J. therm. Biol. Vol. 18, No. 5/6, pp. 465–472, 1993
Printed in Great Britain

0306-4565/93 $6.00 + 0.00
Pergamon Press Ltd

APPLICATION OF FUZZY CONTROL TO AIR CONDITIONING ENVIRONMENT

SAKUO SUGAWARA and TAKANE SUZUKI
Living Environment System Laboratory, Mitsubishi Electric Corporation, 1–1, Ofuna 5-chome, Kamakura-shi, Kanagawa-ken, Japan

Abstract—1. The application method of fuzzy control to air conditioning environment is shown taking home and railcar air conditioners as an example.

2. The control system developed by us includes the capacity control as the basic application example, the control to determine a set temperature, and that to correct automatically the set temperature.

Key Word Index: Fuzzy control; environmental control; home air conditioners; railcar air conditioners; temperature control; airflow control; energy saving

INTRODUCTION

Air conditioners are designed to create a comfortable environment, and are required to be convenient in use and energy saving. Recently, the fuzzy control which represents a sensation close to that of human being has been applied to subway control, elevator group control and home electric appliances such as washers, vacuum cleaners and refrigerators. In order to apply the fuzzy control to an air conditioning environment effectively, the distribution of environment created by the air conditioner, human behavior and sensation, and the air conditioner characteristics should be taken fully into account. The fuzzy control developed for air conditioning environments consists of 4 control sections as follows: (1) to control the air conditioning capacity to make the air temperature equal to the set temperature, (2) to determine a set temperature based on the user's thermal sensation input like hot or cold, and the environmental conditions of the room, (3) to correct the set temperature automatically by detecting the changing environment caused by the outdoor air temperature for example and (4) to control airflow supply so as not to change human sensation.

The basics of such fuzzy control for air conditioning environments is introduced by taking home and railcar air conditioners as examples.

FUZZY CONTROL OF AIR CONDITIONING CAPACITY

Control of railcar air conditioners

As for home air conditioners, railcar air conditioners are being aggressively applied with the variable capacity technique by inverter control and microcomputer application technologies to improve the environment inside railcars. However, the variation of external conditions for the railcar air conditioners such as the number of passengers, ventilation rate, outdoor temperature and solar radiation is far more serious when compared to that for home air conditioners. Under the circumstances, a simulation study was conducted to introduce fuzzy control into the air conditioning capacity control section.

With the fuzzy control applied, the change in the amount of air conditioning capacity was designed to be calculated from the deviation between the temperature inside car and the set temperature, and the fluctuation of that deviation. For the change in the amount, a rule was set to eliminate the deviation between the set temperature and the temperature inside the car and yet to stabilize it. Table 1 shows the fuzzy rule employed under cooling operation. The input and output for the fuzzy inference, the membership functions shown Fig. 1 were defined for fuzzy setting, and tuned through the simulation. Figures 2 and 3 show the result of the simulation conducted by assuming the operation of subway railcar, which compared the conventional (proportional) control and the fuzzy control. It was found that the fuzzy control is excellent in starting-up, and is stable in following the changes in the outdoor temperature and the number of passengers.

To upgrade the controllability in addition, the load factor and door factor were introduced by considering the special characteristics of railcars to correct the air conditioning capacity being obtained. For the correction of air conditioning capacity by load factor,

Table 1. Fuzzy control rule (cooling)

Δ Out	ΔE NB	ΔE ZO	ΔE PB
E			
NB	NB	NB	ZO
ZO	NB	ZO	PB
PB	ZO	PB	PB

PB = positive big; ZO = zero; NB = negative big.

the air conditioning capacity obtained by fuzzy inference was corrected depending on the degree of the air conditioning load at the time. In reducing air conditioning capacity for example, the capacity will be reduced by a small amount when the air conditioning load is high, but is a large amount when the air conditioning load is low (Fig. 4). The degree of the air conditioning load was obtained from the passenger sensor representing the variation of the railcar

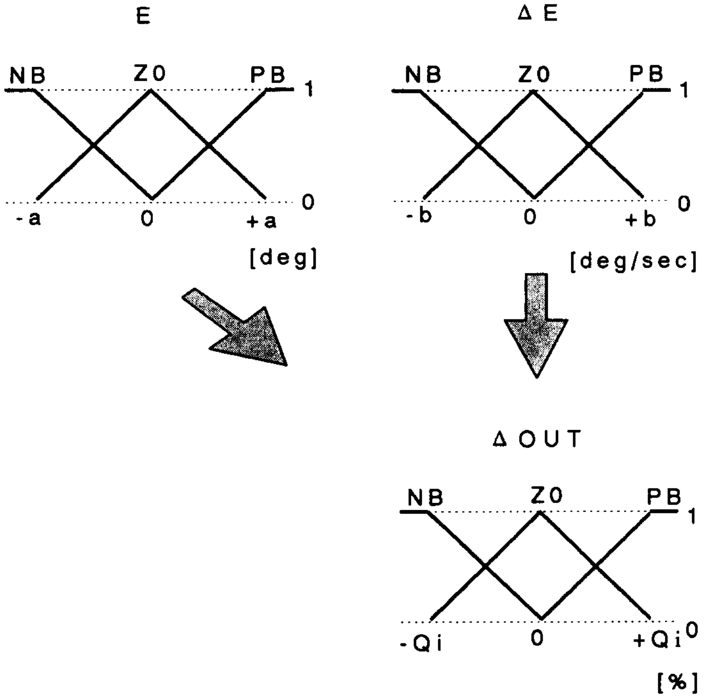

Fig. 1. Membership function.

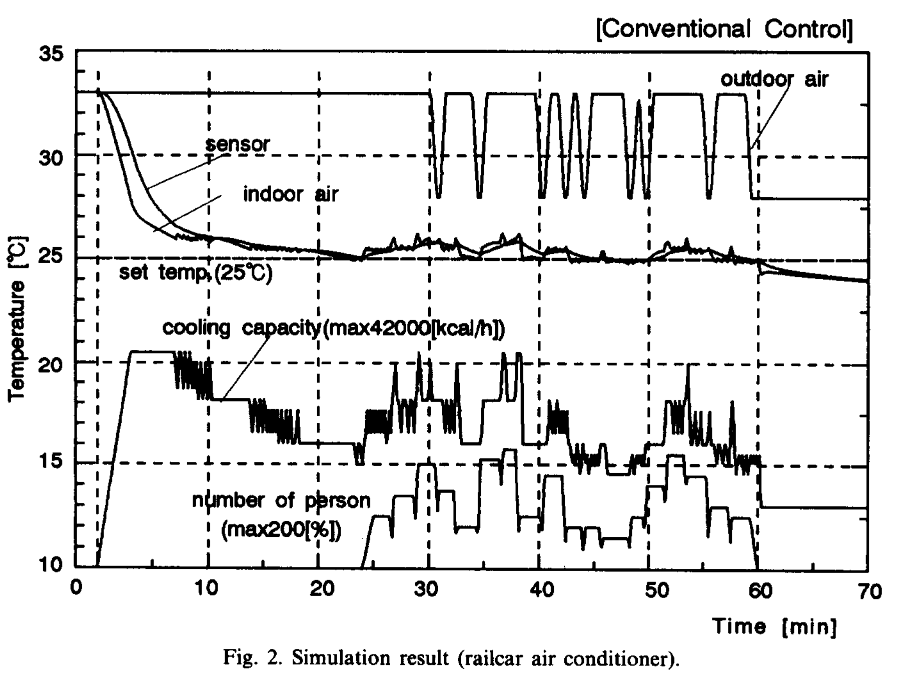

Fig. 2. Simulation result (railcar air conditioner).

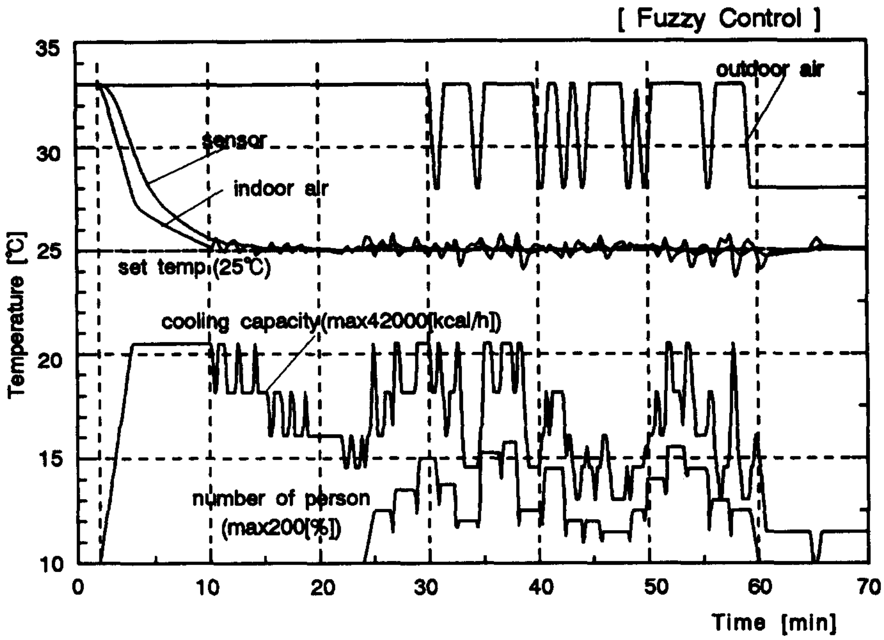

Fig. 3. Simulation result (railcar air conditioner).

weight, and the temperature sensor mounted outside of the railcar. The fuzzy rules used are shown in Table 2. The abrupt change of the load is usually generated at the exit/entrance of passengers through the doors. To cover this abrupt load change, door factor was introduced to correct the air conditioning capacity. As shown in Fig. 5, the door factor was maximized at the opening of the doors, and decreased as the time passes. The door factor obtained through tuning was 5 at the maximum, and became to 1 after passing 100 s. The correction of air conditioning capacity was obtained from; air conditioning capacity after correction = air conditioning capacity × door factor.

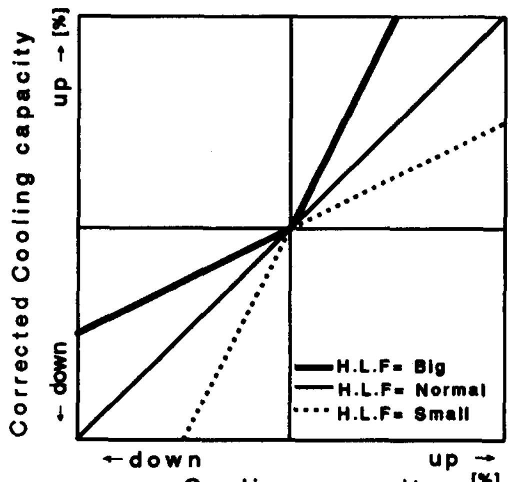

Fig. 4. Heat load factor.

In this way, a system with excellent controllability taking the special characteristics of railcars was established.

Example of home air conditioners

Figure 6 shows the room temperature control of a heat pump type room air conditioner in an experimental room during heating. The experiment was conducted in a model room with a space of 3.6 × 3.6 m and an outdoor temperature of 7°C. Although the membership functions were different, the fuzzy rules were almost same with that for railcars. In the fuzzy control, it was found that the stability can be upgraded with less hunting and overshoot symptoms.

Example of thermal-mannequin

A thermal-mannequin is used for the quantitative evaluation of a thermal environment, and has been employed increasingly in Japan. The shape of the thermal-mannequin is similar to that of a human body. A heater is mounted on each section of the body, and partial temperature control of the core and

Table 2. Fuzzy rule (heat load factor)

	Outdoor temperature		
Heat load factor	Low	Normal	High
Number of passenger			
Many	Normal	Big	Big
Normal	Small	Normal	Big
Few	Small	Small	Normal

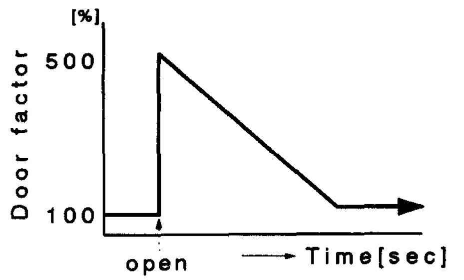

Fig. 5. Door factor.

skin at each section can be adapted. By measuring the electrical amount of each sectional temperature, the radiation from the human body can be measured thus allowing an evaluation of the thermal environment quantitatively.

To conduct the quantitative evaluation of an environment accurately, a temperature control with high accuracy is required. Figure 7 shows the temperature control of a thermal-mannequin. The temperature control method adapted was the PID control, but temperature fluctuation was found near the set temperature. This trend was emphasized on the sections with a smaller surface area. Figure 8 shows the result of the fuzzy control which proved that the controllability is upgraded, even that of conventional control. Although the fuzzy rules adapted to the thermal-mannequin was almost same as that of the capacity control of air conditioner, an independent rule was set to the start-up and stabilized states respectively, which resulted in excellent control with quick start-up and desirable stability.

CHANGE OF SET TEMPERATURE

Our air conditioners are provided with a sensation input function to upgrade the convenience of users. The sensation input function is composed of the "too cool" and "too warm" keys as shown in Fig. 9. In accordance with the thermal sensation entered by users, the set temperature is determined by the equipment allowing anybody to create a comfortable environment. The fuzzy control is used in determining the set temperature. The thermal sensation differs depending on the room temperature, vertical temperature difference, radiation and humidity, and the temperature range selected by the user also differs. Our hot air heater uses a thermal sensor mounted on the equipment leg as shown in Fig. 10. The floor temperature detected by the leg sensor can be regarded as that representing the degree of the radiation inside the room. Based on the floor temperature and room temperature, the range of the change is determined through the fuzzy inference (Fig. 11). Depending on the characteristics, some equipment determined the range of change with two sensors provided at the upper and lower parts, or with the frequency of humidity/sensation input.

CORRECTION OF SET TEMPERATURE

The human thermal sensation is affected by the vertical temperature and/or wall temperature at the time. Furthermore the vertical temperature and wall temperature are also affected by the external environment like the outdoor air temperature. Even though the temperature set by the user is kept unchanged, a

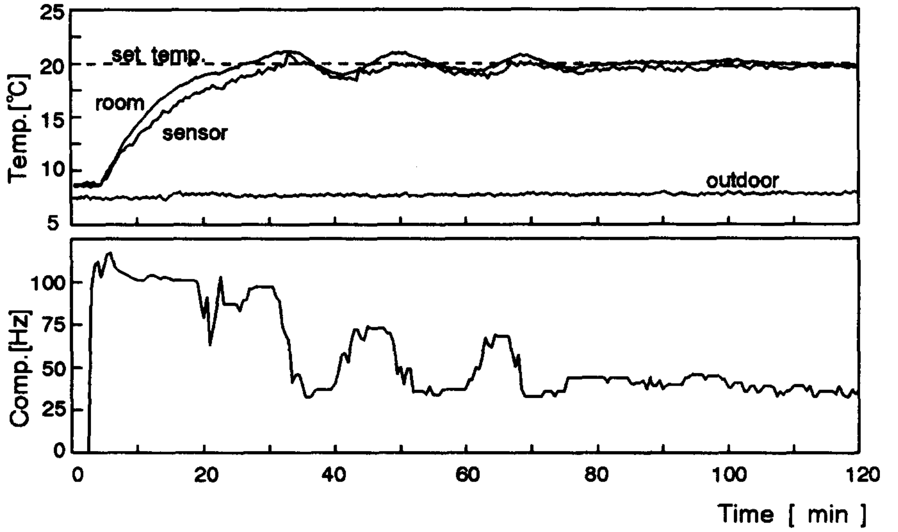

Fig. 6. Experimental result (room air-conditioner).

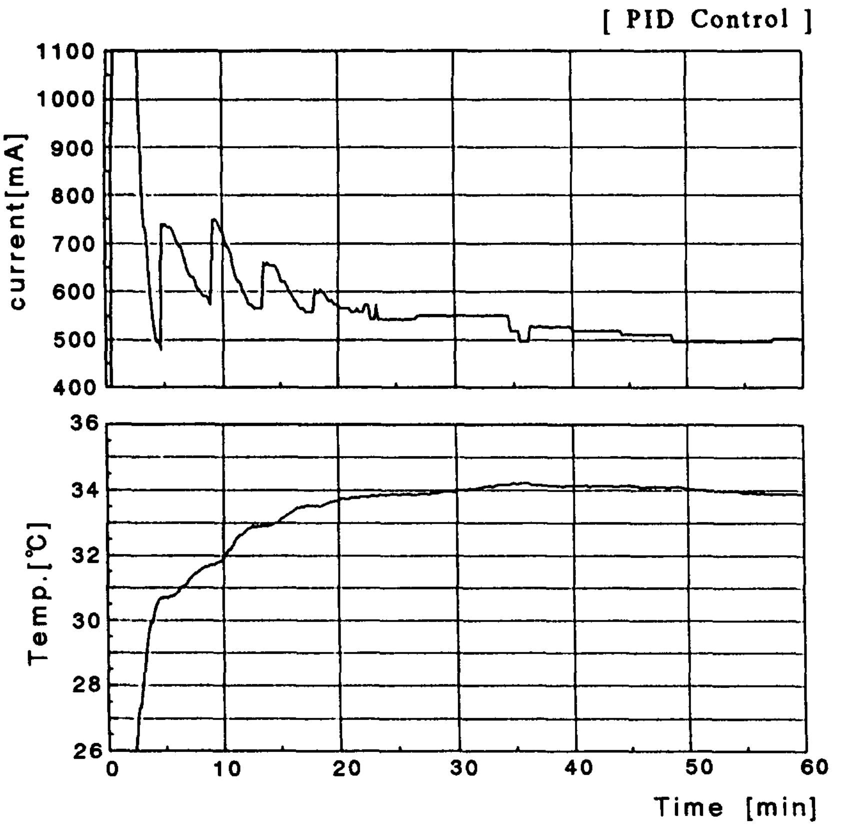

Fig. 7. Experimental result (thermal-mannequin).

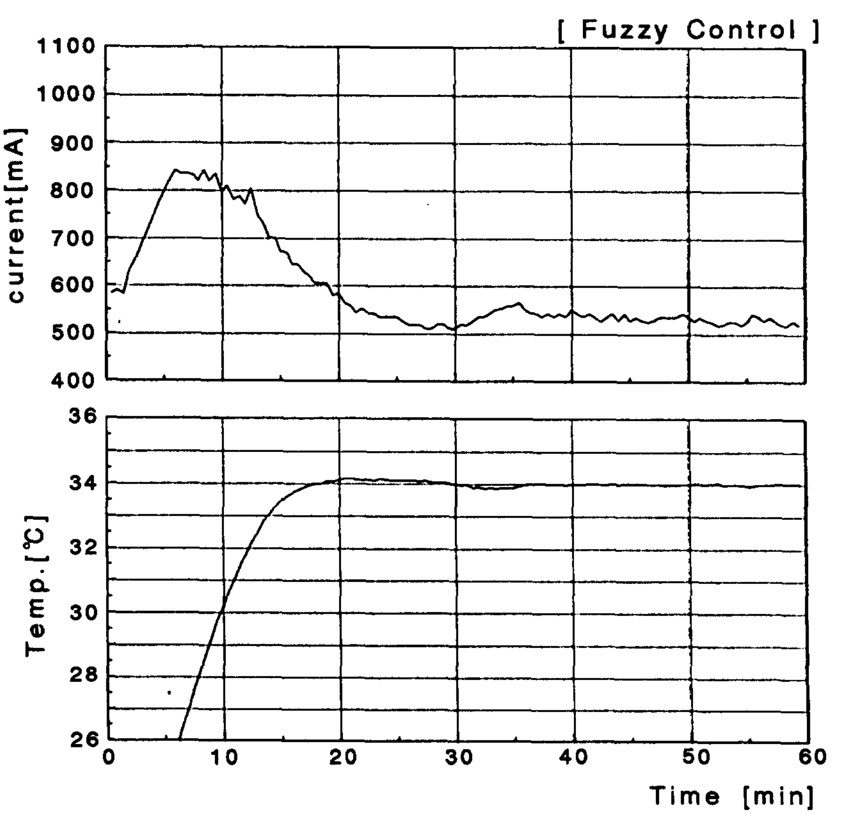

Fig. 8. Experimental result (thermal-mannequin).

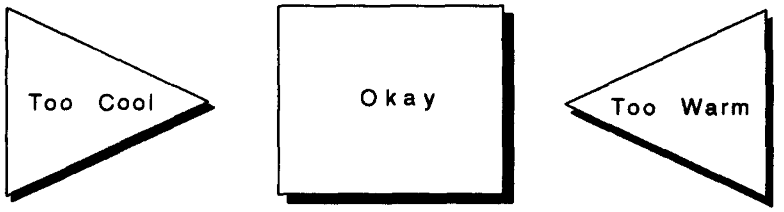

Fig. 9. Sensation input section.

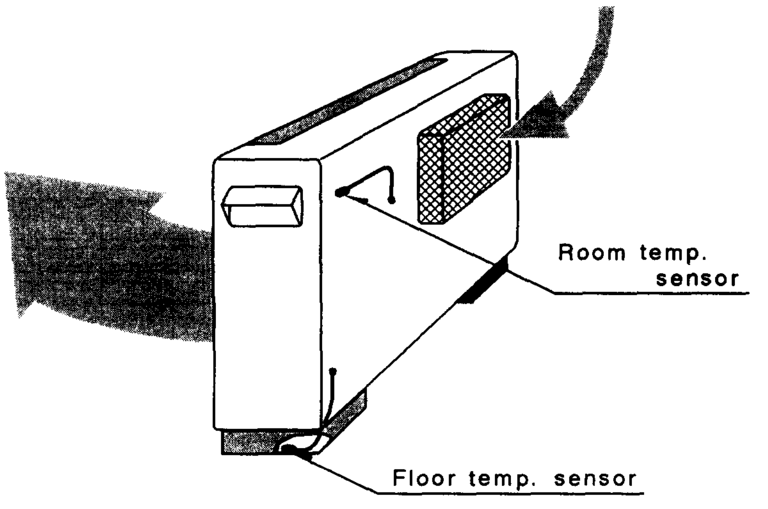

Fig. 10. Detection of room temperature (room air-conditioner).

comfortable environment can not be maintained if the external environment changes, due to the user's sensation also having changed. By detecting the changes in the environment which gives discomfort sensation to the user with the sensor of air conditioner, therefore, the set temperature is corrected not to give discomfort sensation.

Figure 12 is the cross sectional drawing of a railcar provided with various sensors to correct the set temperature. The data to be detected are the values of the temperature sensor, thermal sensor, and humidity sensor mounted at the upper and lower parts of the railcar. Based on not only the temperature but also the vertical temperature difference, radiation and humidity, the set temperature is corrected within $\pm 2°C$ maximum. Figure 13 is the thermal sensor which thermally simulates the skin surface of human body and reacts against temperature, radiation and airflow.

The set temperature is automatically corrected mainly from the temperature being set by the carman, so as to keep a comfortable environment not much affected by the environmental changes.

In case of the home hot air heater, the set temperature is corrected with the floor temperature detected

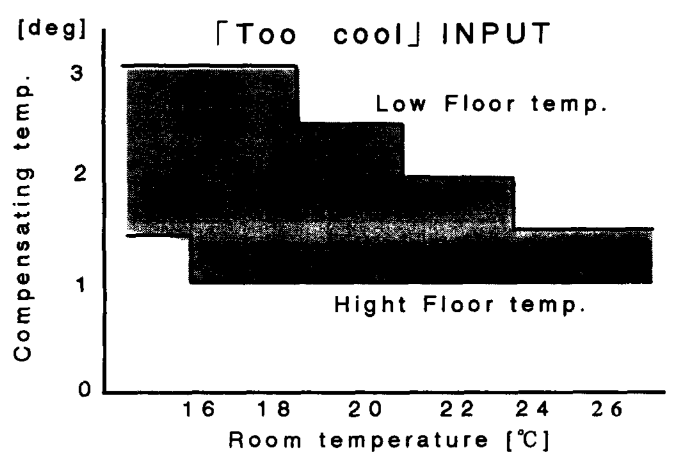

Fig. 11. Relation between room temperature, floor temperature and compensating temperature.

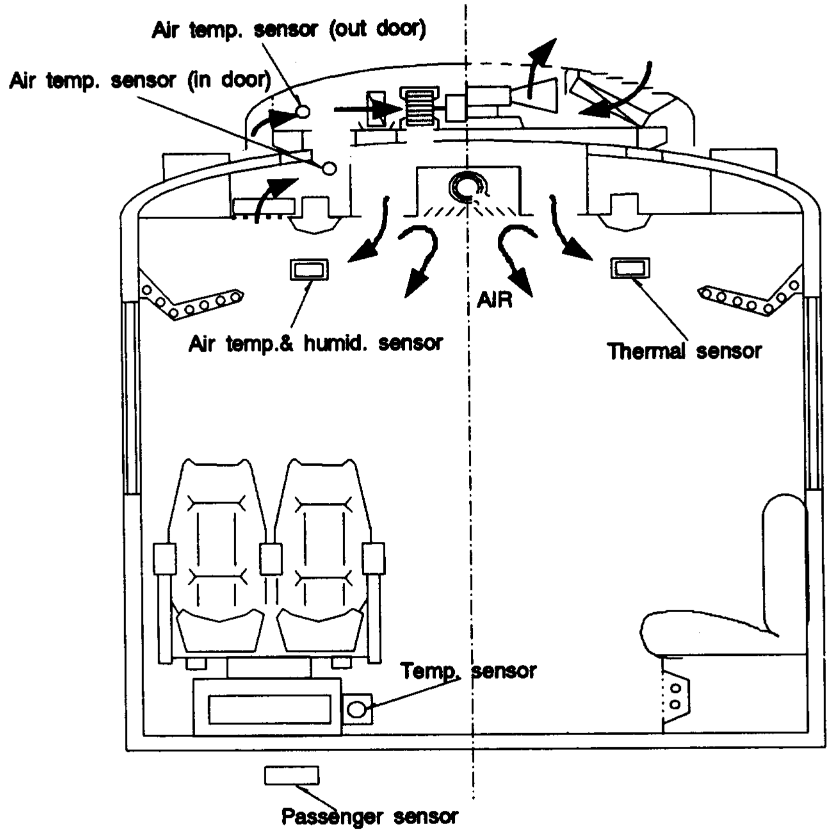

Fig. 12. Railway air-conditioner.

by the sensor on the leg thus minimizing the affect of the radiation. The result in an experimental room is shown in Fig. 14. As the radiation is thought to correlate with the air conditioning capacity of a variable capacity type air conditioner, some equipment corrects the set temperature by the air conditioning capacity. Assuming that the outdoor temperature is 36°C in cooling, and 0°C in heating, a 20 and 10% of energy saving for cooling and heating respectively can be achieved by correcting the set temperature by ± 2°C.

CONTROL OF SUPPLY AIRFLOW

In case of forced convection air conditioners, the supply airflow is a measure air conditioning capacity. However as the airflow rate and/or angle of supply airflow changes, the environmental distribution also

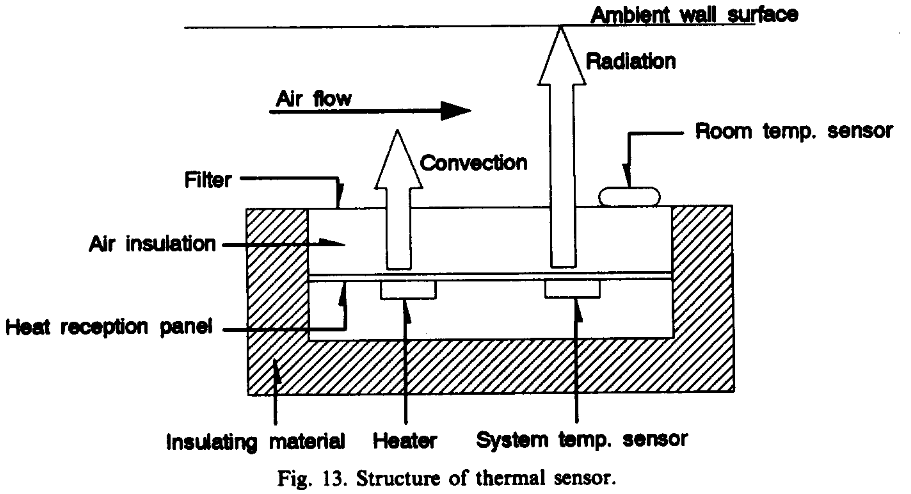

Fig. 13. Structure of thermal sensor.

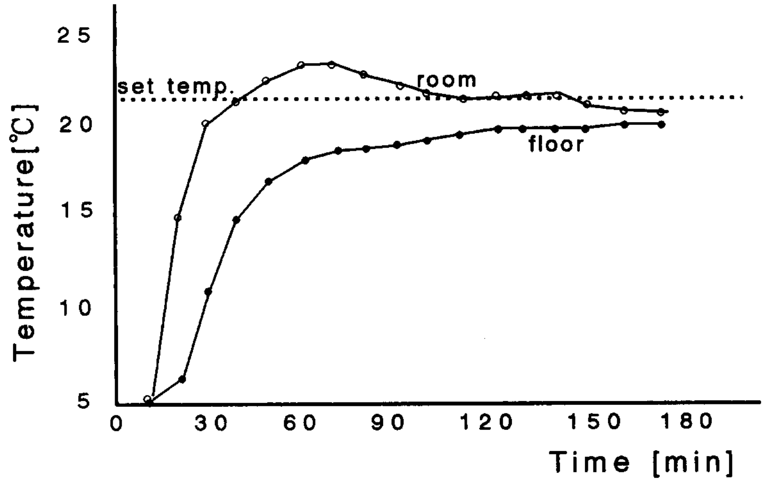

Fig. 14. Experimental result (warming-up condition of room temperature).

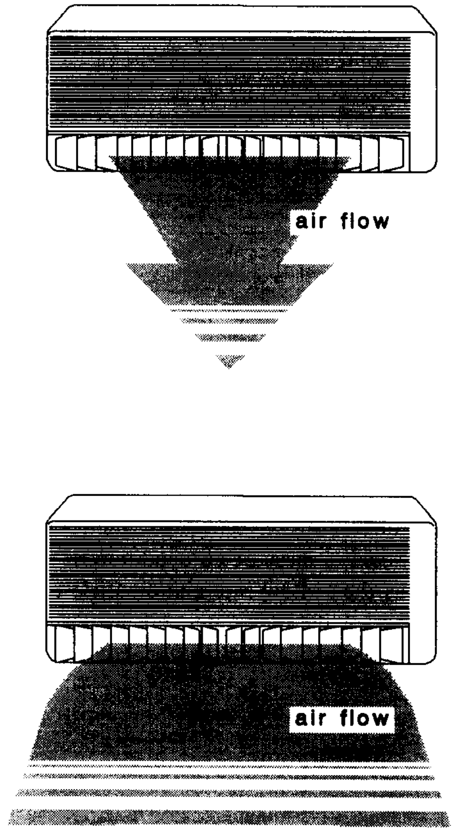

Fig. 15. Control of outlet air flow.

changes thus affecting the users directly or indirectly. By dividing the air outlet of a wall mounted air conditioner in two, left and right, and mounting vertical and horizontal louvers to each air outlet, the supply airflow can be controlled. Controlling the left and right louvers independently in this case can narrow or widen the supply airflow (Fig. 15). This control is performed by establishing the fuzzy rules with the deviation between the room temperature and the set room temperature, and the deviation between the temperature detected by the remote controller around the user and the room temperature. When these deviations are large representing an unfavorable environment, the supply airflow is narrowed to promote the throw for the improvement of temperature distribution. When a favorable environment is restored with a smaller deviation, the supply airflow velocity is increased by widening the supply airflow for better environment.

CONCLUSION

A development example of air conditioning environmental control with fuzzy control introduced was outlined as above. The control system developed includes the capacity control as the basic application, the control to determine the set temperature and that to correct the set temperature automatically. Air conditioners are expected to provide more comfort and convenience in use as for other home appliances. Under such the circumstances, fuzzy control was judged as an excellent control method. The authors further wish to introduce new control methods including fuzzy control aiming at the creation of a comfortable air conditioning environment to meet our future living.

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