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Developing the footplate for shower drain water heat recovery

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Abstract
This paper aims to develop the footplate for shower drain water heat recovery to capture the waste heat from the used hot shower water. In process, the used hot shower water is collected in a water tank and the cold water is guided into the pipe of the heat exchange device of piping tablet immersed in the water tank for heat exchanging. The heated cold water is further mixed with hot water as hot shower water, so that the required hot shower water rate is reduced and the energy consumption also reduced. The results show that employing one heat exchange device of piping tablet immersed into the ca. 40.6℃ water tank of 60 cm × 60 cm × 15 cm and the cold water with flow rate of 2 l/min got the heat exchange efficiency of ca. 44.34 %. Moreover, using three heat exchange device of piping tablet received the average heat exchange efficiency of ca. 94.21 % and the average heat transfer effectiveness($\boldsymbol{\varepsilon}$) was ca. 0.94.

1. Introduction

Recently, the natural resources of energy are becoming rare and the waste energy is paid attention in the world. There are plenty of studies focusing on higher efficiency, newer, and new kind of energy sources [1-4]. However, how to save waste energy in daily life is the most important issue. Most typically waste energy transfer to be heat and the reference had proposed that the historical waste heat in the last 120 years was approximately 15,000 EJ. If all of this heat was absorbed into the atmosphere, the global air temperature would increase to ca. 2.856 K [5]. Therefore, waste heat can be recovered and reused to reduce energy loss and slow down occurrence of the Green House Effect.

The recoverable heat energy is paid attention recently, e.g. geothermal energy is available heat energy. The ground coupled heat pumps (GCHP) systems has been studied around world [6-8]. The GCHP systems are a well alternative to traditional systems for heating and cooling of building. The systems supply considerable savings of the primary non-renewable energy resources while holding the surrounding environment. Moreover, the GCHP systems have been spotlighted as an efficient heating system for reducing CO_2 emissions and great potentials.

The recovery technology of heat energy is mainly by a heat exchange device. In process, the medium of heat exchange is most important, that usually supply the heat pipe as the medium. Heat pipe is a passive cooling device with extremely large thermal conductivity. It is one of the most reliable, with good efficiency, low cost, and high performance cooling elements [9, 10]. In fact, the heat pipe also usually is applied in building of heat recovery systems and recoverable energy [11]. Moreover, the optimum efficiency has studied in a lot of research.

According to the reference which proposed the most amount of used heated water when showering, the second of amount of used heated water in kitchen. However, the differences resident cause the total amount used hot water ca. 89-506 L every day and the energy consumption about 6.5-16.9MJ [12]. The waste heat energy in the drain water can completely be recovered, that can effectively save energy.

In 2013, A. Mcnabola et al. proposed a system, drain water heat recovery (DWHR). The system comprised at 40 mm diameter PVC waste water pipe with a 12.7 mm diameter copper water supply pipe running through, while clean cold water flow into the inner of copper pipe that starting to heat exchange with heated drain water outside the cooper pipe. Moreover, this paper using ANSYS software to build and analyze the model of DWHR, the result show the heat transfer effectiveness was increased 45%, and heat exchange efficiency was increased over 50% [13].

In the large public system of showering, e.g. school, barrack, and swimming pool with more waste heat energy which can be recovered. In 2009, L. Liu et al. proposed a device of recovery waste heat in public showering, that system consists of solar collection, drainage collection, and heat recovery system [14]. However, this system is too large, difficult installation, and high costs.

This paper aims to develop the footplate for waste heat recovery from used hot shower water. In process of the waste heat recovery, first of all, the used hot shower water is collected in to water tank. Secondly, the cold water is guided into pipe of the heat exchange device of piping tablet immersed in the water tank for heat exchanging. Then heated cold water is further mixed with hot water as hot shower water. Finally, the required hot shower water is reduced and the energy consumption is also reduced. This device has more advantages with small occupied space, easily removable, easily placed, convenience, marketability, and size can be customized.

2. Basic Theory

2.1. Effectiveness-NTU Method

In 1955, W. M. Kays and A. L. London proposed effectiveness-NTU method which actually simplify analysis of heat exchange [15]. The heat transfer effectiveness ($\boldsymbol{\varepsilon}$) is

$$\varepsilon = \frac{Q}{Q_{\max}} \tag{1}$$

Where Q is actual heat transfer amount and Q_{max} is maximum heat transfer amount. And

$$Q = m_c C_c (T_{c,out} - T_{c,in}) \tag{2}$$

$$Q = m_h C_h (T_{h,out} - T_{h,in}) \tag{3}$$

Where m_C and $\mathrm{m_h}$ is fluid quality of cold water and hot water, C_C and C_h is specific heat of cold water and hot water, $T_{C,out}$ and $T_{C,in}$ is hot water temperature of outlet and inlet, $T_{C,out}$ and $T_{C,in}$ is cold water temperature of outlet and inlet. Maximum heat transfer amount Q_{max} in terms of Eq. (4).

$$Q_{\max} = C_{\min} (T_{h,in} - T_{c,in}) \tag{4}$$

C_{max} is compare of amount which is lower between m_C times C_C and m_h times C_h.

2.2. Heat Recovery System in Design

According to ideal gas equation, the relationship between temperature and density is inversely. The higher temperature of water owns lower density. In other words, the higher temperature of drain water located at the top of collection tank. Therefore, this paper designed a square water tank, which applied the above mentioned relationship to limit the hotter waste water in the top of water tank. Moreover, the heat exchange device of piping tablet to limit the waste hot water of flow direction. Figure. 1 shows the waste hot water is flow into water tank that is contact the heat exchange device of piping tablet from top to bottom, that is improve heat exchange efficiency and heat transfer effectiveness. Due to the heat exchange rate is increased when clean cold water flow into the heat exchange device of piping tablet from bottom to top.

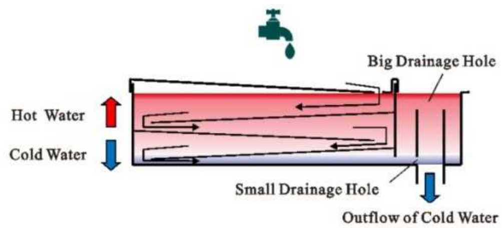

Fig 1. *Schematic illustration the relationship between temperature of drain water and tank height.*

According to figure. 1, the big and small drainage holes is designed in the water tank of right side by connected pipes principle, and the small drainage holes of flow rate is much smaller than the big one. The small drainage hole is set at the bottom position of drain water collection tank, that could be avoid health problems and environmental humidity rise when end shower. The big drainage hole is designed to control water level of water tank that is increase heat exchange efficiency by immersing mode.

3. Experimental Setup

Figure. 2 shows flow chart of waste heat recovery the footplate for waste heat recovery. Figure. 3 shows schematic illustration of application of the footplate for waste heat recovery. This experimental assume the footplate can be placed at shower room. Person can stand on the footplate when start shower, the waste hot water is flowing into the water tank within the footplate.

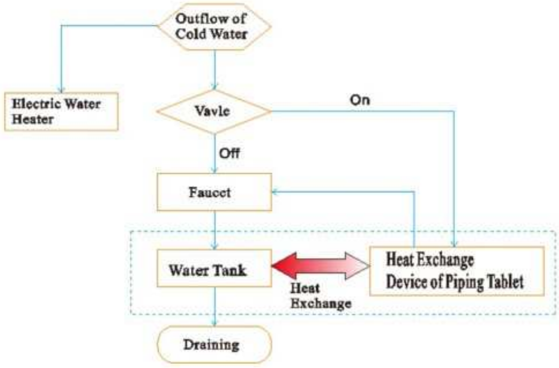

Fig 2. *Flow chart of waste heat recovery.*

Fig 3. *Schematic illustration of application of the footplate for waste heat recovery.*

Figure. 4 shows exploding diagram of the footplate for waste heat recovery that consists of the footplate of top cover, controlling water valve, heat exchange device of piping tablet, water tank, and drainage holes. The footplate of top cover is designed a little of slope that can compel waste hot water flow to the inlet of water tank. This inlet of water tank is devised filter to avoid hair and trash flowing into. This device has many advantages such as convenient cleaning, easy maintenance, and high efficiency, etc.

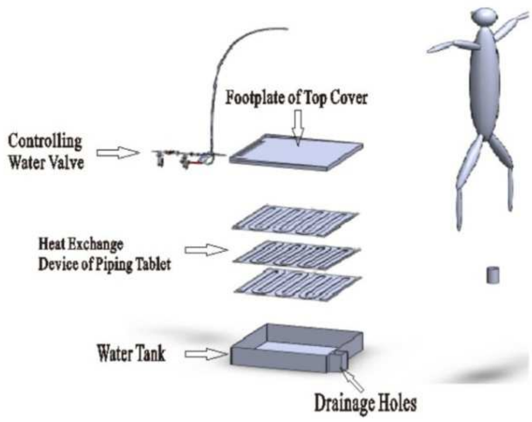

Fig 4. *Exploded diagram of the footplate for waste heat recovery.*

3.1. Heat Exchange Device of Piping Tablet

The heat exchange device of piping tablet with flow channel was designed dimension of $\mathrm{W} \times \mathrm{H} = 4 \times 1.5\ cm^2$ with rectangular cross section geometry and the hydraulic diameter is 20 mm. Moreover, to improve the heat exchange efficiency, the flowing channel was welded as S shape. The innovation design of S shape flow channel owns long channel travel distance in a limited area of heat exchanger plate. Figure. 5 shows schematic illustration of the heat exchange device of piping tablet.

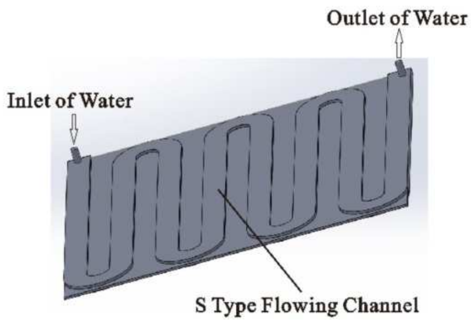

Fig 5. *Schematic illustration of the heat exchange device of piping tablet.*

The heat exchange device of piping tablet is made by using galvanized sheet steel, owns excellent characteristics of without rusty, low cost, and high heat transfer. Figure.6 shows welding process of the heat exchange device of piping tablet and figure.7 shows photo of the heat exchange device of piping tablet.

Fig 6. *Welding process of the heat exchange device of piping tablet.*

Fig 7. *Photo of the heat exchange device of piping tablet.*

3.2. Controlling Water Valve

In this experiment, the footplate for shower drain water heat recovery is experimentally in conjunction with controlling water valve. Figure. 8 shows schematic illustration of the controlling water valve. The controlling water valve has three valve, control clean cold water flow into the heat exchange device of piping tablet or not, the control clean cold water flow into the faucet or not, and the control the heated cold water from the heat exchange device of piping tablet flow into the faucet or not respectively.

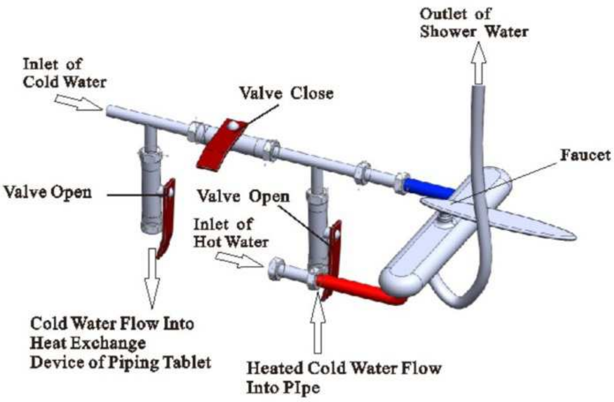

Fig 8. *Schematic illustration of the controlling water valve.*

Moreover, this experimental employed a flowing meter to measure the fluid quality of cold water flow into the heat exchange device of piping tablet to calculate the heat transfer effectiveness. According to experimental results, the fluid quality of cold water and hot water are also 2 l/min. Figure. 9 shows photo of the controlling water valve.

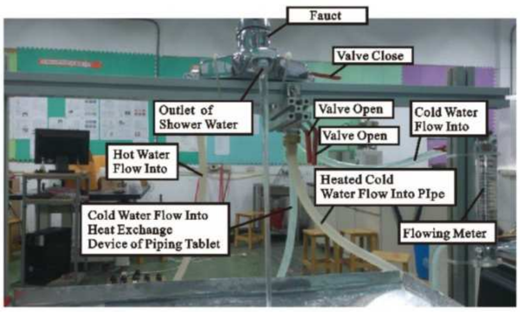

Fig 9. *Photo shows the controlling water valve.*

4. Results and Discussion

Figure. 10 shows the average heat exchange efficiency is 44.34% under a heat exchange device of piping tablet. The average temperature of inlet cold water, outlet cold water, and waste shower drain water is about 23.4℃, 31℃, and 40.6℃ respectively. The result shows average heat transfer effectiveness (**ε**) is 0.44 under a heat exchange device of piping tablet.

Figure. 11 shows the average heat exchange efficiency is 84.2% with two heat exchange device of piping tablet. The average temperature of inlet cold water is about 23℃, average temperature of outlet cold water is about 34.7℃, and average temperature of waste shower drain water is 36.9℃. The result shows average heat transfer effectiveness (**ε**) is 0.84 with two heat exchange device of piping tablet.

Figure. 12 shows the average heat exchange efficiency is 94.21% by using three heat exchange device of piping tablet. The average temperature of inlet cold water, c outlet old water, and waste shower drain water is about 23℃, 37.2℃, and 38.1℃ respectively. The result shows average heat transfer effectiveness (**ε**) is 0.94 by using three heat exchange device of piping tablet.

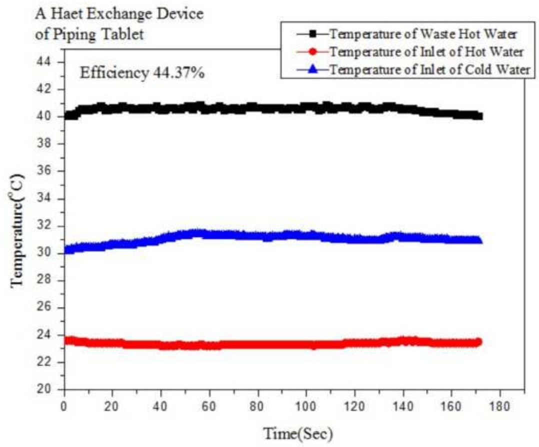

Fig 10. *Heat exchange efficiency of a heat exchange device of piping tablet.*

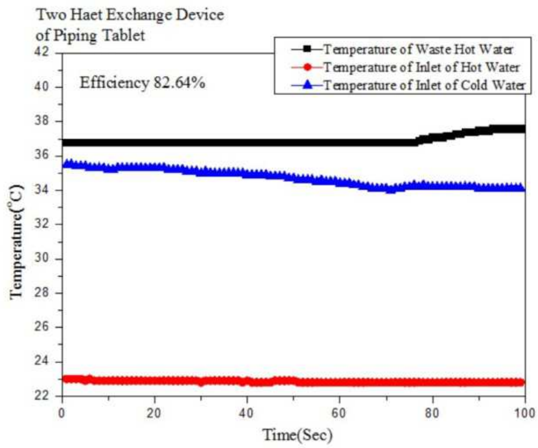

Fig 11. *Heat exchange efficiency of two heat exchange device of piping tablet.*

Figure. 13 shows the heat exchange efficiency and heat transfer effectiveness with one, two and three heat exchange device of piping tablet. The results show that the three heat exchange device of piping tablet has higher heat exchange efficiency and heat transfer effectiveness than one or two heat exchange device of piping tablet.

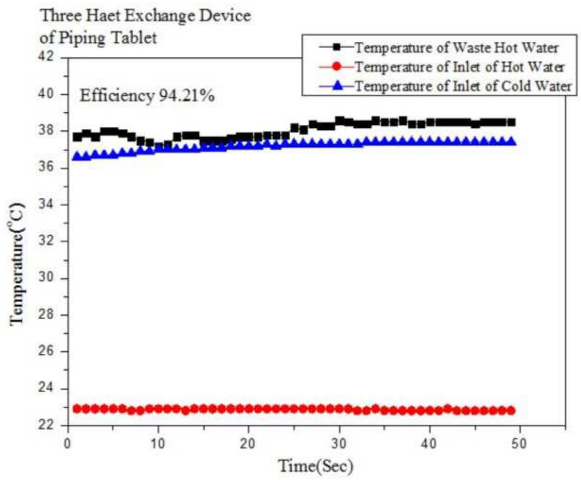

Fig 12. *Heat exchange efficiency of three heat exchange device of piping tablet.*

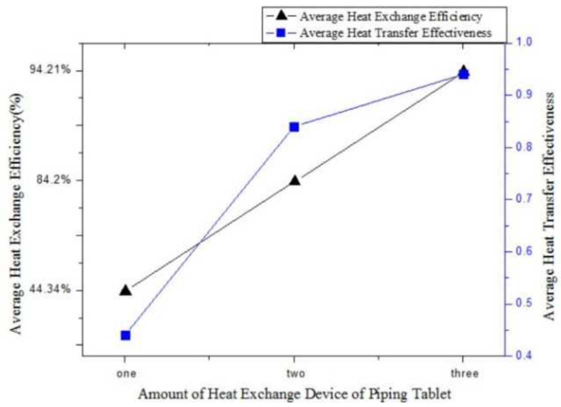

Fig 13. *Heat exchange efficiency and heat transfer effectiveness influenced by different amount heat exchange devices of piping tablet.*

According to the results of figure. 13, the heat transfer efficiency reaches to 94.21% with good performance. Based on the devices cost and energy consumption, we don't consider more than three heat transfer device of piping tablet. Therefore, by using the three exchange device of piping tablet is optimal designed parameter in this study.

5. Conclusions

Design, setup theoretical analysis, and measurements of a footplate for waste heat recovery from shower drain water was successfully carried out. The results show that the average heat transfer efficiency of device are 44.34%, 84.2%, and 94.21%, and the average heat transfer effectiveness($\boldsymbol{\varepsilon}$) of devices are 0.44, 0.84, and 0.94 of different amount of exchange device of piping tablet with one, two and three respectively. In this work, the best average heat transfer efficiency and average heat transfer effectiveness ($\boldsymbol{\varepsilon}$) is 94.21% and 0.94 under three exchange device of piping tablet. Summarizing experimental results, assume a family with 4 people and the total shower time is 60 minutes with hot shower water about 40℃. The innovation design of footplate with three heat exchange device of piping plate for waste shower drain water heat recovery can save about 1.937 kWh. To estimate the construction price, the totally do not over 500 USD. The innovation design is cheap, changeable, easy to setup, and friendly green energy.

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References

[1] C. C. Chen, W. Y. Yan, Y. Y. Wu, and C. C. Ting, "Investigating the Optimum Efficiency of Acoustoelectric Conversion Plate Devices, International Journal of Engineering and Technology Innovation," in press, 2014

[2] J. N. Lee, C. C. Chen, and C. C. Ting, "Numerical Analysis of Exergy for Air-Conditioning Influenced by Ambient Temperature, International Journal of Engineering and Technology Innovation," in press, 2014.

[3] C. C. Chen and C. C. Ting, "Photoelectrode Fabrication of Dye-Sensitized Nano Solar Cells using Multiple Spray Coating Technique, International Journal of Photoenergy," 2013: Article ID 629059, 8 pages, doi:10.1155/2013/629059, 2013.

[4] C. C. Chen, D. Y. Tsai, C. C. Ting, and K. Y. Lin, "Improvement and Noise reduction for the Active Air Inlet Quick Burner by Using Dispersive Combustion Method," American Journal of Energy and Power Engineering, 1: (1):1-8, March, 2014.

[5] H. Tsuchiya, "The Global Resource Balance Table, an Integrated Table of Energy, Materials and the Environment," Energy Policy, vol. 61, 2013, pp. 1107-1110.

[6] H. Yang, P. Cui, Z. Fang, "Vertical-Borehole Ground-Coupled Heat Pumps: A Review of Models and Systems," Applied Energy, vol. 87, 2010, pp. 16-27.

[7] J. M. Choi, Y. J. Park, S. H. Kang, "Temperature Distribution and Performance of Ground- Coupled Multi- Heat Pump Systems for a Greenhouse," Renewable Energy, vol. 60, 2013, accepted. pp. 1-7.

[8] A. Arteconi, C. brandoni, G. Rossi, F. Polonara, "Experimental Evaluation and Dynamic Simulation of a Ground Coupled Heat Pump for a Commercial Building," Energy Research, vol. 37, 2013.

[9] C. C. Ting, C. C. Chen, "Developing the Coaxial Dual- Pipe Heat Pipe for Applications on Heat Pipe Cooler," Journal of Heat transfer of the ASME, vol. 133, 2011, pp. 092901-1-7.

[10] C. C. Ting, C. C. Chen, "Experimental Analysis of Heat Transfer Behavior inside Heat Pipe Integrated with Cooling Plates," Engineering, vol. 3, 2011, pp. 959-964.

[11] H. N. Chaudhry, B. R. Hughes, S. A. Ghani, “A Review of Heat Pipe Systems for Heat Recovery and Renewable Energy Applications,” Renewable and Sustainable Energy Reviews, vol. 16, 2012, pp. 2249-2259.

[12] W. Kempton, “Residential Hot Water: A Behaviorally-Driven System,” Energy, vol. 13, 1988, pp. 107-114.

[13] A. McNabola, K. Shields, “Efficient Drain Water Heat Recovery in Horizontal Domestic Shower Drains,” Energy and Buildings, vol. 59, 2013, pp. 44-49.

[14] L. Liu, L. Fu, Y. Jiang, ”Application of an Exhaust Heat Recovery System for Domestic Hot Water,” Energy, vol. 35, 2010, pp. 1476-1481.

[15] Y. A. Cengel, “Heat Transfer: A Practical Approach [3nd Edition],” ISBN-13:978-007-125739-8, 2007, pp. 620-622.