

# INFLUENCE OF SOLAR RADIATION ON SKIN TEMPERATURE IN STANDING AND WALKING SUBJECTS OUTDOORS

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## INTRODUCTION

Solar radiation is a source of heat for subjects outdoors. There are observed relations between the intensity of solar radiation and skin temperature (1,2). However, simultaneous direct measurements of both parameters are very rare (3,4). The aim of this paper is to present the results of studies dealing with solar radiation and skin temperature of subjects standing and walking outdoors.

## MATERIAL AND METHODS

Field measurements were carried out in June 1996 in Central Poland (in the vicinity of Warsaw) and in August 1997 in the Tatry Mountains (Southern Poland). In 1996 investigations dealt with standing persons. Six healthy volunteers (4 males and 2 females), within the age category of 16 to 46 years, were examined. Solar exposures lasted 120 min. Subjects stood upright facing the sun; after 60 min they sat for 5 min and then stood 55 min. Skin temperature was measured every minute with the use of resistant (Pt100) thermometers connected to the forehead, arm, chest, back, hand, thigh and lower leg. Mean skin temperature ( $\bar{T}_{sk}$ ) was calculated as follows:

$$\bar{T}_{sk} = 0.07 T_{forehead} + 0.05 T_{hand} + 0.15 T_{arm} + 0.175 T_{chest} + 0.175 T_{back} + 0.2 T_{thigh} + 0.18 T_{lower\ leg}$$

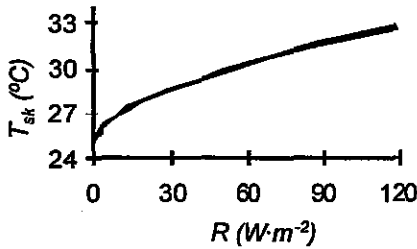
For comparison, the surface temperature was also observed on a manikin facing the sun. The temperature sensors were located on the frontal (sunny) and back (shaded) sides of the manikin's surface.

In 1997, studies dealt with standing and walking subjects. Eight healthy volunteers (2 males and 6 females) within the age category of 20 to 38 years were investigated. Skin temperature was measured every minute on the chest ( $T_{chest}$ ) and thigh ( $T_{thigh}$ ) during the 160-min exposure. Subjects walked at about 4 km·h<sup>-1</sup>; after every 30 min of walking, they sat for 10 min. Standing subjects also took 10 min rest sitting at the same time as walking subjects. The subjects also reported periods with intensive sweating. In 1997, was calculated as mean value of  $T_{chest}$  and  $T_{thigh}$ . Both in 1996 and 1997, subjects used dark grey, cotton sportswear with insulation of 1 clo and albedo of 30%.

Simultaneously with skin temperature, measurements were taken for meteorological parameters (i.e., air temperature and humidity, wind speed, solar radiation [global, direct, diffuse and reflected as well as absorbed solar radiation]) with the use of special heat flux sensors, Ø 50 mm. (3,5).

## RESULTS

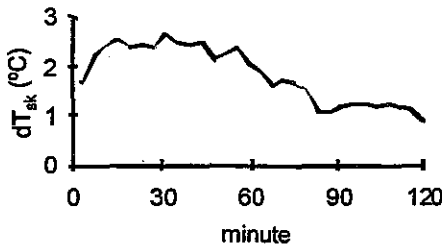
For subjects exposed outdoors to solar radiation, approximately 10 to 15% of global solar radiation reaching ground surface was absorbed, and solar radiation (R) varied from 5 W·m<sup>-2</sup> at low sun altitudes (early mornings, evenings) and at thick cloud cover to 110 to 120 W·m<sup>-2</sup> under clear sky conditions.



**Figure 1.** Relationships between  $T_{sk}$  and absorbed solar radiation (R) for standing subjects, July 1996 ( $n = 2487$ ,  $r = 0.70$ ,  $p < 0.01$ ); Skin temperature at subjects outdoors varied from 24 to 34°C and was influenced also by air temperature (15-28°C) and wind (2-8 m/s)

Changes in absorbed solar radiation influenced skin temperature, and  $\bar{T}_{sk}$  increased significantly according to increase in R value. Almost 50% of the variation in  $\bar{T}_{sk}$  may be explained by the changes in R (other meteorological factors influencing  $\bar{T}_{sk}$  are air temperature and wind speed). General relation between R and  $T_{sk}$  values were as follows:  $\bar{T}_{sk} = 24.11 + 0.78 R$  (Fig. 1).

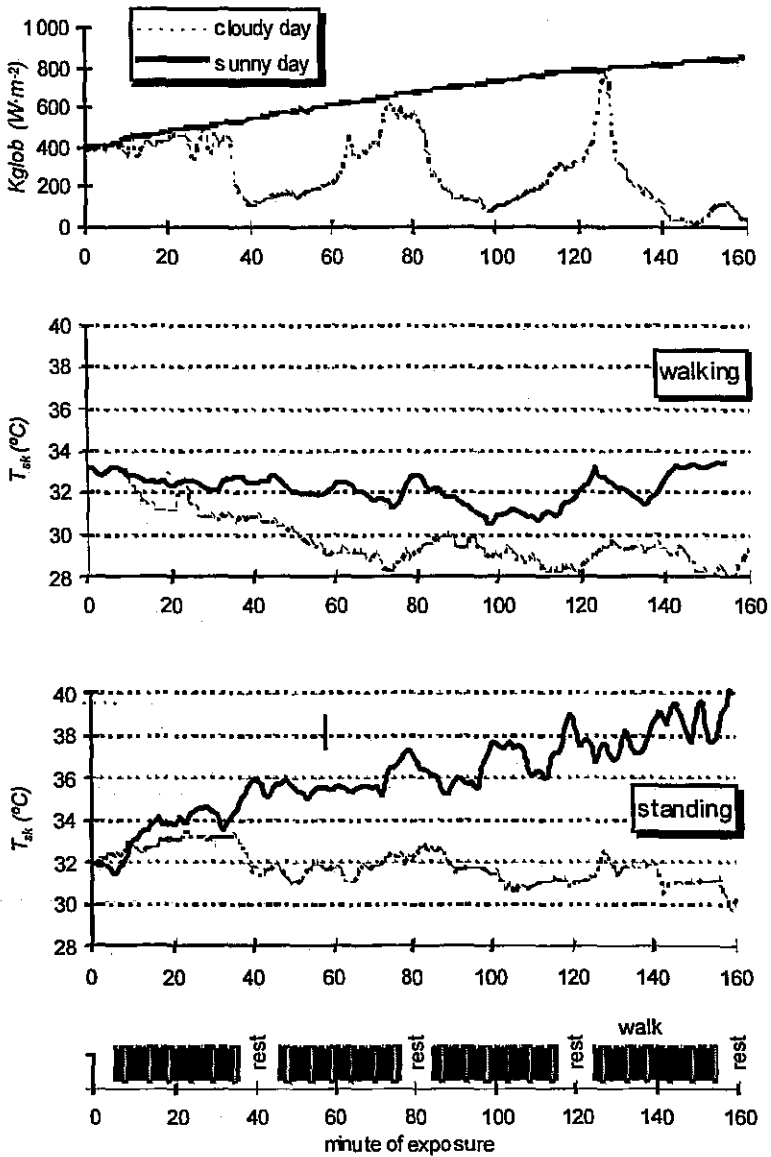
Skin temperature was significantly influenced by direct sunbeams. The temperature of the manikin's surface facing the sun was 5 to 6°C higher than on its rear surface. Subjects' chest-to-back temperature difference was only 1 to 3°C due to evaporation cooling. However, during 2-h solar exposures chest-to-back temperature differences ( $d T_{sk}$ ) decreased, changing from 2.5-3°C to 1°C the last 30 min of exposure (Fig. 2).



**Figure 2.** Difference between chest and back temperature ( $d T_{sk}$ ) during 120 min solar exposure; mean values for 6 subjects, July 1996, midday hours

For walking subjects, 2 days were analyzed (sunny and cloudy) with the same air temperature (of about 18°C) and wind speed (of about 2 m·s<sup>-1</sup>). On the cloudy day,  $\bar{T}_{sk}$  was about 2 to 3°C lower than during the sunny day, and it was kept at the same levels of 28 to 29 and 30 to 31°C, respectively. Both on cloudy and sunny days, subjects reported intensive sweating after about 20 min of walking. In comparison, for the standing person under sunny conditions, the skin was warmer than under cloudy sky

conditions by about 5 to 6°C (Fig. 3). Also observed were significant temporary changes in  $\bar{T}_{sk}$ ; in cloudy conditions, it decreased from 33 to 30°C, and in sunny conditions, it increased from 32 to 39°C during 2-h exposure.



**Figure 3.** Changes of global solar radiation ( $K_{glob}$ ) as well as skin temperature ( $T_{sk}$ ) in walking and standing subjects during sunny and cloudy day, August 1997; the lowest panel illustrates walking and resting periods during solar exposition; during sunny day.

In walking subjects, both on sunny and cloudy days skin started to dry and  $\bar{T}_{sk}$  increased during rest periods (especially 2<sup>nd</sup> and 3<sup>rd</sup>). Then, when subjects

walked again  $\bar{T}_{sk}$  declined significantly. In standing subjects who did not report sweating, changes in  $\bar{T}_{sk}$  can be explained by the temporary fluctuations in meteorological parameters and body position.

## DISCUSSION

The recent papers reporting changes of skin temperature in subjects outdoors (3,4,5) pointed to the influence of solar radiation on  $\bar{T}_{sk}$ . Nielsen et al. (4) observed a reduction in  $\bar{T}_{sk}$  of about 1 to 2°C when subject exercised in the shade in comparison to sunny conditions. Similar relations were observed by Blazejczyk (5) in standing subjects.

In walking subjects, skin temperature was influenced both by solar radiation (mainly direct radiation) and by evaporation of sweat from the body surface (air temperature and wind speed did not change significantly). Thus, for standing subjects, sunny conditions produced a gradual increase in skin temperature. Then during walking,  $\bar{T}_{sk}$  varied, decreasing during exercise and rising while resting but did not exceed pre-exercise  $\bar{T}_{sk}$ . This latter observation points to the great importance of evaporation cooling on body temperature regulation, especially during exercise.

## CONCLUSIONS

For subjects outdoors, skin temperature depends on various meteorological factors (air temperature, wind speed, solar radiation—especially direct solar radiation). However, approximately 50% of the changes in  $\bar{T}_{sk}$  may be explained by changes of absorbed solar radiation. Solar radiation influences skin temperature both in standing and in walking subjects. However, in walking subjects, evaporative heat loss plays a very important role.

## REFERENCES

1. Blazejczyk, K., Nilsson, H. and Holmér, I. 1993, Solar heat load on man (review of different methods of estimation), *International Journal of Biometeorology*, **37**, 125-132.
2. Clarke, R.P. and Edholm, O.G. 1985, *Man and His Thermal Environment*, (London: E.Arnold Ltd).
3. Blazejczyk, K. 1997, Dry heat exchange and skin temperature in subjects outdoors at fluctuated cloud cover, in B. Nielsen-Johannsen and R. Nielsen (eds.), *Thermal physiology*. (Copenhagen: August Krogh Institute), 115-118.
4. Nielsen, B., Kassow, K. and Aschengreen, F.E. 1988, Heat balance during exercise in the sun, *European Journal of Applied Physiology*, **58**, 189-196.
5. Blazejczyk, K. 1998, Solar radiation and heat balance of human organism, *Zeszyty IGI PZ PAN*, **51** (in Polish, summary in English).