# Anti-freeze and Energy-saving Control Method of Ground Source Heat Pump System

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## Abstract

In cold areas, it is common to use antifreeze as heat source water in ground source heat pump systems to prevent freezing. However, concerned that the environment will be polluted if antifreeze leaks, we utilize water as heat source water in this study. The purpose of this research is to develop the anti-freeze and energy-saving control method for heat source water. The parameters of the simulation model are altered in the case study. As a result, raising the threshold temperature of confluence water will reduce the risk of freezing, but the amount of heat processed by the water source heat pumps will decrease because of the maximum capacity control. In addition, the power consumption of the system declines as the threshold water temperature difference between the inlet and outlet of the water source heat pumps increases.

## Keywords

GSHPS, Simulation, Energy conservation, Anti-freeze control

## 1. Introduction

It is expected that by utilizing ground source heat pump systems (GSHPS), not only will power consumption and CO2 emissions be reduced, but the heat island effect will be diminished, MOE (2015). In cold areas, it is common to use antifreeze as heat source water for GSHPS to prevent freezing. However, concerned that the environment will be polluted if antifreeze leaks, water is utilized as heat source water in this study.

The purpose of the paper is to develop an anti-freeze and energy-saving control method for the heat source water of GSHPS. Control methods such as the maximum capacity control of water source heat pumps (WSHP) and variable flow control of pumps are implemented. The accuracy of the simulation model is verified by comparing the simulation results with measured data from 14th March to 16th March 2016. Through the case study involving the changing of simulation parameters, the

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effectiveness of antifreeze control and the power consumption are investigated.

## 2. Outline of target system

The research object is an office room of a factory in Kurobe City, Toyama Prefecture. The chart of the target system and the specifications of the equipment are shown in Figure 1 and Table 1. Though there are package air conditioners installed in the room, in this paper, we only discuss the GSHPS. The ground heat exchanger (GHEX) consists of two sheet-shape heat exchangers which are heat exchange pipes set inside the flexible container. Since shallow groundwater exchanges heat with GHEX, the effectiveness of GHEX is improved.

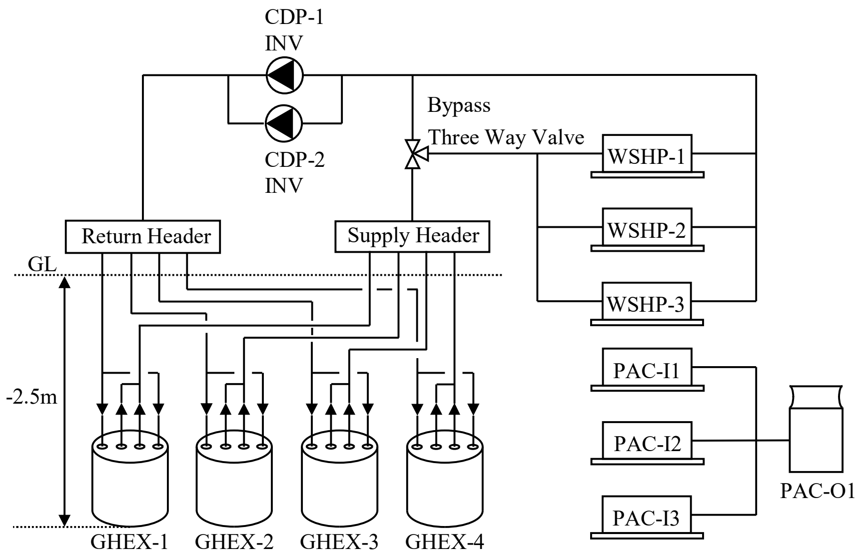


***Figure 1.*** *Target system diagram*

***Table 1.*** *Equipment specifications*

| Equipment | Symbol | Number | Specification | | |
|---|---|---|---|---|---|
| Heat source water pump | CDP-1<br>CDP-2 | 2 | Flow rate : 78L/min<br>Power consumption : 0.75kW<br>INV control | | |
| Ground heat exchanger | GHEX-1<br>GHEX-2<br>GHEX-3<br>GHEX-4 | 4 | Number of sheet-shape heat exchangers : 2<br>Flow rate : 26.4L/min<br>Capacity of heat exchange : 3kW | | |
| Water source heat pump | WSHP-1<br>WSHP-2<br>WSHP-3 | 3 | | Cooling | Heating |
| | | | Capacity[kW] | 5.0 | 5.0 |
| | | | Inlet water termperature[℃] | 7~45 | 5~45 |
| | | | Power consumption[kW] | 0.68 | 1.20 |
| | | | Flow rate[L/min] | 18 | |
| Package air conditioner (Indoor unit) | PAC-I1<br>PAC-I2<br>PAC-I3 | 3 | | Cooling | Heating |
| | | | Capacity[kW] | 5.6 | 6.3 |
| Package air conditioner (Outdoor unit) | PAC-O1 | 1 | | Cooling | Heating |
| | | | Capacity[kW] | 16.0 | 18.0 |
| | | | Power consumption[kW] | 3.90 | 4.40 |

## 3. Simulation model of GSHPS

### 3.1 Outline of the model

The simulation model of GSHPS is developed by combining the control logic model with the equipment unit model (WSHP, GHEX and pumps) of the target system. The calculation flow of the model is shown in Figure 2, and the input and output values of each model are shown in Table 2. The calculation period is one year with the calculation interval of one minute. The confluence is the place where the water from the WSHP outlet and bypass join together.

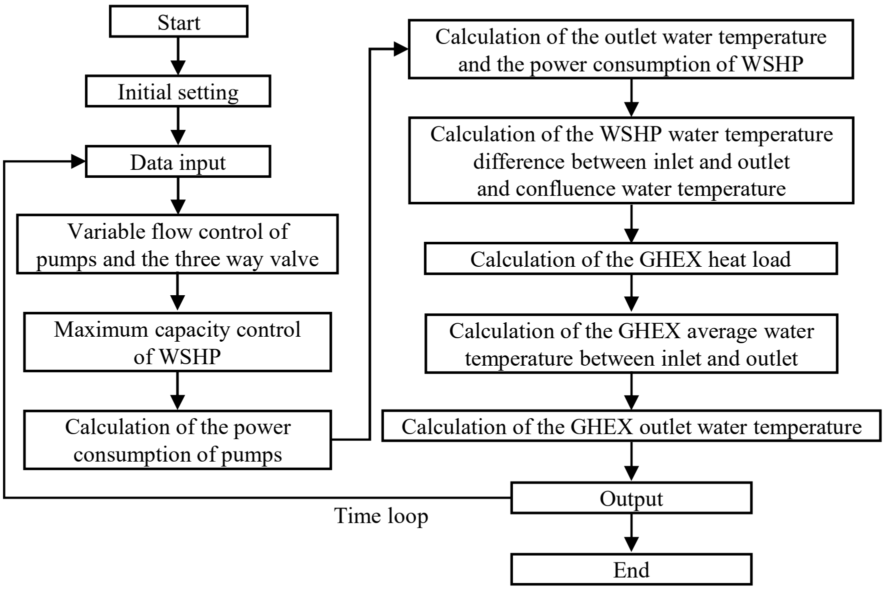


***Figure 2.*** *Calculation flow of the model*

***Table 2.*** *Input and output values of each model*

| | Input values | Output values |
|---|---|---|
| WSHP model | WSHP inlet water temperature<br>Flow rate<br>Air conditioning heat load<br>Indoor air temperature and humidity | WSHP outlet water temperature<br>WSHP capacity<br>WSHP power consumption<br>GHEX heat load etc. |
| Pump model | Current water temperature<br>Threshold of water temperature | Flow rate<br>Pump power consumption etc. |
| GHEX model | GHEX heat load<br>Flow rate | Average water temperature of inlet and outlet<br>GHEX outlet water temerature etc. |
| System model | Air conditioning heat load<br>Indoor air temperature and humidity<br>Initial water temperature | WSHP capacity<br>Water temerature of each point<br>Flow rate of each point<br>Power consumption etc. |

### 3.2 Accuracy verification of equipment unit model

Concerning the equipment unit model, the accuracy of the WSHP model and the GHEX model is verified. The WSHP model calculates the power consumption based on the performance curve of WSHP. The GHEX model calculates the water temperature by using the thermal conductivity measured from the thermal response test, GeoHPAJ (2016). Both models input measured data to calculate the output values. The comparisons of the simulation results and measured data of each model are shown in Figure 3 and Figure 4. In the WSHP model, the simulation results capture measured data with sufficient accuracy. However, in the GHEX model, when WSHP is running, the changes of GHEX outlet water temperature and average water temperature of the inlet and outlet are smaller than measured data. The next morning, the water temperature recovers from the night and shows a similar level of average temperature between the simulation results and measured data. In the future, the cause of the simulation deviation will be analyzed so as to improve the accuracy of the GHEX model.

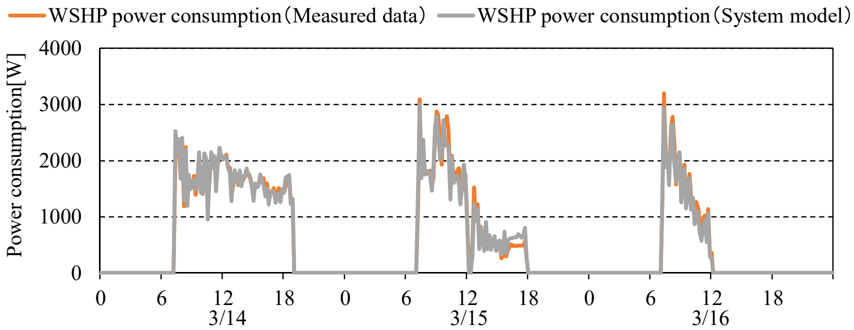


***Figure 3.*** *Verification result of WSHP model (WSHP power consumption)*

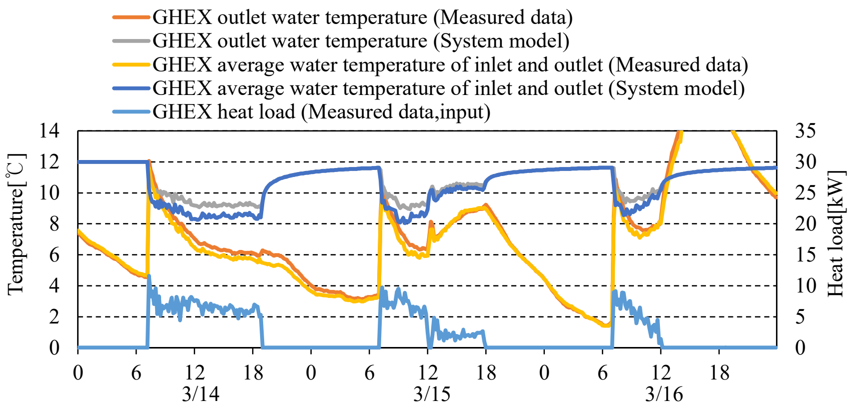


***Figure 4.*** *Verification result of GHEX model (Water temperature)*

### 3.3 Accuracy verification of system model

The comparison of WSHP power consumption and the comparison of GHEX water temperature are shown in Figure 5 and Figure 6. The simulation result of WSHP power consumption is more than measured data because the WSHP inlet water temperature is higher. In the system model, WSHP inlet water temperature equals GHEX outlet water temperature. The simulation deviation of the GHEX model is considered to cause the simulation result of GHEX outlet water temperature to be higher.

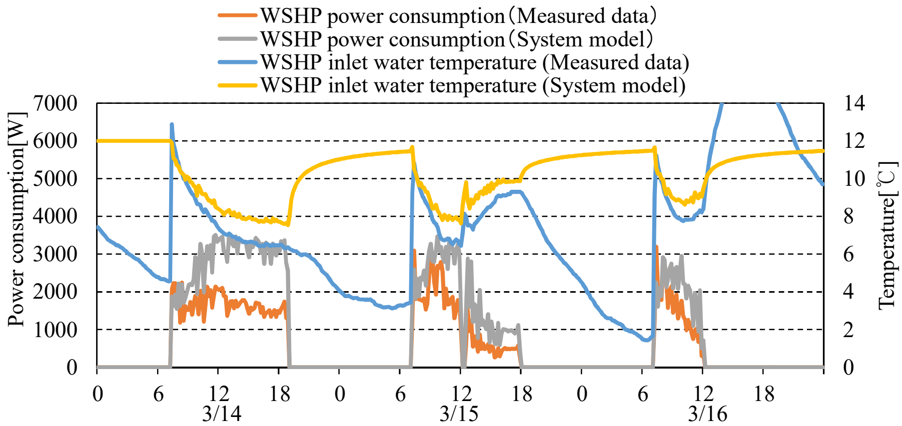


***Figure 5.*** *Verification result of system model (WSHP power consumption)*

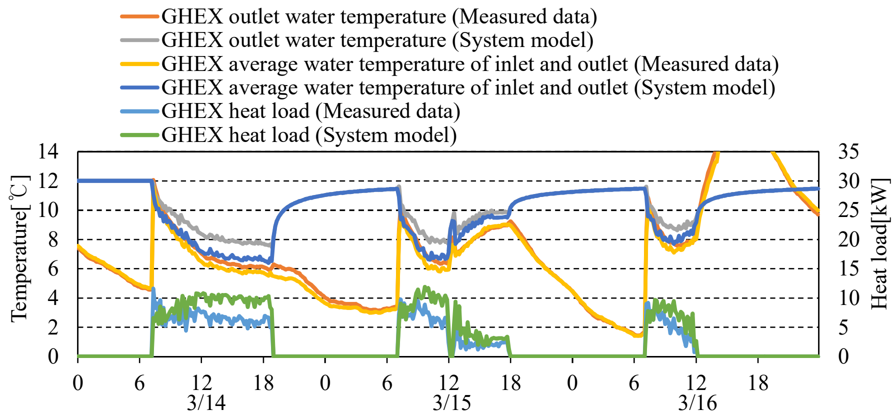


***Figure 6.*** *Verification result of system model (GHEX water temperature)*

## 4. Simulation result

The control method of the target system is shown in Table 3.The case study is shown in Table 4. When the target system is in cooling or heating (normal) mode, the flow of pumps is controlled by the threshold of WSHP water temperature difference between inlet and outlet. When the confluence water temperature is lower than the threshold, the mode will change from heating (normal) to step one of heating (antifreeze). If the confluence water remains at a low temperature, then the step will move from one to two

***Table 3.*** *Control method of the target system*

| Mode | Step | Control method |
|---|---|---|
| Cooling | | Control the flow of pumps to achieve the threshold of WSHP water temperature difference betweeen inlet and outlet |
| Heating (Normal) | 0 | Control the flow of pumps to achieve the threshold of WSHP water temperature difference betweeen inlet and outlet |
| Heating (Antifreeze) | 1 | Control the flow of pumps to achieve the threshold of confluence water temperature |
| | 2 | Maximize the flow of pumps and control the maximum capacity of WSHP(60%) |
| | 3 | Stop the WSHP an hour |

or even three. Also, the step will return to step one when the confluence water temperature rises again or step three lasts an hour. Furthermore, it will move back to normal mode from step one as long as the confluence water temperature is higher than the threshold.

***Table 4.*** *Case study*

| CASE | Contents of changing | | | |
|---|---|---|---|---|
| | WSHP water temperature difference between inlet and outlet(Cooling)[℃] | WSHP water temperature difference between inlet and outlet(Heating)[℃] | Confluence water temperature[℃] | Minimum flow of pumps[L/min] |
| Case_3_3_4_30 | 3 | 3 | 4 | 30 |
| Case_3_3_4_37 | 3 | 3 | 4 | 37 |
| Case_3_3_4_44 | 3 | 3 | 4 | 44 |
| Case_3_3_5_30 | 3 | 3 | 5 | 30 |
| Case_3_3_5_37 | 3 | 3 | 5 | 37 |
| Case_3_3_5_44 | 3 | 3 | 5 | 44 |
| Case_3_3_6_30 | 3 | 3 | 6 | 30 |
| Case_3_3_6_37 | 3 | 3 | 6 | 37 |
| Case_3_3_6_44 | 3 | 3 | 6 | 44 |
| Case_4_4_4_30 | 4 | 4 | 4 | 30 |
| Case_4_4_4_37 | 4 | 4 | 4 | 37 |
| Case_4_4_4_44 | 4 | 4 | 4 | 44 |
| Case_4_4_5_30 | 4 | 4 | 5 | 30 |
| Case_4_4_5_37 | 4 | 4 | 5 | 37 |
| Case_4_4_5_44 | 4 | 4 | 5 | 44 |
| Case_4_4_6_30 | 4 | 4 | 6 | 30 |
| Case_4_4_6_37 | 4 | 4 | 6 | 37 |
| Case_4_4_6_44 | 4 | 4 | 6 | 44 |
| Case_5_5_4_30 | 5 | 5 | 4 | 30 |
| Case_5_5_4_37 | 5 | 5 | 4 | 37 |
| Case_5_5_4_44 | 5 | 5 | 4 | 44 |
| Case_5_5_5_30 | 5 | 5 | 5 | 30 |
| Case_5_5_5_37 | 5 | 5 | 5 | 37 |
| Case_5_5_5_44 | 5 | 5 | 5 | 44 |
| Case_5_5_6_30 | 5 | 5 | 6 | 30 |
| Case_5_5_6_37 | 5 | 5 | 6 | 37 |
| Case_5_5_6_44 | 5 | 5 | 6 | 44 |

## 4.1 Effectiveness of antifreeze control

Annual minimum water temperature is shown in Figure 7. The minimum water temperature of the WSHP inlet varies from 6.8 ℃ to 7.5 ℃. All of them are in the range of 5 ℃ to 45 ℃, which is the specification of WSHP in heating mode. Consequently, the target system can run normally during the whole year without using antifreeze as heat source water. In all cases, WSHP outlet water temperature is almost the same as confluence water temperature. When the threshold of confluence water temperature is 6 ℃, the minimum water temperature of the WSHP outlet and confluence is around 5 ℃, higher than other cases. Annual amount of heat processed by WSHP is shown in Figure 8. For the cases in which the thresholds of confluence water temperature is 4 ℃ and 5 ℃, the processing rate is nearly 100%. But the processing rate decreases when the threshold temperature of confluence water is 6 ℃.

The WSHP altered from step zero of the normal heating mode to step two of the antifreeze heating mode. With the WSHP maximum capacity control, WSHP could not process all of the air conditioning heat load. As a result, the package air conditioners (PAC) should process the remaining heat load.

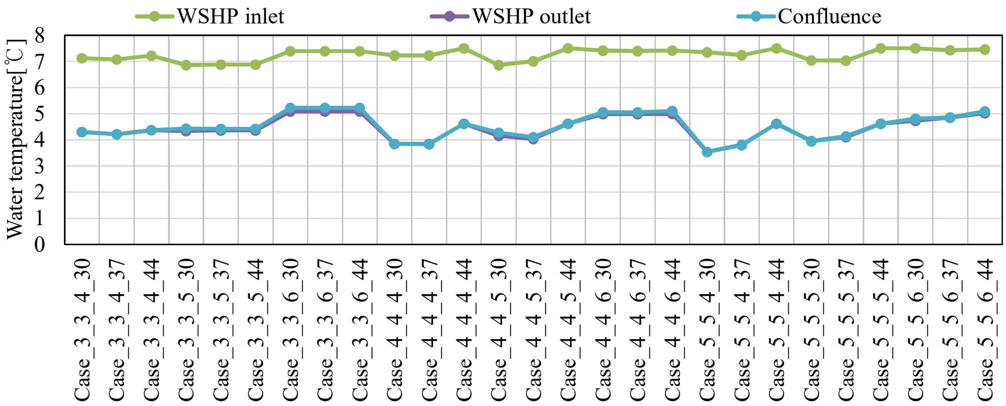


***Figure 7.*** *Annual minimum water temperature*

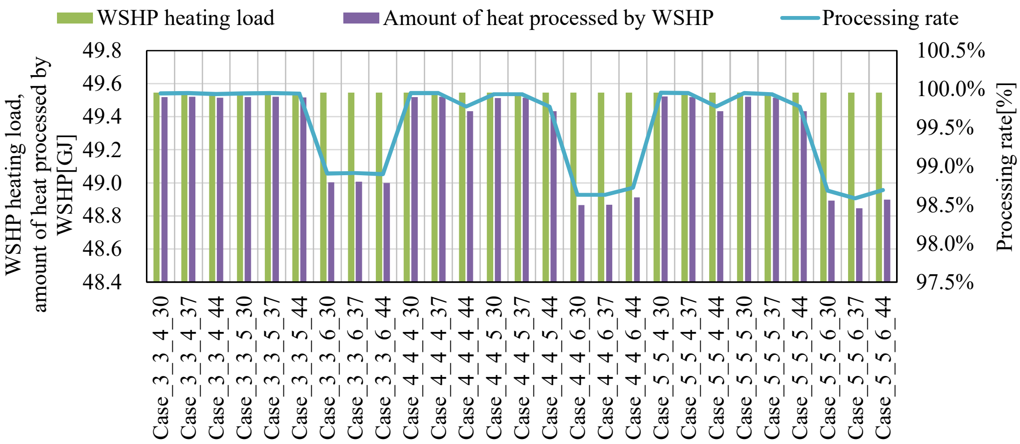


***Figure 8.****Annual amount of heat processed by WSHP*

### 4.2 Power consumption and effectiveness of energy conservation

Annual power consumption and energy-changing rate is shown in Figure 9. The standard case is Case_4_4_5_37. The energy-changing rate shows the proportion of other cases and the standard case. The results which are positive numbers mean that the total power consumption of WSHP and pumps is more than the standard case and vice versa. The power consumption tends to decrease as the WSHP water temperature difference between inlet and outlet increases. The most energy-saving case is Case_5_5_6_37, saving 1.8% power consumption compared to the standard case. But as the processing rate decreases, the power consumption of PAC is probably going to increase. Thus, it is necessary to take the power consumption of PAC into consideration.

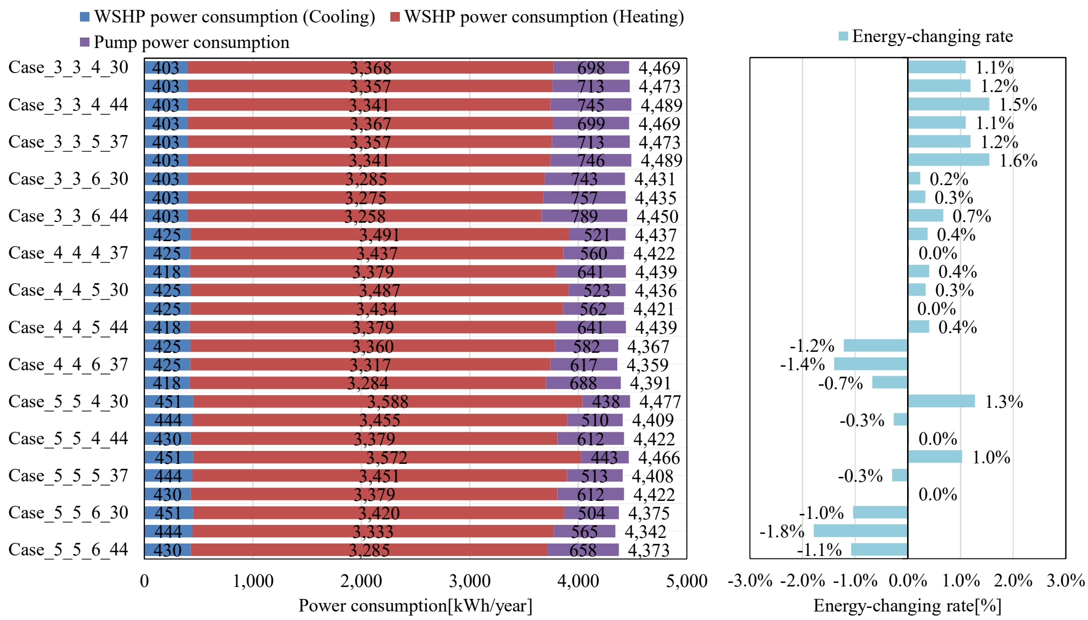


***Figure 9.** Annual power consumption and energy-changing rate*

## 5. Conclusion

In the paper, the simulation model of GSHPS is built and the accuracy of the model is verified. Although the WSHP model shows sufficient accuracy, the simulation deviation in the GHEX model causes an inaccurate simulation result of the system model. By altering the parameters in the case study, the heat source water is less likely to freeze when the threshold temperature of confluence water increases. But the heat processed by WSHP decreases, so it has to be processed by PAC. Furthermore, the effectiveness of the energy conservation of GSHPS improves as long as the threshold of WSHP water temperature difference between inlet and outlet increases. In the future, the accuracy of the GHEX model should be raised and the power consumption of PAC should be taken into account so as to evaluate the effectiveness of the energy conservation of the whole system.

## Acknowledgements

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