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WAVELENGTH DISTRIBUTION OF THERMAL RADIATION IN ROOMS

- and in particular the influence of shortwave thermal radiation on the mean radiant temperature.

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DANFOSS A/S.

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Heating, Ventilating and
Air-Conditioning.

17. - 19.5. 1971
København.

Danfoss

INTRODUCTION

Thermal radiation in rooms originates partly from low temperature objects, e.g. floor, walls, ceiling, furniture, radiators, etc., which all have a temperature in the range from 0 - 100°C, and partly from solar radiation. The latter can be divided into three groups: direct radiation, diffuse sky radiation, and reflected radiation from objects and surfaces outside and inside the room. The temperature of the surface of the sun is approx. 6000 $^{\circ}$K. The sun is radiating with nearly the same spectral distribution as a black body and the lower and upper limits are, in practice, 0.3 μ and 2.5 μ respectively.

Compared with radiation from objects having a temperature of e.g. 30°C, with the limits 3.5 μ and 40 μ, it is realized that the two ranges are separated, which property can be used for determination of the distribution of the thermal radiation on two different wavelength ranges, fig. 1. (Page 20).

The complete effect of shortwave and longwave thermal radiation is usually expressed by the mean radiant temperature[x)]. As this variable is dependent on the objects referred to, it is not always possible to make a direct comparison between e.g. the mean radiant temperature obtained by means of a measuring device and the mean radiant temperature in relation to a person, as - for one thing, the object and the person may have different radiation properties in different ranges of wavelength.

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x) The mean radiant temperature in relation to an object can be defined as the uniform temperature of black surroundings in which the object would exhange the same amount of radiant heat as in the existing surroundings.

In order to decide the practical importance of these conditions and in order to obtain a more detailed knowledge on shortwave and longwave thermal radiation, and the interaction of same on the room's heat balance, equipment has been developed enabling us to measure the distribution of thermal radiation on two different ranges of wavelength, in accordance with a method somewhat like the one used in the reference (1).

The equipment is described in this paper, and some characteristic results obtained in a room are given.

DESCRIPTION OF EQUIPMENT

The equipment consists of two globe thermometers made from 60 mm$^{\varnothing}$ brass spheres, 0.5 mm thick. The temperature is measured by thermocouples, mounted inside the spheres.

The application of the equipment depends on certain special radiation properties of the surfaces of the globe thermometers. One globe thermometer is painted with a black colour[x)] which has an absorptivity of 0.95 independent of the wavelength (2).

The other globe thermometer is painted with zinc oxide[xx)] which has the special property that the absorptivity of same is changing heavily between the short- and longwave range stated in fig. 1. The references and test prove that it will be fair to use an absorptivity of 0.2 in the event of shortwave radiation - solar radiation - and 0.9 in the event of longwave radiation (3).

The two globe thermometers are placed at the same horizontal position at a distance from each other of 30 cm, so that they are in the same convection and radiation field without influencing each other. A thermocouple for measuring the air temperature

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x) Krylon flat black enamel No. 1602

xx) Zinc oxide paint, specially prepared by Sadolin & Holmblad.

is placed between the globe thermometers. The thermocouple is protected against radiation by gold-plating of approx. 20 cm of the copper-constantan wire.

When the globe thermometers are in heat balance with the surroundings, the heat flows transferred by radiation and convection are of same size, but are taking opposite directions. Considering the equations, we will find in the first term the radiant heat transfer, and in the second the convective heat transfer as follows:

$$\varepsilon_b \cdot \sigma \cdot (T_{mrt,b}^4 - T_{g,b}^4) - h(t_{g,b} - t_a) = 0 \qquad (1)$$

$$\varepsilon_w \cdot \sigma \cdot (T_{mrt,w}^4 - T_{g,w}^4) - h(t_{g,w} - t_a) = 0 \qquad (2)$$

where ε = Emissivity
σ = Stefan-Boltzmann's constant
h = Convective heat transfer coefficient
T_{mrt} = Mean radiant temperature (^{o}K)
T_g = Globe temperature (^{o}K)
t_g = Globe temperature (^{o}C)
t_a = Air temperature (^{o}C)

Index b and w refer to the black and the white globe thermometer respectively.

The convective heat transfer coefficient h is a function of the air velocity v and the difference between globe and air temperature:

$$h = f\ (v, t_g - t_a) \qquad (3)$$

The air velocity is measured by an anemometer, which is specially designed for low velocities x). The velocity has been so low

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x) DISA Low Velocity Anemometer

in the cases mentioned in this paper - due to small load of room and lack of forced ventilation - that it was fair to use the following heat transfer coefficient which is obtained by carrying out a special test and which is valid for free convection:

$$h = 2.8 \cdot (t_g - t_a)^{0.25} \quad W/m^2 \cdot {}^oC \qquad (4)$$

When the air temperature and the temperature of the two globe thermometers have been measured, the mean radiant temperatures can be calculated from equation (1), and (2). As the temperatures are dependent on the objects referred to, they can be described as the mean radiant temperature in relation to a thermal grey sphere $T_{mrt,b}$, and the mean radiant temperature in relation to the actual white sphere $T_{mrt,w}$.

Both temperatures, and the two globe temperatures as well, can give a qualitative expression of shortwave radiation, but in the following some quantitative expressions will also be given.

In the equations (1) and (2), the first term represents the total radiant heat transfer. This tern can also be expressed as absorbed radiation minus emitted radiation.

The radiation absorbed by the two globe thermometers consists of two parts, viz.: the absorbed part of the shortwave thermal radiation R_s (W/m^2) and the absorbed part of the longwave thermal radiation R_l (W/m^2), fig. 1, and if the actual absorptivities in the different wavelength ranges are used, the following equations will be obtained:

$$0.95 \cdot \sigma \cdot T_{mrt,b}^4 = 0.95 \cdot R_s + 0.95 \cdot R_l \qquad (5)$$

$$0.90 \cdot \sigma \cdot T_{mrt,w}^4 = 0.20 \cdot R_s + 0.90 \cdot R_l \qquad (6)$$

By means of these two equations it is possible to from the following equations, expressing the mean radiant temperatures by the thermal radiation as well as the longwave radiation by the two mean radiant temperatures.

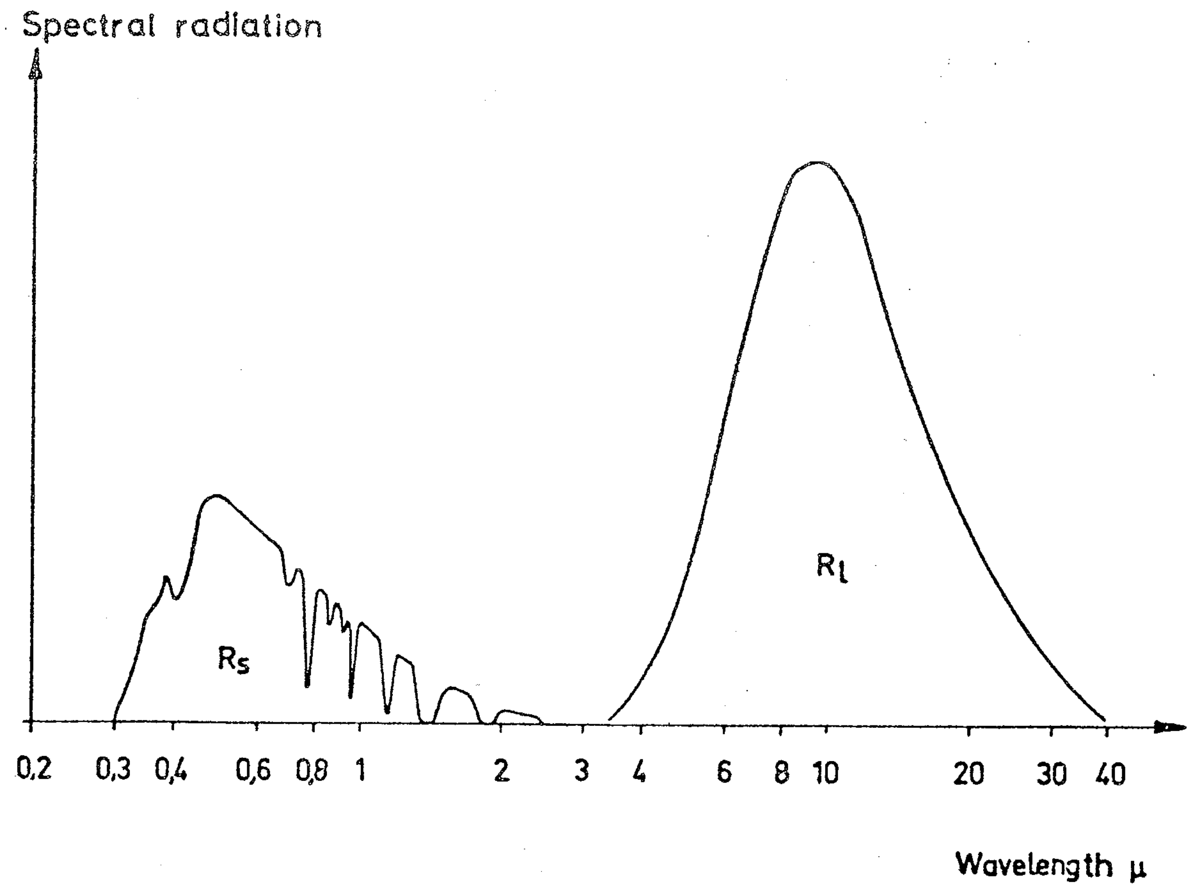

Spectral radiation
Rs
Rl
0,2 0,3 0,4 0,6 0,8 1 2 3 4 6 8 10 20 30 40
Wavelength μ

Fig. 1

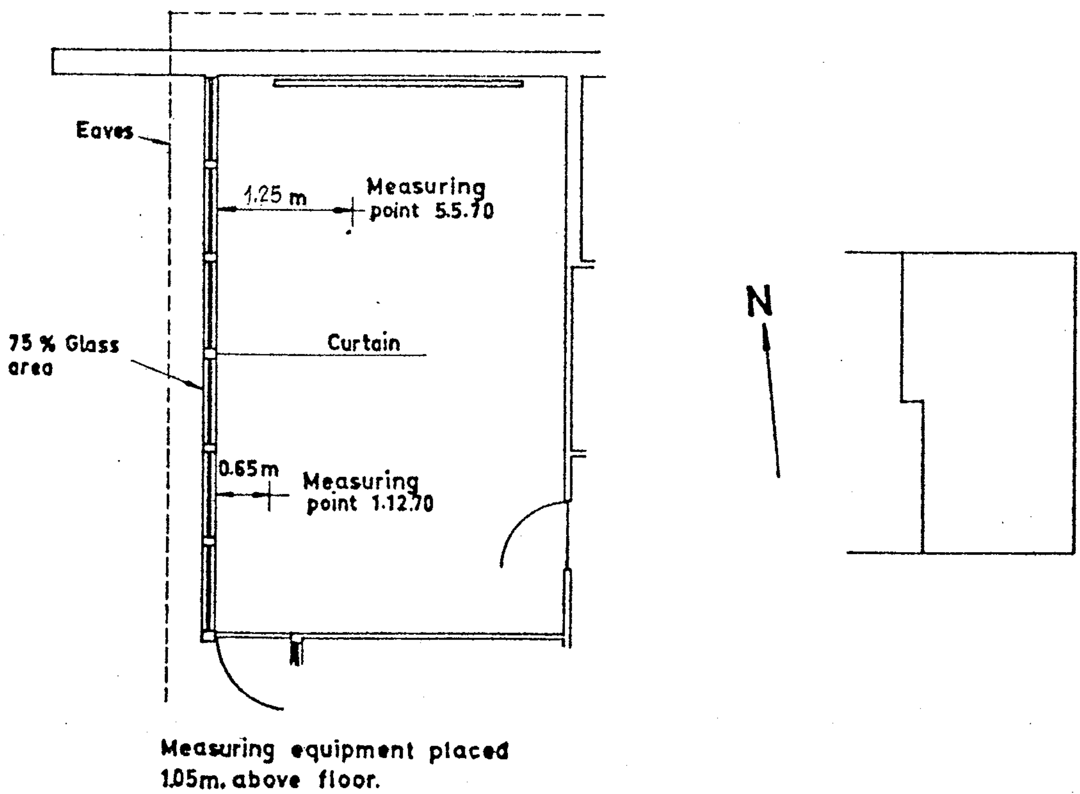

Eaves
1.25 m
Measuring point 5.5.70
75 % Glass area
Curtain
0.65m
Measuring point 1.12.70
N
Measuring equipment placed 1.05m. above floor.

Fig. 2

$$T'_{mrt,b} = \sqrt[4]{\frac{R_s + R_l}{\sigma}} \qquad (7)$$

$$T_{mrt,w} = \sqrt[4]{\frac{\frac{2}{9} R_s + R_l}{\sigma}} \qquad (8)$$

$$R_l = \frac{9}{7} \cdot \sigma \cdot T_{mrt,w}^4 - \frac{2}{7} \cdot \sigma \cdot T_{mrt,b}^4 \qquad (9)$$

The longwave thermal radiation R_l originates from low temperature objects in the room, e.g. floor, walls, ceiling, furniture, radiators, and if expressed by:

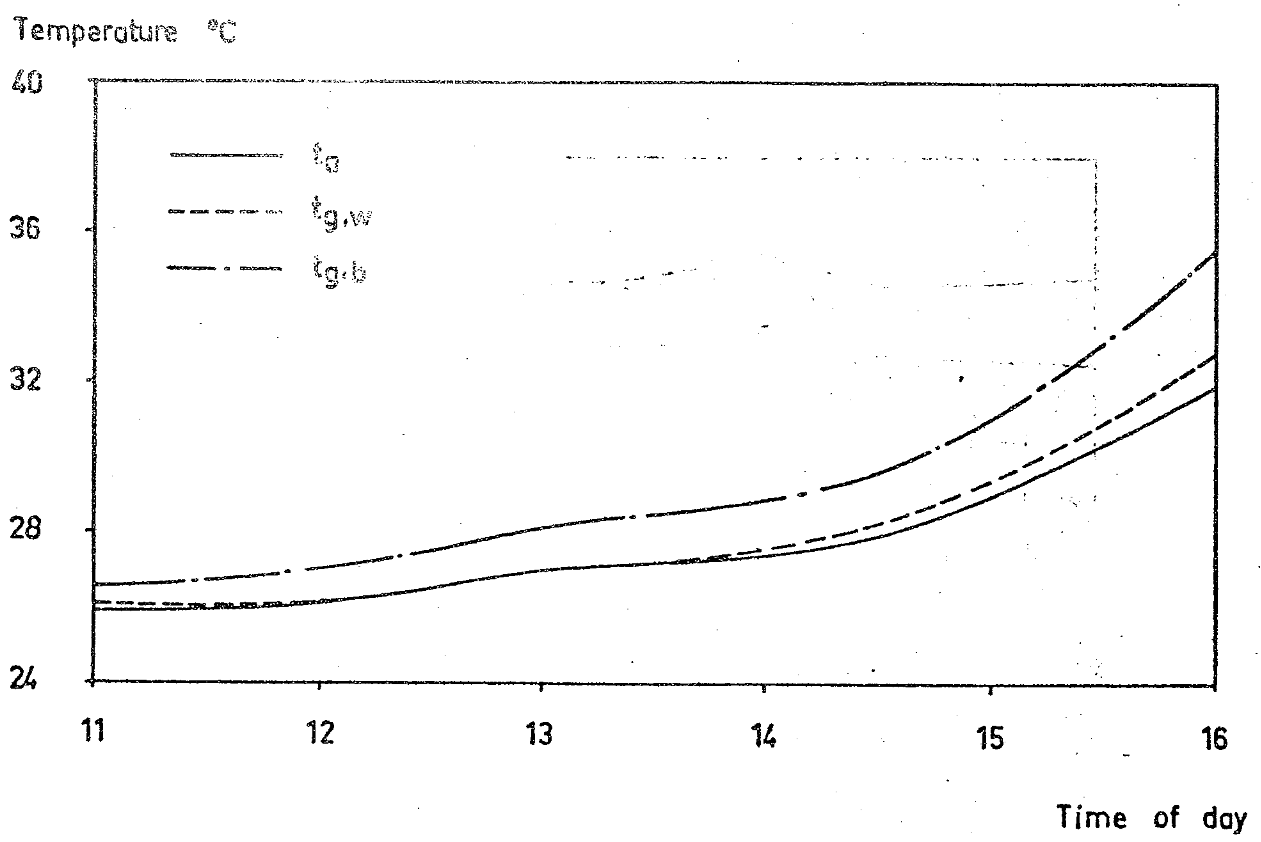
$$T_{mrt,l} = \sqrt[4]{\frac{R_l}{\sigma}} \qquad (10)$$

it will then be reasonable to call $T_{mrt,l}$ (^oK) a mean wall- or mean surface temperature, however, weighted according to the position of the measuring equipment. $T_{mrt,l}$ is also the mean radiant temperature in relation to an imaginary spherical object, absolutely reflecting within the shortwave range, and which is a thermal grey absorber within the longwave range.

When measurements have been made in a room and the results are to be estimated, especially $T_{mrt,b}$, equation (7), and $T_{mrt,l}$, equation (10), will be of interest, as the difference between these temperatures represents a quantitative expression for shortwave radiation. The following paragraph will give some examples of the estimate of such measurements.

RESULTS AND CALCULATIONS

The results mentioned in the following have all been measured in a typical modern Danish one-family house. Fig. 2 shows the orientation of the house as well as the living room, in which the equipment was placed. In connection with the properties of radiation, it should be noted that there is a 75% glass area at the frontage to the west, and that a radiator is placed along the wall to the north.


Temperature °C
40
36
32
28
24
t_a
$t_{g,w}$
$t_{g,b}$
11
12
13
14
15
16
Time of day

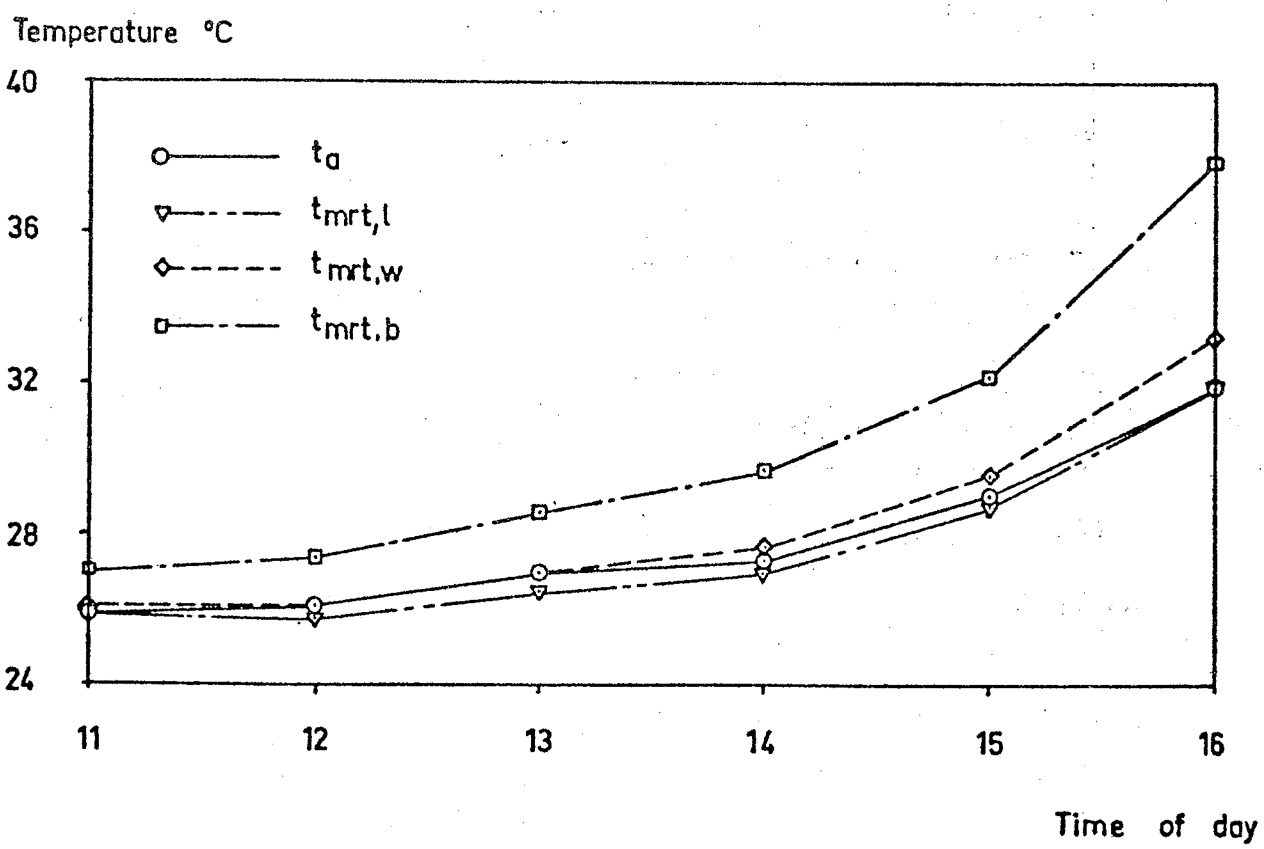

Temperature °C
40
36
32
28
24
t_a
$t_{mrt,l}$
$t_{mrt,w}$
$t_{mrt,b}$
11
12
13
14
15
16
Time of day

Fig. 3 shows the results and calculations obtained on the 5th May, 1970. The weather that day was clear, and at 13h30 a direct radiation from the sun was in the room. There was direct radiation on the globe thermometers approx. 16h20, however, this was 20 minutes later than the last results stated in fig. 3 were obtained. The radiator was closed.

The upper curves on fig. 3 represent the progress of the air temperature t_a and the two globe temperatures $t_{g,b}$ and $t_{g,w}$. The difference between these two temperatures proves that some shortwave radiation is present.

The lower curves in fig. 3 represent the mean radiant temperatures $t_{mrt,b}$, $t_{mrt,w}$, $t_{mrt,l}$, calculated from equation (1), (2), and (10) respectively, converted to degrees centigrade, as well as the air temperature t_a.

It should be noted that the mean radiant temperature $t_{mrt,l}$ and the air temperature t_a are both at almost the same reading. This means that the difference between the mean radiant temperatures $t_{mrt,b}$ and $t_{mrt,l}$, which is an expression for the shortwave radiation, is of the same reading as the difference between the mean radiant temperature $t_{mrt,b}$, and the air temperature t_a.

This situation is characteristic for all results obtained in this room during the summer.

The light level - i.e. the shortwave radiation - gives the essential contribution to a possible difference between the mean radiant temperature $t_{mrt,b}$ and the air temperature t_a, although it is only due to diffuse sky radiation, and reflected radiation from the sun.

Fig. 4 shows the results obtained on the 1st December, 1970. The weather that day was cloudy until late morning, at which time the sun was shining some hours - then it was cloudy again the rest of the day. The radiator was open, and the room was heated according to an outdoor temperature of $8^{\circ}C$.

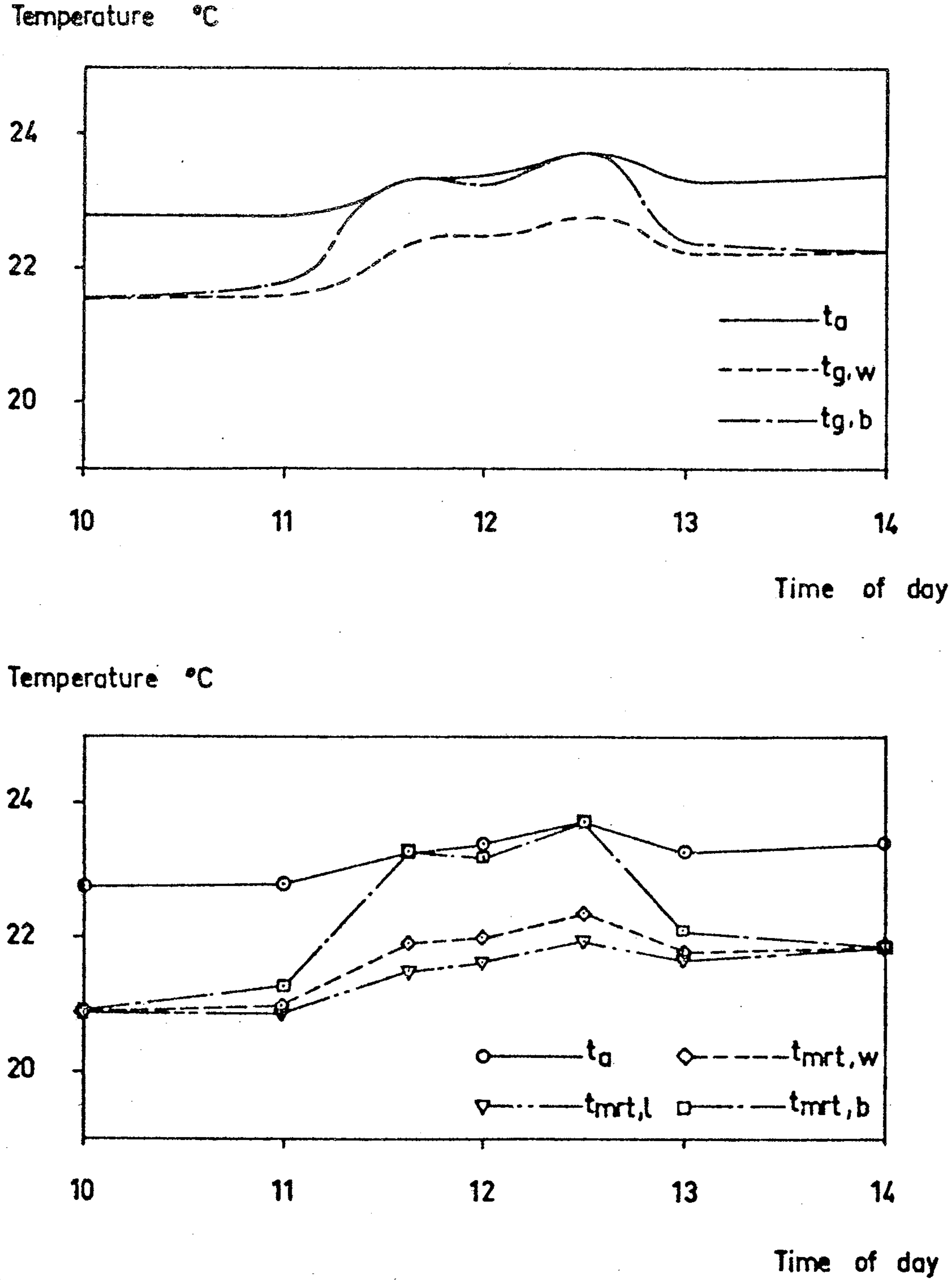

Temperature °C
24
22
20
10
11
12
13
14
Time of day
t_a
$t_{g,w}$
$t_{g,b}$
Temperature °C
24
22
20
10
11
12
13
14
Time of day
t_a
$t_{mrt,w}$
$t_{mrt,l}$
$t_{mrt,b}$

Fig. 4.

The mean radiant temperature $t_{mrt,l}$, which can also be considered as the mean surface temperature, is much influenced by the temperature of the window, due to a great angle factor to the globe thermometers, see fig. 2. The difference between the air temperature t_a and the mean radiant temperature $t_{mrt,l}$ will then practically be an expression for heat loss through the window. This explains the smooth change in this temperature difference during the day hours.

Before 10h00 and after 14h00 the light level was so low that the three mean radiant temperatures $t_{mrt,b}$, $t_{mrt,w}$, and $t_{mrt,l}$ were all identical, which also appears from the equations (7), (8), and (10) for $R_s = 0$.

During two periods the temperature $t_{g,b}$ of the black globe thermometer was equal to the air temperature t_a. In this situation we will find no heat transfer neither by convection nor by total radiation, and the mean radiant temperature $t_{mrt,b}$ is equal to the air temperature t .

In case of another absorptivity, as for example the one valid for the white globe thermometer, a mean radiant temperature is found, viz.: $t_{mrt,w}$, which is different from the air temperature t_a, due to different absorptivities in different wavelength ranges and due to shortwave radiation. This only involves diffuse sky radiation and reflected solar radiation.

CONCLUSION

The mean radiant temperature which is usually found by means of a variety of measuring equipment, including for instance a standard globe thermometer, is the mean radiant temperature in relation to a thermal grey object, $t_{mrt,b}$.

The results obtained prove that diffuse sky radiation and reflected solar radiation may have a great influence on the difference between mean radiant temperature and air temperature.

When calculating the mean radiant temperature in relation to a body, which has different absorptivities in different wavelength ranges, as e.g. a person, this fact ought to be taken into consideration[x)]. This can be done by using a sensor on the measuring device, painted with a colour having a suitable absorptivity in the different wavelength ranges.

REFERENCES

(1) Richards, Charles H., Alice M. Stoll and James D Hardy, The Panradiometer: An Absolute Measuring Instrument for Environmental Radiation, The Review of Scientific Instruments, 22, No. 12, 925-934, 1951.

(2) Strong, John and George W. Hopkins, An Environmental Mean Radiation Temperature Meter, The Review of Scientific Instruments, 41, No. 3, 360-364, 1970.

(3) Sieber W., Zusammensetzung der von Werk- und Baustoffen zurückgeworfenen Wärmestrahlung, Zeitschrift für technische Physik, Nr. 6, 130-135, 1941.

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x) When calculating the mean radiant temperature in relation to a person it is also necessary - in cases of great variation of the radiant intensity in different directions as e.g. in direct solar radiation - to consider the variation of the person's projected area in these directions.