

## Experimental Study on Heat Gain Reduction and Economic Evaluation of Mixed Asphalt Solar Water Heater (MASWH)

<sup>1</sup>Jirasak Pukdum, <sup>2</sup>Krichkanok Sudasna and <sup>1</sup>Tinnapob Phengpom  
<sup>1</sup>Rattanakosin College for Sustainable Energy and Environment,  
<sup>2</sup>Faculty of Architecture and Design,  
Rajamangala University of Technology Rattanakosin, Salaya,  
Puthamonthon, 73170 Nakhonpathom, Thailand

---

**Abstract:** This study studied the Mixed Asphalt Solar Water Heater (MASWH) integrated on the roof top. This solution can reduce ceiling heat gain into the room. Both reference house and house-integrated with MASWH have dimension 1 m width, 1 m length and 1 m height. The MASWH has a thickness of 0.05 m, width of 0.5 m and a length of 1 m. One house equipped with MASWH on the roof top to test in experiments while the other house was served as reference. The roof was inclined at 30° to the horizontal. The experimental result showed that the attic temperature and room temperature. The house-integrated with MASWH could reduce attic temperature of 3°C and room temperature of 4°C, respectively. The percentage of room temperature decreased in the range of 7-10%. Heat gain reduction of the house-integrated with MASWH become better than reference house about 5-12 Wm<sup>-2</sup> and the maximum of outlet water temperature was 52.8°C. Obviously, installing MASWH on the roof top can reduce heat transfer. The economic value was evaluation as the payback period and the result showed that 2.5 years.

**Key words:** Mixed asphalt, solar water heater, heat gain reduction, thermo-economic, temperature, length

---

### INTRODUCTION

Global warming and energy shortage lead to restructuring global energy policy and interesting issue in the development of renewable energy technologies in many countries. Solar energy can contribute to solve such problems and increase the energy security of each country through dependence on clean energy resources. The development of solar energy technologies has long term benefits. Solar water heaters are a kind of solar energy innovation. Flat plate solar collectors are the common type for the applications water heating because they are most likely to be cost-effective for houses or buildings with water heating systems (Shah, 2018). In addition, flat plate solar collector developed and improved the performance of many researchers. Said *et al.* (2015) studied solar collector efficiency of TiO<sub>2</sub>-H<sub>2</sub>O nanofluid as a working fluid. The efficiency of solar collectors using TiO<sub>2</sub>-H<sub>2</sub>O nanofluid had higher exergy and energy efficiency than water. Moreover, Michael and Iniyar (2015) studied CuO nanoparticles can increase the thermal efficiency of solar water heaters of 6.3% at a volume concentration of 0.05%. Meanwhile, He *et al.* (2015) investigated the effect of Cu-H<sub>2</sub>O nanofluids and

thermal conductivities of flat plate solar collector. The results showed that the thermal conductivity of nano-fluid Cu-H<sub>2</sub>O increased significantly. It is suitable for increasing the efficiency of the flat plate solar collector. Moreover, Jouybari *et al.* (2017) had designed flat plate solar water heater using Al<sub>2</sub>O<sub>3</sub>/water nanofluid as the fluid flow. The surface area of the heat exchanger was 0.12 m<sup>2</sup>. The result showed that collector efficiency rises to 14.3% when using Al<sub>2</sub>O<sub>3</sub>/water nanofluid with a flow rate at 2 L min<sup>-1</sup>. Besides, Hussain and Harrison (2017) estimated flat solar collector with integrating passive air-cooling channel and a proper valve control at the outlet opening which could help extend the life of the flat plate solar collector. Furthermore, Zhou *et al.* (2017) applied the flat plate solar collector with high thermal and antifreeze performance in cold areas. Results showed that the performance of the antifreeze flat plate collector could put off fully frosted, in time by 2.5 h. Moreover, Bhowmik and Amin (2017) created the prototype of the solar water heater by using reflective sheeting and the accumulative performance of system improved about 10%. Meanwhile, Jouybari *et al.* (2017) investigated the effect of metal foam on the performance and pressure loss of flat plate solar collectors. The maximum

energy absorbed was 18.5% and increased or decreased with the flow rate. Fluorine-doped Tin Oxide (FTO) was used to improve the performance of the solar water heater system. One system used ordinary glass and the other special glasses. The maximum outlet water temperature with the other systems was 40°C and special glass was 45°C (Prakasam *et al.*, 2017).

Solar water heaters were mostly used to install on the rooftop of the houses or buildings because the roof is direct-exposure to solar radiation. Besides, the energy consumption in houses or buildings can be considered an efficient building design. In addition, reducing heat into the house or building is very important, that leads to the use of installing applications and testing equipment to reduce the heat transfer into the houses or building. The attic heat gain reduction of roof solar collector was studied by Puangsombut *et al.* (2007). Meanwhile, Amornleetrakul *et al.* (2014) presented the Ventilated Roof Tile (VRT) for heat gain reduction into the house. The area of each house for the experiment was 2.25 m<sup>2</sup> (1.5×1.5 m). The surface area of the Ventilated Roof Tile (VRT) was 2.58 m<sup>2</sup>. The results presented that the performance of Ventilated Roof Tile (VRT) could reduce heat gain more than common concrete roof tiles. Furthermore, the tile ventilator was used to reduce ceiling heat gain by Juengpimonyanon *et al.* (2014) Two small houses used for comparison experiments. One house, fitted with ventilation tiles and the other one has used common tile vary as a reference house. The house was integrated tile ventilator shown the temperature attic and room that lower than common tile varied. Afterward, Phiraphat *et al.* (2017) proposed a comparison normal PV panel and between the PV Roof Solar Collector (PV-RSC) to studied the natural convection in a rectangular channel. The inclination angle was fixed at 30° and the air gap channel at 15 cm. The results revealed that PV Roof Solar Collector (PV-RSC) could be enhanced PV performance throughout the day about 25% and prevents roof heat gain. Moreover, the air flow temperature and PV panel temperature affected the efficacy of the PV roof solar collector. Recently, Prommas *et al.* (2019) studied the heat gain reduction into the house by using the light-vent pipe integrated into the attic. The inclination angle of the roof was 30°. The light-vent pipe was made from an aluminum sheet with a diameter of 0.15 m. As a result of the experiment, the light-vent pipe decreased the heat gain through the roof. This study investigates the heat gain reduction into the house by integrated MASWH on the rooftop. The facile Thermo-economic evaluation was studied to forecast the payback period of the MASWH integrated on the rooftop.

## MATERIALS AND METHODS

**Experimental set-up and description:** Figure 1 shows the dimension and schematic diagram of the MASWH<sup>12</sup>. The MASWH was composed of glass cover of 0.04 m on the top. The air gap between the glass cover and the mixed asphalt was 0.05 m. The selective collector made of mixed asphalt which has a thickness of 0.05 m, width of 0.5 m and a length of 1 m. The copper pipe was a serpentine type buried about 3/4 in the mixed asphalt. It has a total length pipe of 9 m and the inner diameter of 0.0952 m. The insulation has the thickness of 0.01 m.

To investigate the heat gain reduction, the comparable two small houses with no windows were built. The test house was integrated the MASWH on the rooftop and reference house used to compare data as shown in Fig. 3 and 4. The water flow rate was feed at 0.02 kg sec<sup>-1</sup> into the MASWH. The structure model of two small houses was built from the steel and roof thatched with the corrugated metal sheet. The roof was base area dimensions of 1.4×1.60 m (2.24 m<sup>2</sup>) and inclination of the roof fixed at 30°. The ceiling was built by gypsum board (0.09 m thickness). Each room was base dimensions of 1×1 m (1 m<sup>2</sup>) and height 1 m from floor to ceiling. The walls covered with the smart board (0.01 m thickness) and all interior and exterior wall surfaces were painted white. There is no opening air ventilation at the attic and room.

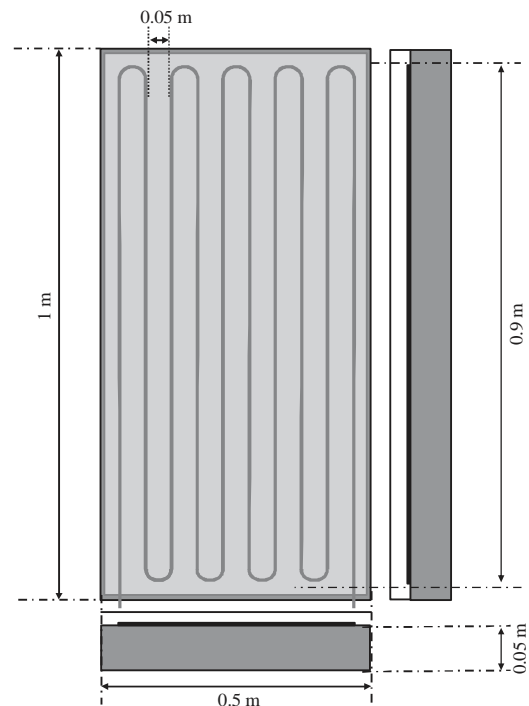


Fig. 1: Dimension of MASWH

The pyranometer (Kipp and Zonen, Model: CMP11, range: 310-2800  $\mu\text{m}$ , uncertainty <2%) was installed on the rooftop for measuring solar radiation intensity. The flow meter (Nitto, Model: Z-5015, accuracy  $\pm 5\%$ ) was used to measure the volume flow rate. The thermocouples type K (range: 0-800 $^{\circ}\text{C}$ , accuracy  $\pm 0.4^{\circ}\text{C}$ ) were connected to the data logger (Hioki: Model LR8422-20, accuracy  $\pm 0.7\%$ ) for measuring the temperature. Heat flux sensor (EKO flow meter: Model MF-180, range: 1-1400  $\text{Wm}^{-2}$ , accuracy  $\pm 2\%$ ) for measuring heat gain as shown in Fig. 2 and 3. The data were recorded from 6:00-18:00 and these data noted every 1 min. Two small houses for testing was built on the rooftop at the Faculty of Architecture and Design Rajamangala University of Technology Rattanakosin Thailand (latitude 13 $^{\circ}$ 47'41.3"N and the longitude 100 $^{\circ}$ 17'56.7" E).

**Data reduction:** The thermal performance of MASWH can be estimated by energy balance that defines the section of the incoming solar radiation delivered as useful energy. The useful energy expresses by the collector and useful heat gain by the fluid follows as:

$$Q_u = A_c F_R [S - U_L (T_{pm} - T_a)] = \dot{m} C_p (T_{fo} - T_{fi}) \quad (1)$$

Where:

- $Q_u$  : Useful energy gain (W)
- $A_c$  : Collector area ( $\text{m}^2$ )
- $F_R$  : Collector heat removal factor (-)
- $S$  : Absorbed solar radiation per unit area ( $\text{W.m}^{-2}$ )
- $U_L$  : Collector overall heat loss coefficient ( $\text{W.m}^{-2}$ )
- $T_{pm}$  : The mean of absorber plate temperature ( $^{\circ}\text{C}$ )
- $T_a$  : Ambient temperature ( $^{\circ}\text{C}$ )
- $\dot{m}$  : Mass flow rate ( $\text{kg.s}^{-1}$ )
- $C_p$  : The specific heat of water ( $\text{kJ.kg.s}^{-1}$ )
- $T_{fi}$  : The fluid inlet temperature ( $^{\circ}\text{C}$ )
- $T_{fo}$  : The fluid outlet temperature ( $^{\circ}\text{C}$ )

## RESULTS AND DISCUSSION

**Solar radiation and ambient temperature:** The experiment investigated the heat gain reduction of a MASWH which was integrated on the roof top to decrease the energy demands in the room. Experimental data were selected the clear day to witness from March to April, 2019 (Summer season). The ambient condition and solar radiation of the experiment were selected to obtain the most benefit as shown in Fig. 4.

As revealed in Fig. 4 has shown solar intensity on the angle of 30 $^{\circ}$  and ambient temperature during daytime (6:00-18:00). Obviously, the solar intensity in the clear day gradually increased from 06:00-12:30 and decreased from 12:30-17:00. Meanwhile, the ambient temperature gradually increased from 06:00-14:30 and

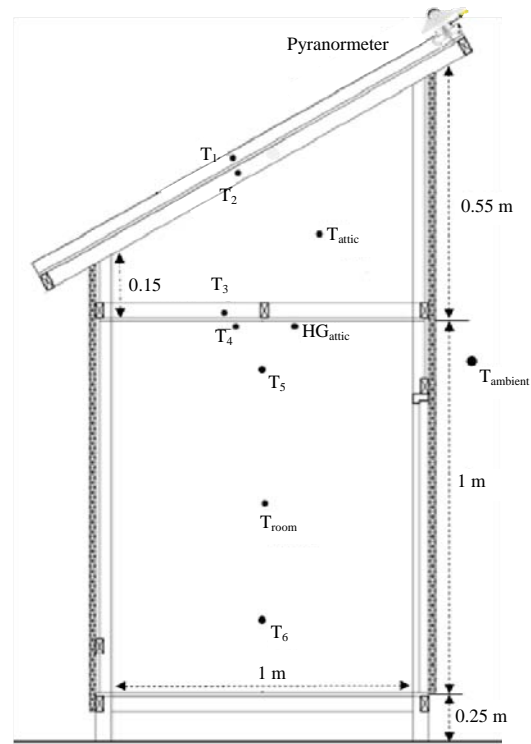


Fig. 2: Schematic reference house

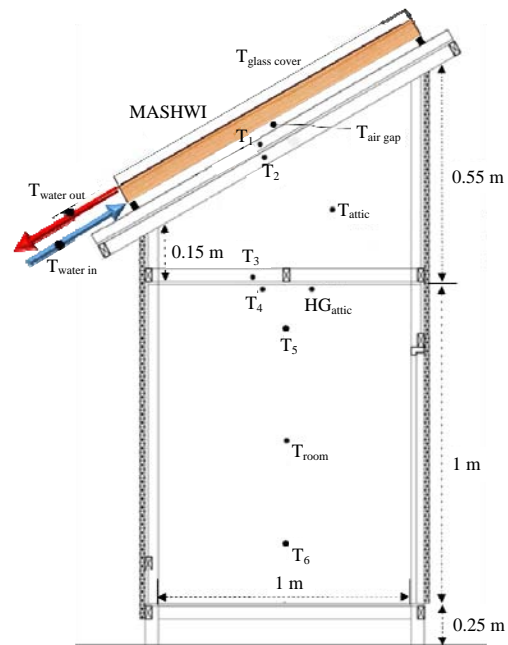


Fig. 3: Schematic house with MASWH

decreased from 14:30-17:00. The solar radiation and ambient temperature were decreased rapidly at 17:00 due to the few clouds and rain just drizzle. The maximum

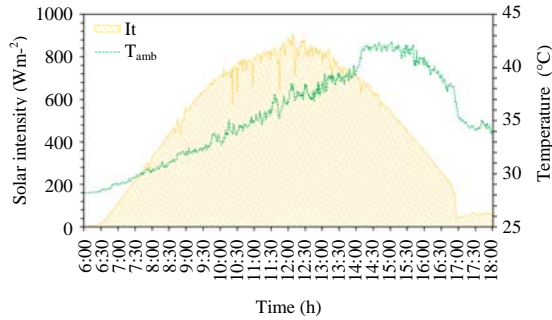


Fig. 4: Variation of solar intensity, ambient temperature

solar intensity on the surface was  $910 \text{ Wm}^{-2}$  at 12:10 with ambient temperature  $37.9^\circ\text{C}$  while the maximum ambient temperature was  $42.5^\circ\text{C}$  at 14:50 with solar intensity  $531.6 \text{ Wm}^{-2}$ . The average ambient temperature and solar intensity were  $34.8^\circ\text{C}$  and  $490 \text{ Wm}^{-2}$  ( $21.28 \text{ MJm}^{-2}\text{-day}$ ), respectively. The average solar radiation and ambient temperature have a high average potentiality in the experimental area. Therefore, it can be utilized effectively for the experiment.

**Attic temperature:** Figure 5 shows a comparison of hourly variation of attic temperature between the house-integrated with MASWH and the common house. The roof will absorb incident solar intensity and transfer heat into the attic during the day. Both houses were nearby the attic temperature in the morning because the heat was starting to accumulate in the attic area. Then the solar intensity and ambient temperature were increased. The maximum attic temperatures of house-integrated with MASWH and reference house were  $44.5$  and  $46.5^\circ\text{C}$ , respectively. The average attic temperature of the reference house was higher than the house-integrated with MASWH of  $1.5^\circ\text{C}$ . The roof house-integrated with MASWH could reduce heat transfer to the attic. That become better than the reference house during 7:00-17:00. Due to the incident solar radiation on the MASWH during the day, it affects the roof top does not receive direct solar radiation. Afterward, the ambient temperature was decreased in the evening. The attic temperature was exuded due to the behavior of heat transfer of the roof.

**Ceiling temperature:** The upper side ceiling (attic side) surface will receive direct heat by the attic during the day. Figure 6 shows the upper side ceiling temperature, each house has the upper side ceiling temperature continuously increased follow ambient temperature until the maximum temperatures were  $45$  and  $43^\circ\text{C}$  at time 14:15 and 14:20, respectively. It was observed that the upper side ceiling temperature of reference house more than the house-integrate with MASWH because of the upper side ceiling temperature of the reference house accumulated

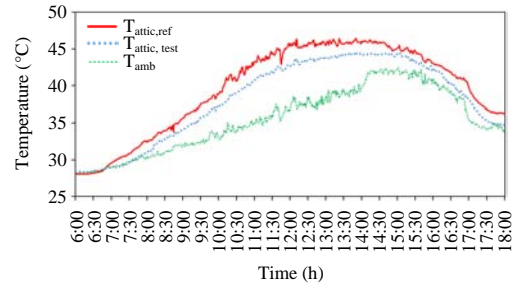


Fig. 5: Variation of attic temperature and ambient temperature

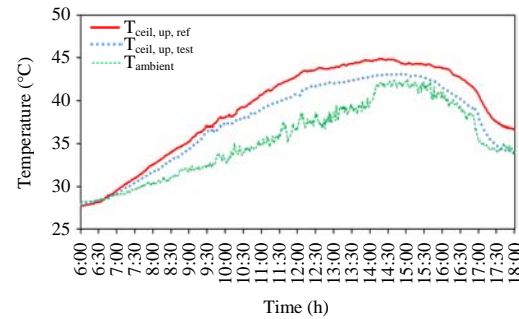


Fig. 6: Variation of upper side ceiling temperature and ambient temperature

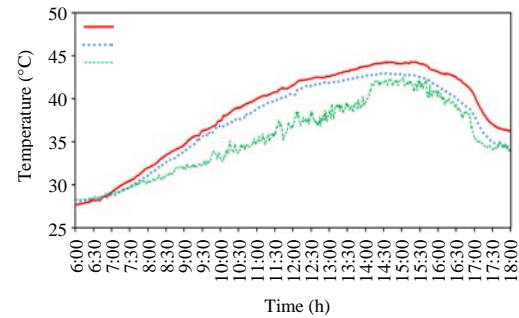


Fig. 7: Variation of underside ceiling temperature and ambient temperature

heat all-day. The different temperature during 6:00-17:00 showed about  $1\text{-}2.7^\circ\text{C}$ . After that, the upper side ceiling temperature of both houses were decreased and heat transfer to the ambient similarly to attic temperature.

Figure 7 shows the underside ceiling (room side) temperature. The underside ceiling temperature of both houses were same the trend graph as the upper side temperature owing to the upper side ceiling surface had heat transfer to the underside ceiling throughout the day. Simultaneously, the underside ceiling of reference house

was accumulated heat and gradually increased the temperature. The maximum temperature underside ceiling of the house-integrated with MASWH lower than the reference house was 2.5°C at 16:20. It is significant to reduce heat gain from the ceiling into the room by MASWH.

**Room temperature:** The comparison rooms temperature as shown in Fig. 8. Solar radiation was incident on the roof top. Afterward, the heat accumulation in the attic will transfer through the ceiling and room non-ventilation during the day. It was apparent that the room temperature of reference house was the same trend with ambient temperature while the average room temperature of the reference house was always higher than house-integrated with MASWH all day long. The maximum different room temperature between house-integrated with MASWH and reference house presented is 4°C. in addition, the house-integrated with MASWH had a temperature lower than ambient temperature from 0.1-0.7°C at 14:10-16:30; it corresponds to integrating MASWH on the roof top. Certainly, the result indicated the MASWH could reduce heat accumulation in the room throughout the ceiling and attic.

**Heat gain and heat gain reduction:** The heat was transferred through the ceiling of the house-integrated with a MASWH and a reference house. It was measured by a heat flux sensor and equipped at the center of the underside ceiling (room side). Figure 9 depicts percentage heat gain and heat gain reduction. The house-integrated with MASWH could reduce heat gain than the reference house about  $5-12 \text{ Wm}^{-2}$ , the percentage heat gain reduction during the effective period of the day varied from 20-85%. It corroborates that the house-integrated with the MASWH on the roof top could decrease heat gain through the ceiling better than the reference house.

**Water temperature:** In this study, the experiment attempted to study water temperature for feeding water at a flow rate of  $0.02 \text{ kg sec}^{-1}$  from an external source into a collector. The water temperature is shown in Fig. 10. The water temperature indicated a low value in the morning. The water temperature significantly increased until the maximum temperature and gradually decreased in the afternoon. It corresponds to varies of solar radiation and ambient temperature during the day. The maximum value of outlet water temperature was  $52.8^\circ\text{C}$  at 12.53 and the maximum different water temperature between inlet water and outlet water showed  $14.8^\circ\text{C}$ . The average inlet water temperature throughout the day indicated that it was different from average outlet water temperature of  $8.4^\circ\text{C}$ .

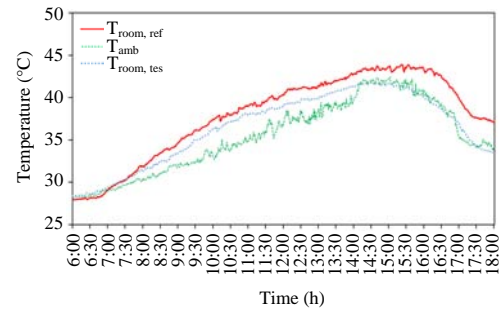


Fig. 8: Variation of room temperature and the ambient temperature

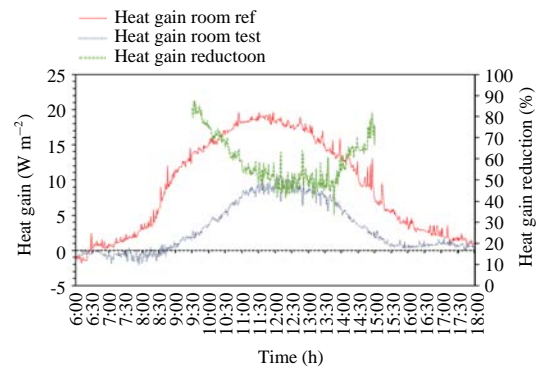


Fig. 9: Variation of heat gain and heat gain reduction

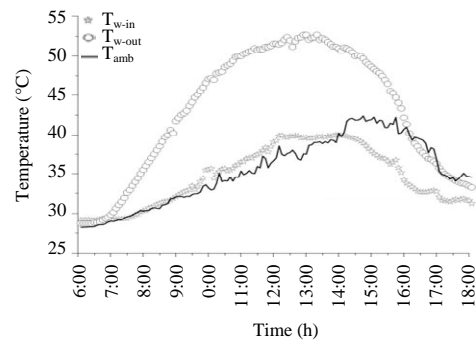


Fig. 10: Variation of water inlet, outlet and the ambient temperatures

**Useful energy:** Figure 11 shows the useful energy obtained from collector at 7.00-17.00 in the range of  $115 - 320 \text{ Wm}^{-2}$  while the solar intensity is in the range of  $120-900 \text{ Wm}^{-2}$ . The useful energy on MASWH is in the range of 30-36%. It was observed that the useful energy has a trend similar to solar intensity.

**Economic evaluation:** In order to assess economic values of the MASWH, it was installed on the roof of the testing house. Base on the first law of thermodynamic, the energy

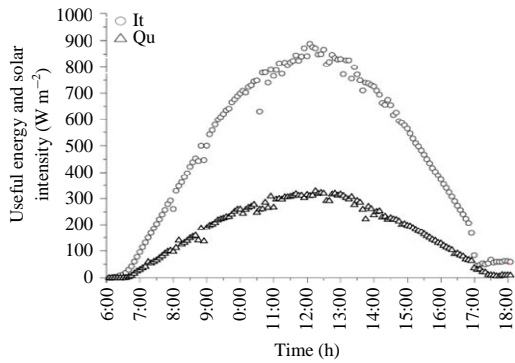


Fig. 11: Useful energy

balance on the attic (roof to ceiling) has been carried out to evaluate heat load into space room. For the attic, the energy balance is shown in Fig. 6 and 7. The following reasonable assumptions are considered.

- Heat transfer across the attic is unsteady state condition
- The attic system is not ventilated
- Heat gain from the walls and floor are neglected
- The flow rate of waters is steady

Energy balance for houses without MASWH (Fig. 12a). It can also be shown that:

$$Q_{\text{ceiling}} = Q_{\text{solar}} - Q_{\text{accum}} \quad (2)$$

In the case of houses-integrated with MASWH (Fig. 12b), the energy balance can be expressed as Eq. 3:

$$Q_{\text{ceiling}} = Q_{\text{solar}} - Q_{\text{useful}} - Q_{\text{accum}} \quad (3)$$

Where:

- $Q_{\text{solar}}$  : Heat from solar radiation (W)
- $Q_{\text{accum}}$  : Heat accumulates at the attic (W)
- $Q_{\text{useful}}$  : Useful energy (W)
- $Q_{\text{ceiling}}$  : Heat accumulates at the ceiling (W) respectively

To estimate the electric water heater and energy-savings of air-condition in houses-integrated with MASWH, a study on energy saving by the assumption of the indoor set-point standard of air-conditioned rooms should be 26°C for Thailand’s climatic conditions. The daily energy consumption of the air conditioner was 6.28 kWh at the set-point temperature of 26°C and each average indoor temperature difference of 1°C assumed that the electricity energy saving can save 6.14% (Lertsatitthanakorn *et al.*, 2009). The average heat gains through the ceiling from both house-integrated with

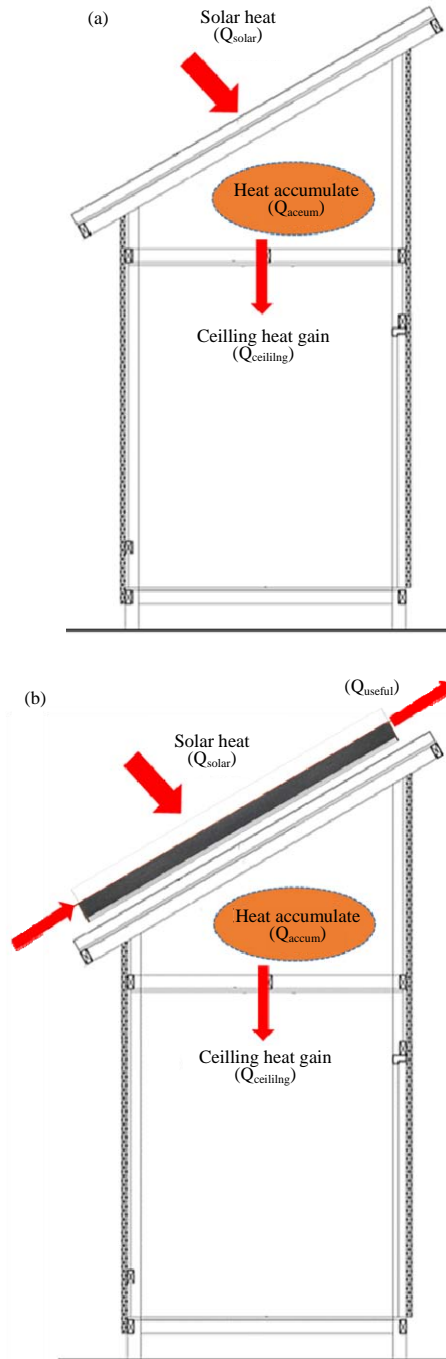


Fig. 12(a-b): (a) Reference house and (b) House integrated with MASWH on roof top

MASHW and reference house obtained from experiment are 14 and 5.4 W, respectively. The average useful energy is 254 W during the day. Heat gain and useful energy can be equivalent to electric power of 14, 5.4 and 254 W, respectively.

Total MASWH cost estimate of 2,660 Baht consists of construction cost, mixed asphalt, copper pipe, glass cover and another material. The payback period is the investment of time required for saving of investment to the equivalent cost of the MASWH. The payback period at a stated to return, define the years (n) by Eq. 4 (Sarachitti *et al.*, 2011):

$$P=B \left[ \frac{(1+r)^n - 1}{r(1+r)^n} \right] \quad (4)$$

Where:

P : Cost of the MASWH

B : Electric energy-saving for heated water

r : Interest rate

Thailand is located in the tropical area and has various seasons: the Winter season starts from November to January, the Summer season starts from February to May and the Winter season starts from November to January (Lertsatitthanakorn *et al.*, 2009). Therefore, the MASWH operated during Winter and Summer seasons. The operating time was 8 h/day (9.00-16.00) and 210 days/year. The room temperature of the house-integrated with a MASWH is lower than the reference room by <1°C to a maximum of 4°C. Therefore, the saving of an air conditioner is 47 kWh/year. The savings of electrical energy for heated water was 213 kWh/year. It can observe that the set-point temperature has a few effects on the payback period. This is due to the electrical energy savings for heated water being much higher than the energy savings of the air condition. The average electrical cost from Electricity Generating Authority of Thailand (EGAT) was 4.217 Baht/kWh and the interest rate of the bank of Thai was approximately 6.2%. Therefore, the MASWH can save the electrical power at 260 kWh/year. It is equivalent to 1,094.5 baht per year. The payback period is 2.5 years.

## CONCLUSION

The use of Mixed Asphalt Solar Water Heater (MASWH) to reduce heat gain was investigated experimentally. The experimental is made by using conducted using two small houses, one house integrates with MASWH on the roof top and other house is a reference for compared heat gain reduction. Based on data analysis, the following conclusions can be drawn: The attic temperature of the house-integrates with MASWH is lower than the reference house varied between 1-1.5°C or in the range of 0-5%. The upper side ceiling temperature of the house-integrates with MASWH is lower than the reference house about 0.2-2.7°C. Likewise, the underside ceiling temperature of both houses was similar trend value of the upper side. The maximum

temperature underside ceiling of the house-integrated with MASWH lower than the reference house was 2.5°C due to the ceiling of the house-integrates with MASWH was received heat gain from attic lower than reference house. The maximum room temperature of the house-integrated with MASWH, lower than that reference house at 4°C and the percentage of room temperature reduction between 10%. Heat gain reduction of the house-integrated with MASWH better than reference house about 1.2-10 Wm<sup>-2</sup>, the percentage heat flux reduction is 20-85% during the effective period. The house-integrate with MASWH was shown both ceilings temperatures, room temperatures and heat gain were lower than the reference house because the water passes to the MASWH reduce solar direct to the roof system, transfer the heat from the roof system. It indicates that the MASWH can reduce ceiling heat gain into the house and energy consumption by integrated on the roof top. The water temperature difference between inlet and outlet was 14.8°C which the maximum of outlet water temperature was 52.8°C. The useful energy is in the range of 115-320 Wm<sup>-2</sup>. Economic analysis shows that the payback period of the MASWH is 2.5 years. The MASWH is suggested for integrating on a roof top for buildings houses and residential due to that it encourages the use of renewable energy (Solar energy) and conserves energy.

## ACKNOWLEDGEMENTS

The researchers are thankful to Rajamangala University of Technology Rattanakosin, Rattanakosin College for Sustainable Energy and Environment (RCSEE) for providing financial support for this research work. Cordial thanks to Assistant Professor Withaya PUANGSOMBUT (Ph.D.) for his moral and scientific advices in this research.

## REFERENCES

- Amornleetrakul, O., W. Puangsombut and J. Hirunlabh, 2014. Field investigation of the small house with the ventilated roof tiles. *Adv. Mater. Res.*, 931: 1233-1237.
- Bhowmik, H. and R. Amin, 2017. Efficiency improvement of flat plate solar collector using reflector. *Energy Rep.*, 3: 119-123.
- He, Q., S. Zeng and S. Wang, 2015. Experimental investigation on the efficiency of flat-plate solar collectors with nanofluids. *Appl. Therm. Eng.*, 88: 165-171.
- Hussain, S. and S.J. Harrison, 2017. Evaluation of thermal characteristics of a flat plate solar collector with a back mounted air channel. *Appl. Therm. Eng.*, 123: 940-952.

- Jouybari, H.J., S. Saedodin, A. Zamzamian and M.E. Nimvari, 2017. Experimental investigation of thermal performance and entropy generation of a flat-plate solar collector filled with porous media. *Appl. Therm. Eng.*, 127: 1506-1517.
- Juengpimonyanon, K., W. Puangsombut and T. Ananacha, 2014. Field investigation on thermal performance of the tile ventilator. *Appl. Mech. Mater.*, 619: 73-77.
- Lertsatitthanakorn, C., S. Atthajariyakul and S. Sophonronarit, 2009. Techno-economical evaluation of a Rice Husk Ash (RHA) based sand-cement block for reducing solar conduction heat gain to a building. *Constr. Build. Mater.*, 23: 364-369.
- Michael, J.J. and S. Iniyani, 2015. Performance of copper oxide/water nanofluid in a flat plate solar water heater under natural and forced circulations. *Energy Convers. Manage.*, 95: 160-169.
- Phiraphat, S., R. Prommas and W. Puangsombut, 2017. Experimental study of natural convection in PV roof solar collector. *Intl. Commun. Heat Mass Trans.*, 89: 31-38.
- Prakasam, M.J.S., A.T. Vellingiri and S. Nataraj, 2017. An experimental study of the mass flow rates effect on flat-plate solar water heater performance using  $Al_2O_3$ /water nanofluid. *Therm. Sci.*, 21: S379-S388.
- Prommas, R., S. Phiraphat and P. Rattanadecho, 2019. Energy and exergy analyses of PV roof solar collector. *Intl. J. Heat Technol.*, 37: 303-312.
- Puangsoombut, W., J. Hirunlabh, J. Khedari, B. Zeghmati and M.M. Win, 2007. Enhancement of natural ventilation rate and attic heat gain reduction of roof solar collector using radiant barrier. *Build. Environ.*, 42: 2218-2226.
- Said, Z., M.A. Sabiha, R. Saidur, A. Hepbasli, N.A. Rahim, S. Mekhilef and T.A. Ward, 2015. Performance enhancement of a flat plate solar collector using titanium dioxide nanofluid and polyethylene glycol dispersant. *J. Cleaner Prod.*, 92: 343-353.
- Sarachitti, R., C. Chotetanorm, C. Lertsatitthanakorn and M. Rungsiyopas, 2011. Thermal performance analysis and economic evaluation of roof-integrated solar concrete collector. *Energy Build.*, 43: 1403-1408.
- Shah, Y.T., 2018. *Thermal Energy: Sources, Recovery and Applications*. 1st Edn., CRC Press, Boca Raton, Florida, USA., ISBN:9781315305950, Pages: 888.
- Zhou, F., J. Ji, J. Cai and B. Yu, 2017. Experimental and numerical study of the freezing process of flat-plate solar collector. *Appl. Therm. Eng.*, 118: 773-784.