Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 75 (2015) 566 – 571

Energy Procedia

The 7th International Conference on Applied Energy – ICAE2015

Design, Fabrication and Experimental Study of a Novel Loop-heat-pipe based Solar Thermal Facade Water Heating System

Peng Xu[a,b], Jingchun Shen[b], Xingxing Zhang[b,c*], Wei He[c,d], Xudong Zhao[b,*]

[a] *School of Environment and Energy Engineering, Beijing University of Civil Engineering and Architecture, Beijing, China*
[b] *School of Engineering, University of Hull, Hull, UK*
[c] *Department of Architecture and Built Environment, University of Nottingham, Ningbo, China*
[d] *Department of Thermal Science and Energy Engineering, University of Science and Technology of China, Hefei, China*

Abstract

This paper investigated a novel loop-heat-pipe based solar thermal facade heat-pump system for hot water from concept design, prototype fabrication and experimental test. Given the specific testing conditions, the solar thermal efficiency of the facade module achieved nearly 0.71 in average and the mean system's COP was about 5.0. It is expected that such novel LHP based solar thermal facade technology would further contributed to the development of the renewable (solar) driven heating/hot water service and therefore lead to significant environmental benefits.

Peer-review under responsibility of Applied Energy Innovation Institute

Kyewaords: Solar; Thermal facade; Loop heat pipe; Heat pump

1. Introduction

The current available solar thermal facade devices are creating a considerable energy saving potential and therefore are expected to boost in the near future [1]. However, these technologies have also been identified with several inherent problems that may become the barrier in future widespread deployment. The common problems lie in: (1) complex structures containing numbers of heat absorbing pipes and heat exchanging units; (2) relatively low solar efficiencies owing to less effective heat absorption of the water pipes (or air ducts) and less efficient heat transfer within the heat exchanging units. As a result, a larger solar facade area and higher system cost become the obvious disadvantages of the existing devices. An innovative solar loop-heat-pipe (LHP) thermal facade is therefore proposed by the authors to remove above critical problems remaining with the current solar thermal facade application in buildings. LHP is

* Corresponding author. Tel.: +86-574-88180000; fax: +86-574-88180188.
E-mail address: Xingxing.Zhang@nottingham.edu.cn; Xudong.Zhao@hull.ac.uk

Peer-review under responsibility of Applied Energy Innovation Institute
doi:10.1016/j.egypro.2015.07.456

an advanced two-phase heat transfer mechanism that is capable to transport large heat flux in long distance. Combination of the facade loop with a heat pump would further enable an efficient thermal control and management of the whole solar thermal system.

The article is implemented as an integration of concept design, prototype fabrication and laboratory testing into the proposed system. By delivering an effective, building integrated and aesthetically appealing solar collecting module/system, the research is expected to promote development of the renewable (solar) driven heating/hot water service for building, district and city scale application, which would lead to significant saving in fossil fuel consumption and reduction in carbon emission.

2. Design and Fabrication

2.1. Concept Design

Schematic of the novel solar LHP facade water heating system is presented in Fig 1.This system includes outdoor and indoor parts by the connection of transportation lines. The outdoor part initially converts the absorbed solar energy into the thermal energy in form of low-temperature vapour, which is prefabricated with a glazing cover, a fin-sheet absorber, a group of novel LHPs incorporated with three-way fitting, the compressed metal chips filer and the thermal insulation. This low-temperature vapour is further transported to indoor part through the transport line and then condensed by releasing heat in the heat exchanger (heat-pump evaporator). A secondary (buffer) water tank here is designed to temporarily store the additional instant condensation heat and reduce the corresponding heat dissipation, which also mitigates the fluctuation of heat-pump evaporation temperature. Thereafter, the condensed heat is further uplifted by the heat pump cycle to required level and stores in the primary water tank for later utilization.

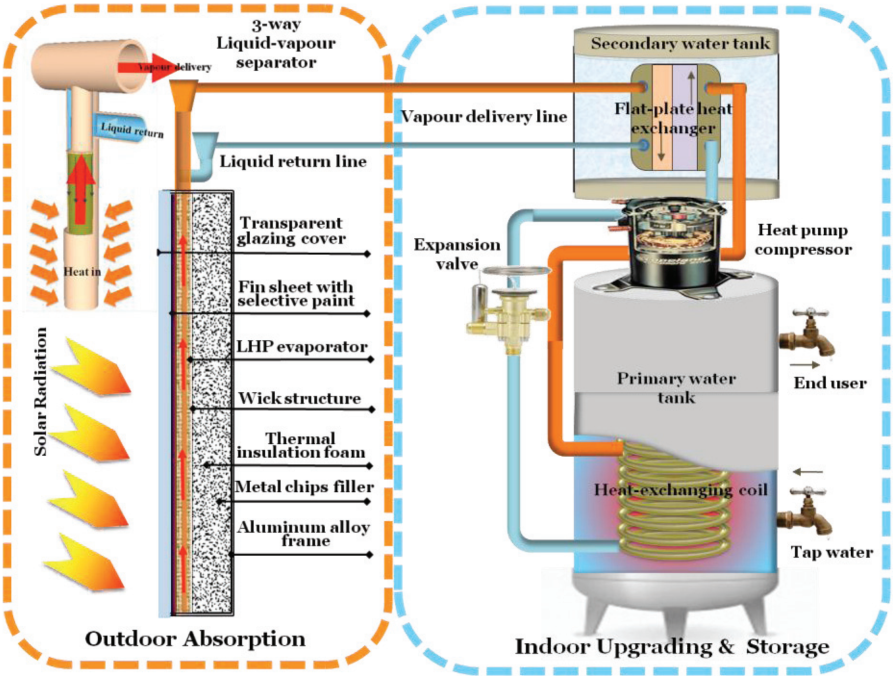


Fig 1. Schematic of the novel solar LHP thermal facade heat pump water heating system

A novel LHP with the top-positioned vapour-liquid separator is designed to overcome the ‘dry-out’ potential among those conventional gravity-assisted LHPs. A piece of ‘工’-shaped copper tube with expanded edges is internally connected to a refined three-way fitting. When compressing the bottom expander edge against the wick structure tightly, the returned liquid will be evenly distributed from the evaporator top across the wick surface owing to the equivalent capillary force in the wick. The three-way tube, meanwhile, could deliver the vapour upward to the exchanger through the vapour transportation line. This will create a clear separation between the liquid and vapour flows in the heat pipe.

Besides a reliable hot water supply, the distinct features of the employment of heat pump lie in that the LHP working temperature can be maintained within a lower range via the control of evaporation temperature of the refrigerant in the cycle. This would reduce the evaporation temperature of the solar collector, and increase both LHP thermal efficiency and solar output per unit of absorbing area.

2.2. Prototype Fabrication

A prototype of the novel solar LHP thermal facade water heating system was constructed, which consists of two solar collecting modules. In each solar collecting module, there are 10 LHPs with the absorbing area of 1.2 m^2. The solar collecting module was further fixed to the 90^o vertical frame, and fitted with the single glazing cover on top. A 2 mm thick aluminium Ω-type fin-sheet absorber embraced the wicked LHP evaporator (containing 160 x 60 copper meshes as the internal wick structure). The evaporator, when being connected to the liquid and vapour transportation lines and condensing heat exchanger, formed up a loop that was evacuated and then filled with 700 ml of refrigerant R600 as the working fluid [2]. The detailed technical data relating to the loop components, e.g., tube, fins, three-way fitting, liquid/vapour transportation lines and condensing heat exchanger, are given in Table 1. The metal chips filler was compressed into the gaps between the LHP evaporators. There are two circuits that indirectly exchange the heat in the 40 litres secondary (buffer) water tank while the 200 litres primary water tank with built-in copper heat-exchanging coils is connected to the heat pump cycle, acting as the condenser for the heat pump cycle. In this heat pump, the 1,100W-rated compressor was charged with popular environmentally friendly R134a and controlled by the thermostats in both the secondary water tank and the primary water tank. Several insulation materials including the foamy polyurethane for piping and polystyrene board for exchangers were also used to minimise the heat loss of the system components. Some fabrication process and components are given in Fig 2 and Fig 3.

Table 1. Designed parameters of LHP in each solar collecting module

Technical Data	Value	Technical Data	Value
Evaporator external/internal diameter [mm]	16/13.6	Internal diameter at three-way structure [mm]	14
Evaporator length [mm]	1200	External/internal diameter at transport line [mm]	32/29.6
Number of LHP	10	Evaporator-to-condenser height difference [mm]	150
Wire diameter of wick layer 1 [mm]	7.175×10^{-2}	Heat exchanger plate thickness	0.00235
Layer thickness of wick layer 1 [mm]	3.75×10^{-1}	Heat exchanger plate height	0.206
Mesh number of wick layer 1 [mm]	6299	Heat exchanger plate cluster width	0.076
Wire diameter of wick layer 2 [mm]	12.23×10^{-2}	Heat exchanger plate cluster length	0.055
Layer thickness of wick layer 2 [mm]	3.75×10^{-1}	Heat exchanger plate conductivity	16.28
Wick conductivity [W/m.K]	394	Heat exchanger number of plate	20

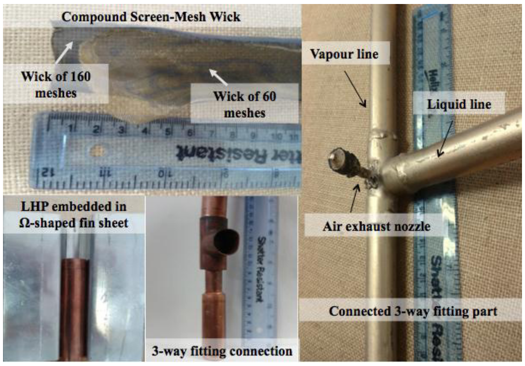


Fig 2. Fabrication of the LHP components

Fig 3. Fabrication of the solar collecting module

3. Experiment set up and results

3.1. Experimental set up

Thermal performance of the prototype system was evaluated under the set laboratory testing conditions including solar radiation of 626W, surrounding air temperature and speed of 20±2^{o}C and 0.01m/s, respectively. The initial water temperature in the primary and secondary tank was about 27.1^{o}C and 29.2^{o}C. The turn-on and turn-off evaporation temperatures of the heat pump were 35±0.5^{o}C and 25±0.5^{o}C (above 35^{o}C, heat pump on; below 25^{o}C, heat pump off). The measurement data was recorded at 10-second interval and logged into the computer system using two DT500 data loggers. There were five major parameters measured during the test, i.e. temperature, pressure, power, solar irradiation and air velocity. Several thermal sensors were placed, respectively, at the heat-absorbing pipe, the transporting lines, the refrigerant cycle and both the primary and secondary water tank, while four pressure sensors were located along the refrigerant cycle. Table 2 lists all the involved measurement instruments and Fig 4 illustrates the onsite testing rig.

Table 2. List of the experimental testing and monitoring devices

Devices	Specification	Value
OEM pressure sensor – Model: Tecsis-P3297	Measuring range [bar]	0 ~ 25
	Output signal [mA]	2 wire, 4 ~ 20
	Accuracy	≤1.0% of F. S.
	Power supply/load [VDC]	8 ~ 30

Thermocouple T welded glass insulated	Min/max temperature sensed [°C]	-200 ~ 350
	Probe diameter [mm]	0.3
PT100 sensor	Min/max temperature sensed [°C]	-50 ~ 200
	Probe diameter [mm]	6
Data logger and data recording equipment -Model: DataTaker-TD500 series	Channel number	10
Power sensor	WB1919B35-S/WBP112S91 (Weibo)	--
Pyranometer -Model: Hukseflux-LP02-TR-05	Calibration uncertainty	< 1.8 %
	Sensitivity [μV/(Wm^{-2})]	14.45
	Transmitted range [W/m^2] / [mA]	0 ~ 1600 / (4 ~20)
Pocket anemometer -Model: Skywatch-Xplorer 1	Air Velocity Resolution [kph]	0.1
	Best Air Velocity Accuracy	±3 %
	Maximum Air Velocity [kph]	150
	Probe type	Rotary vane
Solar simulator system -Model: SolarConstant4000	Similar global radiation to CIE Publ.85, Tab.4 IEC 60904-9/Class B	
	Radiation intensity [W/m^2]	1,000/ [280-3000mm]
	Homogeneity	±10 % or better (class C)

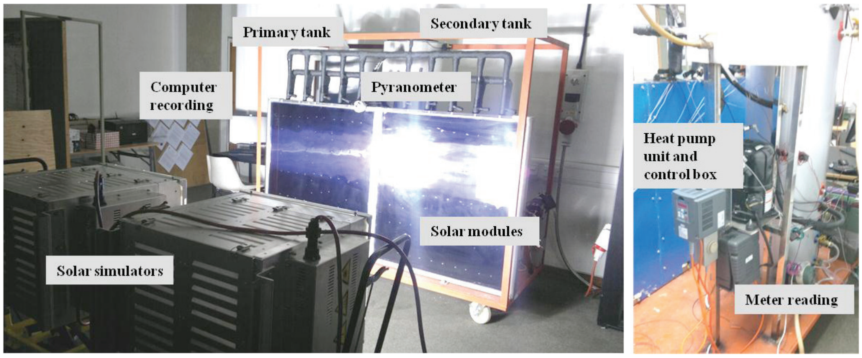


Fig 4. Experimental rig of the solar LHP thermal facade heat pump water heating system

3.2. Experimental results

Thermal efficiency (η_{th}) of the solar facade LHP module is defined as the ratio of module heat gain (Q_{th}) to incident irradiation (I) striking on the collecting area (A)

$$\eta_{th} = Q_{th} / IA \quad (1)$$

Thermal performance coefficient (COP) of the whole system is defined as the ratio of system heat gain (Q_w) to the electrical energy consumed by the compressor (W)

$$COP = Q_w / W \quad (2)$$

Fig 5 displays the operation results under the given testing conditions and the simulation results by using the simulation model in authors' previous work [2]. The temperature of LHP evaporator inside the module varied between 36.81°C to 41.55°C. The water temperature in the primary tank kept on increasing to 55.35°C. The solar thermal efficiency of the module fluctuated between 0.58 and 0.78, with nearly 0.71 in average. The overall system's COP changed in range of 4.60 to 5.37, addressing the mean value of 5.0. It is therefore concluded that such novel LHP based solar facade water heating system has an efficient thermal performance, which would further contributed to the development of the solar driven heating/hot water service and lead to significant saving in fossil fuel consumption and reduction in carbon emission.

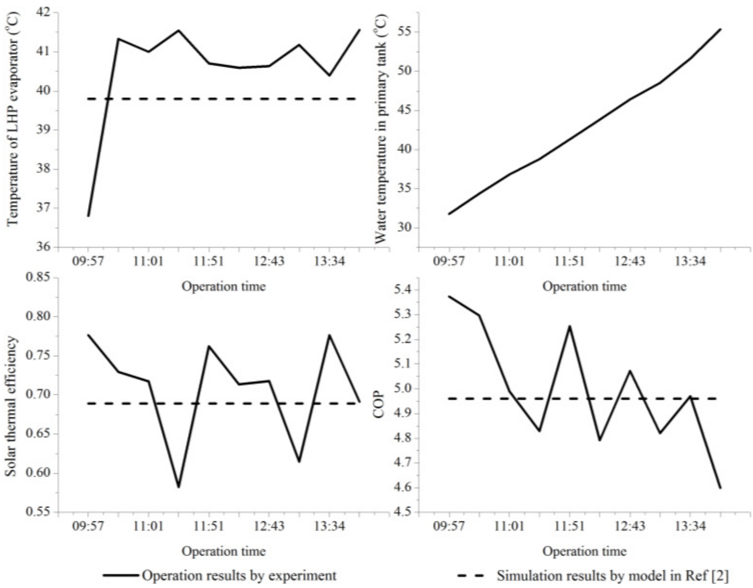


Fig 5. Operation results of the solar LHP thermal facade heat pump water heating system

4. Conclusion

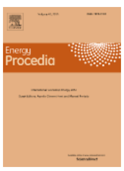
This paper reported a novel LHP based solar thermal facade heat-pump system for hot water. Under the given testing conditions, the solar thermal efficiency of the facade module fluctuated between 0.58 and 0.78, with nearly 0.71 in average. The overall system's COP had a changing range of 4.60 to 5.37, resulting in the mean value of about 5.0. It is expected such novel technology would further contributed to the development of solar driven heating/hot water service and lead to significant environmental benefits.

Acknowledgements

The authors would acknowledge our appreciation to the financial supports from the EU Marie Curie Actions-International Incoming Fellowships (FP7-PEOPLE-2010-IIF-272362) and the Beijing Key Lab of Heating, Gas Supply, Ventilating and Air Conditioning Engineering.

References

[1] Solar Heating and Cooling for a Sustainable Energy Future in Europe, *European Solar Thermal Technology Platform*. 2009.
[2] W He et al., Theoretical investigation of the thermal performance of a novel solar loop-heat-pipe facade-based heat pump water heating system, *Energy and Buildings* 77 (2014) 180–191.



Biography

Dr. Zhang is currently an Assistant Professor at the Department of Architecture and Built Environment, University of Nottingham, Ningbo, China. He has active research interests in solar energy, green-building design and consultancy, simulation and monitoring of building energy performance, energy efficient techniques and building economics.