The influence of optimum stratified tank in heat pump water heater operation for different climates condition

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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 optimum stratified tank modeling. The working fluid which is used in this HPWH research is R32. The tank model performance test is based on different size of tank. In this report, the performance of overall system is evaluated by 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 tank that used in this HPWH is stratified that will be discuss deeper in modeling session. The tank consists of 2 inlet and 2 outlet. The expansion valve used in this HPWH is Electronic Expansion Valve (EEV) and the evaporator is fin-tube heat exchanger. Simulation schematic of this research is based on figure 1

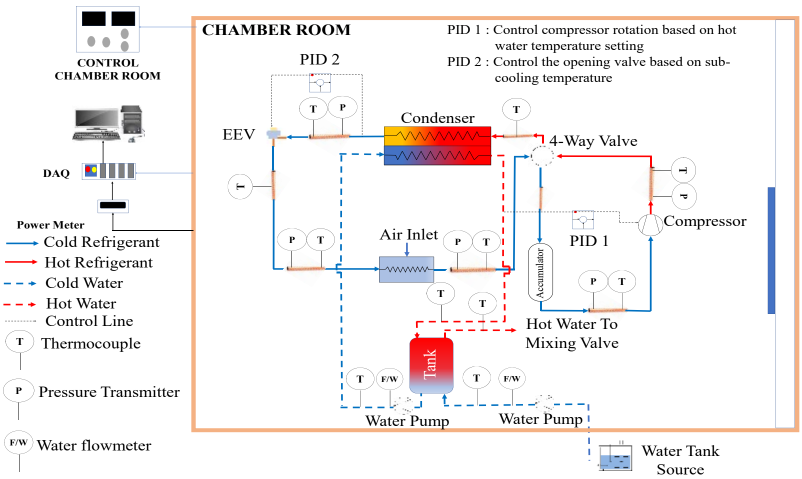

Fig. 1 Scheme of heat pump water heater

2.2 Modeling

Tank model that describes in this research was dividing into N constant volume section (Nodes). The node is described as X_t1[1] in upper, X_t1[i] in middle and X_t1[Idiv) in the bottom of tank. Each node assumed to be fully mixed and at a uniform temperature as can be seen at figure 2.

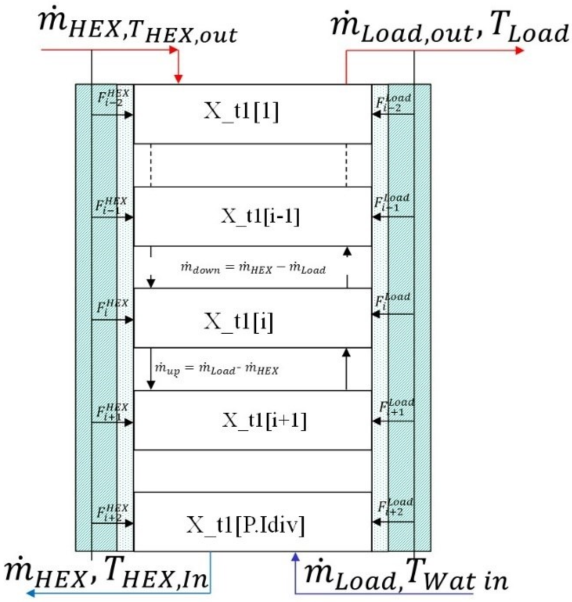

Figure 2. Node configuration

The predicted at each node performing an energy balance, thermal loss to surrounding, and the influence of the adjacent nodes (ie, mass and energy flows, including conduction between layers and vertical conduction trough the tank wall) as described in eq below

Node X_t1[1]

Mass balance

$$\frac{d\dot{m}_{cv}}{dt} = \left(\dot{m}_{HEX,in} + \dot{m}_{Load,in}\right) - \left(\dot{m}_{HEX,out} + \dot{m}_{Load,out}\right) \tag{1}$$

Energy balance

$$m_{X_{t1[1]}}.C_p.\frac{dT_{stratified}}{dt} = \dot{m}_{HEX}.\left(h_{HeX} - h_{Xt1[1]}\right) + \dot{m}_{Load}\left(h_{Xt1[2]} - h_{load,out}\right) - q_{cond,out} - q_{Losses} \tag{2}$$

Node X_t1[i]

Mass balance

$$\frac{d\dot{m}_{cv}}{dt} = \left(\dot{m}_{up,in} + \dot{m}_{down,in}\right) - \left(\dot{m}_{up,out} + \dot{m}_{up,out}\right) \tag{3}$$

Energy balance

$$m_{X_{t1[1]}}.C_p.\frac{dT_{stratified}}{dt} = \dot{m}_{down}.(h_{i-1} - h_i) + \dot{m}_{up}(h_{i+1} - h_i) - q_{cond,in} - q_{cond,out} - q_{Losses} \tag{4}$$

Node X_t1[Idiv]
Mass balance

$$\frac{d\dot{m}_{cv}}{dt} = \left(\dot{m}_{Load,in} + \dot{m}_{down,in}\right) - \left(\dot{m}_{HEX,out} + \dot{m}_{up,out}\right) \tag{5}$$

Energy balance

$$m_{X_{t1[1]}}.C_p.\frac{dT_{stratified}}{dt} = \dot{m}_{Load}.(h_{Load} - h_{Idiv}) + \dot{m}_{HEX}(h_{Idiv-1} - h_{Idiv}) - q_{cond,in} - q_{cond,out} - q_{Losses}$$

(6)

Condition of simulation as below:

If $\dot{m}_{HEX} > \dot{m}_{Load}$, then the water flow will downward $\dot{m}_{up} = 0$

If $\dot{m}_{HEX} < \dot{m}_{Load}$, then the water flow will downward $\dot{m}_{down} = 0$

The conduction between layers was calculated based on equation below

$$q_{con} = \frac{k.A_{C,i}}{\Delta y_{i,i+1}}(T_i - T_{i+1}) \tag{6}$$

The heat losses to environment were calculated as below

$$q_{Losses} = U.A.\Delta T \tag{7}$$

$$q_{Losses} = U.A.(T_{water} - T_{Environment}) \tag{8}$$

And then the overall heat transfer was calculates using equation below

$$U = \frac{1}{\frac{1}{h_1.A_i} + \frac{ln\left(\frac{r_{pipe,out}}{r_{pipe,in}}\right)}{2\pi k_1 L} + \frac{ln\left(\frac{r_{Insulation,out}}{r_{Insulation,in}}\right)}{2\pi k_2 L} + \frac{1}{h_2.A_O}} \tag{9}$$

The Reynold number calculated

$$R_e = \frac{\rho.v.D}{\mu} \tag{10}$$

2.3 Simulation Condition

In this simulation the condition of tank was variated based on table 1. The initial water temperature was set at 30°C and final water temperature

No	Diameter of tank (m)	Height of tank (m)	Volume (Liter)	AR
Var 1	0.40	0.93	118	2.3
Var 2	0.49	1.40	218	2.3
Var 3	0.57	1.31	318	2.3
Var 4	0.61	1.42	418	2.3
Var 5	0.66	1.52	518	2.3
Var 6	0.83	0.59	318	0.7
Var 7	0.65	0.97	318	1.5
Var 8	0.51	1.58	318	3.1
Var 9	0.47	1.84	318	3.9

2.4 Temperature Profile in the Tank of fix AR 2.3

The result show for fix AR 2.3 can be seen in Figure 3. By considering 68 lt of tank is as remain water not to heat, the result can be shown that increasing tank volume (with constant AR) will affected to increase the water temperature at the bottom of tank, in this result seen that tank design 318 lt have better result to keep temperature with water demand around 250lt

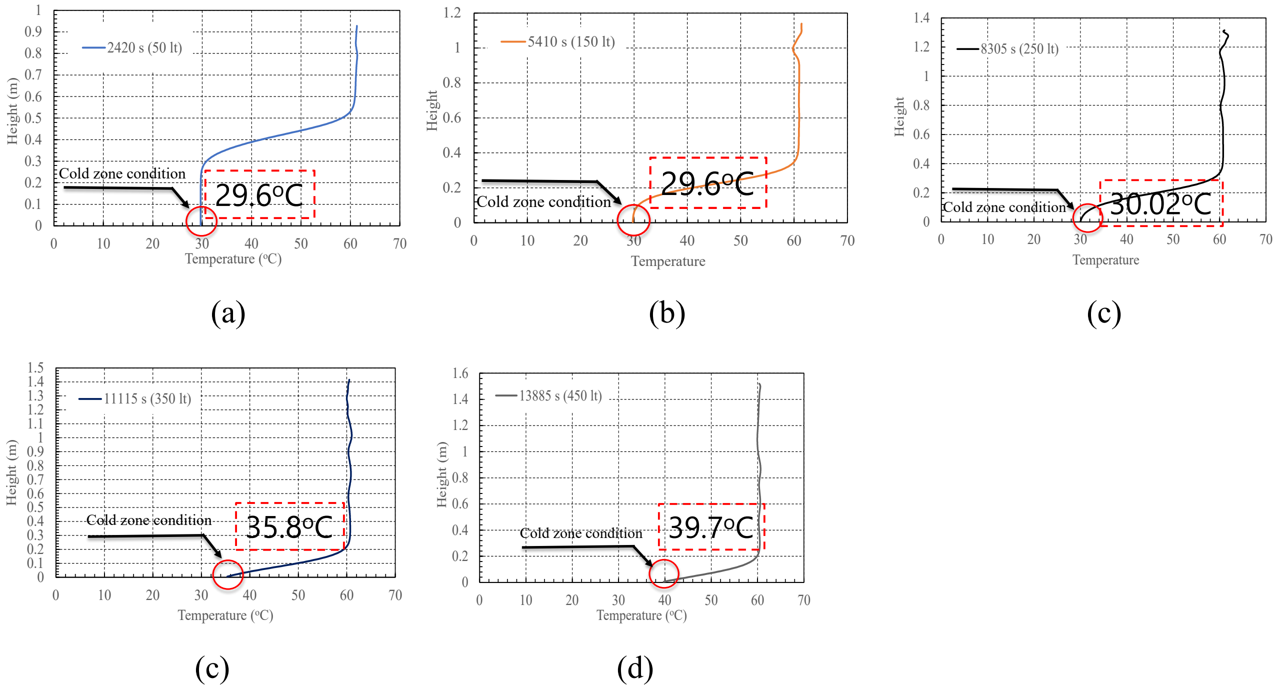

Figure 3. Temperature profile result fix AR : (a) Var 1, (b) Var 2, (c) Var 3, (d) Var 4, (e) Var 5

2.5 Temperature Profile in the tank of different AR

The result show for different can be seen in Figure 4. By considering 68 lt of tank is as remain water not to heat, the result can be shown that increasing AR (with constant volume, bigger diameter and lowest height) have higher potency to increase temperature in the bottom side of tank

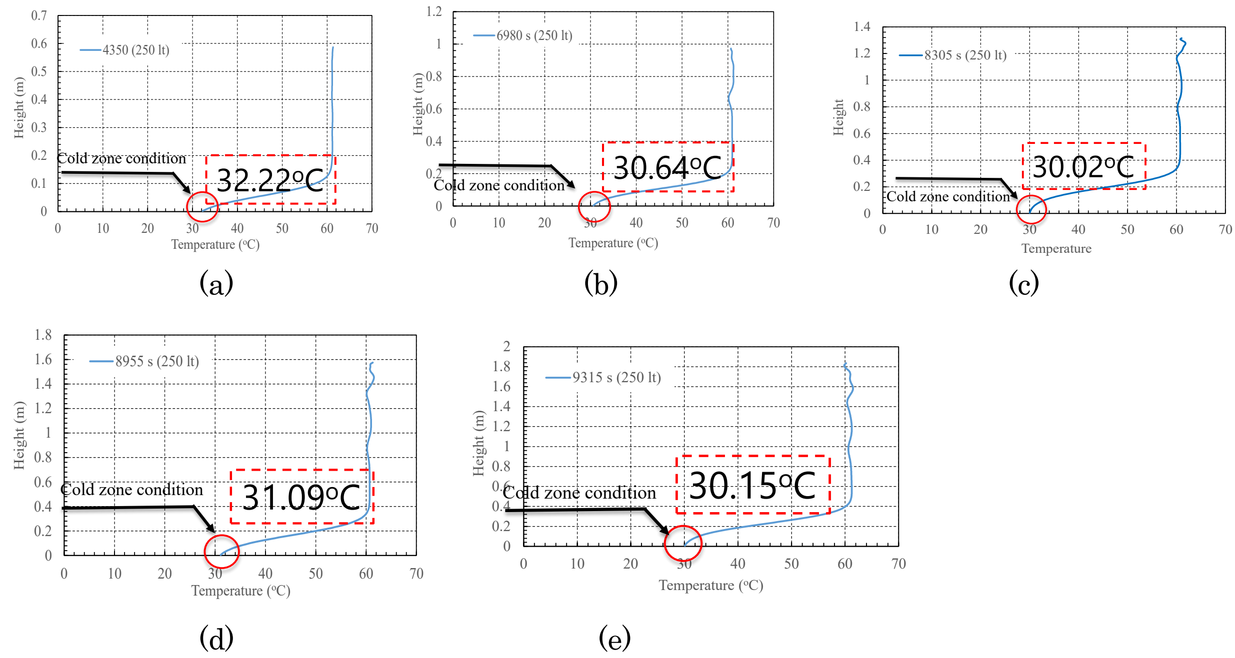

Figure 4. Temperature profile result fix AR : (a) Var 6, (b) Var 7, (c) Var 3, (d) Var 8, (e) Var 9

2.6 Performance and LCCP fix AR 2.3

Figure 5 show the performance and LCCP for a tank with fix AR 2.3. Power consumption for previous condition is not change about 0.59kw as long as the temperature at cold zone is not increase. But the total energy consumption is increase depend on heating time. Heating time is increase linearly based on the water demand. In this simulation show that the smaller tank consumes more power than bigger tank because in the bigger tank have bigger diameter that produce higher conduction to each layer in the tank that reduce the heating time. Increasing the duration time will affected to increasing the CO_2 emission

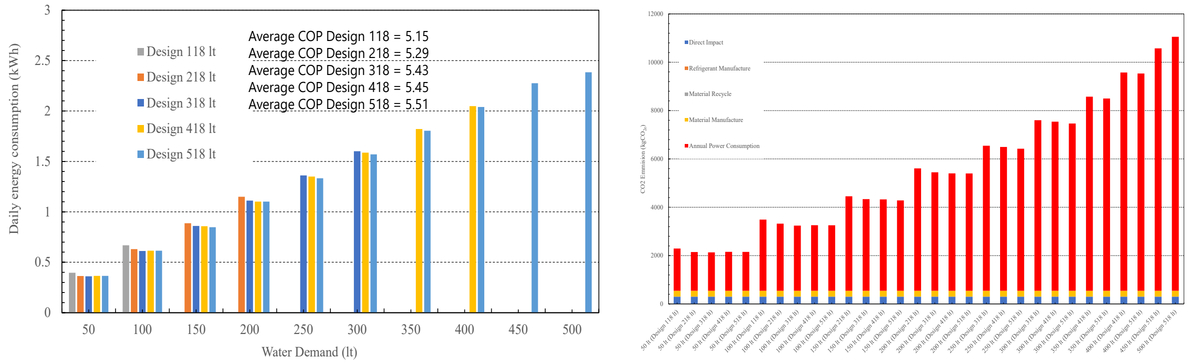

Figure 5. Performance result fix AR : (a) Var 1, (b) Var 2, (c) Var 3, (d) Var 4, (e) Var 5

2.7 Performance and LCCP different AR

Figure 6 show the performance and LCCP for a tank with different AR. On daily energy consume can be seen that the smallest AR with bigger diameter and lowest height will consume smallest energy consume due to it will produce smallest heating time of HPWH. Event though the tank with AR 0.7 have smallest energy consume but it have effect increasing temperature in the bottom of tank around 32.22°C. This is occurs due to the Higher AR have bigger diameter that produce higher conduction to each layer in the tank

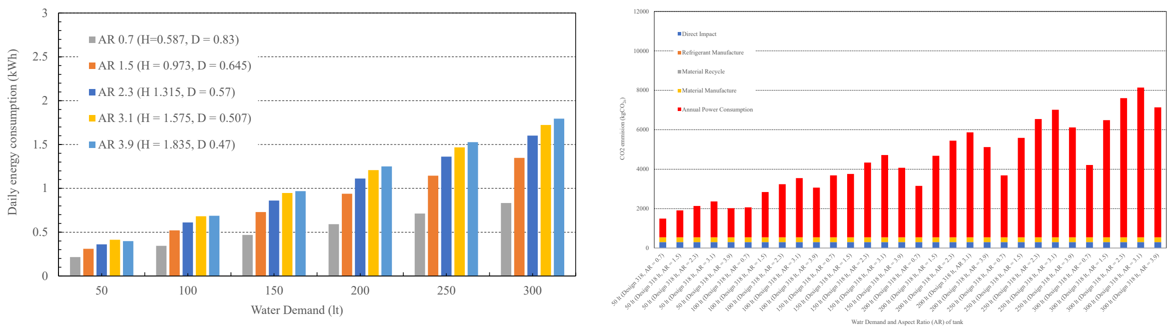

Figure 6. Performance result fix AR : (a) Var 6, (b) Var 7, (c) Var 3, (d) Var 8, (e) Var 9

3 Collaborator

Kiyoshi Saito (Faculty of Science and Engineering, Department of Applied Mechanics, Professor)
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Niccolo Gianetti (Waseda Institute for Advanced Study, Associate Professor)
Zheng Ge (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 Gianetti., Liang Li., Kiyoshi Saito., 2021. Performance assessment of an R32 commercial heat pump water heater in different climates. Sustainable Energy Technologies and Assessment. 49, 101679

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

[1]. Best Paper in the 12th Thermofluids International Conference 2021

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]. **Muhamad Yulianto**., Niccolo Giannetti., Yoichi Miyaoka., Zheng Ge., Takashi Tsuchino, Masakazu Urakawa., Shigeru Taira, Jongsoo Jeong, Kiyoshi Saito., 2021. Effect of Refrigerant Charge on the Performance and Environmental Footprint of R32 Heat Pump Water Heater. International Conference The 12th Thermofluid Conference, Yogyakarta Indonesia 10-11th November 2021

[3]. 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

5 Issues and Prospect of Research Activities

This study has a limitation about the heat pump water heater that modelled is without validation. Therefore, in the future the comprehensive experiment result will be considered to close the actual condition.