# Development of an advanced smooth and spiral heat exchanger model for the analysis of optimum heat pump operation in different climates

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## １. Research Objective 1

The purpose of this study is to evaluate the performance of Heat Pump Water Heater (HPWH) in areas with some different climate based on smooth and spiral heat exchanger (HEX) modeling. The working fluid which is used in this HPWH research is R32. The HEX model performance test is based on water temperature in several climate condition such as tropical, summer, interim and winter condition. In this report, the performance of overall system is evaluated by both experiment and simulation based on water temperature outlet HEX, heat capacity, COP and LCCP (Life Cycle Climate Performance) for tropical climates only.

## ２. Major Research Result

### 2.1 Schematic of Heat Pump Water Heater

Fig. 1 show the scheme of Commercial Heat Pump Water Heater. The component of this HPWH Consist of compressor, condenser, expansion valve, evaporator, accumulator, 4-way valve, water pump, water tank storage and PID Controller to make better performance of the system as seen in Fig. 1. The compressor used in this commercial HPWH is electrical driven scroll compressor with power requirement based on specification about 1.060-1.200 kW. The condenser that used in this HPWH is spiral heat exchanger that will be discuss deeper in modeling session. The expansion valve used in this HPWH is Electronic Expansion Valve (EEV) and the evaporator is fin-tube heat exchanger. All measured data were recorded and collected every 5 s in a data acquisition logger (DAQ) and transferred to a computer. The accuracy of the measurement equipment is listed in Table 2.

Table 2. Accuracy of measurement instrumentation

| Equipment | Type | Range | Accuracy |
|---|---|---|---|
| Thermocouple | Type T | -50 °C–200 °C | ±0.35 °C |
| Pressure | Transmitter | 0–5 MPa | ±3% |
| Water flowmeter | Electromagnetic | 0–5 L/min | ±2% |
| Power meter | Bench | 0-6000 W | ±0.3% |
| Humidity | Portable | 0-100% | ±5% |

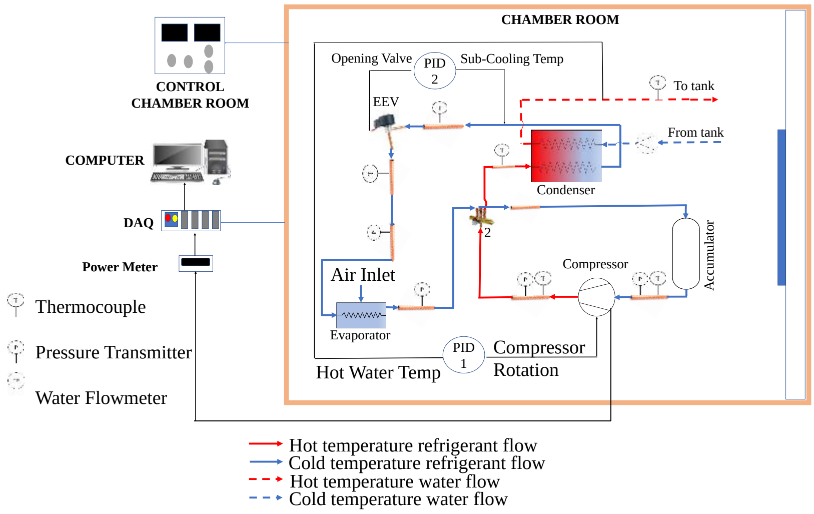


Fig. 1 Scheme of heat pump water heater

## 2.2 Modeling

The heat exchanger modeling is generalized based on Fig. 2. The generalization of the model is done with assume that in HEX there are 2 flow, that's are refrigerant and water flow. The flow of the fluid is counterflow.

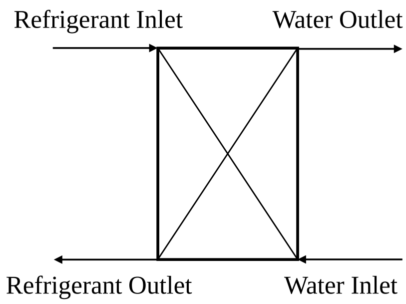


Fig 2. Heat Exchanger configuration

The condenser was modeled as a refrigerant-water counter-flow tube-in-tube heat exchanger (HEX). A multizone moving boundary model was implemented. In each zone of the condenser, calculations were performed with reference to one-dimensional continuity (Eqs. (1–8)), the energy, and pressure drop equations of both the refrigerant and the waterside.

$$\frac{\partial \rho_r}{\partial t} + \frac{\partial(\rho_r v_r)}{\partial z} = 0 \quad (1)$$

$$\frac{\partial \rho_w}{\partial t} + \frac{\partial(\rho_w v_w)}{\partial z} = 0 \quad (2)$$

The energy balance is expressed per unit volume of both refrigerants (Eq. (8)) and the water side (Eq. (9)), while considering the heat flux $(q)$ transferred at the exchange surface of the tube with circumference $(L_C)$ and cross-sectional area $(S)$.

$$\frac{\partial(\rho_r u_r)}{\partial t} + \frac{\partial(\rho_r v_r h_r)}{\partial z} = -\frac{L_C}{S} q \quad (3)$$

$$\frac{\partial(\rho_w u_w)}{\partial t} + \frac{\partial}{\partial_z}[\rho_w v_w h_w] = \frac{L_C}{S} \mathrm{q} \quad (4)$$

Pressure drops are estimated in one dimension along the *z* direction for both the refrigerant (Eq. (10)) and water (Eq. (11)) flows. The friction factors of both the refrigerant $(f_r)$ and water $(f_w)$ were calculated by relying on the correlation provided by another researcher

$$\frac{\partial P_r}{\partial_Z} = -f_r \frac{1}{d_{H,r}} 2\rho_r v_r^2 \quad (5)$$

$$\frac{\partial P_w}{\partial_Z} = -f_w \frac{1}{d_{H,w}} 2\rho_w v_w^2 \quad (6)$$

The heat flux was calculated by applying Eq. (12) with reference to the flow and heat transfer conditions for each control volume of length *dz*.

$$q = \frac{UA}{L_c L}(T_r - T_w), \quad (7)$$

where *A* denotes the heat-transfer area. The overall heat transfer coefficient, *U*, is calculated using Eq. [13].

$$U = \left(\frac{d_{out}}{\alpha_{r,in} d_{in}} + \frac{d_{out}}{2\lambda_{tube}} ln \frac{d_{out}}{d_{in}} + \frac{1}{\alpha_w}\right)^{-1} \quad (8)$$

The conductivity of the tube material $(\lambda_t)$ is estimated with reference to the physical properties of copper, and the heat transfer coefficient for both the refrigerant $(\alpha_r)$ and water $(\alpha_w)$ is referred from others researcher.

## 2.3 Heat Exchanger (HEX) Model Testing Performance

The model of HEX is tested the performance based on water temperature inlet in several climate condition such as : 29.6°C for tropical condition, 24.92°C for summer condition, 17.69°C for interim condition, and 9.39°C for winter condition. The parameter study in this test performance is water flowrate inlet HEX that variate from 0.75 lpm to 2 lpm for each climate condition as can be seen in Fig 2.

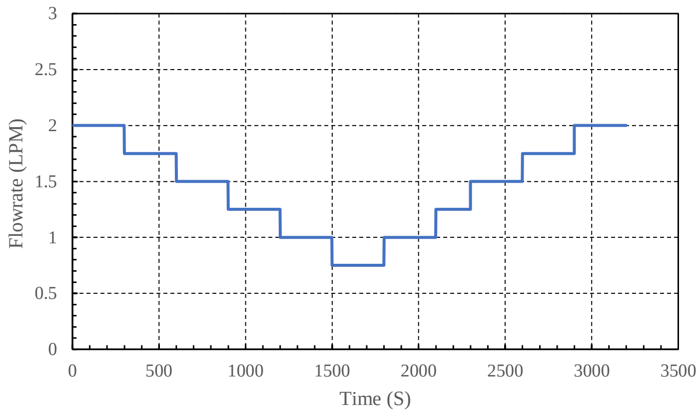


**Fig 2. Water flowrate as parameter study**

The effect of water flowrate on the achievement of water temperature outlet HEX and average heating capacity can be seen in Fig 3 and 4 respectively. As can be seen in Fig 3, the temperature of water outlet HEX is increase due to decreasing in water flowrate in al climatic condition. The optimum water outlet temperature occurs on winter condition with flowrate 0.75 lpm around 72.5°C. Fig 4 provide the information that increasing water flowrate have affect on increasing the heating capacity. Optimum heating capacity is occurring when the condition is winter with water flowrate 2 lpm

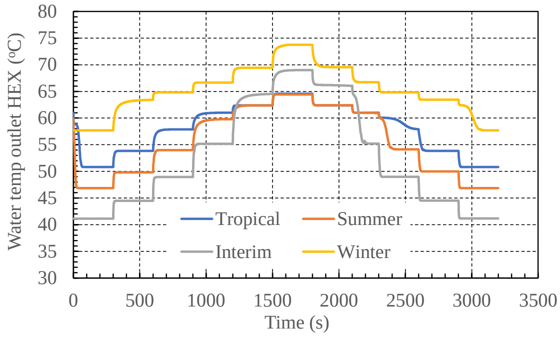


**Fig. 3. Effect on temperature outlet**

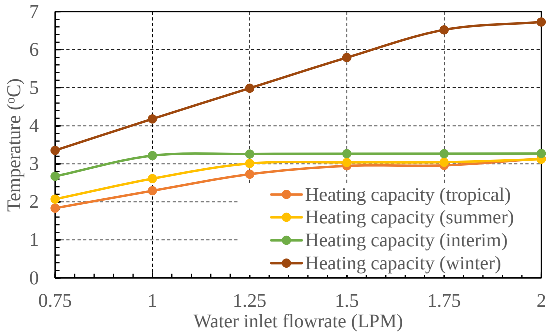


**Fig 4. Effect on average heating capacity**

## 2.4. Overall performance of HPWH on tropical climate condition

Overall performance of HPWH such as water outlet temperature, power consumption, heating capacity and LCCP calculation on tropical climate condition are shown in Fig 5-8 respectively. The result show that on tropical condition with air temperature around 35°C and water inlet temperature 29.6°C the water outlet temperature, power consumption, and heating capacity can achieve around 60.8°C, 0.6kW, and 3.3 kW respectively. LCCP calculation show that this HPWH will produce CO2 contributor around 4000 $kgCO_{2e}$ in tropical condition that consist of annual power consumption 3500 $kgCO_{2e}$, material manufacture 240 $kgCO_{2e}$ and direct impact around 298 $kgCO_{2e}$.

From Fig 5-8 also can be consulted that between simulation and experiment for water outlet temperature, power consumption, heating capacity and LCCP analysis have a good deal with error less than 20%.

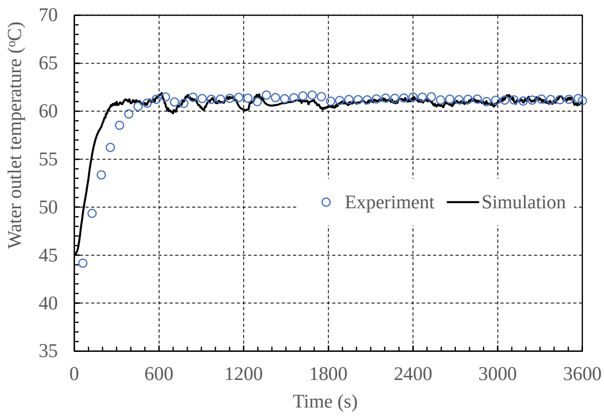


**Fig 5. Water outlet HEX**

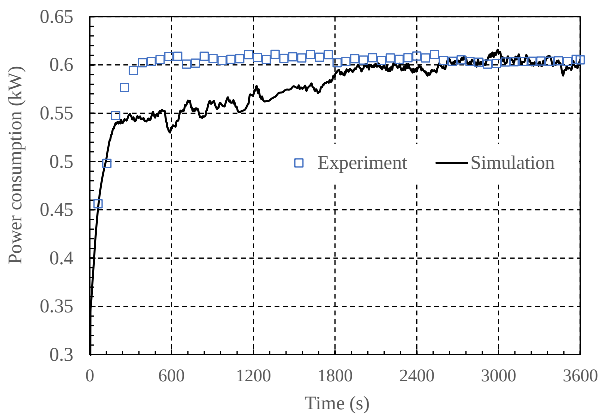


**Fig 6. Power consumption of compressor**

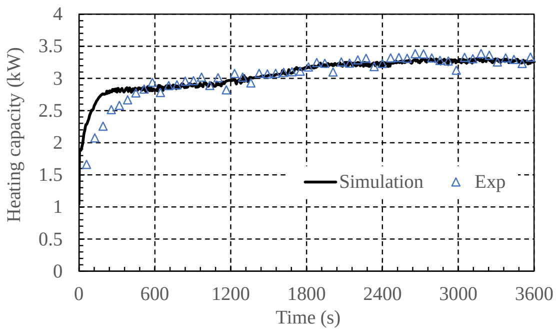


**Fig 7. Heating Capacity**

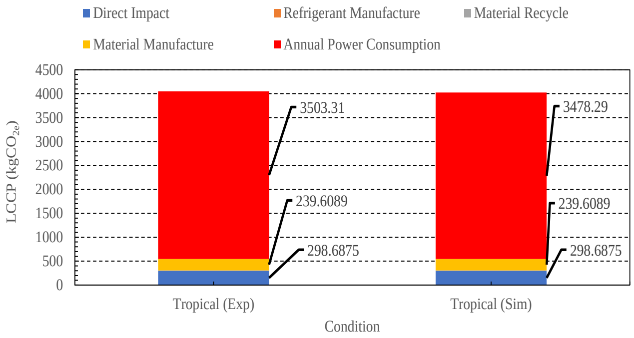


**Fig 8. LCCP result**

## 3. Collaborator

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Niccolo Gianetti (Waseda Institute for Advanced Study, Assistant Professor)

Takaoki Suzuki (Faculty of Science and Engineering, Department of Applied Mechanics, M2 Student)

## 4. Research Achievement

4.1 学術論文

[1]. **Muhamad, Yulianto**., Takaoki Suzuki., Zheng Ge., Takashi Tsuchino, Masakazu Urakawa, Shigeru Taira., Yoichi Miyaoka., Niccolo, Giannetti., Liang Li., Kiyoshi Saito. Performance Investigation of R32 Commercial Heat Pump Water Heater Under Different Climate Condition. submitted to Int. Journal of Sustainable Energy Technologies and Assessments. **(Submitted with paper ID：SETA-S-21-01172)**

4.2 総説・著書 特になし

4.3 招待講演 ・ 特になし

4.4 受賞・表彰 特になし

4.5 学会および社会的活動

**[1].** **Yulianto, Muhamad**., Suzuki, Takaoki., Miyaoka, Yoichi., Ohno, Keisuke., Gianetti, Niccolo., Saito, Kiyoshi., Yamaguchi, Seiichi., 2020. Numerical Investigation of CO2 Heat Pump Water Heater Performance., International Conference The 14th Gustav Lorentzen, Kyoto Japan, 6th – 9th December 2020 **(Published)**

**[2].** Takaoki, Suzuki., Zheng, Ge., **Muhamad, Yulianto**., Yoichi, Miyaoka., Seiichi, Yamaguchi., Kiyoshi, Saito. 2021. Annual performance assessment of heat pump water heaters applying R32 and CO2 refrigerants., the 13th International Energy Agency Heat Pump Conference, Jeju, Korea, 26-29 April 2021 **(Published)**

## ５．Issues and Prospect of Research Activities

The limitation in this study is the modeling that carried out without the tank . Therefore, in the future the comprehensive modelling including tank will be considered to close the actual condition. The tank model that will be considered in the future is stratified tank models. This model uses in thermal storage. comprehensive modelling that considered stratified tank for overall system may ensure the better result.