenarios. Overall, 3.44%, 4.78%, 7.67%, 15.87%, 11.45%, 10.21%, and 6.23%, respectively, were reduced heat gain, according to seasonal average statistics (7 months) as shown in figures (4,5). Since the bulk of heat absorption or heat transfer occurs through the roof throughout the day, this is a significant reduction and reflects an acceptable result.

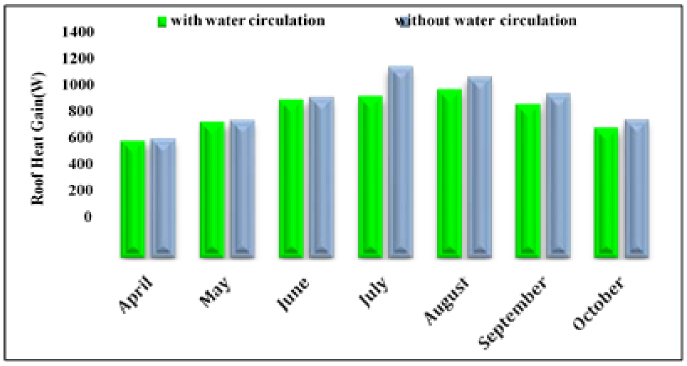

Fig (4): Effect of Water-Circulation on roof heat gain with months.

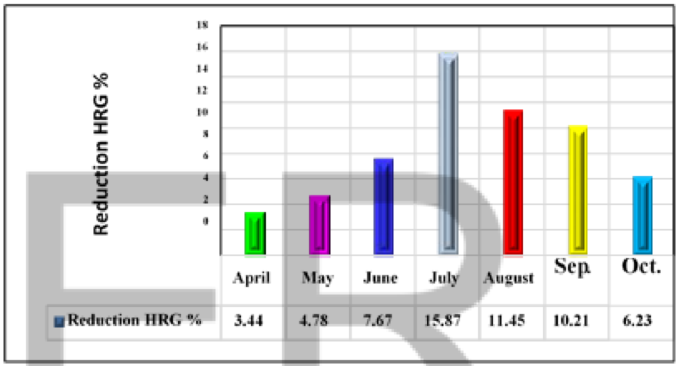

Fig (5): Percentage reduction amount of heat gained with months.

9 POWER CONSUMPTION

Figure 6 shows the amount of power consumed with and without a phase-changing material for the studied space for seven consecutive months during the summer from April to October, respectively. The obtained values showed the importance of the effect of a PCM on reducing power consumption in varying proportions, and for each of the previously mentioned months, as follows: 3.8%, 6.65 %, 7.34%, 8.57%, 5.85%, 4.77%, 3.53% as shown in Figure 7.

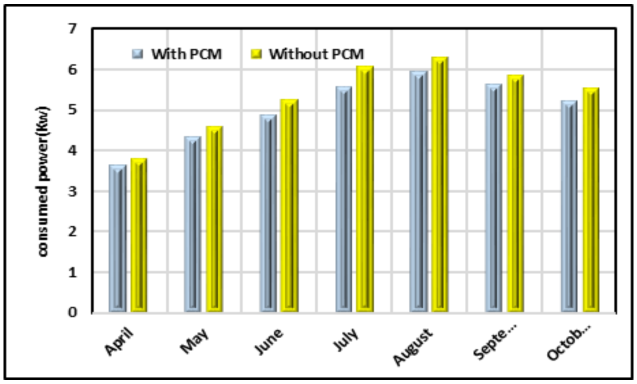

Fig (6): Power consumed with months.

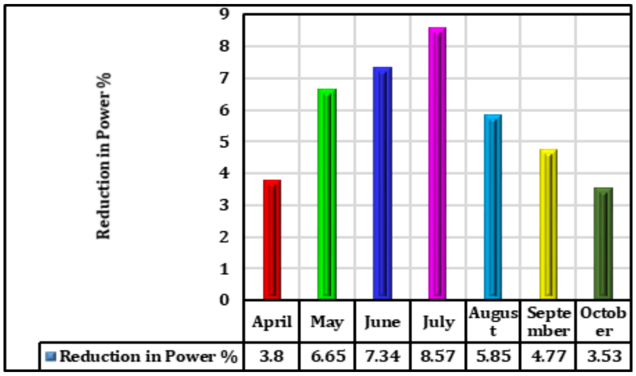

Fig (7): Percentage reduction in power with months.

10 EFFECT OF DISCHARGING PCM PROCESS ON PARAMETERS

Other illustrations in figure (8) allude to the average variation of energy consumed by A/C to discharge the PCM inside TES presuming constant duration of time, it is showing the energy consumed is increasing about 1 *KW* with the warmest summer months (June, July, and August), this justifies the hypotheses of the effect of heat gain during night resulted from the temperature difference between ambient and indoor to be presented as an extra thermal load on A/C evaporator at which won't participate on discharging PCM.

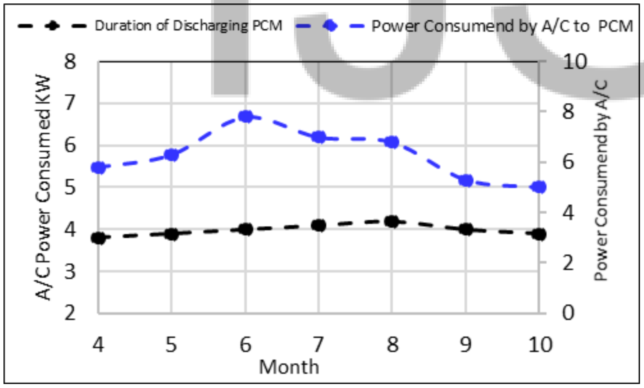

Fig (8): Effect of Power Consumed PCM vs. Duration

11 EFFECT OF CHARGING PCM PROCESS ON PARAMETERS

Figure (9) is showing the PCM is behaving in an almost similar range of charging (Heating) over months, that was for the Test, whilst the heat gain over three hours of peak time of charging was increasing with warm summer months, reasonably because of the effect of environment temperature and solar radiation.

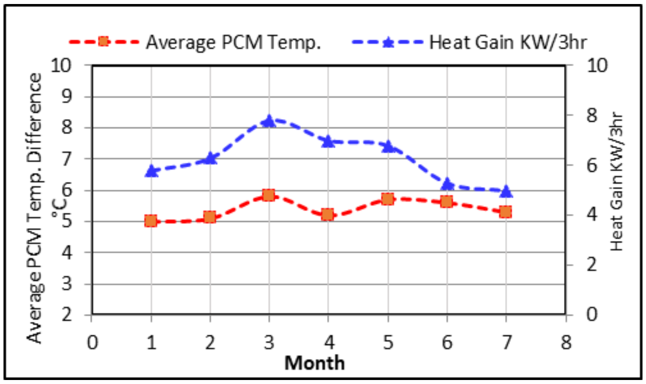

Fig (9): Heat Gain & PCM temp. Difference During 3hrs.

12 EFFECT OF A/C COP ENHANCEMENT ON OVERALL SYSTEM.

Figure (10) illustrates the average value of COP for an entire season and the enhancement level in Test 1. The COP is shaped in curvature concave maintaining the lowest values in the hottest month July and August 2.32 and 2.27 respectively, even though it is below the nominal CPO =2.83, the justification of such behavior is the extreme ambient temperature which directly influences the heat rejection from the condenser. Whilst the COP showed a significant increase with lower ambient temperature months, from this concept ambient temperature was cooled by the water evaporation process and pushed to the condenser on the reason of COP enhancement, Test 1 in the same figure (11) shows the blue trends is on top as it is diverging in low ambient temperature months because the evaporation cooling is more efficient.

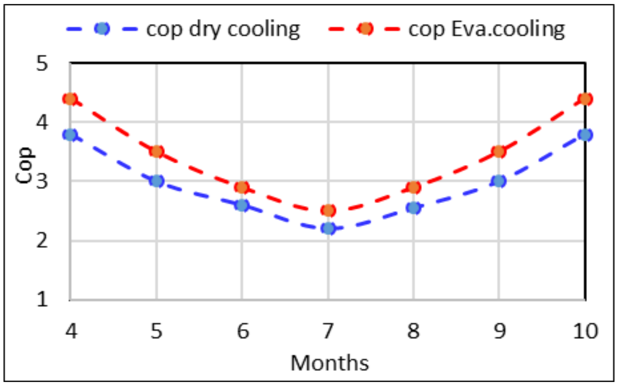

Fig (10): Average COP Variation Through Months.

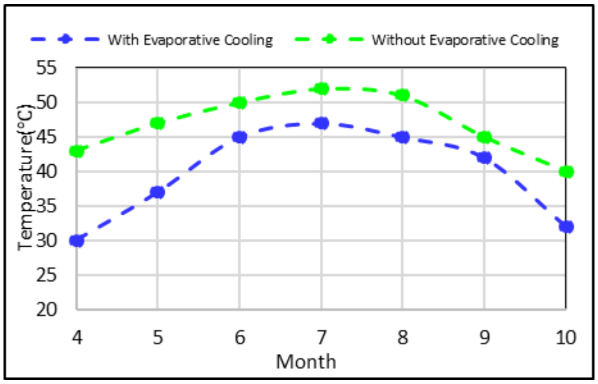

Fig (11): Average Monthly Temp. of Air Leaving Condenser

13 CONCLUSIONS

1-The experimental results showed that the reduction in the percentage of heat gained through the ceiling using water was 3.44%,4.78%, 7.67%, 15.87%, 11.45%, 10.21%, and 6.23% respectively.

2-The results also showed a reduction in power consumption by using paraffin for the summer months 3.8%, 6.65%, 7.34%, 8.57%, 5.85%, 4.77%, and 3.53% respectively.

3-A/C COP enhances by minimizing average condenser temperature, with air supplied from evaporative cooling can be enhanced within 9.01% during warm and dry summers in Iraq.

4-Ultimate heat gain timing shifting is directly affected by building material and overall building thermal capacitance.

5-PCM material is used in the application of residence cooling, its phase conversion temperature must be within the comfort temperature range of 22 to 27°C.

6-Only 27% of the energy spent on the discharging process alone by the A/C is going to discharge the PCM heat casing and minimize its temperature because the A/C must cool down the entire space during the night as well as the effect of TES effectiveness.

7-TES maintains the room temperature within a comfortable temperature range during the peak time of over 2.5 hours. In the last half hour, there has been a significant temperature increase. Especially during very warm summer days.

8-Maximum heat gain participation was through the roof at 43% without operating the systems, and water circulation was minimized to 21%.

14 NOMENCLATURE

Symbol	Description	Unit
A/C	Air Conditioner	-
Cop	Coefficient of performance	-
Cp	Specific heat of air	(J Kg^{-1} K^{-1})
Evap.	Evaporation	-
f	Final	-
h	Enthalpy	(J Kg^{-1})
HVAC	Heating, ventilation, and air conditioning	-
l	Liquid	-
m	Mass flow rate	(kg.sec^{-1})
Q	Heat transfer rate	(W)
T	Temperature	(°C or K)
TES	Thermal Energy Storage	-

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REFERENCES

[1] M. He, L. Yang, W. Lin, J. Chen, X. Mao, Z. Ma, Preparation, thermal characterization and examination of (PCMs) enhanced by carbon-based nanoparticles for solar thermal energy storage, Journal of Energy Storage. 25 (2019).

[2] Y. Zhang, J. Zhang, X. Li, X. Wu, Preparation of hydrophobic lauric acid / SiO 2 shape-stabilized PCMs for TES, Journal of Energy Storage. 21 (2019) 611–617.

[3] N. Aslfattahi, R. Saidur, A. Arifutzzaman, R,N. Bimbo, M.F.M. Sabri, P.A. Maughan, L. Bouscarrat, R.J. Dawson, S.M. Said, B.T. Goh, N.A.C. Sidik, C. Sidik, Experimental investigation of energy storage properties and thermal conductivity of a novel organic PCMs/MXene as A new class of nanocomposites, Journal of Energy Storage. 27 (2020).

[4] S.G. Ranjbar, G. Roudini, F. Barahuie, Fabrication and characterization of phase change material-SiO2 nanocomposite for thermal energy storage in buildings, Journal of Energy Storage. 27 (2020).

[5] W. Yang, R. Xu, B. Yang, J. Yang, Experimental and numerical investigations on the thermal performance of a borehole ground heat exchanger with PCM back fil, Energy. (2019).

[6] X. Bao, Y. Tian, L. Yuan, H. Cui, W. Tang, W.H. Fung, Development of high performance PCM cement composites for passive solar buildings, Energy and Buildings. 194 (2019) 33–45.

[7] S. Jeong, S. Wi, S. Jin, J. Lee, S. Kim, An experimental study on applying organic PCMs to gypsum-cement board for improving thermal performance of buildings in different climates, Energy and Buildings. 190 (2019) 183–194.

[8] Y. Song, C. Li, H. Yu, Y. Tang, Z. Xia, Optimization of the phase-change wallboard test method: Experimental and numerical investigation,

Journal of Energy Storage. 30 (2020).

[9] A.O. Acheampong, Economic growth, CO2emissions and energy consumption: What causes what and where? Energy Economics. 74 (2018) 677–692.

[10] K. Sohag, R.A. Begum, S.M. Syed Abdullah, M. Jaafar, Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia, Energy. 90 (2015) 1497– 1507.

[11] V. Andreoni, S. Galmarini, Drivers in CO2emissions variation: A decomposition analysis for 33 world countries, Energy. 103 (2016) 27–37.

[12] K. Ahmed, M. Bhattacharya, Z. Shaikh, M. Ramzan, I. Ozturk, Emission intensive growth and trade in the era of the Association of Southeast Asian Nations (ASEAN) integration: An empirical investigation from ASEAN-8, Journal of Cleaner Production. 154 (2017) 530– 540.

[13] Ibrahim, S.I.; Ali, A.H.; Hafidh, S.A.; Chaichan, M.T.; Kazem, H.A.; Ali, J.M.; Isahak, W.N.R.; Alamiery, A. Stability and thermal conductivity of different nano-composite material prepared for thermal energy storage applications. S. Afr. J. Chem. Eng. 2022, 39, 72–89.

[14] Wijesuriya, S.; Booten, C.; Bianchi, M.; Kishore, R.A. Building energy efficiency and load flexibility optimization using phase change materials under futuristic grid scenario. J. Clean. Prod. 2022, 339, 130561.

[15] Sheriyev, A.; Memon, S.; Adilkhanova, I.; Kim, J. Effect of Phase Change Materials on the Thermal Performance of Residential Building Located in Different Cities of a Tropical Rainforest Climate Zone. Energies 2021, 14, 2699.

[16] Sun, X.; Zhu, Z.; Fan, S.; Li, J. Thermal performance of a lightweight building with phase change material under a humid subtropical climate. Energy Built Environ. 2022, 3, 73–85