Assessment of recreational potential of bioclimate based on the human heat balance

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Abstract: Recreation outdoors strongly depends on actual weather conditions. To assess recreational potential of bioclimate new weather classification was used. It bases on the human heat balance. Bio-thermal features of weather as well as physiological response in man are the base to characterise the weather types It also includes information dealing with daily precipitation, snow cower, daily amplitude of air temperature and sultriness. The classification was used for day-by-day analysis of weather as well as for evaluation of seasonal and regional differentiation of bioclimate.

Key words: Recreation, Bioclimate, Human heat balance, Weather classification

1. Introduction

Recreation is a way of spending leisure time, i.e. it is any particular activity which is done for amusement and enjoyment. Many forms of recreational activity are related to the outdoor climate. Actual weather conditions are one of the main factors that limit recreational activity outdoors. They influence the form of recreation, its duration as well as its effectiveness. In assessment of bioclimatic recreational potential not only precipitation and others meteorological phenomena (e.g. fogs, storms etc.) are very important but also thermal conditions (intensity of warm/cold stress, daily amplitude) (de Freitas 1985, 1990, Matzarakis, Mayer 1994).

Most of existing methods of weather evaluation for recreation based on simple thermal characteristics (e.g. maximal and minimal temperature, its amplitude and temporal changes) as well as on simple biometeorological or climatic indices, e.g. Wind Chill Index, Equivalent and Effective Temperature - (Kozlowska-Szczesna et al. 1997, Lee 1980, Maarouf, Bitzos 2001), Tourism Climatic Index (Mieczkowski 1985). To assess thermal conditions we should consider not only physical parameters of the air but also physiological response of the human organism (Beaumont, Bullard 1965, Blanc 1975, Blazejczyk. 1997, 1998, 1999, Blazejczyk et al. 1999, Fanger 1970, de Freitas 1990, Mitchell 1977). Its intensity and heat state of man depend on the full complex of atmospheric stimuli: temperature, humidity, solar and thermal radiation, air movement, cloudiness (Fig. 1).

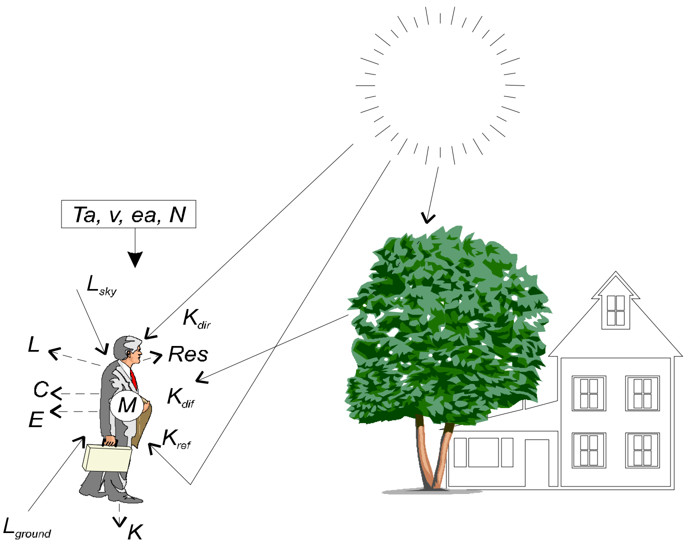

Fig. 1 Man in a complex thermal environment
Ta - air temperature, *ea* - vapour pressure, *N* - cloudiness, *v* - wind speed,
Solar radiation: *Kglob* - global, *Kdir* - direct, *Kdif* - diffuse, *Kref* - reflected,
Thermal radiation: *Lground* - ground, *Lsky* - sky,
Heat fluxes: *M* - metabolism,
C - convection, *E* - evaporation,
L - long-wave radiation,
Res - respiration, *K* - conduction

Complex of meteorological elements influences both, particular fluxes of man-environment heat exchange and also physiological parameters: skin temperature, metabolism, peripheral blood flow etc. (Blanc 1975, Blazejczyk 1997, 1999, Clark, Edholm 1985, Mitchell 1977, Nielsen et al. 1988, Yoshimura, Morimoto 1974). The resultant value of man-environment heat exchange at actual weather conditions is net heat storage (Fig. 2).

There are two principal considerations of climate-recreation relationships. The first one bases on the analysis of separated meteorological elements or simple biometeorological indices. The second one try to evaluate full complex of weather from the point of view of recreation. The aim of the paper is to present new weather classification for recreation based on the human heat balance outdoors and some examples of its applications in climate-recreation research at the Polish health resorts.

2. Method

2.1. Principles of the human heat balance

Various models estimated human heat balance indoors exist (Bligh, Johnson 1973, Fanger 1970, Holmér 1988, ISO/DIS 7933, ISO/DC 11079, Parsons 1993). However for outdoor conditions only few models can assess physiologically significant components of man-environment heat exchange: Brown, Gillespie (1986), Budyko's model (Budyko, Cicenko 1960), HEBIDEX and STEBIDEX (de Freitas 1985, 1990), Klima-Michel-Model (Jendritzky 1990), MEMI (Höppe 1984), MENEX (Blazejczyk 1994), Nielsen et al. (1988).

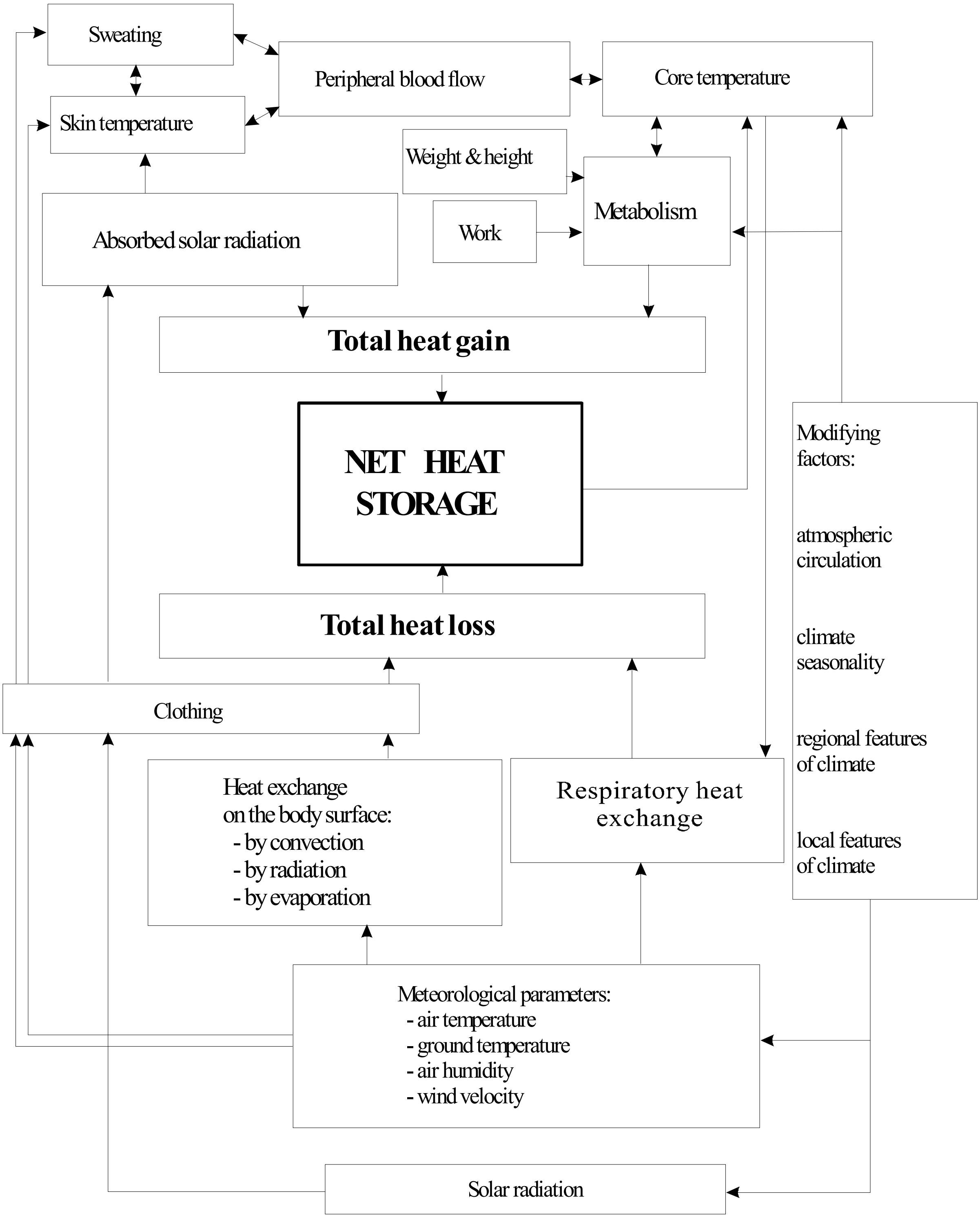

Fig. 2. Relationships between physiological and meteorological parameters considered in man-environment heat exchange model MENEX (Blazejczyk 1994).

According to the MENEX model the general equation of the human heat balance has the following form:

$$M + R + E + C + L + Res = S \qquad (1)$$

where: M is metabolic heat production (W m^{-2}), *R* – solar radiation absorbed by man (W m^{-2}),

E – evaporative heat loss (W m^{-2}),

C – heat exchange by convection (W m^{-2}),

L – heat exchange by long wave radiation (W m^{-2}),

Res – respiratory heat loss (W m^{-2}),

S – net heat storage, i.e. changes in body heat content (W m^{-2}).

The *S* is resultant value of heat exchange between man and his surrounding. For long periods (24 hours or longer) *S* can be considered as equal to zero, i.e. heat gains are equilibrated by heat losses. However, in particular moments the *S* has positive or negative values. Positive *S* value points out the accumulation of heat in the body. However at negative values of net heat storage the cooling of body core occurs.

Metabolic heat is produced in the internal cell processes and by the work of mussels. It depends on human activity, body posture, age, sex, weight and height as well as on thermal conditions and climatic seasonality (Schofield 1985, Yoshimura, Morimoto 1974). *M* volume is assessed according to ISO 8996.

Evaporative heat loss depends on the difference in vapour pressure in the atmospheric air and at the skin surface. Some physical and physiological coefficients are taken into account as well:

$$E = \{he\,(e_a - e_{sk})\,w\,Ie - [0.42\,(M - 58) - 5.04]\}sex \quad (2)$$

where: e_a – air vapour pressure (hPa),

e_{sk} – vapour pressure at the skin surface (hPa),

he – coefficient of evaporative heat transfer (W m^{-2} hPa^{-1}),

w – skin wetedness coefficient (dimensionless),

Ie – reduction coefficient of heat transfer through clothing (for evaporation) (dimensionless),

sex – coefficient depended on sex (1.0 – for man, 0.8 for woman) (dimensionless).

Vapour pressure at the skin surface and the wetedness coefficient are the functions of skin temperature (*Tsk* in ºC):

$$e_{sk} = EXP(0.058Tsk + 2.003) \quad (2.1.)$$

$$w = 1.031/(37.5 - Tsk) - 0.065 \quad (2.2.)$$

(at *Tsk* > 36.5ºC *w* = 1.0)

Another coefficients are calculated as follows:

$he = [Ta\ (0.00006Ta - 0.00002ap + 0.011) + 0.02ap - 0.773]\ \text{SQRT}(v + v')$ (2.3.)

where: Ta – air temperature (ºC),

ap – air pressure (hPa),

v – wind speed (m s^{-1}),

v' – velocity of man (m s^{-1}).

$Ie = hc'/(hc' + hc)$ (2.4.)

where: hc – coefficient of convective heat transfer (W m^{-2} K^{-1})

hc' – coefficient of conductive heat transfer through clothing (W m^{-2} K^{-1}),

$hc = (0.013ap - 0.04Ta - 0.503)\ \text{SQRT}(v + v')$ (2.5.)

$hc' = (0.013ap - 0.04Ta - 0.503)\ 0.53/\{Icl\ [1 - 0.27(v + v')^{0.4}]\}$ (2.6.)

where: Icl – clothing insulation (clo)

<u>Convective heat loss</u> depends on temperature difference between the air and the skin surface as well as on heat transfer coefficients:

$C = hc\ (Ta - Tsk)\ Irc,$ (3)

where: hc is the same as (2.5.),

Irc – reduction coefficient of heat transfer through clothing (for convection and radiation) (dimensionless).

$Irc = hc'/(hc' + hc + 4s\sigma T^3)$ (3.1.)

where: hc' – is the same as (2.6.),

s – emissivity coefficient (=0.95),

σ - Stefan-Boltzman constant (=5.67 10^{-8} W m^{-2} K^{-4}),

T – air temperature (K)

<u>Heat loss by long-wave radiation</u> is an effect of heat transfer by thermal radiation which occurs - according to the Stefan-Boltzman low - between any surfaces with the temperature >0 K. Its resultant value depends on the temperature differences between the skin, the air and the ground as well as on emissivity coefficient:

$L = [2s\sigma T^3\ (Tg - Ta) - 0.5s\sigma T^4\ (0.254 - 0.005e_a)\ (1 - 0.01cN) + 4s\sigma T^3\ (Ta - Tsk)]\ Irc$ (4)

where: Tg – ground temperature (ºC),

Irc – the same as (3.1.),

N – cloudiness (%),

c – coefficient depended on clouds type: 0.2 for *Ci*, *Cc*, 0.3 for *Cs*, 0.4 for *Ac*, *As*, 0.5 for *Cu*, 0.6 for *Cb*, 0.7 for *Sc*, *St*, 0.8 for *Ns*

Respiratory heat loss consists of two components: convective and evaporative heat loss. The first one depends on temperature differences between the atmosphere and exhaled air (assumed as 35ºC). The second component depends on difference between air vapour pressure and vapour pressure of exhaled air (assumed as 56,2 hPa.

$$Res = 0.0014\, M\, (Ta - 35) + 0.00173\, M\, (e_a - 56.2) \quad (5)$$

Skin temperature can be taken from direct measurements, assumed as a constant value or estimated according to the empirical equations derived from experimental research. They regard the relationship between skin temperature and various meteorological elements (Blazejczyk 1994):

$$Tsk = (0.004K_{glob} + 0.09Ta + 0.08e_a - 0.1v + 26.4) + [(Icl - 1)\, 0.6] + 0.00128M \quad (6.1)$$

or

$$Tsk = [0.29Ta + 0.001f - 0.08v + 26.0] + [(Icl - 1)\, 0.6] + 0.00128M \quad (6.2)$$

or

$$Tsk = [0.29Ta + 0.001f + 1.12\,(1 - 0.01N) - 0.08v + 26.03] + [(Icl - 1)\, 0.6] + 0.00128M \quad (6.3.)$$

Absorbed solar radiation can be calculated with the use of the one of the following models: **SolDir**, **SolGlob** or **SolAlt**. The models were derived from the experimental research carried out both, on the mannequin and on the human subjects (Blazejczyk 1998, 2000 b).

SolDir model may be used when we have in our disposal data of all solar radiation fluxes (direct – K_{dir}, diffuse – K_{dif} and reflected – K_{ref}). Depending on Sun altitude absorbed solar radiation is calculated as follows:

- for $h \leq 5°$

$$R = 1.4\, [K_{dir}\, \mathrm{EXP}(-0.51 + 0.368h) + (K_{dif}+K_{ref})\, (0.0013 + 0.033\, \mathrm{LN}\, h)]\, (1 - 0.01a_c)\, Irc \quad (7.1.)$$

- for $h > 5°$

$$R = 1.4\, [K_{dir}\, (18.816/h - 0.235) + (K_{dif}+K_{ref})\, (0.0013 + 0.033\, \mathrm{LN}\, h)]\, (1 - 0.01a_c)\, Irc \quad (7.2.)$$

where: *ac* – albedo of skin and/or clothing (%),

h – Sun altitude (degree),

Irc – the same as (3.1.)

When we have only data of global radiation (K_{glob}) then absorbed solar radiation can be calculated using **SolGlob** model as follows:

- for $h \leq 10°$,

$R = 1.4\ K_{glob}\ (0.546 – 0.224\ \mathrm{LN}\ h)\ (1 – 0.01a_c)\ Irc$ (8.1.)

- for $h > 10°$ and N = 0-20%

$R = 1.4\ K_{glob}\ (2.764\ h^{-0.694})\ (1 – 0.01a_c)\ Irc$ (8.2.)

- for $h > 10°$ and N = 21-90%

$R = 1.4\ K_{glob}\ (0.04 + 5.166/h)\ (1 – 0.01a_c)\ Irc$ (8.3.)

- for $h > 10°$ and $N > 90\%$

$R = 1.4\ K_{glob}\ (0.0013 + 0.033\ \mathrm{LN}\ h)\ (1 – 0.01a_c)\ Irc$ (8.4.)

- for $h > 10°$, N = 21-90% at the shaded place

$R = 1.4\ K_{glob}\ \mathrm{EXP}(-1.86 – 12.702/h)\ (1 – 0.01a_c)\ Irc$ (8.5.)

Very often we did not have in our disposal any data of solar radiation. In this case we can estimate (with an error up to 20%) absorbed solar radiation using **SolAlt** model:

- for $h \leq 4°$

$R = 1.4\ (1.388 + 0.215h)^2\ (1 – 0.01a_c)\ Irc$ (9.1.)

- for $h > 4°$ and N = 0-20%

$R = 1.4\ (-100.428 + 73.981\ \mathrm{LN}\ h)\ (1 – 0.01a_c)\ Irc$ (9.2.)

- for $h > 4°$ and N = 21-50%

$R = 1.4\ \mathrm{EXP}(5.383 – 16.072/h)\ (1 – 0.01a_c)\ Irc$ (9.3.)

- for $h > 4°$ and N = 51-80%

$R = 1.4\ \mathrm{EXP}(5.012 – 11.805/h)\ (1 – 0.01a_c)\ Irc$ (9.4.)

- for $h > 4°$ and $N > 80\%$ or for h > 4° and N = 21-80% (at the shaded places)

$R = 1.4\ 0.679h^{1.039}\ (1 – 0.01a_c)\ Irc$ (9.5.)

Heat load of an organism both, warm and cold stress, is evaluated as a combination of the three principal heat fluxes: net heat storage (S), absorbed solar radiation (R) and evaporative heat loss (E). Heat Load index (HL) is calculated as follows:

- for $S \leq 0$ W m^{-2} and $E \geq -50$ W m^{-2}

$HL = [(S+360)/360]^{[2-1/(1+R)]}$ (10.1.)

- for $S > 0$ W m^{-2} and $E \geq -50$ W m^{-2}

$HL = [(S+360)/360]^{[2+1/(1+R)]}$ (10.2.)

- for $S \leq 0$ W m^{-2} and $E \leq -50$ W m^{-2}

$HL = (E/-50)\ [(S+360)/360]^{[2-1/(1+R)]}$ (10.3.)

- for $S > 0$ W m^{-2} and $E \leq -50$ W m^{-2}

$$HL = (E/-50)\,[(S+360)/360]^{[2+1/(1+R)]} \qquad (10.4.)$$

All the calculations can be very easy made with the use of BioKlima© v. 1.61 software package (Blazejczyk K, Blazejczyk M 1997). The software may be downloaded from: www.igipz.pan.pl./klimat/blaz/bioklima.htm

2.2. Principles of thermophysiological weather classification

According to C R de Freitas (personal communication) climate evaluation should consists of three elements: aesthetic (e.g. Sun, clouds, visibility, day length), physical (e.g. rain, wind, snow, UV, pollution), thermal (common effect of climate and physiology). Actual weather is one of the basic demand indicators of recreational potential of any time, season and/or region. The weather classification presented in this paper includes most of the components considered by de Freitas.

2.2.1. Weather types

Recreational activity should bring the people rest, joy and amusement. When recreation is going outdoors the heat state of an organism must be considered as a main indicator of enjoyment. Thus the weather type should give the people information about actual bio-thermal conditions (Blazejczyk 2000 b). They depend both, on meteorological conditions and on physiological parameters of an organism (Tab. 1). Description of weather consists of three elements: heat load (HL), intensity of radiation stimuli (R') and physiological strain in man (PS).

The first element of digital description tells about heat load in man which occurs at actual weather and actual man's activity as follows:

HL	≤ 0.810	- great cold stress,
	0.811 – 0.930	- moderate cold stress,
	0.931 – 1.185	- thermoneutral,
	1.186 – 1.600	- moderate warm stress,
	> 1.600	- great warm stress.

The next meteorological factor influencing humans outdoor is solar radiation (Blazejczyk 1997, 1998, Blazejczyk et al. 1993, Brown, Gillespie, 1986, Nielsen et al. 1988). Thus the second digit in the classification brings the message regarded the intensity of solar radiation stimuli. In this purpose the value of solar radiation absorbed by nude man (according to one of the 7.1. - 9.5. formulas, without *Irc* coefficient) was applied as follows:

R' ≤ 60.0 W m^{-2} - weak,

60.1 – 120.0 W m^{-2} - average,

> 120.0 W m^{-2} - great.

The third element of description deals with physiological strain (PS) of an organism. It is define by the main way of heat elimination from the body as follows:

C - heat loss by convection = cold strain,

E - heat loss by evaporation = warm strain.

Cold physiological strain is manifested by (Blanc 1975, Clark, Edholm 1985, Holmér 1988, ISO/DC 11079):

- decrease in skin temperature,
- reduction of peripheral blood flow,
- increase in blood pressure,
- increase in thermal insulation of skin tissue,
- shivering.

Warm physiological strain leads to (Kenney 1985, Clark, Edholm 1985, Mitchell 1977):

- increase in peripheral blood flow,
- decrease in blood pressure,
- increase in heart rate (Blazejczyk et al. 1999),
- intensive sweating (Beaumont, Bullard 1965)
- dehydration,
- temporal changes in skin temperature, from very high during warming the skin to low, during sweating phase Blazejczyk 1997, 1998, Malchaire 1991)

Finally, 30 weather types can be distinguished. They represent various combinations of heat load, intensity of solar stimuli and physiological strain of an organism during recreation.

2.2.2. Weather classes

As was mentioned some general features of weather influence the possibility of recreation outdoors. There are: daily precipitation, daily amplitude of air temperature, snow cover and sultriness.

Table 1 Thermophysiological weather types

Heat load	**Intensity of solar radiation stimuli**		
	weak **(1)**	average **(2)**	great **(3)**
great cold stress **(-2)**	***C***	***C***	***C***
	E	***E***	***E***
moderate cold stress **(-1)**	***C***	***C***	***C***
	E	***E***	***E***
Thermoneutral **(0)**	***C***	***C***	***C***
	E	***E***	***E***
moderate warm stress **(1)**	***C***	***C***	***C***
	E	***E***	***E***
great warm stress **(2)**	***C***	***C***	***C***
	E	***E***	***E***

Physiological strain: ***C*** – cold, ***E*** – warm

Recreation can be strongly limited by precipitation. The great importance has the duration of rain- or snow-falls during the daytime hours. However, this information are not commonly putted into meteorological data bases. Hence, daily totals of precipitation (RR) were applied in classification (at RR ≥ 1 mm the day was assumed as rainy).

Daily amplitude of air temperature (*dt* = *tmax* – *tmin*) illustrates the range of temperature fluctuations which gains importance while recreation lasts for many hours a day. Two classes of daily changes in air temperature were assessed: at *dt* ≤ 8 deg weather was assessed as neutral and at *dt* > 8 deg - as stimulative.

Snow cover (SC) is very important for winter recreation. It can be effectively used when its depth is ≥ 10 cm, i.e. a snowy day.

At summer recreation sultriness intensity (SI) limits its active forms at several groups of people (Steadman 1979). To assess sultriness intensity Heat Stress Index (*HSI*) of Belding and Hatch (1955) was adapted. 3 classes of weather were distinguished: no-sultry (at *HSI* < 40), moderate sultriness (at *HSI* of 40-70) and great sultriness (at *HSI* > 70). Finally, 20 classes of weather can be defined (tab. 2).

Table 2 Weather classes

Daily precipitation	**Daily amplitude of air temperature**			
	0-8 deg **(0) neutral**		> 8 deg **(1) stimulative**	
< 1 mm **(0) non rainy**	0 **1**	*0* ***1*** ***2***	0 **1**	*0* ***1*** ***2***
≥ 1 mm **(1) rainy**	0 **1**	*0* ***1*** ***2***	0 **1**	*0* ***1*** ***2***

Snow cover: 0 – non snowy, 1 – snowy

Sultriness intensity: *0* – no-sultry, ***1*** – moderate sultriness, ***2*** – great sultriness

Digital description of the thermophysiological weather types and classes can be applied. Every digit contains information dealing with the considered weather characteristics as follows:

Heat load	**Solar radiation**	**Physiological strain**	**Daily precipitation**	**Air temperature amplitude**	**Snow cover**	**Sultriness intensity**
1	2	3	4	5	6	7
-2 **-1** **0** **1** **2**	**1** **2** **3**	***E*** ***C***	**0** **1**	**0** **1**	**0** **1**	***0*** ***1*** ***2***

First three digits bring information regarded weather type. First one tells about the intensity of heat load in man, the second – about the intensity of radiation stimuli, the third – about main way of heat elimination. Other digits, in lower case, get message dealing with: the fourth – daily precipitation, the fifth – daily amplitude of air temperature, the sixth – the occurrence of snow cover, the seventh – the sultriness intensity. If information about any weather component is not available its place in digital pattern must be filled by x.

For example the record $12E_{0102}$ means the weather: with moderate warm stress, average radiation stimuli and with warm physiological strain. There is no precipitation but stimulative temperature amplitude; with no snow cover but with great sultriness observed.

3. Results

Fig. 3 Location of selected recreation resorts

Day by day weather analysis for the period of 1971-1990 was made for three Polish health resorts and recreational centres:
Kolobrzeg – situated in the central part of the Polish shore of the Baltic Sea,
Polanica – located in the south-west part of Poland, in Sudety Mts. and
Krynica – in south-east Poland, in Beskidy Mts. (Fig. 3).

The calculations of the human heat balance were made using BioKlima© v. 1.61 software package for walking man (metabolism of 135 W m^{-2}), wearing clothing with insulation of 1 clo in the warm half-year (May-October) and 2 clo in the cold half-year (November-April).

3.1. Weather evaluation at particular days

Weather evaluation at particular days for the needs of recreation is an essential application of the human heat balance analysis. Tables 3 and 4 present day by day digital description of weather conditions in Krynica. Two months were chosen: January and July 1990. We can see that in January 1990 almost every day great cold stress occurs; only in the last decade thermoneutral weather was registered. Radiation stimuli were weak or average. Thermal conditions of the ambient air led to cold physiological strain. There were some days with precipitation. Only on few days stimulative amplitudes of air temperature were noted. Snow cover was observed in the first and in the third decades.

In July 1990 weather conditions were very differentiated. Days with great warm stress predominated, however days with moderate warm stress occurred as well. Radiation stimuli were great or average. Most days warm physiological strain was observed. 11 rainy days and 23 days with stimulative temperature amplitudes were noted. Only on 7 days no-sultry weather occurred and on 12 days great sultriness was observed.

Similar analysis can be made in the weather forecasts. Information about predicted bio-thermal conditions may be very useful in planning of recreation activity outdoors to eliminate the risk of organism overcooling or overheating.

Table 3 Weather conditions in Krynica, January 1990

day	*HL*	*R'*	PS	RR	*dt*	SC	SI
1	-2	1	*C*	0	0	1	*0*
2	-2	1	*C*	0	0	1	*0*
3	-2	1	*C*	0	0	1	*0*
4	-2	2	*C*	0	0	1	*0*
5	-2	2	*C*	0	0	1	*0*
6	-2	2	*C*	0	0	1	*0*
7	-2	2	*C*	0	1	1	*0*
8	-2	2	*C*	1	0	1	*0*
9	-2	1	*C*	0	0	1	*0*
10	-2	1	*C*	0	0	0	*0*
11	-2	2	*C*	0	0	0	*0*
12	-2	1	*C*	0	0	0	*0*
13	-2	1	*C*	0	0	0	*0*
14	-2	1	*C*	0	0	0	*0*
15	-2	1	*C*	1	0	0	*0*
16	-2	1	*C*	0	0	0	*0*
17	-2	1	*C*	0	0	0	*0*
18	-1	2	*C*	0	0	0	*0*
19	-2	1	*C*	1	0	0	*0*
20	-2	1	*C*	0	0	0	*0*
21	-2	1	*C*	1	0	1	*0*
22	-2	1	*C*	1	0	1	*0*
23	-2	1	*C*	0	0	1	*0*
24	-2	1	*C*	0	0	1	*0*
25	-1	2	*C*	0	1	1	*0*
26	-2	1	*C*	0	0	1	*0*
27	0	2	*C*	0	0	1	*0*
28	-2	1	*C*	0	0	1	*0*
29	-2	1	*C*	1	0	1	*0*
30	0	3	*C*	0	1	1	*0*
31	0	3	*C*	0	1	1	*0*

Table 4 Weather conditions in Krynica, July 1990

day	*HL*	*R'*	PS	RR	*dt*	SC	SI
1	2	3	*E*	1	1	0	*2*
2	2	2	*E*	1	1	0	*1*
3	2	2	*E*	1	0	0	*1*
4	2	2	*E*	1	1	0	*2*
5	2	3	*E*	0	0	0	*2*
6	0	2	*C*	1	0	0	*1*
7	1	2	*C*	0	0	0	*0*
8	2	3	*E*	0	1	0	*2*
9	1	2	*E*	1	1	0	*0*
10	1	2	*C*	1	0	0	*1*
11	1	3	*C*	0	0	0	*0*
12	2	3	*E*	0	1	0	*0*
13	2	3	*E*	1	1	0	*2*
14	1	2	*C*	0	1	0	*1*
15	2	3	*E*	0	1	0	*2*
16	2	3	*E*	0	1	0	*2*
17	2	3	*E*	1	1	0	*2*
18	2	3	*E*	1	0	0	*1*
19	2	3	*C*	0	0	0	*0*
20	2	3	*E*	0	1	0	*2*
21	2	3	*E*	0	1	0	*2*
22	2	3	*E*	0	1	0	*1*
23	2	3	*E*	0	1	0	*1*
24	2	3	*E*	0	1	0	*1*
25	2	3	*C*	1	1	0	*0*
26	2	3	*E*	0	1	0	*0*
27	2	3	*E*	0	1	0	*1*
28	2	3	*E*	0	1	0	*1*
29	2	3	*E*	0	1	0	*1*
30	2	3	*E*	0	1	0	*2*
31	2	3	*E*	0	1	0	*2*

3.2. Seasonal differentiation of bioclimate

We can use day-by-day weather evaluation for the seasonal analysis of recreational potential of bioclimate. In this purpose we should calculate the frequency of particular weather types and classes. Figure 4 gives an example of the annual course of the frequency of some weather types and classes in Krynica. Ten weather situations the most frequently observed in this resort were chosen.

In general in Krynica the most frequent is the weather with great cold stress, weak radiation stimuli and cold physiological strain (about 18% of days: 9% rainy – $-21C_{1000}$ – and 9% non rainy days – $-21C_{0000}$). It is observed mainly in the cold half-year with culmination in December (25% and 24%, respectively). About 11% of days have the weather with great warm stress, great radiation stimuli and warm physiological strain. At 4% of days stimulative daily temperature amplitudes occurred also ($23E_{0100}$) and at 7% of days great sultriness was noted as well ($23E_{0102}$). The maximal frequency of sultry weather is observed in August (22%). The thermoneutral weather ($13C_{0100}$) as well as the moderate warm stress weather ($03C_{0100}$) with stimulative temperature amplitudes are noted in the Spring (March-April) and in the Autumn (October). During the Summer there are not observed.

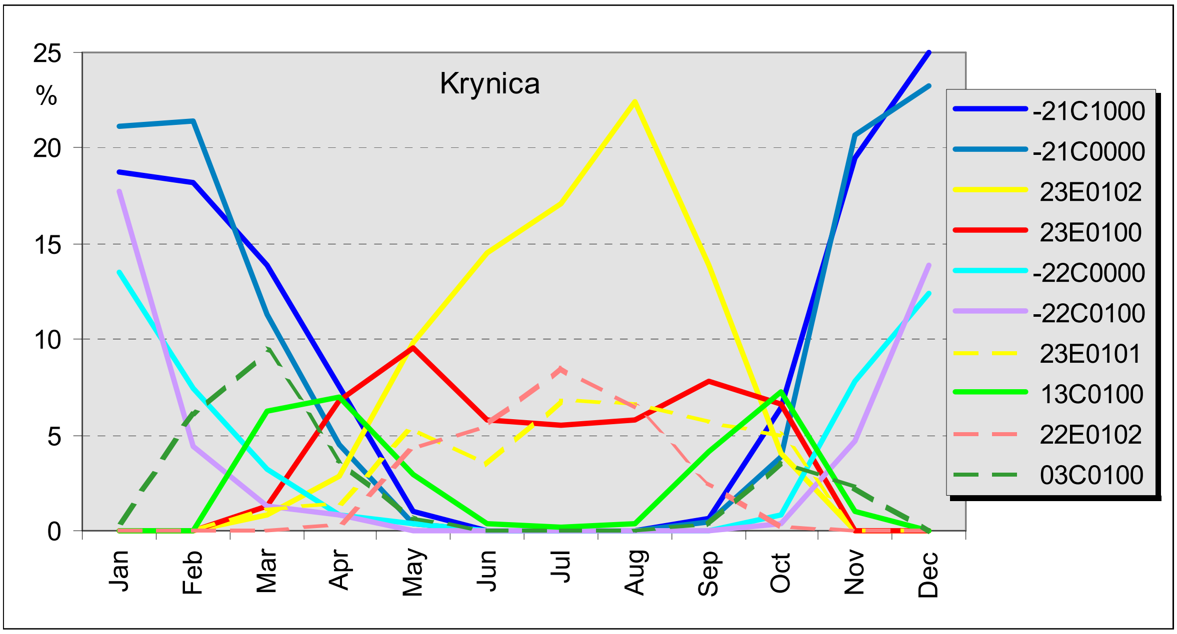

Fig. 4 Annual course of the frequencies of some weather types in Krynica, 1971-1990.

3.3. Spatial variability of bioclimate

The territory of Poland is about 312,000 km^2. The maximal difference in the longitude is 10° and in the latitude - about 6°. Geographical environment of Poland is relatively differentiated. The landscapes varies from the seashore up to alpine. The Polish recreational resorts are located in every region. However, most of them are situated at the seashore, in the mountains as well as in the lakeland regions.

When analysing weather types frequency some patterns were found. The most sensitive for the regional climate variability are the following weather components: heat load in man, daily amplitudes of air temperature, snow cover and intensity of sultriness.

Comparing HL patterns in selected stations we can note significant differences in the frequency of heat load extremes. At the seashore (Kolobrzeg) in the period of November-March great cold stress weather predominates. At the same time in the mountain relatively often is thermoneutral weather. Some differences are also observed between Sudety and Beskidy Mts. In Beskidy (Krynica) the frequency of thermoneutral and moderate warm stress weather is greater then in Sudety (Polanica). In the summer, the most unpleasant weather (the great warm stress) is very frequent in Krynica (Beskidy Mts.), and relatively rare - in Kolobrzeg (seashore) (Fig. 5).

The regional differences in weather conditions are very well seen when comparing frequency of sultry conditions. In the seashore resort (Kolobrzeg) sultry weather appears only during few summer days. In Sudety Mts. (Polanica) sultry conditions are observed relatively often, up to 27% of days in August. Great intensity of sultriness appears very seldom. However, in Beskidy Mts. (Krynica), sultry weather appears from March up to November. In the Summer its frequency is 70-75%. The great intensity sultriness can be found every second day (Fig. 6).

The annual patterns of snowy weather and stimulative temperature amplitude weather are differentiated between seashore and mountains resorts. These weather components are considerably less frequent in Kolobrzeg then in Polanica and Krynica. There are no significant differences in SC and *dt* annual patterns between west (Sudety) and east (Beskidy) mountain regions.

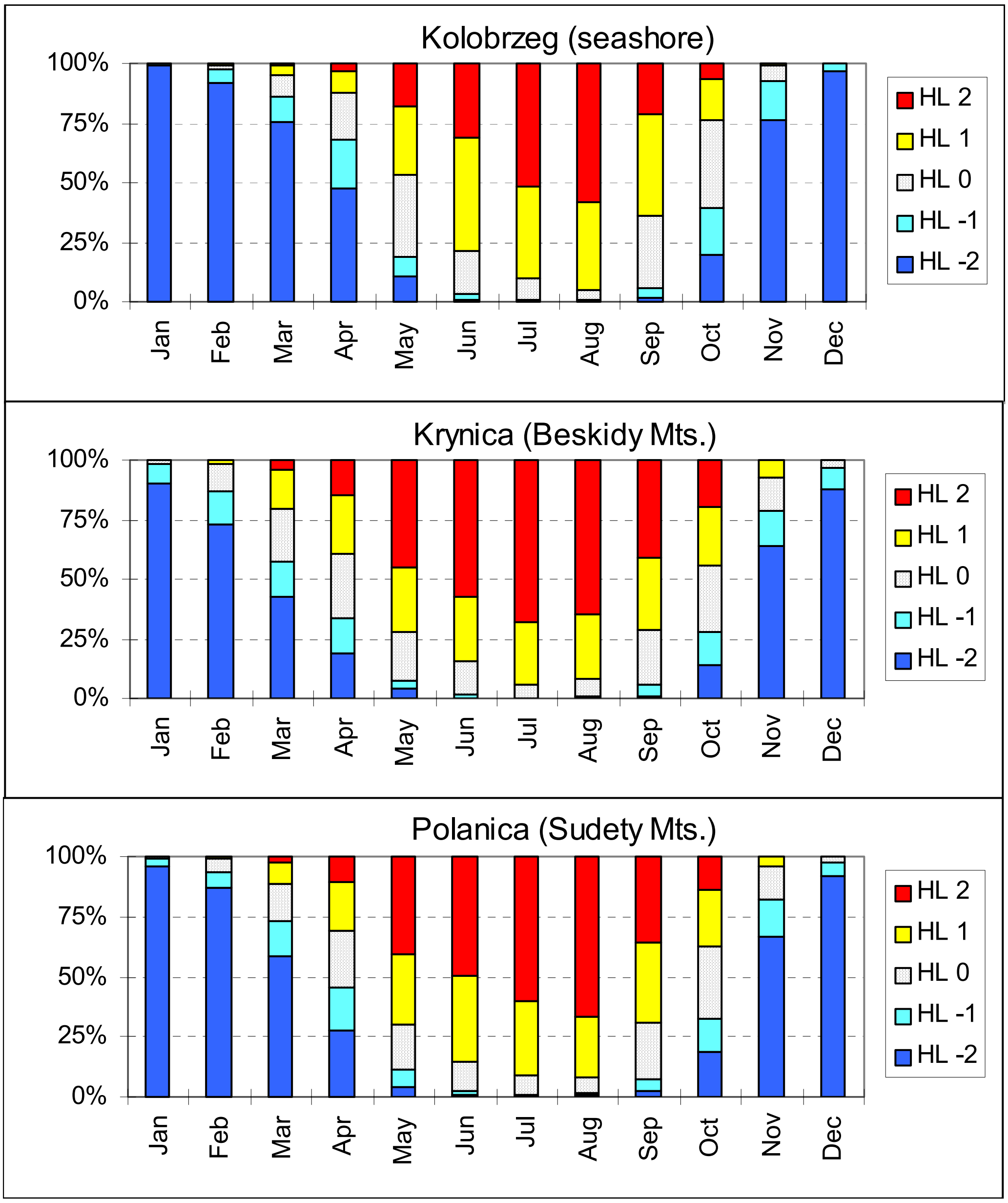

Fig. 5 Frequency of weather with different heat load

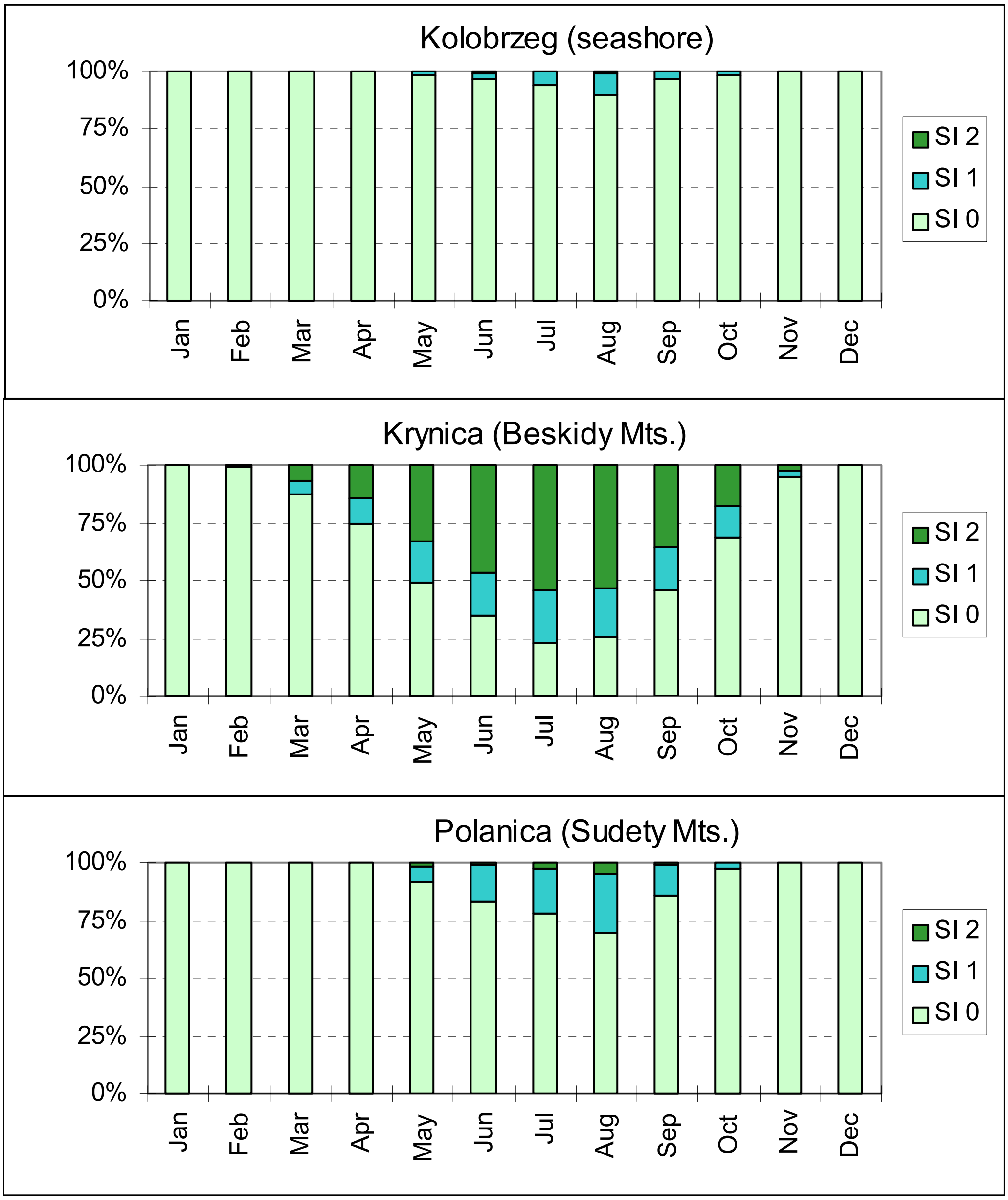

Fig. 6 Frequency of weather with various sultriness intensity

Discussion

Recreation very strongly depends on actual weather conditions. The weather classification based on the human heat balance seems to be an useful tool in research of climate-recreation relationships.

Day-by-day weather analysis gives detail information regarded actual outdoor conditions. It can be very useful for planning of recreational activity, its intensity and duration. The examples given in the paper shows great risk of cold stress in relation to insufficient radiation stimuli and to intensive body cooling by convection, leading to cold strain, in January 1990 in Krynica. On the other hand in July 1990 the warm stress, sultry weather occurred; it resulted in considerable evaporative heat loss and great warm strain of an organism. We can of course to consider not only archival data. Very important is also the possibility to predict thermophysiological strain in man based on traditional weather forecasts.

Bioclimatic characteristics of weather, i.e. the frequency of various weather types and classes, can be used in the studies dealing both, with seasonal and regional differentiation of bioclimatic conditions, from the point of view of recreation. The temporal analysis points to specific features of weather that can be found in particular seasons. They give the possibility for recreation planners and for decision makers to propose to the public the most adequate and safety forms of recreation for particular seasons. In Krynica, the most favourable weather conditions occur in the Spring and in the Autumn. Summer weather is too warm and too sultry.

Similar analysis of weather frequency in the spatial perspective points out the regions or resorts with the most favourable bioclimatic conditions. Taking into consideration three selected station it seems that Polanica has better bioclimatic characteristics then Krynica and Kolobrzeg.

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