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Simple Thermal Energy Storage Tank for Improving the Energy Efficiency of an Existing Air-conditioning System

Simple Thermal Energy Storage Tank for Improving the Energy Efficiency of an Existing Air-conditioning System

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Abstract. This study aims to improve the energy efficiency of heating, ventilation, and air-conditioning (HVAC) system in existing building by adding a thermal energy storage (TES) tank. By installing the TES tank with volume of 1 m3 in the chilled water loop of HVAC system. it can make charge/discharge surplus heat from heat source equipment. The chilled water can be delivered not only to secondary side but also to TES tank, while the required heat load is less than the rated capacity of the heat source equipment, it does not need to shrink its output and can be operated under the relatively higher load ratio without falling down efficiency. The charge/discharge progress is considered occurring within short-term less than an hour. During the discharge progress the heat source equipment can be turn off or idling operation yields reduce operation hour of heat source equipment and achieve energy-saving. In this paper, a case study is conducted to evaluate the energy efficiency improvement by adding TES tank into HVAC system using system energy simulation, coupling two-dimensional, steady-quasi TES numerical model that is verified by comparison with the measurement data. The error of the TES numerical model compared with the experiment was less than 5%. From the case study results, it is found that the TES tank can improve energy efficiency of HVAC system because of increasing the COP of the heat-source equipment reduces its energy consumption and reducing operation time of the primary chilled water pumps.

1. Introduction

The overall energy consumption in Japan has increased more rapidly in the civilian sector than in other sectors over the past 40 years [1]. Thus, it is necessary to encourage the introduction of energy-saving technologies, especially in the civilian sector. This study focuses on existing small- to medium-sized commercial buildings that have a total floor area even or less than 10,000 m^2 [2]. Such buildings are likely to have a multi split-type air-conditioning system, centralized heating, ventilation, and air-conditioning (HVAC) system, or combination of both. Typically, however, the energy management of these systems is inadequate because of budget constraints or insufficient knowledge. Hence, improving the energy efficiency of such systems could save a significant amount of energy. We focus on the centralized HVAC system and propose a technology to improve its operational efficiency. This involves a relatively simple idea of installing small thermal-energy-storage (TES) water tanks in an existing HVAC system to level the heat-load fluctuation due to the charging and discharging heat and achieving a high efficiency of the heat-source equipment by increasing the part-load ratio.

2. Outline of proposed system

A conceptual diagram of the proposed system is shown in Figure 1. The TES tank is added on a bypass pipe and charges heat when the volume of chilled water from the heat-source equipment exceeds that required by the secondary side. Simultaneously, the heat-source equipment improves the operational load factor as heat is charged in the TES tank. Once charge process done, chilled water is supplied to the secondary side from the tank. Also, the heat-source equipment and the chilled-water pumps can be stopped their operation. This system is considered acceptable at the heating season, because the daily average of the operational load ratio is relatively low.

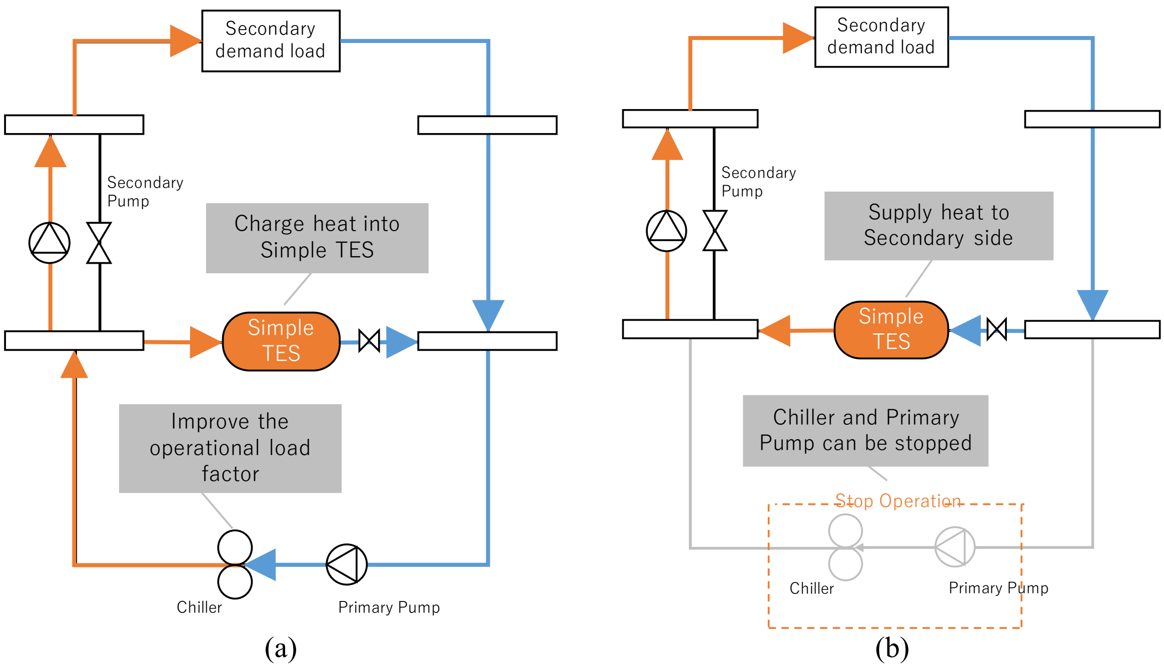

Figure 1. Charge and discharge modes of proposed system: (a) charge; (b) discharge.

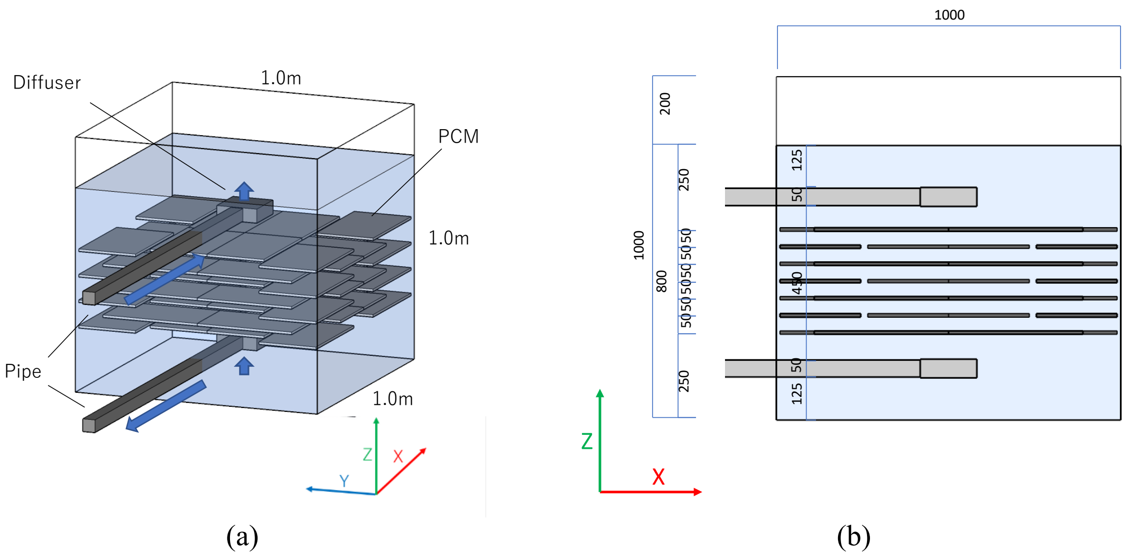

Figure 2. Overview of the TES tank: (a) perspective view; (b) XZ cross section.

An overview of the TES system is shown in Figure 2. The unit size is 1 m^3, and charge and discharge process is induced by temperature stratification inside the tank; the water level is 0.80 m. Diffusers are installed to mitigate the inlet flow velocity [3]. There are 56 phase change materials (PCMs) arranged horizontally, eight PCMs on each shelf and seven overlapping shelves. When the temperature difference is 5 K, the ideal thermal capacity is ~19.8 MJ per unit. Adding PCMs to a thermal water tank could increase its thermal capacity by ~20%.

3. TES simulation model

An overview of the two-dimensional TES simulation model that is used for the PCM heat transfer is shown in Figure 3 [4]. The model is discretized length-wise into eleven cells. The depth of the model, Y is determined by ensuring the same area as that of the real heat-transfer area between the PCMs and water. The opening width of the model is Xw. Where there are PCMs, we use Xwp_w and Xwp_p for the width of the water and PCMs, respectively. These values are determined by ensuring the same cubic volume as that of the real system.

In the heat-transfer calculation, only advection is considered between each control volume consisting of water. However, advection, heat conduction in the PCMs, and heat transfer between the water and PCMs are considered in the water/PCM control volume. The PCM temperature is determined by the contained heat quantity, as shown in Figure 4 (the figure is constructed by integrating the heat rate as the standard condition at 40 °C by differential scanning calorimetry [5]). In this simulation, the heat losses from the tank and the water/PCM heat transfer at planes X = 0 and the max were ignored.

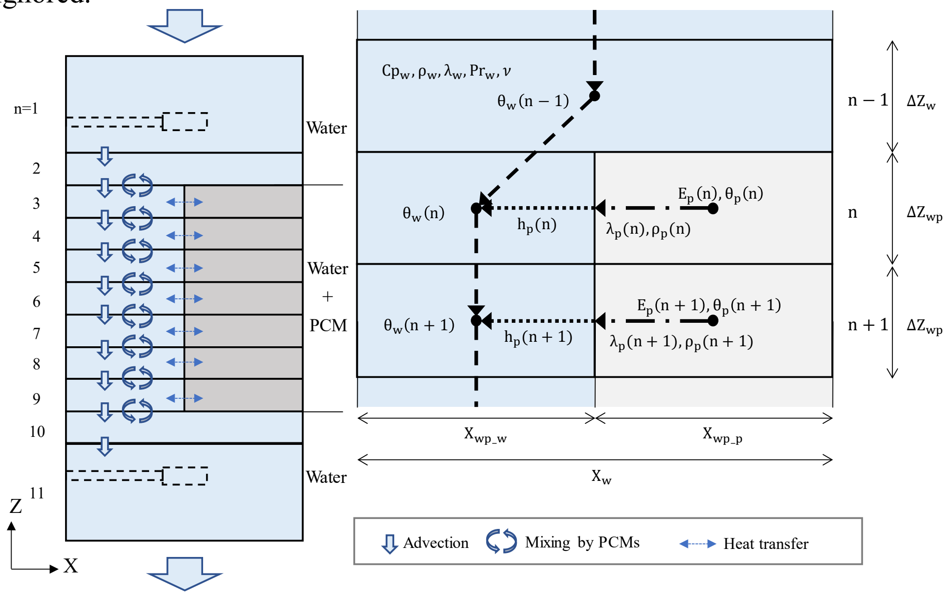

Figure 3. Overview of heat transfer model.

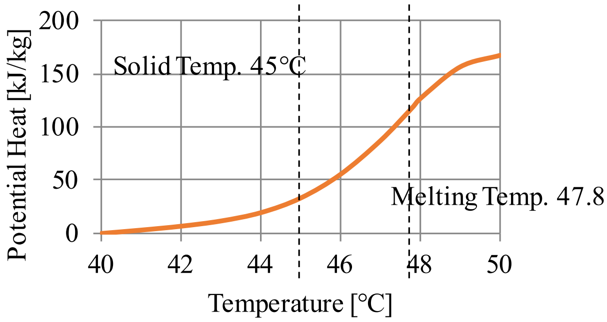

Figure 4. PCM properties. [5]
Melting temperature is 47.8, and solid temperature is 45.

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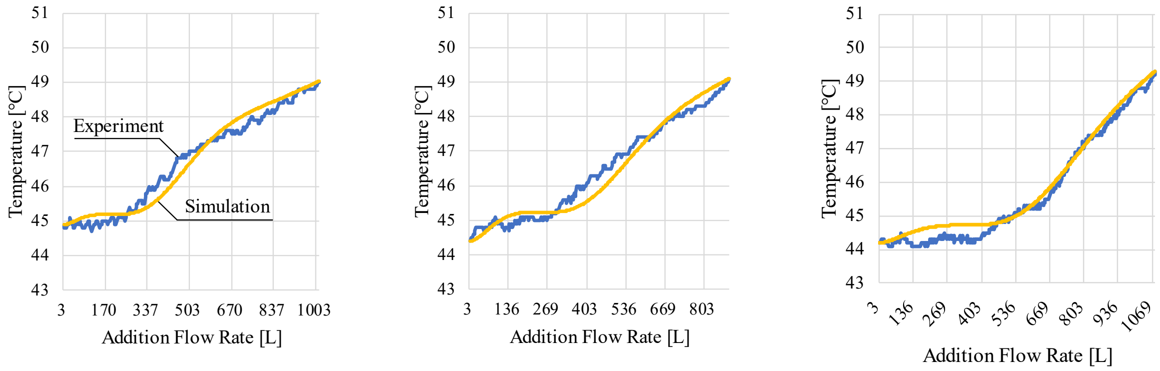
4. Verification of the TES simulation model

We made a full-size experimental equipment, and compared the temperature change between experiment and simulation model for verification. Water flow rate is set by 3 patterns, 200, 160, 120 L/min. Figure 5 shows outlet temperature change of TES during charge heat from 45°C. In cases of every flow rate, simulation model can represent almost same temperature changes as experimental equipment. Table 1 shows an error of the heat charge-discharge rate between experiment and simulation. The error was within 5% in cases of every flow rate, therefore it can be said that the simulation model has enough accuracy.



(a) 200[L/min] (b) 160 [L/min] (c) 120 [L/min]

Figure 5. Comparetion of temperature change

Table 1. Simulation error of charge-discharge to experiment data

Flow rate [L/min]	Error of charging [%]	Error of discharging [%]
200	+2.16	+3.39
160	+3.70	+2.65
120	-2.84	-3.80

5. Summary of simulation

We estimate the effect of the operating efficiency improvement and energy saving of the HVAC/TES system caused by introducing the proposed system by using a simulation model. The model building is a ten-story office building, located in Tokyo. The air-conditioned area is 500 m^2 on each floor, and the total floor area is 5,000 m^2.The HVAC system equipment is listed in Table 2. The system is consisting of primary- and secondary pumps with air-source heat-pump chillers, air handling unit (AHU) and fan coil unit (FCU).

An HVAC system adding the proposed TES system into an existing bypass pipe is shown in Figure 6. The temperatures at points T1 and T2 shown in the figure determine the switching between heat charging and discharging. The chilled water bypasses through the TES tank to avoid increasing the amount of heat-source equipment in operation when the return temperature is too low. In this simulation, we ignore a load for start-up each machine.

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Table 2. List of HVAC system equipment.

Notation	Name	Specification	Power	Num. of Units
RR- 1, 2, 3	Air-source heat pump chiller (basic type)	Cooling capacity: 265 kW Rated flow: 760 L/min (7–12°C) COP rating: 2.91	Cooling 91.0 kW	3
		Heating capacity: 300 kW Rated flow: 860 L/min (45–40°C) COP rating: 3.19	Heating 94.0 kW	
PCH-R-1, 2, 3	Primary pump	Rated flow: 860 L/min Lifting height: 250 kPa	5.5 kW	3
PCH-B1-2~4	Secondary pump	Rated flow: 590 L/min Lifting height: 250 kPa	5.5 kW	3
AHU	Air Handling Unit (Interior zone)	Air Flowrate: 7,840m^3/h Outside Air Flowrate: 2,220m^3/h Cooling capacity: 46.4 kW Fluid flowrate(C): 133L/min Heating Capacity: 27.3kW Fluid flowrate(H): 79L/min	3.7 kW	10
FCU_S	Fan Coil Unit (South zone)	Air Flowrate: 420 m^3/h Cooling capacity: 1.8 kW Fluid flowrate(C): 5.2 L/min Heating Capacity: 1.1 kW Fluid flowrate(H): 3.2 L/min	0.022 kW	40
FCU_W	Fan Coil Unit (West zone)	Air Flowrate: 1,120 m^3/h Cooling capacity: 4.9 kW Fluid flowrate(C): 14.1 L/min Heating Capacity: 1.2 kW Fluid flowrate(H): 3.5 L/min	0.059 kW	30
FCU_E	Fan Coil Unit (East zone)	Air Flowrate: 840 m^3/h Cooling capacity: 3.9 kW Fluid flowrate(C): 11.2 L/min Heating Capacity: 1.2 kW Fluid flowrate(H): 3.5 L/min	0.046 kW	30

6. Case study by simulation

Case study is conducted to evaluate the energy-saving effect caused by introducing TES tanks into HVAC system, also the influence of reducing the number of TES tanks. When the number of TES tanks are reduced, inlet flow rate per unit will be increased and causing low charging rate. Although the TES tanks should be established as many as possible, considering the available space in the existing buildings and initial costs, we should evaluate the influence of reducing the number of TES units. In this paper, two cases are simulated which are 6 and 4 units to reveal their energy saving performance.

Figure 7 shows TES tank inlet and outlet temperature and flow rate over time. Flow rate at 6 units is transiting around 70 L/min, but 4 units is around 110 L/min. This is caused by increasing flow rate per a unit, and that occur short charging-discharging time, three hours at 6 units and 1.5 hours at 4 units.

The energy consumption and system-average coefficient of performance (COP) are shown in Figure 8. We conduct a simulation at a day in December which is heating period. Looking at the results, the energy consumption of the proposed HVAC system (6 units) is ~30% lower than conventional system, and that of the primary pump is lower too. The energy consumption of the heat-source equipment is reduced by improving the average COP, which is caused by charging and discharging the TES tank. The primary pump can then be stopped when the tank is discharging. Comparing two cases which have different number of TES units, there are few gaps in energy consumption and system COP. It is found that even if number of TES units are decreased and charging efficiency is reduced, proposed system can maintain enough energy saving.

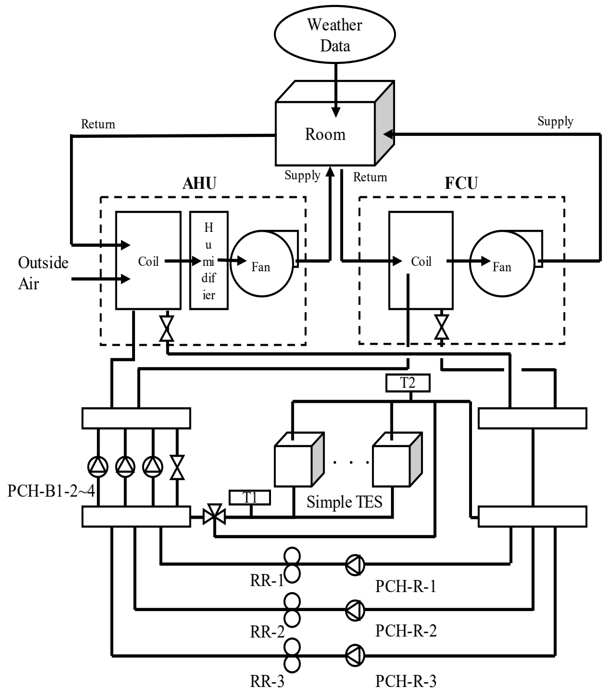

Figure 6. Proposed HVAC system.

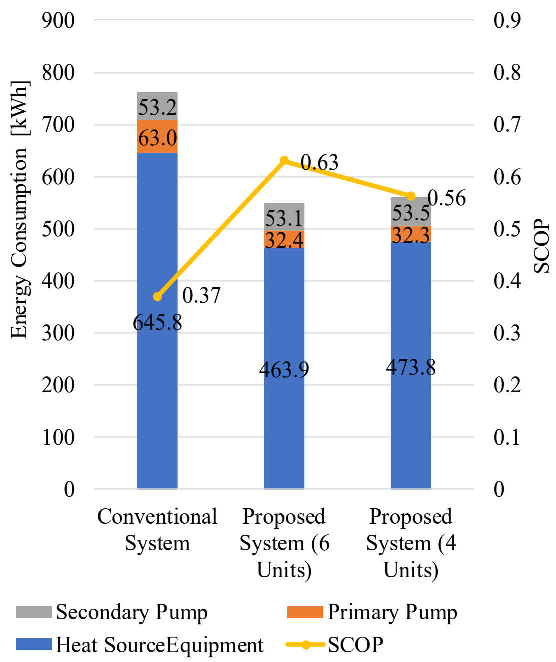

Figure 8. Energy consumption and COP

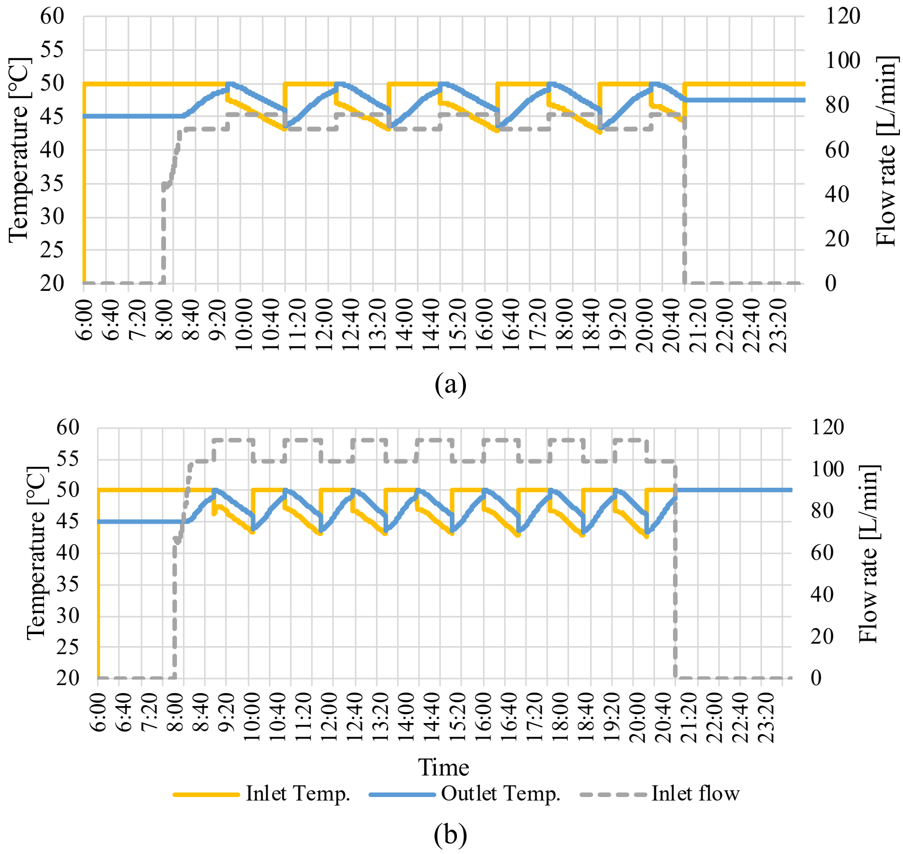

Figure 7. TES inlet and outlet temperature and flow rate by time:
(a) 6 units; (b) 4 units.

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7. Conclusions

In this paper, we proposed a system which can to improve the energy efficiency of HVAC system in existing building by adding a simple TES tank on bypass pipe. We designed TES numerical model and verified by comparison with the experimental data, and showed enough accuracy. By using this model, case study showed proposed system is effective for energy saving. Furthermore, it is found that the influence on energy savings was limited when the number of TES tanks are changed. We now intend to make a manual of proposed system for design and operation by using these simulation model.

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