Solar radiation and heat balance of the human organism

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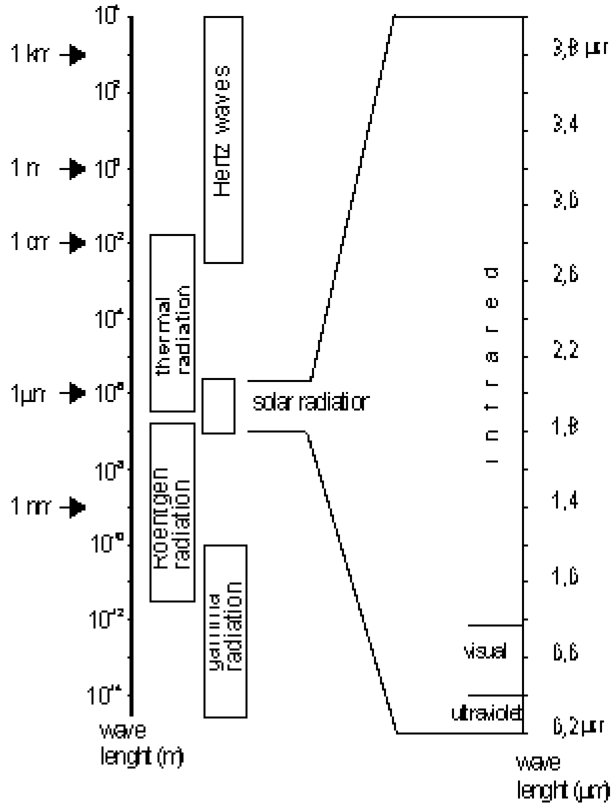
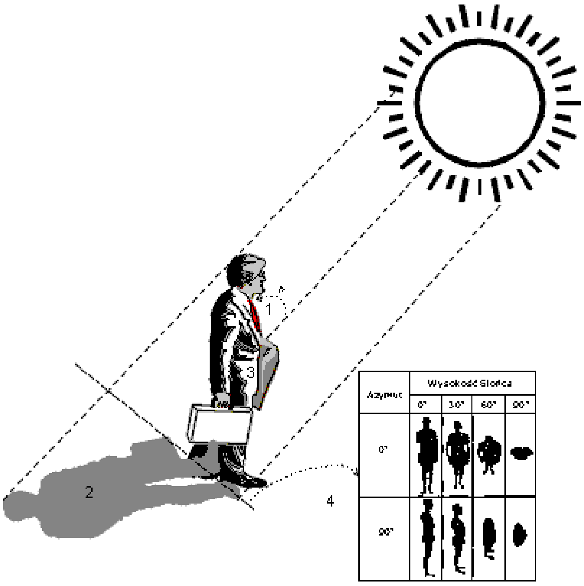
Solar radiation is very important factor influencing human life and development. Physically it is kind of electromagnetic waves with the length of 0,1-4,0 µm. There are three ranges of solar radiation: ultraviolet (< 0.4 µm.), day-light (0.4-0.76 µm) and infrared (> 0.76 µm). Each range of radiation has its specific, biological activity. UV radiation has bactericidal properties; it also produces vitamin D_3 and burning of skin surface. Day-light radiation is a source of visual and mental impressions in man. However infrared beams have thermal features.



The man outdoor is under the influence of direct (K_{dir}) and diffuse (K_{dif}) radiation fluxes as well as of solar flux reflected from the ground (K_{ref}). The general equation of absorbed solar radiation (R) has the following form:

$$R = (\beta_{dir} \cdot K_{dir} + \beta_{dif} \cdot K_{dif} + \beta_{ref} \cdot K_{ref}) \cdot \alpha \cdot Cl$$

Absorption of solar radiation were studied both, on a mannequin and on subjects. Mannequin was used as a geometrical, analogue model of man.



Characteristics of solar angle used in various models of absorbed solar radiation:
1 - trigonometric function,
2 - body shade cast on the ground,
3 - body area reciving solar beams,
4 - projected body area

Mannequin "Marta" with solar sensors

Subject with solar sensors

Absorbed dose of solar radiation was derived from direct measurements of dry heat exchange (S_m, S) observed on the surfaces of mannequin and subjects bodies. S and S_m values were measured with the use of special, elastic heat flux plates. The sensors were attached on forehead, forearm, palm, chest, back, thigh and lower leg (Fig. 14). There were also controlled convective (C_m, C) and radiative (long-wave - L_m, L_c) heat exchange. The temperature of the surfaces of mannequin and subjects bodies was measured as well using resistant thermometers. There were made five series of measurements: in July 1995, October 1995, July 1996, July 1997 and August 1997 on the research stations of the Institute of Geography and Spatial Organization of the Polish Academy of Sciences in Borowa Góra (next to Warsaw) and Hala Gąsienicowa (in the Tatry Mtns.). Simultaneously, meteorological elements, i.e. air temperature, wind speed, air humidity, solar radiation (global, direct, diffuse and reflected) and long wave radiation (of the sky and of the ground) were controlled. The data were registered automatically as 1 minute averages. In 1997 circulatory system parameters (heart rate, diastolic and systolic blood pressure) were also examined.

The measurements carried out on the mannequin were used to define β

Because of various kinds of insolation data we can have in our disposal there were proposed 3 new, numerical models of absorbed solar radiation in subjects. **SolDir** model may be used when we have measured data of solar radiation fluxes (K_{dir}, K_{dif} , K_{ref}). Then absorbed solar radiation may be calculated as follows:

$$R = 1.4\ [K_{dir}\ e^{(-0.51\ +\ 0.368\ h)} + (K_{dif}+K_{ref})\ (0.0013 + 0.033 \ln h)]\ (1 - 0.01\ a_c)\ Irc$$

- for Sun altitude (h) ≤5° and

$$R = 1.4\ [K_{dir}\ (18.816/h - 0.235) + (K_{dif}+K_{ref})\ (0.0013 + 0.033 \ln h)]\ (1 - 0.01\ a_c)\ Irc$$

- for Sun altitude > 5°,

where: a_c - albedo of skin and/or clothing (in %), h - Sun altitude (in degree), Irc - coefficient reducing heat transfer due to clothing.

Very often we have only data of global solar radiation (K_{glob}) and general information about cloudiness. In this case we can use **SolGlob** model of absorbed solar radiation. R equations have various form depending on insolation conditions:

$$R = 1.4\ K_{glob}\ (0.546 - 0.224 \ln h)\ (1 - 0.01\ a_c)\ Irc$$

- for h < 10°,

$$R = 1.4\ K_{glob}\ (2.764\ h^{-0.694})\ (1 - 0.01\ a_c)\ Irc$$

- for h ≥10° and cloudiness of 0-20%,

$$R = 1.4\ K_{glob}\ (0.04 + 5.166/h)\ (1 - 0.01\ a_c)\ Irc$$

- for h ≥10° and cloudiness of 21-80%,

$$R = 1.4\ K_{glob}\ (0.0013 + 0.033 \ln h)\ (1 - 0.01\ a_c)\ Irc$$

- for $h \geq 10°$ and cloudiness > 80% and

$$R = 1.4\ K_{glob}\ e^{(-1.86 - 12.702/h)}\ (1 - 0.01\ a_c)\ Irc$$

- for $h \geq 10°$ and cloudiness of 21-80% as well as lack of direct solar radiation.

SolAlt model may be used when we have in our disposal data of an amount of cloud cover only. Then we can assess absorbed solar radiation by the following formulas:

$$R = 1.4\ (1.388 + 0.215\ h)^2\ (1 - 0.01\ a_c)\ Irc$$

- for $h < 4°$,

$$R = 1.4\ (-100.428 + 73.981 \ln h)\ (1 - 0.01\ a_c)\ Irc$$

- for h ≥4° and cloudiness of 0-20%,

$$R = 1.4\ e^{(5.383 - 16.072/h)}\ (1 - 0.01\ a_c)\ Irc$$

- for h ≥4° and cloudiness of 21-50%,

$$R = 1.4\ e^{(5.012 - 11.805/h)}\ (1 - 0.01\ a_c)\ Irc$$

- for h ≥4° and cloudiness of 51-80% and

$$R = 1.4\ 0.679\ h^{1.039}\ (1 - 0.01\ a_c)\ Irc$$

- for h ≥4° and cloudiness of 0-20% as well as lack of direct solar beams or

for h ≥4° and cloudiness > 80%.

The accuracy of proposed models was verified during direct measurements of solar radiation absorbed by subjects. 6 volunteers healthy subjects within the age category of 16-46 years were taken under investigation. Absorbed solar radiation observed on subjects was compared with *R* values calculated with the use of **SolDir**, **SolGlob** and **SolAlt** models. Some previous models considered another analogue models of man (cylinder, ellipsoid) were taken into account as well. At **SolDir** and **SolGlob** models mean differences of calculated and measured *R* values changed from -10,0 to +4,6 $W˘m^{-2}$, i.e. from -22,1 to +12,5% of measured values. Satisfied are also *R* values derived from **SolAlt** model.

The results of investigations related to the influence of solar radiation exposure on thermoregulatory system show that the regulation of body surface temperature was especially complicated during varying cloud cover; temperature of skin reacted on sudden income or lack of solar beams in about 5-8 minutes; the changes of insolation influenced also thermal sensations in subjects.

Very important role in temperature regulation under sunny conditions plays colour of clothing. At white clothing the heating of the body surface was lower then at black one. White clothing protects also man against high temperature fluctuations during sudden changes in income of direct radiation.

The first results dealing with reactions of circulatory system on sun exposition show that the solar exposition has influenced heart rate (HR) as well as systolic (BPS) and diastolic (BPD) blood pressure in subjects. BPD and HR when wearing white clothes were higher in comparison with black clothes. Comparing BPS, BPD, HR and the intensity of global (Kglob) and absorbed (R) solar radiation it was found that in subjects wearing white clothes, the exposure parameters were significantly correlated only for HR vs. Kglob and BPD vs. R. In subjects wearing black clothes the correlation was significant for almost all observed parameters except systolic blood pressure.

Absorption of solar radiation is influenced by regional geographical factors (e.g. latitude, air mass circulation etc.). Very typical are relatively small *R* values observed in subtropical regions during midday hours; it is caused by high solar angle which results in reducing of effective body area receiving Sun beams.

Local features of geographical environment influence absorbed solar radiation in man as well. *R* values depend mostly on orography, land use and albedo of ground. Very typical for urban and forested areas are great periodical fluctuations of direct solar beams and consequently of absorbed solar radiation. In the mountain regions important role play: great horizon shading into valleys, great midday cloudiness, provoked by air vapour condensation around high mount ridges (midday "cap" of clouds) as well as the additional income of solar radiation reflected from the slopes.

The investigations refereed have found answers for some questions. However there are still number of problems to study. Detail recognising of regional and local differentiation as well as influence of various types of atmospheric circulation on absorbed solar radiation should be the main problems investigated in the future. There are still open for discussion questions dealing with impacts of solar radiation on the functioning of thermoregulatory and circulatory systems of man as well on his water and mineral balances.