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https://hdl.handle.net/2324/8116

出版情報：BIOTRONICS. 14, pp.7-13, 1985-12. Biotron Institute, Kyushu University

BIOTRONICS **14**, 7–13, 1985

SENSING OF AIR TEMPERATURE AND HUMIDITY IN CONTROLLED ENVIRONMENT FOR PLANT RESEARCH

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(Received September 24, 1985)

KITANO M. and EGUCHI H. *Sensing of air temperature and humidity in controlled environment for plant research.* BIOTRONICS **14**, 7–13, 1985. For accurate control of ambient air temperature and humidity in plant growing area in phytotron and growth chamber, sensing method were examined under radiation. In the case that feedback sensors were equipped in the return air duct, ambient air temperature and humidity in plant growing area were different from the desired values. On the other hand, in the case that the sensors were equipped in the plant growing area, radiation to the sensors caused measurement error, and resulted in disturbing control action. To remove the influence of radiation, two types of shelter shielding the sensors against radiation were developed for feedback detection and equipped at the center of plant growing area. These sensing systems were effective for feedback detection to control the ambient air in plant growing area and made it possible to expose plants exactly to desired environment.

INTRODUCTION

Air temperature and humidity are important factors in environment control for plant research. In phytotrons or in growth chambers, plants are exposed to the controlled air, but the ambient air temperature and humidity in plant growing area are not necessarily same to the desired values (*3*, *4*). Differences in air temperature and humidity between ambient air and the desired values are mainly caused by disturbances from radiation: Radiation results in distributions of air temperature and humidity within space of a room, and these distributions are influenced by feedback sensing system of air temperature and humidity. Furthermore, radiation incident on the sensors causes errors in measurement for environment control (*5*, *6*). Present paper deals with methods of air temperature and humidity sensing for the environment control under radiation.

SENSING POSITION UNDER RADIATION

In controlled environment room of phytotron or growth chamber, the controlled air receives the sensible heat mainly brought by solar or artificial light radiation. So, air temperature control is disturbed, and temperature distribution is enlarged. The range of this temperature distribution can be given as

$$\Delta T_a = \frac{3.6 \times 10^6 \cdot SH}{C_p \cdot \rho \cdot Q} \tag{1}$$

where: T_a, air temperature (°C); ΔT_a, range of air temperature distribution within controlled environment room (°C); SH, sensible heat received by controlled air in controlled environment room (kW); C_p, specific heat of air (Jg^{-1} $°C^{-1}$); ρ, density of air ($g\ m^{-3}$); Q, flow rate of air ($m^3\ hr^{-1}$). SH is increased in proportion to radiant flux density. As a matter of course, relative humidity of controlled air is influenced by the air temperature distribution. The range of this relative humidity distribution can be given as

$$\Delta RH = \frac{\Delta T_a \cdot \left\{ \frac{dW(T)}{dT} \right\}_{T=T_a}}{W(T_a)} \times 100\% \tag{2}$$

where: RH, relative humidity (%); ΔRH, range of relative humidity distribution in controlled environment room (%); $W(T)$, saturation vapor density at temperature of T°C ($g\ m^{-3}$).

Figure 1 shows diurnal patterns of T_a and RH of a phytotron glass room (12.6 m^2 in area, 41 m^3 in volume) on a clear day in winter season, where the desired values were set at air temperature of 25°C and relative humidity of 70%. In this phytotron, controlled air flows out of perforated floor to the controlled environment

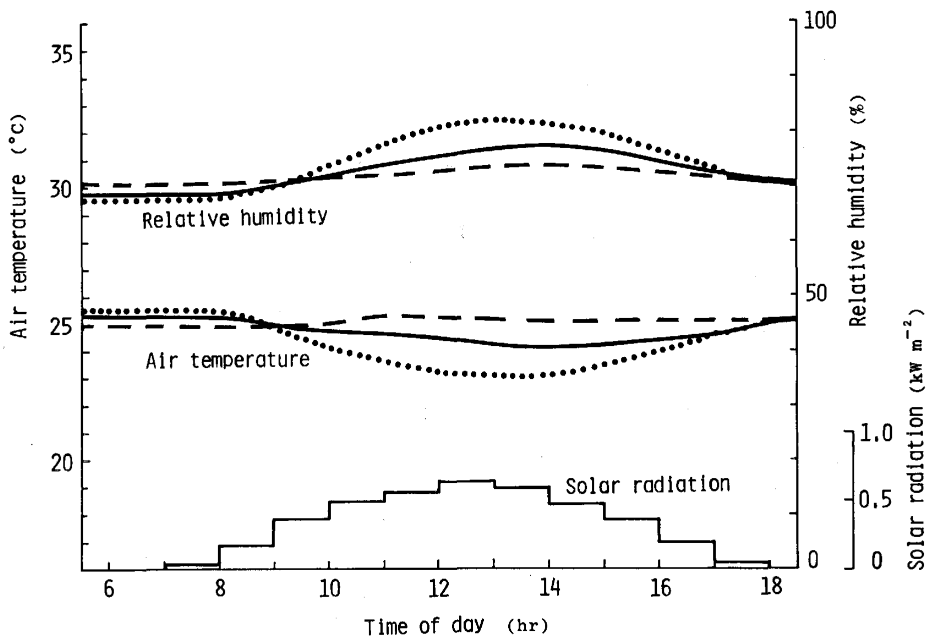

Fig. 1. Intensity distribution of solar radiation on a clear day in winter, and diurnal patterns of air temperatures and humidities measured in mixing chamber (····), in plant growing area (——) and in return air duct (– – –) in a phytotron glass room where the air was controlled at the desired values of 25°C and 70% RH by using feedback sensors equipped in the return air duct.

room and flows up to the return air duct located at an upper side with air velocity of about 0.3 m sec^{-1}, and feedback sensors are equipped in the return air duct. T_a and RH were measured by ventilated psychrometers of resistance thermometers (R220-10, CHINO WORKS, LTD.) (*2*) at different three positions in the air pass of the control system; the psychrometers were set in a mixing chamber below the floor, in plant growing area (center of the controlled environment room) and in the return air duct. T_a measured at the three positions appeared in different patterns. T_a in the return air duct was very closed to the desired value in day and night. However at the time before sunrise, T_a in the mixing chamber was 0.6°C higher, and T_a in the plant growing area was 0.2°C higher than T_a in the return air duct. These differences in temperature among three positions were estimated to be caused by the negative sensible heat from radiational cooling and heat transfer to outdoor air of lower temperature. At the time after sunrise, T_a in the mixing chamber became lower with increase in solar radiation and became about 2°C lower than T_a in the return air duct at noon when solar radiation was the highest. Hence, ΔT_a in the room ranged at about 2°C. T_a in the plant growing area was about 1°C lower than the desired value (T_a in the return air duct). In the afternoon, ΔT_a was reduced with decrease in solar radiation and became about 0°C just after sunset. RH at each of the positions varied with changes in T_a. ΔRH in the room was 10% at its maximum, and RH in the plant growing area became about 7% higher than the desired value. In summer season under higher solar radiation, these influences of radiation seems to enlarge much more. In many phytotrons and growth chambers, feedback sensors are equipped in mixing chamber or return air duct. From these results (Fig. 1), it could be suggested that the controlled variable must be detected at the center of plant growing area to expose plants exactly to desired environmental condition.

SHIELDING AGAINST RADIATION

For air temperature measurement in plant growing area, the sensing system is exposed to the radiation, and brings error (difference in temperature between the sensor and air). This error can be given as follows (*5*, *6*).

$$\Delta T_e = \frac{R_n}{h} \tag{3}$$

with

$$R_n = A_b \cdot R_s + \varepsilon \cdot \{L_i - \sigma \cdot (T+273)^4\} \tag{4}$$

and

$$h = \frac{K}{D} \cdot \left\{ \mathrm{A} + \mathrm{B} \cdot \left(\frac{V \cdot D}{\nu} \right)^{1/2} \right\} \tag{5}$$

where: ΔT_e, difference in temperature between the sensor and air (°C); R_n, net radiant flux density (kW m^{-2}); h, convective heat transfer coefficient (kW m^{-2} °C^{-1}); R_s, short wave radiant flux density incident on the sensor (kW m^{-2}); A_b, short wave absorptivity of the sensor; ε, emissivity; L_i, long wave radiant flux density incident on the sensor (kW m^{-2}); σ, Stefan-Boltzmann constant (kW m^{-2} K^{-4}); K, thermal conductivity of air (kW m^{-1} °C^{-1}); D, sensor diameter (m); V, air velocity (m sec^{-1}); ν, kinematic viscosity of air (m^2 sec^{-1}); A and B, positive constants (dimensionless).

Hence, ΔT_e can be reduced with decrease in R_n and increase in h. R_n can be decreased by shielding the sensor against radiation, while h can be increased by ventilation (increase in V) and decrease in D. Thus, for adequate measurement, small sized sensor ventilated and shielded against radiation must be used in plant growing area. One of the typical temperature sensors for feedback detection is the resistance thermometer of Pt 100 Ω (at 0°C). This sensor is more reliable in accuracy and stability as compared with thermistor and thermocouple, but size (D) of Pt 100 Ω is, in many cases, larger than that of others. So, attention must be paid to shielding for using Pt 100 Ω.

Figures 2 and 3 show a large sized shelter for shielding against radiation and a small sized one, respectively. Both shelters were made of double or triple alminium plates which were finished with polished outer surface and blacked inner surface. As shown in Fig. 2, the large sized shelter is ventilated by a fan and has enough space to equip large sized sensors. This system is suitable for measurement

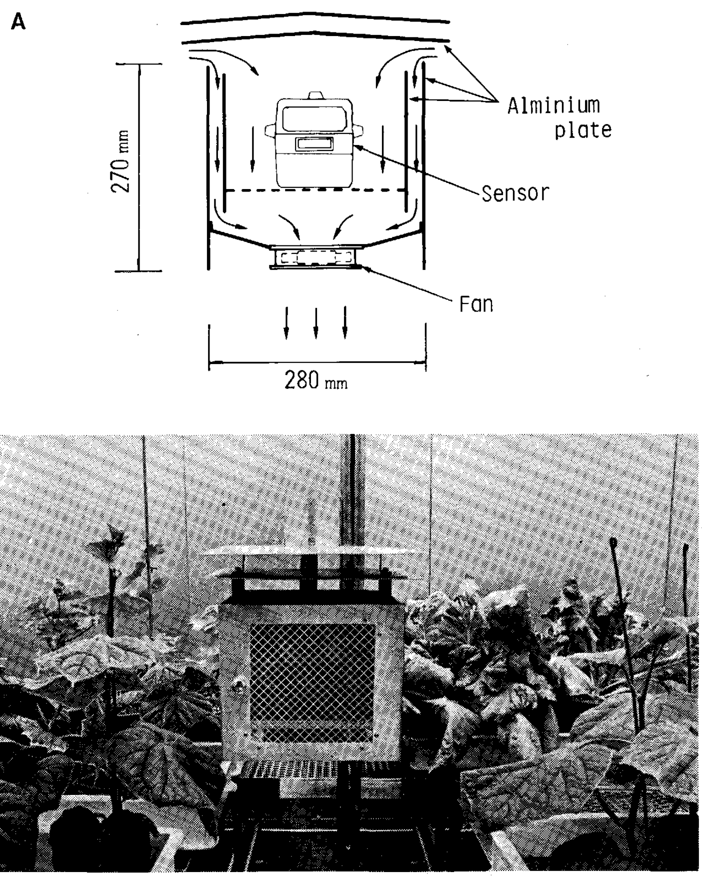

Fig. 2. Schematic diagram (A) and photograph (B) of large sized shelter for shielding the sensor against radiation.

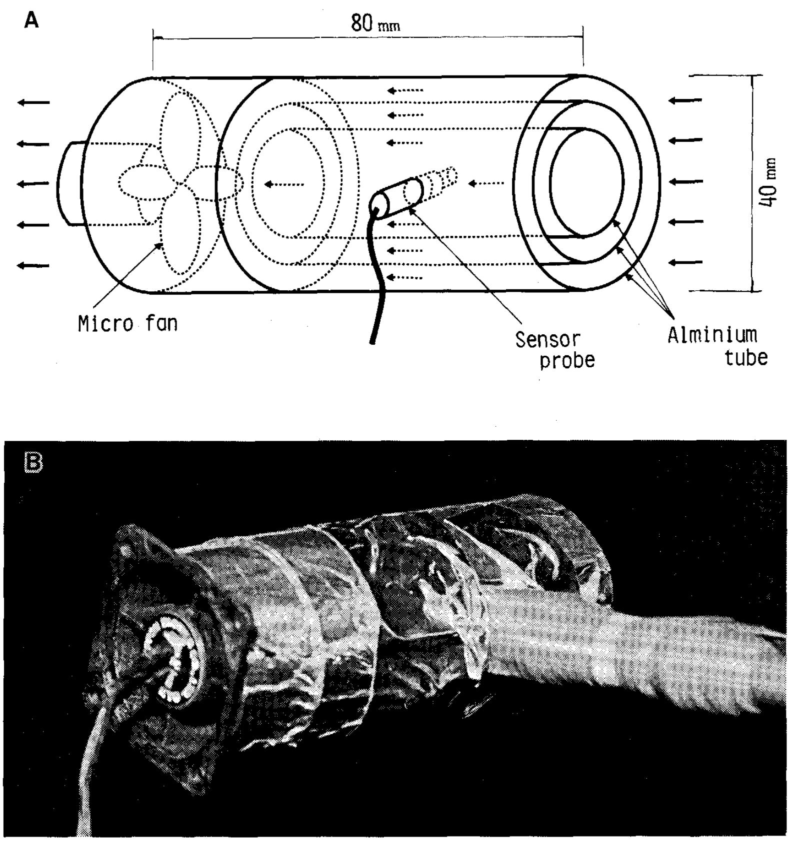

Fig. 3. Schematic diagram (A) and photograph (B) of small sized shelter for shielding the sensor against radiation.

in the phytotron glass room or the walk-in-type growth chamber. The small sized shelter shown in Fig. 3 is ventilated by a micro fan with air velocity of about 3 m sec^{-1} and usable for measurement in the narrow space in reach-in-type growth chamber.

In this shelter, a bead thermistor and a humidity sensor (HMP 15, Vaisala Oy) (*2*) were equipped and used as feedback sensors for air temperature and humidity control in a reach-in-type growth chamber (*1*) in which artificial light (metal halide lamps) is radiated with an intensity of 0.26 kW m^{-2} and controlled air flows laterally with velocity of about 0.3 m sec^{-1}. In this experiment, the desired values were set at air temperature of 25°C and relative humidity of 70%, and T_a and RH were measured by the ventilated psychrometers of resistance thermometers at different three positions in the air pass of the control system; the psychrometers were set in a mixing chamber, in plant growing area and in a return air chamber. Figure 4 shows respective patterns of T_a and RH when feedback sensors were directly exposed to radiation without shelter (a) and when the sensors were shielded by the shelter (b). When the shelter was not used, control was remarkably disturbed after lighting on, and T_a and RH in plant growing area became at 0.3°C lower and 3% higher than the desired values, respectively. This deviation was estimated to be caused by the measurement error in the feedback sensors absorbing the incident radiation. On

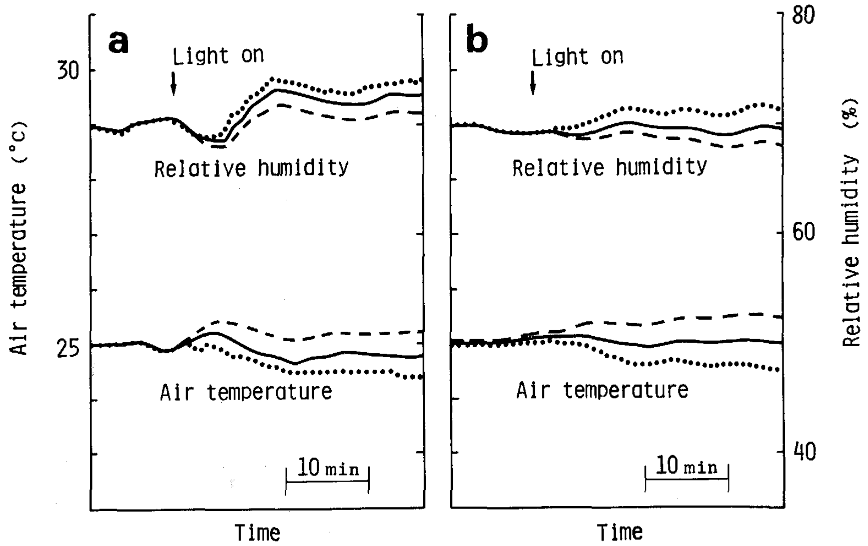

Fig. 4. Patterns of air temperatures and humidities measured in mixing chamber (····), in plant growing area (——) and in return air chamber (- - -) in a growth chamber where the air was controlled at the desired values of 25°C and 70% RH by using respective feedback sensors without shelter (a) and covered with shelter (b) in the plant growing area, and artificial light (metal halide lamps) was radiated with an intensity of 0.26 kW m^{-2}.

the other hand, when the feedback sensors were shielded by the shelter (Fig. 4b), T_a and RH in plant growing area were controlled very closely at the desired values. Distribution ranges of T_a and RH in the controlled environment room were almost the same in the both cases that the shelter was used and not used; ΔT_a and ΔRH became 0.8°C and 4%, respectively. From these results, it could be estimated that the shelter is effective for preventing the disturbance from radiation and indispensable to high accurate control of environment in plant growing area.

CONCLUSION

In general, feedback sensors for environment control are equipped in a mixing chamber or in a return air duct. In this system, controlled variables distributed in controlled environment room, and air temperature and humidity in plant growing area were different from those in the mixing chamber and in the return air duct. In particular, under higher radiation of solar or artificial light, this distribution was enlarged with the sensible heat brought by radiation. So, it could be suggested that air temperature and humidity must be detected at a position close to plants. In sensing in such plant growing area, the sensors are exposed to radiation, and measurement errors are caused by radiation incident on the sensors. To such influence of radiation, the sensors were shielded against radiation. The method presented in this paper made it possible to control ambient air temperature and humidity accurately.

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