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APPLICATION OF HEAT PUMP SYSTEM TO THE AIR TEMPERATURE CONTROL IN GROWTH CHAMBER

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CHIKUSHI J., TOH K. and EGUCHI H. *Application of heat pump system to the air temperature control in growth chamber.* BIOTRONICS **18**, 67–73, 1989. The heat pump system with a comparator and a blind controller was applied to the air temperature control in a growth chamber. Settling time in step response, the accuracy in the fixed command control of air temperature and the power requirements of the control were examined. It was found in the characteristics that the response times are relatively short, and the accuracies are about ±1°C. The system was simpler and able to be driven with smaller power requirements, as compared with the other prevailed systems. Thus, the construction cost and the running energy were extremely low. From these facts, it was suggested that the heat pump system is useful for the air temperature control in the growth chamber.

Key words: heat pump; air temperature; growth chamber; inverter; comparator; response time; power requirements.

INTRODUCTION

For controlling air temperature in a growth chamber, an air conditioner which is composed of cooling and heating coils has been generally used, and various control methods have been employed for a desired accuracy (*2*, *3*). We tried to simplify the apparatus and to save energy and cost by developing new control system with a commercial heat pump. The present paper deals with the analysis of characteristics of the control system and of the power requirements for the air temperature control.

CONTROL SYSTEM AND EXPERIMENTAL METHODS

Figure 1 shows the schematic diagram of the control system. A coil set in the air conditioner in the growth chamber system was connected with a heat pump (*1*). We propose to call this system "inverter-heat pump (IH) type." This type has a merit that both cooling and heating manipulations can be made with one coil. The coil is composed of 6 rows and 15 columns. Heat exchange area is 24.5 m^2 and air velocity through the coil is 1.5 $m\ s^{-1}$. Air temperature in the chamber was measured by a platinum resistance thermometer. Measured data were accumulated in the computer system. The air temperature in the chamber was also

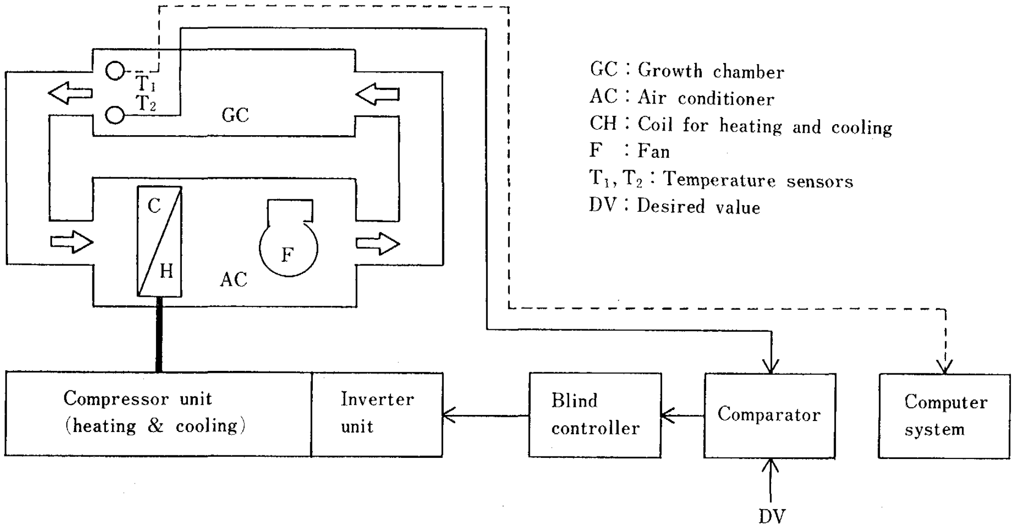

Fig. 1. Schematic diagram of the control system.

detected by a thermistor. The signal of the air temperature was transmitted to a comparator, and used as a feedback signal in a blind controller. In the comparator, either of heating or cooling was splitted on the basis of the sign of the deviation which is obtained by subtracting the present temperature from the desired value. In the controller, the deviation was converted into manipulating variable of an analog signal. The signal was transmitted to an inverter unit, and was converted into a digital signal. On the basis of this signal, the flow direction of the refrigerant can be changed by the manipulation of the valve with four directions, and the rotating rate of the compressor, which is a value assigned with the step of 1.8 Hz in the range of 30 to 90 Hz, is determined. The ability of the compressor can vary from 2800 to 5000 kcal h^{-1} for cooling and from 2800 to 6200 kcal h^{-1} for heating according to the rotating rate of 30 to 90 Hz. The power requirement for a fan is 0.75 kW, the air flow rate is 20 m^3 min^{-1}, the air turn-over rate is 75 h^{-1}, and the average air velocity is 0.3 m s^{-1}. Total air space is about 15 m^3. The length of refrigerant pipe connecting the compressor unit and the coil was about 30 m which is allowable length for this apparatus. In the experiments, stepwise desired air temperatures were commanded for increase from 15 to 35°C with 5°C step (rising process), and for decrease from 35 to 15°C with 5°C step (falling process). The response time (settling time), the accuracy of controlled variable, and the power requirements were measured.

Respective control systems of IH, standard and high accuracy types were built in the same growth chamber for the comparison of these characteristics. In the standard type, the on-off control action is employed with refrigerator (1.5 kW) for cooling, and the PID control action is employed by using the electric heater (8 kW) through the silicon controlled rectifier (SCR) for heating. In the high accuracy type the refrigerator is operated continuously, and implies the requirement for continuous heating load, where the PID control action is employed for manipulation of the electric heater (8 kW) through the SCR.

RESULTS

Figures 2, 3 and 4 show the controlled variables of air temperature and power requirements in the IH type, the standard type and the high accuracy type, respectively. These data were obtained under the outdoor air temperature of 25°C. The accuracy of the controlled air temperature in the IH type was higher than that in the standard type, but was lower than that in the high accuracy type. In the IH type the most reliable accuracy was found at controlled temperature of 20°C in the rising process. The accuracy at lower desired air temperatures appeared better than that at higher temperatures except the case of 20°C in the rising process. The overshoot was scarcely found in the step responses in the IH type. Power requirements varied according to the on-off action of compressor at the steady state in the IH type. In the standard type, the power requirements fluctuated in the range of 7 to 10 kW. In the high accuracy type, power requirements was used at high level, because of continuous running of refrigerator and electric heater.

Table 1 shows the response time in dynamic process, the accuracy occurring at steady state and the power requirement. In each of the types, the response time was longer in the rising process than in the failling process. The response time was extremely large at 35°C in the high accuracy type.

Controlled accuracies were almost 0°C in the high accuracy type, 0.4–1.5°C

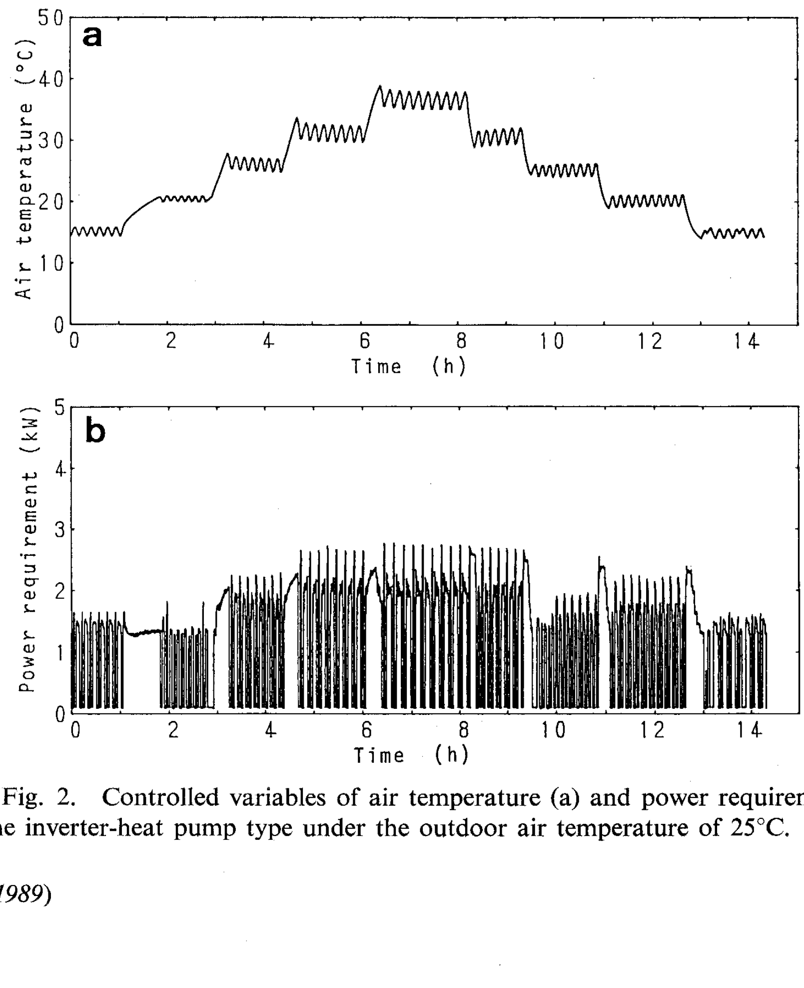

Fig. 2. Controlled variables of air temperature (a) and power requirement (b) in the inverter-heat pump type under the outdoor air temperature of 25°C.

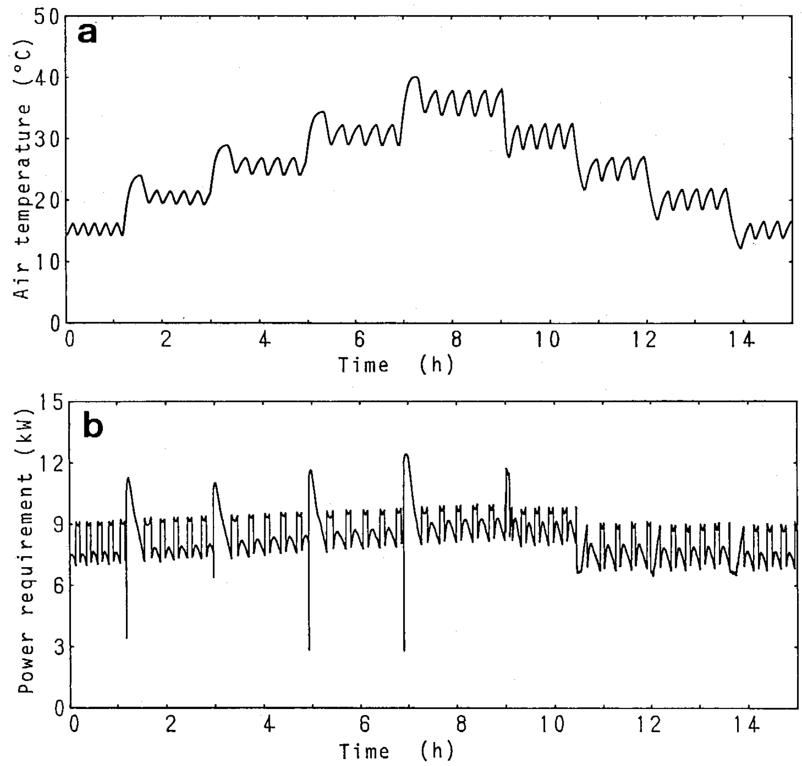

Fig. 3. Controlled variables of air temperature (a) and power requirement (b) in the standard type under the outdoor air temperature of 25°C.

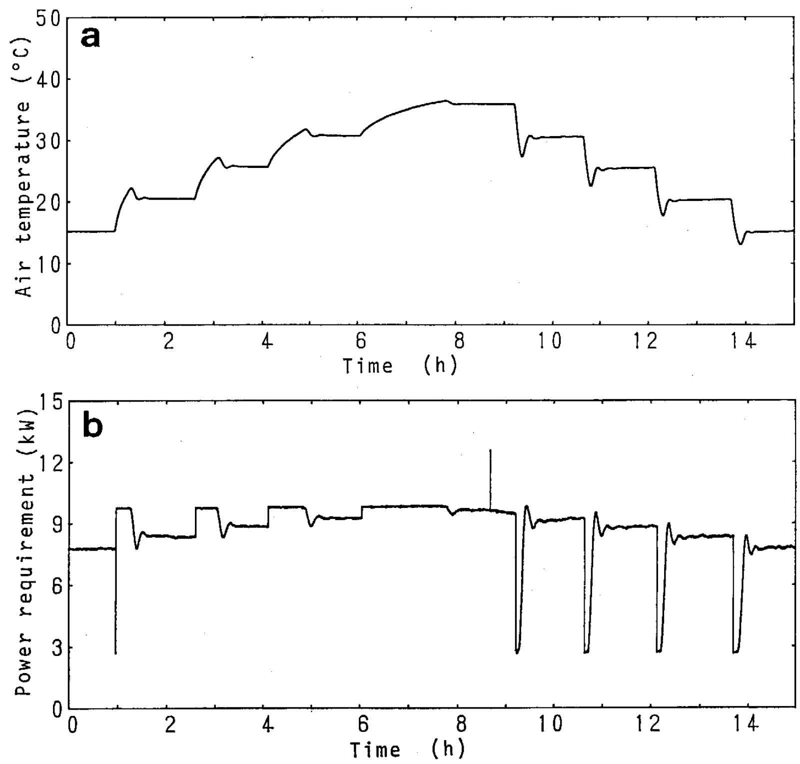

Fig. 4. Controlled variables of air temperature (a) and power requirement (b) in the high accuracy type under the outdoor air temperature of 25°C.

Table 1. The response time in dynamic process, the accuracy occurring at steady state and the power requirement

	Type	Desired air temperature (°C)								
		15	20	25	30	35	30	25	20	15
Response time (min)	IH*	—	35.5	29.6	17.9	20.0	3.9	6.3	6.0	9.0
	ST**	—	26.6	26.9	21.1	24.1	11.0	17.0	18.6	20.6
	HA***	—	27.7	37.4	54.7	111.6	16.8	16.2	16.8	18.6
Accuracy (±°C)	IH	0.7	0.4	1.1	1.4	1.5	1.3	1.0	1.0	0.8
	ST	1.0	1.1	1.3	1.7	2.0	2.0	1.9	1.7	1.4
	HA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Power requirement (kW)	IH	0.8	0.7	1.0	1.3	1.4	1.2	0.9	1.0	0.8
	ST	4.8	5.0	5.0	5.5	5.7	7.6	7.2	6.6	6.8
	HA	7.8	8.4	8.8	9.2	9.6	9.2	8.8	8.3	7.8

* IH: Inverter-heat pump.
** ST: Standard.
*** HA: High accuracy.

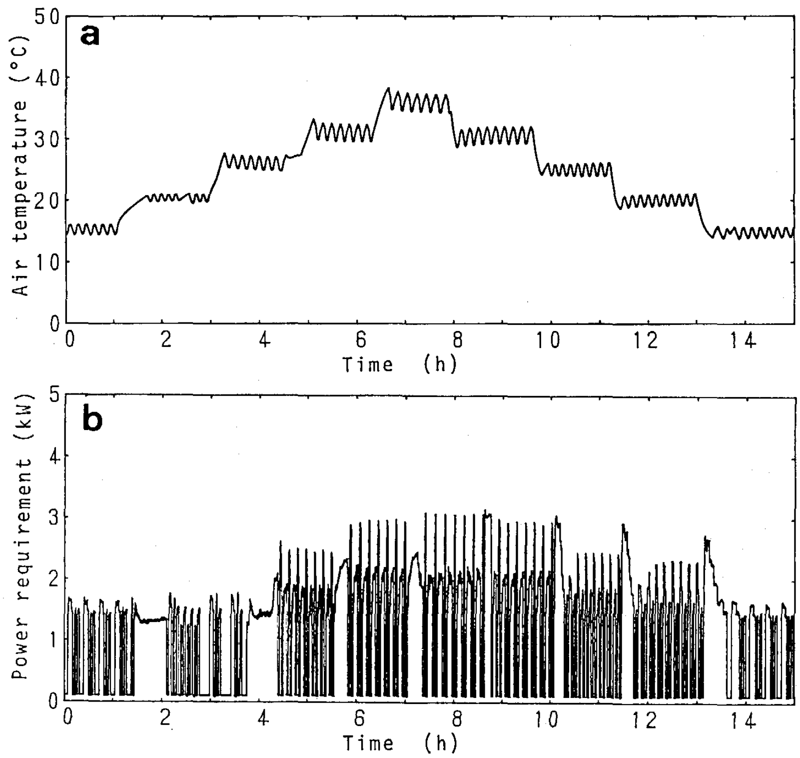

Fig. 5. Controlled variables of air temperature (a) and power requirement (b) in the inverter-heat pump type under the outdoor air temperature of 35°C.

in the IH type, and 1.0–2.0°C in the standard type. The accuracy deteriorated at higher desired air temperatures in all types.

The difference in power requirement was found clearly among the three types at every desired air temperatures; the IH type required power requirements smaller

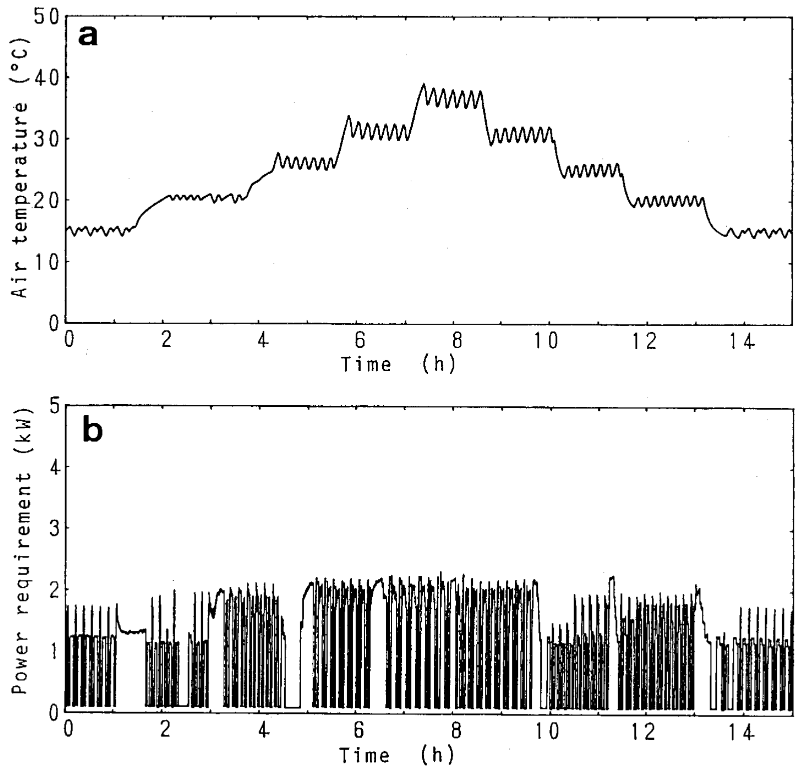

Fig. 6. Controlled variables of air temperature (a) and power requirement (b) in the inverter-heat pump type under the outdoor air temperature of 5°C.

than other types. The ratio of the power requirement in the IH type to that in the high accuracy type ranged from 6.9 at 35°C to 12.0 at 20°C in the rising process. The power requirements also varied with desired air temperatures. The differences in power requirement were larger among the types of the system than among the desired values.

Furthermore, possibilities of the control in the IH type under the different outdoor air temperatures were examined. Figures 5 and 6 show the results under the outdoor air temperature of 35 and 5°C respectively. The accuracy and the response time at these temperatures were similar to those under the temperature of 25°C. At higher outdoor air temperatures, however much more power requirements were needed.

DISCUSSION

Recently the heat pump has been prevailed widely for air conditioning as it is low cost. Thereby the heat pump has been applied to the control of air temperature in the greenhouse (*4–6*), where the charged heat in day has been utilized for heating at night.

In the present paper, the heat pump was employed for the air temperature control in a growth chamber. For this control, heating and cooling were required to repeat reversibly with higher frequency according to the change in the load of the heating and cooling. This control was achieved by using the comparator and the controller devices for manipulation of the heat pump.

The response time is one of the characteristics to assess the control system. In the IH type, the response time, in general, was shorter than those in other two types.

The running cost is expended on the electric power consumption. The power requirements were about 1 kW for the IH type, about 7 kW for the standard type and about 9 kW for the high accuracy type (Table 1).

In the high accuracy type, controlled air temperature completely coincided with the desired value. The accuracy of the IH type was about 1°C. This degree of the deviation of controlled air temperature seems to be permissible for the plant research.

Thus, newly developed IH type could be considered to be more reliable for higher accuracy, more sensitive dynamics and energy saving. Furthermore the IH type is a simple system which could be constructed at lower cost.

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