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Testing facility for unsteady performance of air conditioning system

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Abstract

Since annual performance indexes, such as the SEER and APF, have been established for air conditioning systems, their annual performance has considerably improved. However, both SEER and APF are calculated from steady-state data by fixing the compressor's operating frequency. Therefore, the unsteady performance and the actual control strategy are not considered. By this approach, the actual operating performance of the air conditioner cannot be determined.

This study aims to evaluate the actual operating performance of an air conditioning system. We therefore developed a new testing facility for reliable evaluation of its operability, with the final goal of establishing the optimal control strategy for the air conditioner.

The greatest feature of this facility is that it can reproduce the real time virtual room environment. The computer simulates indoor air conditions and calculates the return air temperature. The condition generator recreates the return air conditions of return air, which has been virtually obtained by the simulator. Therefore, the likewise generated return air is delivered to the test section.

The experimental data obtained from this testing facility was used to obtain the actual unsteady operating state of the air conditioner under the effect of indoor heat load fluctuations. In addition, the indoor heat capacity and the heat load were observed to be the dominant factors during the unsteady operation of the air conditioner. As a future step, on the basis of these results, we aim to establish the optimal operability and control methods of the air conditioner.

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Keywords: control, evaluation, compression type heat pump, dynamics

1. Introduction

Vapor compression heat pumps are widely used in refrigeration and air conditioning applications. A vapor compression heat pump is expected to contribute to energy savings because it has very high energy consumption efficiency. In addition, when used in an air conditioner, this heat pump is extremely efficient because cooling and heating can be adjusted. To use a vapor compression heat pump for energy savings and comfort, various technological innovations have been introduced. As a result, it can be said that the current performance of this heat pump at the rated point has significantly improved but is approaching its limit.

However, according to previous studies [1–6], it is known that the rated operating performance and the actual operating performance are different. This is because the room temperature in actual operation is not constant, and the vapor compression heat pump is sometimes used in unsteady conditions, such as during intermittent operation. In addition, the evaluation method for a vapor compression heat pump that is widely used is limited to

evaluating the performance in steady state operations such as those in an environmental testing chamber, which does not consider unsteady states. Therefore, to evaluate performance during actual operation, it is necessary to consider unsteady conditions at the room temperature and during unsteady operation such as intermittent use of the heat pump.

The goal of this study is to establish an evaluation method for determining the actual operating performance of a vapor compression heat pump. This is accomplished through the construction and verification of an evaluation device that can reproduce unsteady temperature changes in a virtual room. Then, an analysis of the results is conducted.

2. Overview of the evaluation device

Figure. 1 shows the overall structure of the evaluation device. A block diagram of the evaluation device is shown in Fig. 2. A photograph of the evaluation device is shown in Fig. 3.

The significant feature of this evaluation device is that it can virtually reproduce any operating condition. The evaluation apparatus can reproduce the behavior of the heat pump at unsteady temperatures and humidity for various heat capacities and heat load conditions in a room.

First, the device reproduces a virtual room temperature by detecting the outlet air temperature from an indoor heat exchanger and calculates the room temperature on a computer while considering the conditions in the room. Assume that the calculated room temperature is the same as the air temperature at the inlet of indoor heat exchanger.

Next, we enter the calculated inlet air temperature into the load equipment as a target value to control the capacity of the load facility. The load facility is composed of a duct, cold-water heat exchanger, hot-water heat exchanger, humidifier, and fan. The air temperature, humidity, and air volume are controlled by the load facility.

At the entrance of the test section, the inlet-side air temperature and humidity are measured using a temperature and relative humidity meter. At the exit of the test section, the outlet-side air temperature is measured using a thermocouple. The air volume is detected by measuring the differential pressure across the orifice in a circular path at the exit duct of the experimental apparatus.

The heat exchange of the air-side test section is calculated using the difference in the air specific enthalpy between the inlet and outlet and the air volume. The controller for the compression heat pump is shown in Fig. 2.

A PI controller is generally used in an air conditioner. The PI controller keeps a constant room temperature to the target value by operating the compressor.

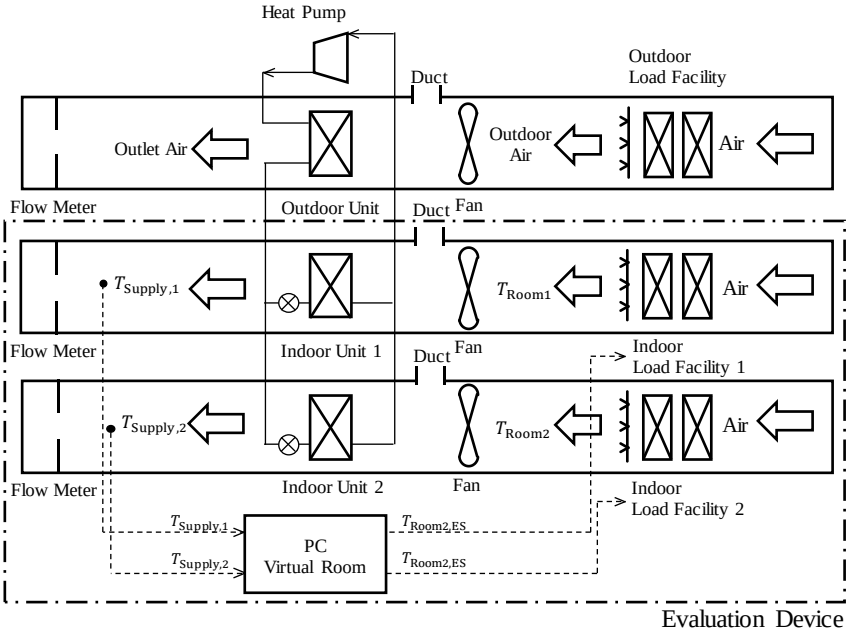


Fig. 1 Overview of Evaluation device

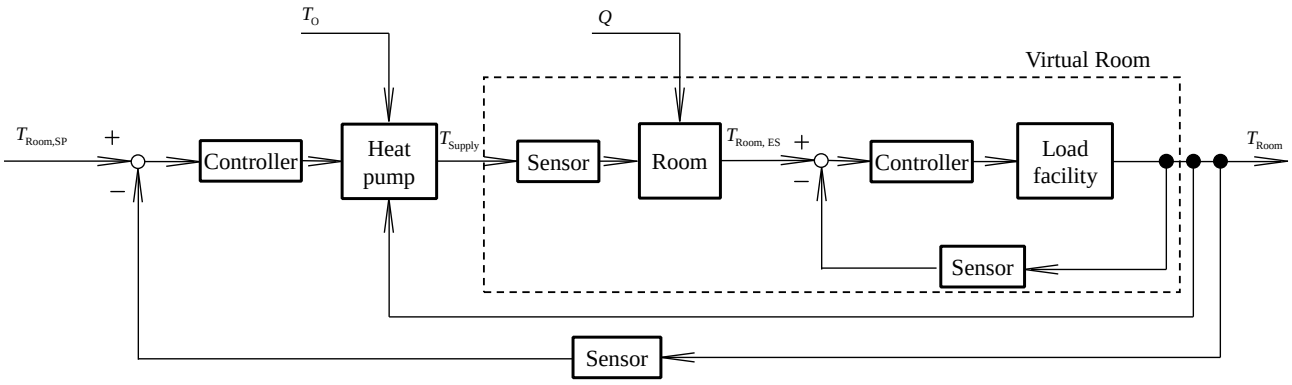


Fig. 2 Block diagram of evaluation facility



Fig. 3 Appearance of evaluation facility

3. Result and discussion

3.1. Verification of room model

Fig. 4 shows the verification target area of block diagram of evaluation facility. Fig. 5 and Fig. 6 show the results of the verification of the evaluation apparatus alone. It was verified whether the apparatus is able to reproduce the virtual room. The model of the virtual room was a first-order lag system, as shown in Eq. (1). The temperature in the room was changed in steps. The time constants of the room were 300 s and 600 s. It was confirmed that the system could generally reproduce an accurate room temperature.

$$\rho c V \frac{\mathrm{d}T}{\mathrm{d}t} = G_{\mathrm{A,I}} h_{\mathrm{A,I}} - G_{\mathrm{A,O}} h_{\mathrm{A,O}} + Q \tag{1}$$

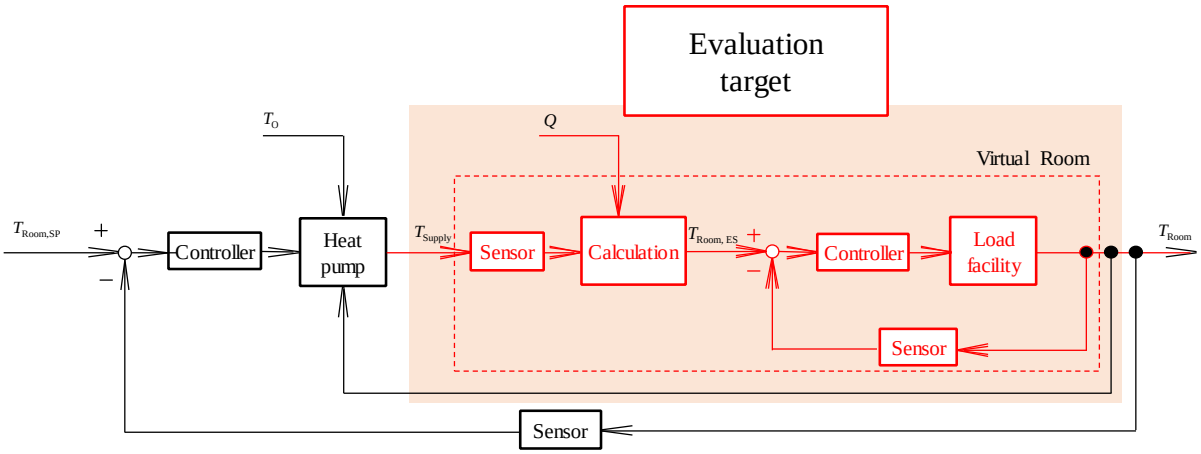


Fig. 4 Block diagram of evaluation facility and evaluation target.

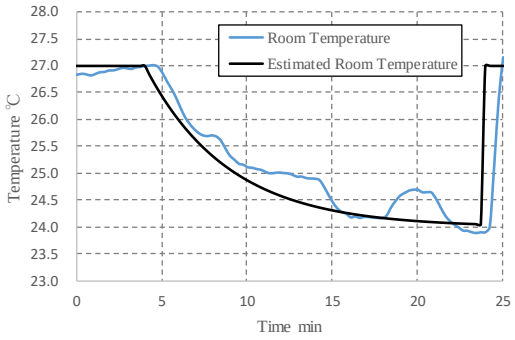


Fig. 5 Virtual room temperature verification result (Time constant:300s)

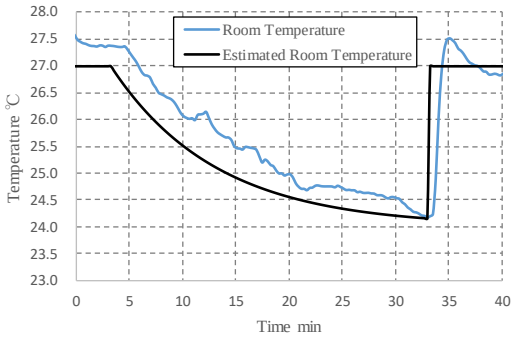


Fig. 6 Virtual room temperature verification result (Time constant:300s)

3.2. Verification of heat pump operation

In order to carry out a verification of the evaluation system, a VRF was set up with two indoor heat exchangers. As previously mentioned, the model of the virtual room shown in Eq. (1) is a first-order lag system. Temperature distribution is not taken into consideration. The operating conditions are the two patterns for evaluation. We checked whether the air temperature generated by the load equipment matched the calculated target air temperature in the virtual room.

The test conditions are listed in Table 1. The virtual room under the test conditions is assumed to have a heat capacity equivalent to a time constant of 600 s. The air volumes of the indoor unit and outdoor unit are assumed to be constant. Inlet air dew point temperature is controlled to be constant. In this condition, dew condensation does not occur. Cooling capacity includes only a sensible heat in the experiment.

Fig. 7 shows the verification target area of block diagram of evaluation facility. Fig. 8 and in Fig. 9 show a comparison of the indoor temperature and the target air temperature during intermittent operation. Figs. 10 and 11 show a comparison of the indoor temperature and the target air temperature during continuous operation. Using both the operating modes, it was possible to measure the unsteady behavior of the system in a virtual room. T_{Room}, the variation in room temperature, became a first-order lag and succeeded in reproducing the indoor environment.

In addition, it shows that air temperature T_{Room} generated by the load equipment generally matches the target air temperature $T_{Room,ES}$ calculated for the virtual room. It can be confirmed that the compression-type heat pump controls the room temperature to the target value. and that the compression-type heat pump controls the room temperature to the target value. In Case 1, the compressor is controlled such that the air temperature T_{Room}, during intermittent operation, reaches the target value.

From the above experiments, it was confirmed that we could reproduce unsteady variations in room temperature by using this device, which can contribute to establishing an evaluation method for the actual operating performance of the compression heat pump.

Table 1 Testing condition

	Case 1		Case 2	
	Room 1	Room 2	Room 1	Room 2
Outdoor temperature, °C	35.0		35.0	
Indoor temperature set point, °C	27.0	27.0	27.0	27.0
Inlet air dew point temperature, °C	5			
Indoor heat load, kW	1.08	0.538	1.61	0.806
Indoor air flow rate , m^3/h	400	400	400	400
Outdoor air flow rate , m^3/h	1300		1300	

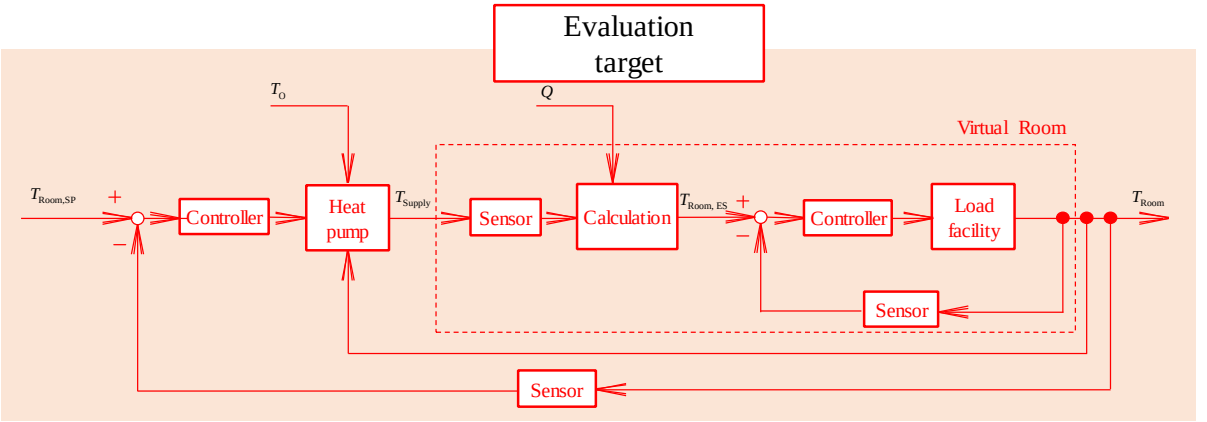


Fig. 7 Block diagram of evaluation facility and evaluation target.

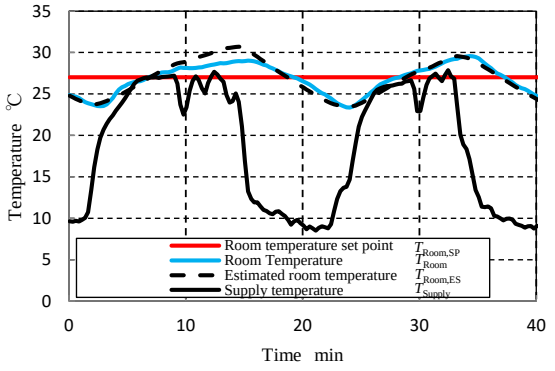


Fig. 8 Comparison between room temperature and estimated room temperature on Case1 (Room 1)

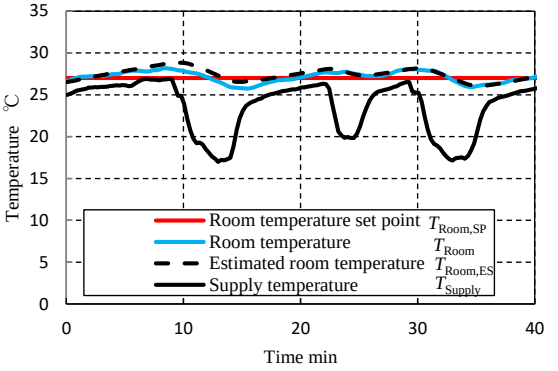


Fig. 9 Comparison between room temperature and estimated room temperature on Case 1 (Room 2)

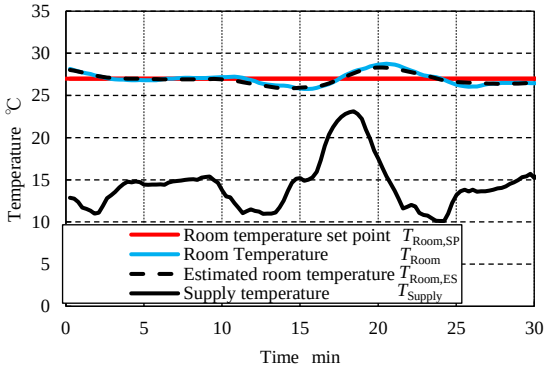


Fig. 10 Comparison between room temperature and estimated room temperature on Case 2 (Room 1)

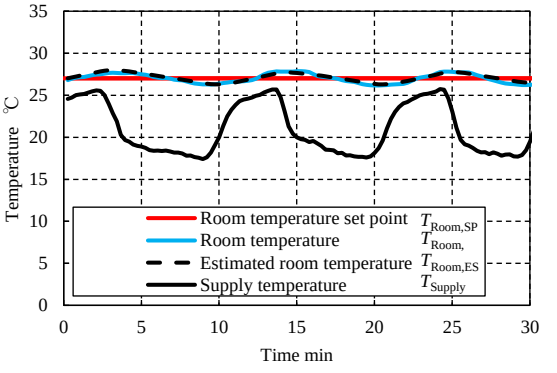


Fig. 11 Comparison between room temperature and estimated room temperature on Case 2 (Room 2)

4. Conclusion

In this study, to evaluate the actual operating performance of a vapor compression heat pump, an evaluation device that can virtually reproduce a room was proposed. The constructed device was verified by the actual equipment. As a result, the device can reproduce unsteady state variations in the indoor temperature. Using this testing facility, we will evaluate the performance of a compression heat pump, and we are planning to establish an evaluation method for actual operating performance. As a future step, based on these results, we aim to establish optimal operability and control methods for an air conditioner.

5. Acknowledgements

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6. NOMENCLATURE

c : specific heat at constant pressure, $J \cdot kg^{-1} \cdot K^{-1}$
G : mass flow rate, $kg \cdot s^{-1}$
h : specific enthalpy, $J \cdot kg^{-1}$
Q : heat load, W
T : temperature, °C
t : time, s
V : volume, m^3
ρ : density, kg/m^3

SUBSCRIPT

A.I : air inlet
A.O : air outlet
ES : estimated
Supply: Supply air
Room : Room air

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