Quest Journals
Journal of Research in Mechanical Engineering
Volume 2 ~ Issue 11 (2016) pp: 01-07
ISSN(Online) : 2321-8185
www.questjournals.org

Research Paper

A Study of a Hybrid Solar Heat Storage Wall (Trombe Wall) Utilizing Paraffin Wax and Water

Miqdam T Chaichan[1], Khalil I Abaas[2], Dina S M Al-Zubaidi[3]

Received 25June, 2016; **A**ccepted 09 July, 2016© The author(s) 2014. **P**ublished with open access at **www.questjournals.org**

ABSTRACT: *In this study, a simple storage wall (Trombe wall) was built and tested in winter days in Baghdad City. The wall area was 1 m^2 facing south. The wall consisted of wooden box isolated by glass wool layer and covered by a glass cover with 4 mm thickness. Thirty-three plastic water bottles were arranged inside the box each has a 1.5-liter capacity, and a quantity of paraffin wax as phase change material (PCM) was put after this layer in a glass box. The paraffin wax amount was about 10 kg, and an aluminum plate with 4 mm thickness was fixed after it. This plate was colored by non-selective black color to attract as high as possible from solar heat.*
The study conducted in Baghdad City winter days in December 2015 and January 2016. The temperature distribution of the different parts of the Trombe wall was measured, and the stored energy inside these parts was evaluated. The results revealed that this wall is efficient in storing solar energy. This wall can be used as an assistant method to heat homes after sunset.
Keywords:*Trombe wall**, sensible heat, latent heat, paraffin wax, charging and discharging periods.*

I. INTRODUCTION

The term thermal energy storage refers to several techniques that store heat in thermal storage containers to be used at other times. The stored heat is used to work as an energy balance between day and night [1]. This energy will be stored in containers at temperatures too high or even low temperatures, and this stored energy is used typically in heating and cooling applications [2]. The energy storage technologies are used by solar powered applications, as it contains solar energy stored in the morning to be employed after sunset in heating or even in the electricity production [3 & 4].

The phase change materials (PCM) are considered as heat reservoir materials, which are inexpensive and can be applied at temperatures suitable for home applications [5 & 6]. These materials which store energy as latent energy called as phase change materials (PCM), and it is one of the efficient ways to save energy and characterized by high storing efficiency compared to materials that store energy as sensible energy [7 & 8]. The PCM can conserve energy equal to 5 to 14 times greater than stored in the sensible storing materials like gravel, water or concrete [9 & 10].

One of the practical applications of solar energy is placing a wall facing the sun in the wintertime. This wall is made from high-energy storage materials such as concrete, water, or wax to store heat, covered with a glass lid to prevent air streams from cooling the trapped air by convection [11]. In general, the wall is painted with a dark color to absorb solar radiation as heat [12]. The solar radiation short- waves pass through the glass cover and the long wave spectrum reflect from the wall could not return because of the glass cover which works in the impact of the greenhouse. The amount of heat absorbed from the wall depends on the heat capacity of the wall material, and the angle of the sun fall on the wall, color, and its reflectivity [13 & 14].
This wall is called the Trombe wall in proportion to the French Felix Trombe, who developed the idea of the wall in 1961, relying on the basic idea that of Edward Morse in 1881 [15]. Trombe Wall is used for heating in winter, where the wall heats the air trapped between it and the glass cover, which is raised by convection streams heading to the space to be heated from a top slot in the wall [16]. Also, Trombe wall can be used in ventilation in summer [17]. The wall thickness of 100 mm can be obtained theoretically at 8 hours heating, and practically Trombe wall can reduce the heat load up to 20 % [18 & 19].

Abaas built a simple type solar heat storage wall with an area of 0.91m^2. The wall consisted of 18 plastic water bottles (2.25 liter capacity) arranged in the wall. A reflector was put to increase solar energy reflected the bottles, and this mirror became as a cover at night. The wall was tested in Baghdad city at winter of years 2006 and 2007. The results showed the ability of this wall as a sun energy storage device. The maximum water temperature reached was 64.6°C while the maximum metal plate temperature of the wall was 74.4°C [20].

Faris solved the problems of turbulent flow and heat transfer characteristics through a room with Trombe wall by employing the fully Navier-Stokes and energy equations and a finite volume method. The Trombe wall system was made from water collector to heat a room with dimensions of (1×0.8×0.8) m. The study used the winter climatic conditions of Baghdad city as the affected atmospheric conditions. The thickness of air gap was changed (1, 2, 3 and 4 cm) while the thickness of Trombe wall was considered constant. The inlet velocity of 2 m/s was assumed on this system. The speed and temperatures distribution are predicted and compared. The study revealed that air velocity increased depending on air gap thickness, and the stagnant core region represents the center of the room where losses are very high, where heat increases and the buoyancy forces become dominant and increases by reducing speed [21].

In his article, Chaichan studied the Trombe wall concept by designing and fabricating one. The wall built from simple, locally available and cheap materials. The study tests conducted in Baghdad-Iraq wintertime to confirm the suitability of such walls for the Iraqi houses. The designed wall results indicated that it is suitable for utilization in Iraq wintertime. PCM usage in such wall showed a significant effect on the results. The paraffin wax as PCM appeared adequate storing media, besides of its availability and low prices [22].

Chaichan designed and fabricated two Trombe walls to investigate the effect of adding nano-Al_2O_3 to the paraffin wax on its thermal conductivity, and on the charging and discharging period of the wall. The study results showed that adding nan-Al_2O_3 enhanced the charging and discharging times. The nano-paraffin wall had stored higher temperatures and its charging time was faster compared to the wall with wax only. The discharge of the stored energy was faster, depending on the entering outside air temperature and its mass flow rate. Adding nanomaterial to the paraffin wax in the studied Trombe wall had gained overall higher temperatures up to 29.08% compared to the wax alone wall. The paraffin wax with nano-material temperatures discharges its stored energy faster than that for the wax alone case with about 42.68% [23].

In continuous of previous studies [24 to 51] in the Energy and Renewable Energies Technology Center, this paper investigated a simple solar storage wall (Trombe wall), which was designed and fabricated and fixed facing south and used in winter days. The sensible heat storage media (water) was used with the aid of latent heat storage media (PCM) in a Trombe wall at Baghdad city winter days. The study aimed to determine the energy supplied to the Trombe wall, the charging time and the practical conditions of its performance.

II. MATERIALS AND METHODS

Working Principle of Trombe Wall

Trombe wall is a passive solar system, which its applications are simple, economical and suitable for variable latitudes locations. A Trombe wall, in general, consists of a massive thermal wall covered with a transparent glass cover and a convective air gap between the two materials [52 & 53]. The heated wall collects and stores solar radiation energy. The solar radiation during the day passes through the glazing cover and is absorbed by the dark surface of the massive thermal wall. This heat is stored in the wall and permeates through the wall slowly with a time delay about the wall surface. A high transmission glass is used to maximize the solar gained by the wall [54]. The stored energy is used as a space heating source, as well as, the air inside the wall gap moves by convections streams for this purpose. Also, the air movement can be used for ventilating the building. The thermal conductive characteristics of the Trombe wall states the space heating/cooling performance, as it depends on the airflow specification whether in the air gap or in the room itself. Sliding panels, shading devices may be used with Trombe walls to prevent overheating in summer months. Also, forced air recirculation can be equipped [55].

The studied wall design

Was to build a model of the wall of the treasurer of solar energy a component of wood box dimensions meters and thickness of 1 cm from the open top and an envelope from the outside of the glass wool insulation to increase the thermal insulation of the Fund. In the inner part of the wooden box and put a plate of aluminum painted in black and a thickness of 4 mm. Then put a glass sheet of 3 mm thickness at a distance of 1 cm from the plate. The space between the plate and the bottle was filled with paraffin wax produced by Al-Dora Refinery in Baghdad-Iraq, which its specifications are included in Table 1. In front of the paraffin wax, 33 water bottles with 1.5-liter capacity each were arranged in the wooden wall. Fifteen thermocouple type K were distributed: 5 in different locations in the paraffin wax, 5 in variable water bottles, two on the aluminum plate and the last three were used to measure the air in the air gap. The tests were conducted in Dec-2015 and Jan-2016 which represents the winter season in Iraq. The tests carried out in 8 days each month, and the average was taken to represent the wall parts behaviors. The experiments were conducted starting at 8 AM until the wall parts temperature return to equalize the outdoor temperature. Solar power meter type Iso-Tech ISM-410 (Taiwan made) was used to measure the solar intensity each hour.

The instruments uncertainty

In this study 15 thermocouples, type K were used. They were connected to a selector switch type 4XM, and the temperature was measured using a digital thermometer type GX5. All the measuring devices were calibrated in the laboratory, and their uncertainty was evaluated. The instruments uncertainty was 2.03 which is an acceptable value that confirms the efficient study results

The following equations were used in the study:

The thermal energy stored in the wax when it was in its solid state (from 8 AM till about 1 PM):

$$Q_{wax} = m_{wax} \times Cp_{s,wax} \times (T_{i+1} - T_i)$$

When the paraffin wax started to melt (fusion phase)

$$Q_{wax} = m_{wax} \times h_{fg}$$

After all the paraffin wax turned into liquid

$$Q_{wax} = m_{wax} \times Cp_{l,wax} \times (T_{i+1} - T_i)$$

The thermal energy stored in the water

$$Q_{water} = m_{water} \times Cp_{water} \times (T_{i+1} - T_i)$$

As the aluminum plate is in contact with the wax, the plate temperature will be equal to the paraffin wax temperature. For the aluminum plate:

$$Q_{Al} = m_{Al} \times Cp_{Al} \times (T_{i+1} - T_i)$$

The hourly efficiency for the wall

$$\eta_h = \frac{Q_{total}}{I \times A}$$

$$Q_{total} = Q_{wax} + Q_{water} + Q_{Al}$$

Fig. 1, the studied Trombe wall

III. RESULTS AND DISCUSSIONS

In this study, we had designed and manufactured Trombe Wall suitable for home heating applications in Iraq. Winter is characterized by a moderate degrees atmosphere of Iraq most he time, not less than 10ºC in the morning, and goes down below zero Celsius at night. The highest value for the intensity of solar radiation in the winter ranges from 290 to 450 W/m^2.

In the current Trombe wall, a combination of the two methods of storing heat (sensible and latent) was used. Water was used to store the sensible heat and the Paraffin wax as a phase change material for the storage of latent heat. The mixing of two storage methods was for the purpose of creating a thermal storage wall with a potential dynamic air heating.

Fig. 1 represents the solar intensity for the tested period. The figure reveals that the solar intensity in Dec.-2015 was less than Jan.-2016. These differences in solar intensity have a significant effect on the heat gained by the wall. From the measured solar intensity, we can assume that the heat acquired by the wall will be higher on Jan. compared to that of Dec.

Figs. 3 & 4 indicate the temperature of the central parts of the wall. For the three sections, the temperature increased from the first morning until 1 PM, and then it declines after 4 PM. This period from 8 AM to 4 PM can be represented as the charging period where the wall parts heated till its reach its maximum storage ability. For the time from 8 to 12 AM, the wax temperature was higher than the water temperature although the most incident solar radiation was falling on water as it was at the front of the wall. The high water specific heat made the increments in temperature lower than that for the wax which has less specific heat. For the period from 12 AM to 4 PM. The water temperature exceeded the other parts temperatures, and the sensible heat of storage rose. For the time from 4 PM till 10 PM, this period can be named as discharge period, where all the storage heat will be transferred to the cold air to heat it. In this time the water temperature declines faster than the other parts, due to two reasons: first, the air comes into contact with the bottled water entirely as it entered the wall, while touching one end of the wax. The aluminum plate, as it is the last part of the wall isolated from the air by the wax, its temperature remain higher than the other parts.

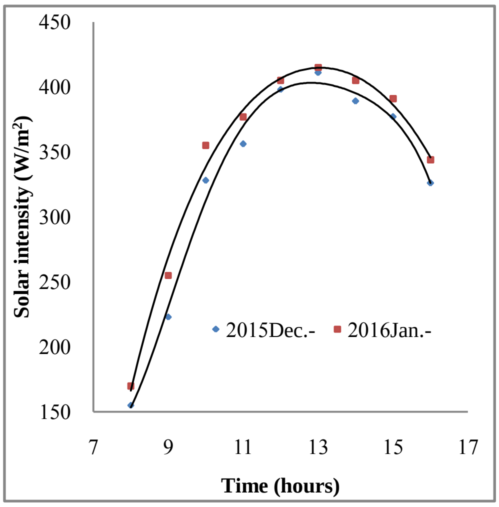

Fig. 2,the average solar intensity values for the two months.

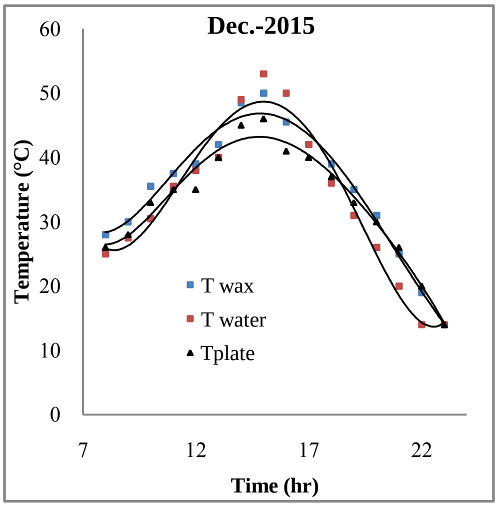

Fig. 3,the temperature of the Trombe wall parts during December test period

The time needed to equalize the wall parts temperature with the air temperature was 6 hours (which represents the discharge period). This period is long enough to confirm the success of the designed wall. The increase of the discharge time depends mainly on the wall size. As a comparison between figures 3 & 4, at January the wall parts were higher due to higher solar intensity.

Fig. 4 shows the average thermal energy stored in the fabricated Trombe wall for the two winter months. The aluminum plate has low energy storage capability due to its small mass and specific heat. The wax storage energy was less than the water due to the weight of the water used in the experiments was higher several times than that of wax. In addition to the water specific heat is greater by more than double of those of paraffin wax. In general, the total heat stored in the wall during the charging period was high, which confirm the success of employing this cheap and easily manufactured wall for heating applications in Iraq.

Fig. 5 clarifies the hourly efficiency during the tests period. The efficiency depends mainly on how much utilized from the solar radiation falling on the wall. The results reveal high efficiencies were gained, although most of the solar devices have low efficiencies. This result confirms the suitability of this wall for heating applications.

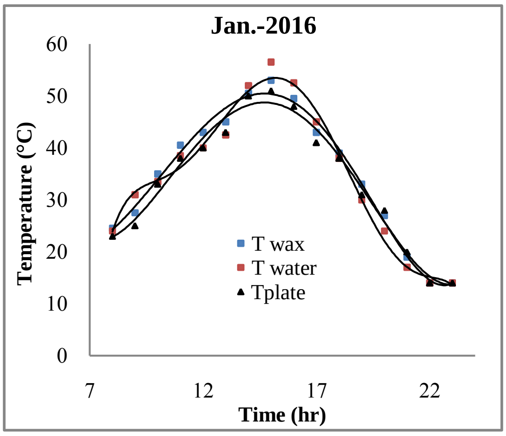

Fig. 3,the temperature of the Trombe wall parts during January test period

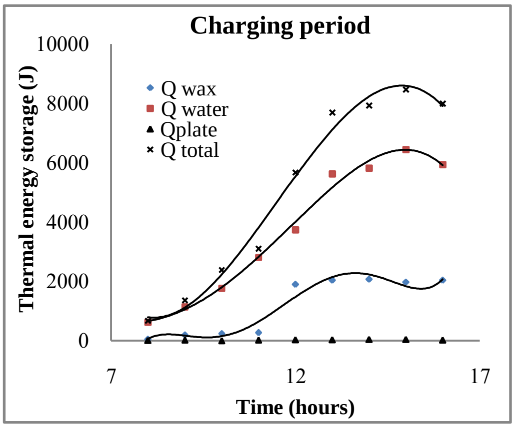

Fig. 4,the average thermal energy storage of the Trombe wall parts during the charging period

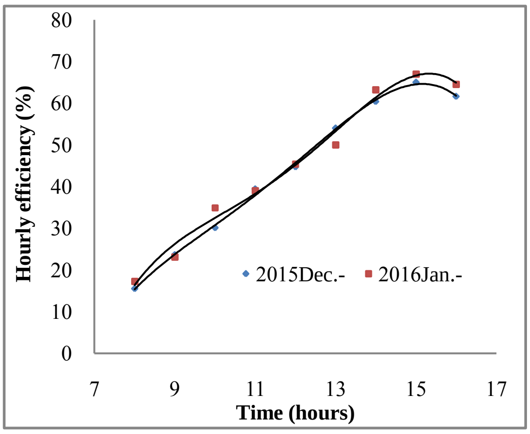

Fig. 5, the average hourly efficiency of the Trombe wall for the tested period

IV. CONCLUSIONS

In this study, a hybrid Trombe wall was designed and manufactured to run on both sensible and latent heat storage modes. This wall characterized by simple and inexpensive parts. The experiments were conducted on the wall in the winter days of Baghdad city of Iraq (December-2015 and January-2016). The study results confirmed the success of this type of wall to be applied for heating air in Iraq. The high solar intensity of Iraq enables the wall of storing temperature as sensible and latent heat. This stored thermal energy is the heat source for the air at night. The majority of the stored heat was by the water due to its high mass and specific heat compared with the other wall parts. Although the paraffin wax has lower mass and specific heat compared to water, it contributed significantly to the heat stored during the phase change period and in heating the air in the discharge time.

REFERENCES

[1]. J A Tenorio, J. Sánchez-Ramos, A. Ruiz-Pardo, S. Álvarez andL. F. Cabeza, Energy efficiency indicators for assessing construction systems storing renewable energy: application to phase change material-bearing façades, Energies, 8, 2015, 8630-8649; doi:10.3390/en8088630.

[2]. J Giro-Paloma, C. Barreneche, M. Martínez, B. Sumiga, A. I. Fernandez, L. F. Cabeza, Mechanical response evaluation of microcapsules from different slurries, Renewable Energy, 85, 2016, 732-739.

[3]. SUshak, M. J. Cruz, L. F. Cabeza, M. Grágeda, Preparation and characterization of inorganic PCM microcapsules by fluidized bed method, Materials, 9(24), 2016; doi:10.3390/ma9010024.

[4]. FAscione, N. Bianco, R. F. De Masi, F. de' Rossi, G. P. Vanoli, Energy refurbishment of existing buildings through the use of phase change materials: energy savings and indoor comfort in the cooling season, Appl. Energy, 113, 2014, 990–1007.http://dx.doi.org/10.1016/j.apenergy.2013.08. 045.

[5]. CBarrenechea, M. E. Navarroa, L. F. Cabezab, A. I. Fernández, New database to select phase change materials: Chemical nature, properties, and applications, Journal of Energy Storage, 3, 2015, 18–24.

[6]. S Khare, M. Dell'Amico, C. Knigh, S. McGarry, Selection of materials for high temperature sensible heat energy storage, Sol. Energy Mater. Sol. Cells., 115, 2013, 114–122.

[7]. A M Thiele, G. Sant, L. Pilon, Diurnal thermal analysis of microencapsulated PCM-concrete composite walls, Energy Conversation Management, 93, 2015, 215–227;

[8]. http://dx.doi.org/10.1016/j.enconman.2014.12.078.

[9]. J Giro-Paloma, M. Martínez, L. F. Cabeza, A. I. Fernández, Types, methods, techniques, and applications for microencapsulated phase change materials (MPCM): A review, Renewable and Sustainable Energy Reviews, 53, 2016, 1059–1075.

[10]. M Saffari, A. de Gracia, S. Ushak, L. F. Cabezaa, Economic impact of integrating PCM as passive system in buildings using Fanger comfort model, Energy and Buildings, 112, 2016, 159–172.

[11]. M Dabaieh, A. Elbably, Ventilated Trombe wall as a passive solar heating and cooling retrofitting approach; a low-tech design for off-grid settlements in semi-arid climates, Solar Energy, 122, 2015, 820–833.

[12]. K Irshad, K. Habib, N. Thirumalaiswwamy, M. W. Kareem, Thermal comfort analysis of building assisted with photovoltaic Trombe wall, MATEC web of Conference, vol. 38, 02003, 2016, DOI: 10.1051/matecconf/2016382003

[13]. Z Hu, B. Luo, W. He, An experimental investigation of a novel Trombe wall with venetian blind structure, Energy Procedia, 70, 2015, 691–698.

[14]. O Saadatian, K. Sopian, C. H. Lim, Trombe walls: A review of opportunities and challenges in research and development, Renewable and Sustainable Energy Reviews, 16, 2012, 6340-6351.

[15]. ABriga-Sáa, A. Martins, J. Boaventura-Cunha, J. C. Lanzinhaa, A. Paiva, Energy performance of Trombe walls: Adaptation of ISO 13790:2008(E) to the Portuguese reality, Energy and Buildings, 74, 2014, 111–119.

[16]. W Sun, J. Ji, C. Luo, W. He, Performance of PV-Trombe wall in winter correlated with south façade design, Applied Energy, 88, 2011, 224–231.

[17]. R.Nowzari, U. Atikol, Transient performance analysis of a model building integrated with a Trombe-Wall, 7th Int. Conf. on Heat Transfer Thermal Engineering and Environment (HTE'09), 20-22 August, Moscow, Russia, 2009.

[18]. T G Özbalta, S. Kartal, Heat gain through Trombe wall using solar energy in a cold region of Turkey, Scientific Research and Essays, 5 (18), 2010, 2768-2778.

[19]. M Bensafi, N. E. Kaid, K. Hami, M. Abdeldjabar, M. Hasnat, B. Draoui, Modeling the energy effect of a passive heating system provided with a Trombe Wall, International Journal of Engineering Science Invention, 3 (7), 2014, 66-71.

[20]. SJaber, S. Ajib, Optimum design of Trombe wall system in Mediterranean region, Solar Energy, 85, 2011, 1891–1898.

[21]. K I Abaas, Experimental study to improve thermal performance of simple solar energy collecting wall, Wassit Journal for Science & Medicine, 2 (2), 2009, 212-221.

[22]. S SFaris, M. T. Chaichan, M. F. Sachit and J. M. Jaleel, Simulation and numerical investigation of effect air gap thickness on Trombe wall system, International Journal of Application or Innovation in Engineering & Management (IJAIEM), 3 (11), 2014, 159-168.

[23]. M T Chaichan andAbaas K H, Performance amelioration of a Trombe wall by using phase change material (PCM), International Advanced Research Journal in Science, Engineering and Technology, 2 (4), 2015, 1-6.

[24]. M T Chaichan,Al-Hamdani A H, Kasem A M, Enhancing a Trombe wall charging and discharging processes by adding nano-Al_2O_3 to phase change materials, International Journal of Scientific & Engineering Research, 7 (3), 2016, 736-741.

[25]. M T Chaichan andAbaas K I, Practical investigation for improving concentrating solar power stations efficiency in Iraqi weathers, Anbar J for Engineering Science,.5 (1), 2012, 76-87.

[26]. M T Chaichan and Kazem H A, Status and future prospects of renewable energy in Iraq, Renewable and Sustainable Energy Reviews, 16 (1), 2012, 6007–6012.

[27]. AAKazem, M. T. Chaichan, H. A. Kazem, Dust effect on photovoltaic utilization in Iraq: Review article, Renewable and Sustainable Energy Reviews, 37, 2014, 734-749.

[28]. M T Chaichan andKazem H A, Thermal storage comparison for variable basement kinds of a solar chimney prototype in Baghdad-Iraq weathers, International Journal of Applied Energy, 2 (2), 2011, 13-20.

[29]. M T Chaichan,K. I. AbaasandH. A. Kazem H A, The effect of variable designs of the central receiver to improve the solar tower efficiency, International J of Engineering and Science, 1 (7), 2012, 56-61.

[30]. M T Chaichan and K. I. Abaas, Productivity amelioration of solar water distillator linked with salt gradient pond, Tikrit Journal of Engineering Sciences,19 (4), 2012, 24-34.

[31]. H A Kazem, M. T. Chaichan, I. M. Al-Shezawi, H. S. Al-Saidi, H. S. Al-Rubkhi, J. K. Al-Sinani and A. H. A. Al-Waeli, Effect of Humidity on the PV Performance in Oman, Asian Transactions on Engineering ,2 (4), 2012, 29-32.

[32]. M T Chaichan, K. I. Abaas, H. A. Kazem, H. S. Al JiboriandU. Abdul Hussain, Novel design of solar receiver in concentrated power system, International J. of Multidispl. Research &Advcs. in Eng. (IJMRAE), 5 (1), 2013, 211-226.

[33]. Z ADarwish, H. A. Kazem, K. Sopian, M. A. Alghoul and M. T. Chaichan, Impact of some environmental variables with dust on solar photovoltaic (PV) performance: Review and research status, International J of Energy and Environment, 7 (4), 2013, 152-159.

[34]. A A Al-Waeely, S. D. Salman, W. K. Abdol-Reza, M. T. Chaichan M T, H. A. Kazem and H. S. S. Al-Jibori, Evaluation of the spatial distribution of shared electrical generators and their environmental effects at Al-Sader City-Baghdad-Iraq, International Journal of Engineering & Technology IJET-IJENS, 14 (2), 2014, 16-23.

[35]. M T Chaichan andH. A. Kazem, Using aluminum powder with PCM (paraffin wax) to enhance single slope solar water distillator productivity in Baghdad-Iraq winter weathers, International Journal of Renewable Energy Research, 1 (5), 2015, 151-159.

[36]. M T Chaichan,H. A. Kazem, Water solar distiller productivity enhancement using concentrating solar water heater and phase change material (PCM), Case Studies in Thermal Engineering, Elsevier, 5, 2015, 151-159.

[37]. M T Chaichan,B. A. Mohammed and H. A. Kazem, Effect of pollution and cleaning on photovoltaic performance based on experimental study, International Journal of Scientific and Engineering Research, 6 (4), 2015, 594-601.

[38]. M T Chaichan,H. A. Kazem, A. A. Kazem, K. I. Abaas, K. A. H. Al-Asadi, The effect of environmental conditions on concentrated solar system in desertec weathers, International Journal of Scientific and Engineering Research, 6 (5), 2015, 850-856.

[39]. M T Chaichan,K. I. Abaas, H. A. Kazem, Design and assessment of solar concentrator distillating system using phase change materials (PCM) suitable for desertec weathers, Desalination and water treatment, 2015, 1-11.

[40]. DOI: 10.1080/19443994.2015.1069221

[41]. H M S Al-Maamary, H. A. Kazem, M. T. Chaichan, Changing the energy profile of the GCC States: A review, International Journal of Applied Engineering Research (IJAER), 11 (3), 2016, 1980-1988.

[42]. H AKazem andM. T. Chaichan, Experimental analysis of the performance characteristics of PEM Fuel Cells, International Journal of Scientific & Engineering Research, 7 (2), 2016, 49-56.

[43]. M T ChaichanandH. A. Kazem, Experimental analysis of solar intensity on photovoltaic in hot and humid weather conditions, International Journal of Scientific & Engineering Research, 7 (3), 2016, 91-96.

[44]. H A Kazem, M. T. Chaichan, S. A. Saif, A. A. Dawood, S. A. Salim, A. A. Rashid, A. A. Alwaeli, Experimental investigation of dust type effect on photovoltaic systems in north region, Oman, International Journal of Scientific & Engineering Research, 6 (7), 2015, 293-298.

[45]. M T Chaichan,S. H. KamelandA. N. M. Al-Ajeely, Thermal conductivity enhancement by using nano-material in phase change material for latent heat thermal energy storage Systems, SAUSSUREA, 5.(6), 2015, 48-55.

[46]. H A Kazem and M. T. Chaichan M T, Effect of humidity on photovoltaic performance based on experimental study, International Journal of Applied Engineering Research (IJAER), 10 (23), 2015, 43572-43577.

[47]. H A Kazem, A. H. A. Al-Waeli, A. S. A. Al-Mamari, A. H. K. Al-Kabi, M. T. Chaichan, A photovoltaic application in car parking lights with recycled batteries: A techno-economic study, Australian Journal of Basic and Applied Science, 9 (36), 2015, 43-49.

[48]. H. A. Kazem, A. H. A. Al-Waeli, M. T. Chaichan, A. S. Al-Mamari, A. H. Al-Kabi, Design, measurement and evaluation of photovoltaic pumping system for rural areas in Oman, Environ Dev Sustain, 2016. DOI 10.1007/s10668-016-9773-z.

[49]. M T ChaichanandH. A. Kazem, Experimental analysis of solar intensity on photovoltaic in hot and humid weather conditions, International Journal of Scientific &Engineering Research, 7 (3),2016, 91-96.

[50]. M T Chaichan,H. A. Kazem, A. M. J. MahdyandA. A. Al-Waeely, Optimal sizing of a hybrid system of renewable energy for lighting street in Salalah-Oman using Homer software, International Journal of Scientific Engineering and Applied Science (IJSEAS), 2 (5), 2016, 157-164.

[51]. M T Chaichan, Enhancing productivity of concentrating solar distillating system accompanied with PCM at hot climate, Wulevina, 23 (5), 2016, 1-18.

[52]. M T Chaichan,H. A. Kazem, K. I. Abaas, A. A. Al- Waeli, Homemade solar desalination system for Omani families, International Journal of Scientific & Engineering Research, 7 (5), 2016, 1499-1504.

[53]. M T Chaichan,H. A. Kazem, A. M. J. MahdyandA. A. Al-Waeely, Optimization of hybrid solar PV/ diesel system for powering telecommunication tower, International Journal of Engineering Sciences & Emerging Technologies (IJESET), 8 (6), 2016, 1-10.

[54]. JJie, Y. Hua, H. Wei, P. Gang, L. Jianping andJ. Bin, Modeling of a novel Trombe Wall with PV cells, Building and Environment, 42 (3), 2007, 1544-1552.

[55]. JJie, Y. Hua, H. WeiandP. Gang P, PV-Trombe wall design for buildings in composite climates, J. Solar Energy Eng. ASME, 129, 2007, 431-437.

[56]. P TorcelliniandS. Pless, Trombe walls in low-energy buildings: Practical experiences preprint, World Renewable Energy Congress VIII and Expo Denver, Colorado, NREL, 2004.

[57]. A Kianifar, M. Rezazadeh, An improved design method for estimating the annual auxiliary energy requirement for solar heating building, Desalination, 209, 2007, 182-189.