

THERMAL COMFORT INDEX

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Abstract: We are showing some bioclimatic indices (formulas or nomograms) for medical purposes, therapeutic tourism, sports. or regionalization. They are based on one, two, three or more different meteorological parameters.

Introduction

One of the important properties of the human body is *the homoeothermie* which means keeping constant internal body temperature (about 37,5⁰C). This property is achieved by *thermoregulation mechanisms*. The body produces heat in case of low temperature environment (e.g. chills, peripheral vasoconstriction, metabolic burning etc.) and gives off heat to the outside in case of too high temperature (e.g. sweating, convection, heat radiation).

This property is linked to the notion of *thermal comfort*. There is a narrow zone called the zone of neutrality, thermal indifference or thermal comfort when a human body, relatively healthy, easily dressed stand, not loose and does not receive heat. Thermal comfort depends on various parameters.

Such are the physical parameters: air temperature, moisture, air speed, pressure, light intensity. Important are and the organic parameters (age, gender, health status, genetic features (and national) and external parameters: the level of human activity, noise, type of clothing, social conditions (of work, housing, concern).

It has been found that the thermal comfort varies depending of its geographic position. Thus researchers have determined the boundaries of comfort, for England: 14.4 - 20,6⁰C, for USA: 20.2 - 26,7⁰C, for tropical regions: 23.3 - 29,4⁰C (for relative humidity 30- 70 %). In the European temperate zone the thermal comfort is appreciated at 16.8⁰ - 20,8⁰TEE.

TEE is *equivalent effective temperature* and is considered the temperature in °TEE felt by the human body in certain conditions: air temperature (in ⁰C),

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moisture (relative% or tension of water vapor in mb or hPa), currents of air (m / s), exposure to solar radiation (in °TEER) and other parameters as pressure, precipitation, etc. (by purpose: tourism, therapeutic etc.)

In these circumstances, researchers have found it necessary to establish some bioclimatic indices, which reflect the real feeling that the human body has in different environmental conditions.

1. Indices based on a single element.

They are obtained directly from data from meteorological stations and give some information on bioclimatic conditions.

Such *temperature indices* (also called thermal thresholds) are *the summer days* (t.max. $\geq 25^{\circ}\text{C}$), which shows that during the day are comfortably, *tropical days* (t. max $\geq 30^{\circ}\text{C}$) showing that the vast majority of day thermal conditions are uncomfortable, restrictive for sick or elderly people, and *hot days* (t.max. $\geq 35^{\circ}\text{C}$) when the majority of the population is recommended to reduce outdoor activity, especially in the sun, when thermal discomfort is maximum.

British climatologists have discussed other temperature thresholds: 21°C , 24°C , 27°C , depending on the activity practiced on vacation (beach, picnic, tennis, golf) (Smith, 1975) *Wind indices* (Escourrou, 1989, see Agostini et al.) indicates that the speed of $\leq 3 - 4$ m/s are recorded convenience, speed 5-9 m/s, require protection, and to > 10 m/s health problems may occur at different affection (e.g. from cardiac patients)

Indices of moisture refers to water vapor pressure (*pulmonary stress index*) (Besancenot 1974, see Teodoreanu 2002), showing (relaxing) comfort (to between 7.5 and 11.6 hPa. At values ≤ 7.5 hPa, stress is dehydrated (hard) and at > 11.6 hPa stress is moisturizer (emollient, depressing). If we take into account relative humidity, comfort is $\approx 50\%$ (30-70%). Below 30%, the air is dry, over 70-80%, the air is humid, in both cases people can suffer with heart disease and lung. Using average in drawing maps may serve the purpose of a bioclimatic regionalization.

Indices pressure refers to variation in space, depending in particular vertical gradient of partial pressure of O_2 . If it falls to ≤ 150 hPa (at an altitude of about 2700m) can lead to a state of discomfort for cardiac people or with hypertension, etc. In exchange may recommend people with anemia, increase red blood cells and hemoglobin and blood.

Atmospheric pressure variation over time, in meteorological instability conditions,

is uncomfortable to large variations in short time: $\pm 10 \dots 15$ hPa / 24h.

2. Indices based on temperatures and moisture.

Researchers from different countries have found that feeling cold or especially heat, at the same degree of temperature is even higher, as the air humidity is higher.

They tried to put into the equation subjective feeling individual by a formula that includes temperature and humidity values (expressed as relative humidity, water vapor pressure or dew point). Based on empirical formulas established scales were developed effective temperature felt by the body under certain conditions of temperature and moisture. So they could give medical advice.

Humidex index (heat index) (Masterton and Richardsohn 1979, after Agostini et al, 2005)

$H_u = T + 0,5555 (e - 10)$ where:

T = temperature $^{\circ}\text{C}$,

e = water vapor pressure in the hPA

H_u (conventionally expressed in $^{\circ}\text{C}$) <25 - state of comfort,

> 35 - starts discomfort,

> 45 - unbearable restlessness,

at 54 is entering the danger zone for the human body

Humiture Index (Winterling 1979, see Enache, 2001)

$T_h = t_a + (\tau - 18)$ for $t_a \geq 30^{\circ}\text{C}$, where:

t_a = Air temperature

τ = dew point

Apparent temperature (second, of Steadman, 1979) (Maheras, Balafoutis, 1992, Agostini, 2005)

$AT = 1,003T_a + 0,399T_d - 4,358$ where:

T_a = air temperature $^{\circ}\text{C}$

T_d = dew point temperature $^{\circ}\text{C}$

Thom index, (1958) for calculating the effective temperature

$TE = 0.4 (td + tw) + 4.8$, where:

TE = effective temperature

td = dry bulb temperature

tw = wet bulb temperature

Comfort zone = around 20°C ($18-22^{\circ}\text{C}$); at $\geq 26,5^{\circ}\text{C}$ = thermal discomfort; at $\geq 33^{\circ}\text{C}$

($\rightarrow$ body temperature $> 40^{\circ}\text{C}$) $\rightarrow$ possible for the sick, elderly a heat stroke if no action is taken)

Thom index THI (Temperature Humidity Index) (1959) (Escourrou, 1989, cf. Agostini, 2005)

$THI = T - [(0,55 - 0,0055 \times U \times 5)(T_{\max} - 14,5)]$

Classes thermal comfort index after THI: (from torrid... to extremely cold)

Summer Index Simmer (Pepi, 1987)

$SSI = 1.98 [T - (0.55 - 0.0055 \times UR) (T - 58)] - 56.83$, where:

T = dry bulb temperature ($^{\circ}\text{F}$)

RH = relative air humidity (%)

Being a summer show, scale of values goes from cool - comfortable to very warm, sultry

Arakawa Index DI_a (Discomfort Index 1960) (Agostini, 2005)

$$DI_A = 0,81 T + 0,01U (0,99T + 14,3) + 46,3$$

(From difficult to bear the cold <55...to difficult to bear the heat >80)

Comfort temperature-humidity index (recommended by the National Meteorological Agency) (Dragotă, cf. *** 2003):

ITU = $(T + 32 \times 1.8) - (0.55 - 0.0055 \times U) [(T \times 1.8 + 32) - 58]$ (from comfort – alert - to the discomfort)

3. Indices based on the values of temperature and wind speed.

In bioclimatology it was found that wind is an important element in establishing the feeling of comfort or discomfort of the body. Thus at a low temperature, in the wind conditions, the sensation of cold increases. In contrast, to an elevated temperature, wind reduces the sensation of discomfort and increases the feeling of thermal comfort (obviously if the wind speed does not exceed the tolerability).

Steadman Index (1998) (felt real temperature, T_e)

$$T_e = 1,41 - 1,162 + 0,98 \times T + 0,0124 \times V^2 + 0,185 (VT)$$

(It is a variation in *wind chill*) (from glacial, to comfortably until very hot)

Wind chill (wind chill index, gélivent, coetaneous stress, thermal-anemometers complex) (Siple and Passel 1945, see Besancenot, 1974 Escourrou, 1989 Teodoreanu, 2002) is expressed by the cooling capacity in kcal / m²h

$$P (+ 10.45 10^{\sqrt{v-v}}) (33-T_a).$$

He presents three main types of stress levels: by triggering thermolysis summer (atonic-hypotonic), relaxing (with a cooling capacity from 300 to 900 kcal/m²h and hypertonic, by triggering thermogenesis winter.

This index, outside the actual values used in general and other indices for determining comfort (uncomfortable) heat felt at one time can be used by average monthly values for determining skin stress environment of a region, with purpose a regionalization bioclimatic.

4. Thermal comfort (with three parameters)

Given the complexity of atmospheric and influence on the human body, researchers have proposed various methods to determine the bioclimatic comfort or stress, formulas or nomograms that include major climatic parameters, particularly temperature, moisture and wind. *Formula Misenard* (cf. Krawczyk, 1975) renders effective temperature equivalent ⁰TEE felt by the human body to specific values of air temperature, humidity and wind speed:

$$TEE = 37 - \frac{37 - t_s}{0,68 + 0,00014f + \frac{1}{1,76 + 1,4v^{0,75}}} - 0,29t_s(1 - f/100)$$

T = air temperature °C

f = relative humidity%

v = wind speed m / s

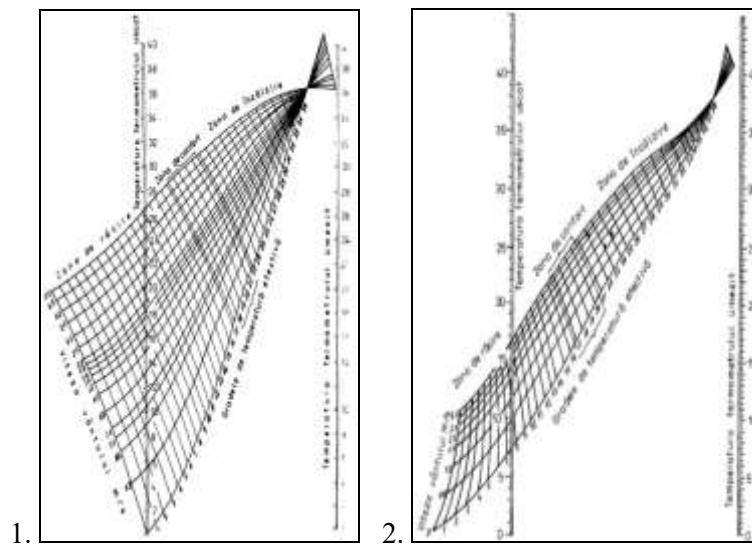


Fig.1 Nomograms Yaglou-Yakovenko for: basic scale (man naked, in the shade, resting) (1) and normal scale (man dressed lightly) (2)

The results can be reported to comfort values on the next diagram where the comfort temperature is between 16.8 and 20.8⁰TEE (after normal scale). Under 16,⁰TEE records discomfort by cooling, over 20.8⁰TEE, uncomfortable heat.

Below are some examples of nomograms used in bioclimatic and aerotherapy and heliotherapy by physicians balneologist.

Such are the two nomograms Yaglou-Yakovenko (1927) (cf. Agostini 2005 and Baibakova et al, 1964). Determinations are with psychrometers, dry and wet thermometer and with anemometer for wind speed. (Fig.1)

Follows nomogram Seifert (1958), (see Teodoreanu, 2002) (Fig.2):

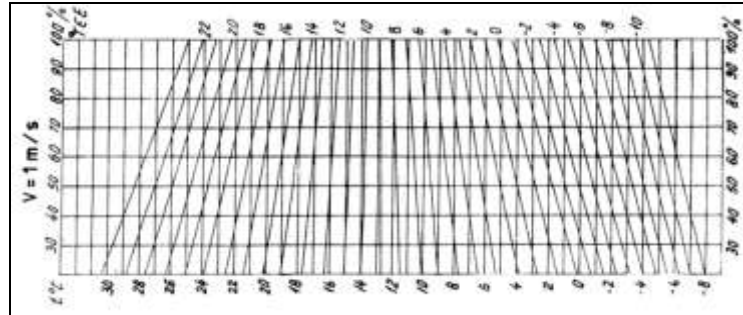


Fig.2. Nomogram Seifert for 1 m/s. They are 10 in number, separately for specific wind speed values 0, 1, 2, 3 ... 9 m / s.

They are useful and nomograms Hentschel (cf. Licht, 1964) and domestic comfort nomogram (Givoni 1978, cf. Hufty, 2005) (Fig.3)

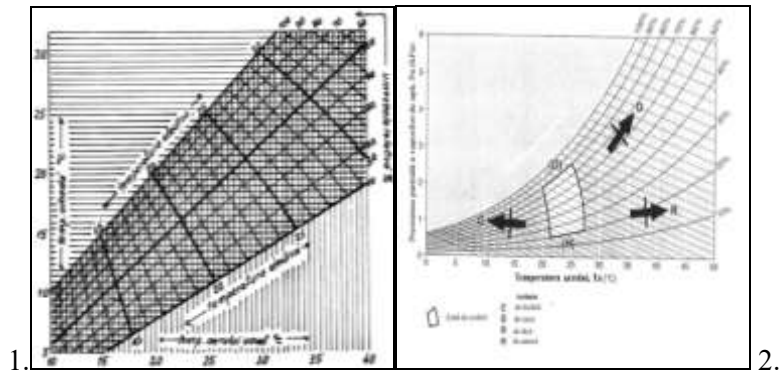


Fig.3. Nomograms Hentschel (1) and domestic comfort nomogram (2)

Tab.1. Thermal comfort 20°TEE for different values of the main climatic parameters

$T^{\circ}\text{C}$ dry thermometer	$T^{\circ}\text{C}$ wet thermometer	U%	V m/s
22	16.5	50	0
23	14.7	40	0
23	17.5	60	0.5
24	13.2	37	0
24	18	56	1
24	24	100	2.5
25	16	38	1
25	18.1	51	1.5
25	20	63	2

In these two nomograms thermal comfort area is marked (as in the diagram Yaglou-Yakovenko), so calculating thermal comfort is graphic.

Here for example the temperature of thermal comfort 20°TEE for different values of the main climatic parameters t , u (wet thermometer and relative humidity) and v (Teodoreanu et al, 1984) (Tab.1).

Further illustrate maps of comfort and discomfort by heating in Romania at the time of maximum heating of year (Teodoreanu, 2011) (Fig. 4)

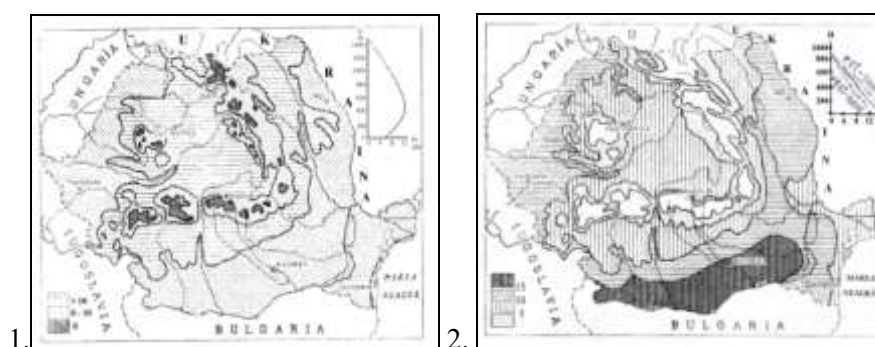


Fig. 4. The mean number of days with thermal comfort (1) and heat discomfort(2), July at 13

It appears that the maximum number of days with thermal comfort of 10- 12 days / month is in the hills between 300 and 700 m altitude. Above, in the mountains, this number decreases due to the low temperature and wind growing stronger; above approximately 1500 m, there is no thermal comfort only in some places exposed to the south and sheltered from the wind. Under this limit, in the lowlands, the number of days of comfort decreases in July, mainly due to high temperatures. The maximum number of days with discomfort in the middle of summer is in Bărăgan Plain, about 15 days per month. This number decreases with altitude up to 900-1000m when heat discomfort practically disappears.

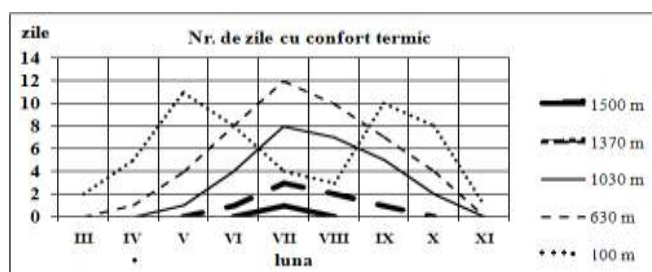


Fig.5. Average number of days with thermal comfort in Romania (Teodoreanu, 2011)

During the year, the mean number of days with thermal comfort varies with altitude in the Carpathian-Danubian region, from 0 (November to March) to 12 days in July at an altitude of about 600 m. In plain recorded two peaks thermal comfort, in May and September, 10-11 days, when air temperatures, moisture and atmospheric dynamics are moderated. (Fig.5)

Japanese researchers have developed a material for a planetary atlas of various human bioclimat based on various bioclimatic indices, with 32 maps to extremes months. (After Gregorczuk, Cena, 1967, in accordance Iwakuma, 1994). They considered 20° TEE = boundary demarcation thermal comfort, moving between 20° latitude N and 30° lat. S in January, to the 40° lat. N and 20° lat. S, in July.

1. Thermal comfort by radiation ($^{\circ}$ TEER)

Şeleihovski nomogram (1948) (cf. Baibakova and all., Teodoreanu, 2002) add to the comfort calculated according t, u, v, and total radiation values.

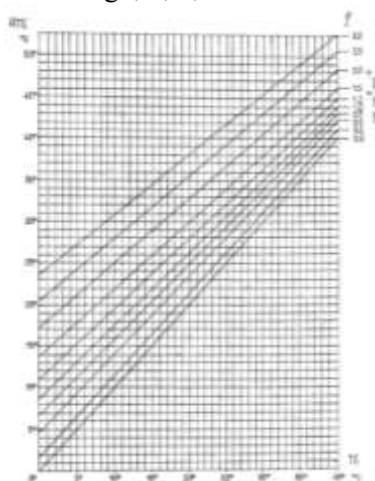


Fig.6. Nomogram thermal comfort in terms of sun exposure

Solar radiation ρ , expressed in $\text{cal} / \text{cm}^2 \text{min}$: $\rho = (1 - \alpha) i$, where

α = albedo skin

i = intensity of the direct radiation on the surface perpendicular to in $\text{cal} / \text{cm}^2 \text{min}$.

For $i = 1$, to the pigmented skin $\alpha = 0.11$ and $\rho = 0.89$,

and to the unpigmented skin $\alpha = 0.28$ and $\rho = 0.72$.

Example discomfort or uncomfortable heat at 22° C, depending on the humidity and wind, unpigmented skin (Tab.2)

Tab.2 Thermal comfort and discomfort (in TEE and TEER) when dry thermometer shows 22°C (c. = comfort, i.c. = discomfort by heat; i.r. = discomfort by cooling)

T°C wet bulb	U%	V m/s	⁰ TEE	⁰ TEER
22	100	0	22 i.c.	28 i.c.
22	100	1	22 i.c.	26.5 i.c.
22	100	2	19 c.	25.8 i.c.
18.5	70	0	20.8 c.	27 i.c.
18.5	70	1	18.5 c.	25.5 i.c.
18.5	70	2	17.2 c.	24.5 i.c.
15.5	50	0	19.5 c.	26 i.c.
15.5	50	1	18 c.	25 i.c.
15.5	50	2	17 c.	24 i.c.
12.5	30	0	19 c.	23 i.c.
12.5	30	1	17 c.	22 i.c.
12.5	30	2	16 i.r.	21 c.

Empirical Correlation: temperature 0C - 0TEE - 0TEER.

It is established after Yaglou-Yakovenko basic scale (Teodoreanu, 1995).

Based on the relationship between the effective temperature in the shade and sun exposure felt they could establish a correlation empirical (under $i = 1$, unpigmented skin, moderate humidity, little wind) formulas are :

$${}^0\text{TEE} \approx t^0\text{C} - 6.4$$

$${}^0\text{TEER} \approx {}^0\text{TEE} + 6.1$$

$${}^0\text{TEER} \approx t^0\text{C} - 0.3$$

To note that the error is higher in wet or very dry air and wind over 2 m/s.

6. Total Index bioclimatic stress (Besancenot, 1974). It is expressed in conventional units following formula: S.T.A. = S.C.A. + S.P.A. (Annual total stress= coetaneous stress + lung stress).

Monthly and annual bioclimatic average values are used for bioclimatic regionalization.

We give below the map Romania bioclimatic established after total values stress. (Fig.7)

From this map bioclimatic shown that stress is dependent on the relief. It is minimal (relaxing) in the hills, at altitudes between 400 and 800 m, where the temperature but also humidity and wind speed are moderate. The plain stress increases, mainly due to high summer temperatures and low winter temperatures, low moisture in summer and active dynamics all year. Doctors have called exciting – seeking this stress. At higher altitude, stress grows due to low temperatures, high humidity and high wind speeds. Stress bioclimatic mountain is called tonic - stimulant. Also there are differences between stress gradients, depending on the prevailing atmospheric circulation. Values are the largest in the eastern and

southern Romania, where is evident continental climate character, from Eastern European winter and warm southern air masses.

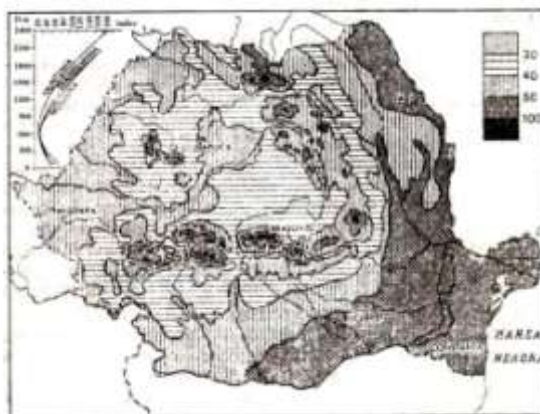


Fig. 7. Average annual total bioclimatic stress in Romania (Teodoreanu et al, 1984)

7. Other indices used for different purposes: tourism, aero-therapy, helio- and hydro-therapy

Air baths are based on ^0TEE (Mikhailov, 1961, cf. Baibakova, 1964). They depend on ^0TEE and on heat loss ($\text{cal} / \text{cm}^2\text{sec}$), and they are cool ... cool, indifferent ... to very hot.

Sun bath are based on $^0\text{TEER}$ (Şeleihovski, 1948, cf. Baibakova, 1964, Teodoreanu, 2002)

Heart rhythm (Escourrou, 1989) using the heart rate, metabolism, $t_0\text{C}$, U (hPa) the formula $\text{RC} = 0,029\text{M} + 22.4 + 1,26\text{T} + 0,53\text{U}$ where:

RC = heart rate (rhythm, the number of heart beats per minute)

M = metabolism (the calories produced by the body at rest, in time unit)

T = air temperature ^0C

U = water vapor tension in hPa

RC = tachycardia > 95 ; bradycardia < 60

It is estimated that the index is indicating exactly when tachycardia.

Heart rate (Sutour, 1995 Teodoreanu 2011) in formula

$\text{Fc} = 0.116 \text{M} + 1,26t_0 + 0,525\text{U} + 22.4$ where:

Fc = heart rate (beats per minute)

t_0 = ^0C temperature

U = water vapor pressure (hPa)

M = metabolism ($\text{kcal} / \text{m}^2 / \text{h}$)

If adopted for M mean value of $150 \text{kcal} / \text{m}^2 / \text{h}$, the formula becomes:

$$Fc = (0.116 \times 150) t^0 + 0.525 + 1.26 + 22.3 U \text{ i.e.}$$

$$Fc = 1.26 t^0 + U + 0.525 \text{ } 39.8$$

Formula was used to seaside resorts in France. In the Nordic resorts, the heart rate is kept

within normal limits. In Mediterranean resorts, there is an acceleration of heart rate, which means a bioclimatic stress for the body tired, elderly or not adapted.

Skin temperature as an index of comfort (Kozłowska-Szczesna, 1985 quoted Twardosz, 1995): temperature ($^{\circ}\text{C}$), forehead skin (T_1), of the chest (T_2), hand (T_3), thigh (T_4), the foot (T_5), after the formula:

$$T_s = 0.07T_1 + 0.50T_2 + 0.05T_3 + 0.18T_4 + 0.20T_5$$

Formula was used to Krakow in June 1993, establishing the relation between thermal sensations and skin temperature T_s from cold to very hot.

Tonicity coefficient Kt (Sutour, 1995), for spas, after the formula:

$$Kt = \frac{I}{\frac{P_{mm}}{P_j} \times \frac{H}{N} \times \frac{V}{B}} \times \frac{T_x - T_n}{1} \text{ where:}$$

I = duration of insolation (h)

T_x and T_n = maximum and minimum temperatures ($^{\circ}\text{C}$)

P_{mm} = rainfall (mm)

P_j = number of days with precipitation

H = relative humidity (%)

N = cloud cover (in eighths of sky covered)

V = average wind speed (m / s)

B = number of days with fog

Classes after the index Kt for establishing tonicity resorts are: the resort sedative, calming resort stimulating, to even exciting

Biomedical aggressive Index (Rivoliier et al, 1967, Gaceu, cf. *** 2003), which takes into account air humidity, amount and duration of rainfall, wind speed and sunshine duration, resulting in a value that indicates if the day is favorable or with aggressively weather

- *Enthalpy or the amount of calorific energy contained in an air mass* (Boer, cf. Hufty, 2005). Thermodynamic enthalpy is a quantity expressed by the internal energy of a substance and the product of pressure and volume. The formula is:

$$i = 1.004 (t_h + 1555 \cdot e_i / P) \text{ where:}$$

i = enthalpy in KJ.kg^{-1}

t_h = wet bulb temperature

e_i = absolute moisture saturation for ambient temperature

P = atmospheric pressure. P and e_i have the same unit: mb, hPa, Pa, mmHg

On this basis, Brazol (1954), Gregorczuk and Cena (1967) conducted a global bioclimatic classification (especially suitable for hot climates) from the suffocating heat, hot, comfortable to ... cool

Climatic and marine attraction index (Sarramea, 1980. Cf. Teodoreanu 2002 Gaceu, cf. *** 2003), after the formula

$I = (T_j + T_m + H_j) - (v_i + B_j + P_j + G_j + N_j)$ where in order:

air temperature, seawater temperature, the number of sunshine hours, number of days with rain. days with strong winds ($> 16 \text{ m / s}$), days with nautical foggy, days with frost, and number of days with snow.

Charts and monthly curves were calculated for 16 French spas.

Tourism climatic index (Claus, Guerault, Fărcaș et al, 1970, cf. Teodoreanu et al, 1984):

$I = (S + T + 5D) / 5$ where:

S = duration of sunshine, hours

T = average monthly temperature (in decimal degrees)

D = duration of rainfall during the day

This reveals the optimal duration of tourist season and cures outdoors especially during the warm season.

Climatic balneary Index ICB (Burnet, 1963, Gaceu, cf.*** 2003) , Sorocovschi, 2008)

$ICB = N / T$ respectively the number of rainy days in the four months of summer season and $t^{\circ}\text{C}$ during that period.

The potential tourism of the region: high, satisfactory, low.

There are still many bioclimatic indices: *Weather summer touristic index* (Davis 1968, cf. Teodoreanu, 2002), *Predicted 4 hours sweat rate index P_4SRI* (Mc ARDL 1947), *Index relative effort RSI*, (Lee and Henschel, 1963), *Fanger's effort equation, predicted mean vote, PMV, Weather classes* (Baibalova et al, 1964, Teodoreanu, 2002), *The equivalent blackbody temperature, T_{eq}* (Campbell, 1977) etc.

Conclusions

The big number of bioclimatic indices show that researchers trying to quantify in a single formula the relationship between climatic stress and the human body. But it is obvious that thermal comfort depends on many factors: geographical and physical parameters, but and the organic individual parameters and also social parameters.

Thermal comfort indices are generally characteristic for the warm season. For the cold season, are inserted besides *wild chill* parameters formula with special units of clothing (in units *Clo*)

Some different indices give complementary results and highlight certain aspects. Such thermal comfort and bioclimatic stress give results that converge in interpretation: when thermal comfort is great, bioclimatic stress is reduced and vice versa. (As shown in the Romania maps of comfort and stress)

This big number of bioclimatic indices show that does not exist a general planetary index for all of these conditions. We cannot establish a general formula, valid for any kind of geographical and weather conditions and thus to satisfy medical requirements for health or tourism.

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