The evaluation of the thermal sensation is often a crucial matter of indoor environments assessment since their quality affects the health safeguarding as well as the productivity of subjects\(^1\). Thermal sensation depends on the subject-environment heat transfer which is strictly related to subjective variables (metabolic rate and clothing thermo-physical properties) and four environmental variables (air temperature, mean radiant temperature, air velocity and relative humidity) according to the following energy balance equation:

\[ M - W - E - E_{\text{res}} - C_{\text{res}} - C - R = S \]  

Equation (1) can be profitably used both in moderate environments, where the main designer goal is reaching thermal comfort conditions, and in severe environments where workers health protection to cold or hot stress is required. Nevertheless using equation (1) does not result in a friendly evaluation of the thermal environment; therefore, the only road to be turned into is making use of a right microclimatic index\(^2\)–\(^5\) usually based on:

- subjective evaluation of climatic conditions by means of investigations in situ;
- grouping the whole of six variables in a single index based on analytical or empirical investiga-
...identification of the combinations of climatic parameters producing the same physiological effect.

These different approaches have leaded to the formulation of several indices (see Table 1) aimed to reach a balanced compromise among a reliable assessment, an easy calculation and a reduced number of measurements (i.e. some indices need only the air temperature and relative humidity values).

Table 1 clearly shows that in Nineties, due to a continuous enhancement of the basic know-how of thermal environment field, a large number of new indices for moderate and severe environments (based also on sophisticated thermoregulation models as UTCI) has been formulated. The presence of a so large number of new indices generates some confusion, especially if we take into account that:

- some indices (often validated only under outdoor conditions) after their issue appear almost ignored by the scientific community in spite of their interesting features;
- International Standard Organisation (ISO) has devoted to the thermal environment assessment field an impressing number of Standards (see Fig. 1). On this point of view, ISO Standard 15265 requires for each environment category (moderate and extreme) the calculation of a special index dispelling any doubt on both evaluation and prevention strategy (see Table 2). In particular:
  a) moderate environments should be treated by means of PMV index (adopted by ASHRAE also in favour to ET* index) according to ISO 7730 Standard;
  b) hot extreme environments should be roughly assessed through the WBGT index, purpose of ISO 7243 Standard. For a more in-depth analysis the PHS (Predicted Heat Strain) approach, based on the equation (1) solved under transient conditions, is required, according to ISO 7933 standard;
  c) cold extreme environments have to be evaluated through the IREQ index, as suggested by ISO 11079 Standard.

Moreover, almost the whole of indices proposed by ISO, on the heat balance equation (1) is based on (apart from WBGT and indices involved in the local discomfort assessment of moderate environments).

In spite of the regulation clearness on both methods and investigation procedures supported by a wide numerical and experimental analyses and by the continuous enhancement of the human thermoregulation modelling, it is anyway necessary to underline that thermal environment assessment does not appear an easy matter. In fact, depending on the index which has to be calculated, more or less complicated algorithms requiring special software as well as the measure-

\begin{table}[h]
\centering
\begin{tabular}{|l|l|l|}
\hline
Cold Environments & Moderate Environments & Hot Environments \\
\hline
IS, Sharlau Index & IS\(^6\), Sharlau Index (1950) & P4SR\(^21\), Predicted 4 h sweat rate (1947) \\
DL, Discomfort Index\(^7\) (1959) & DT\(^7\), Discomfort Index (1959) & IS\(^6\), Sharlau Index (1950) \\
T\(_{eq}\)\(^8\), Equivalent temperature Index (1984) & HD\(^{14, 15}\), Humidex (1965, 1979) & HSI\(^{22}\), Heat Stress Index (1955) \\
IREQ\(^9, 10\), required insulation (1993, 2007) & ET*\(^{16}\) (1971) & DT\(^7\), Discomfort Index (1959) \\
WCI, wind chill index\(^9\) (1993) & T\(_{eq}\)\(^8\), Equivalent temperature Index (1984) & RHS\(^{23}\), Relative Heat Strain (1964) \\
THI\(^{11}\), temperature humidity index (1994) & SSI\(^{17}\), New Summer Simmer Index (1987) & HD\(^{14, 15}\), Humidex (1965,1979) \\
Pt\(^{12}\), Perceived Temperature (1997) & RS\(^{18}\), Relative Strain Index (1992) & Hi\(^{25}\), Heat index (1979) \\
PET\(^{13}\), Physiological Equivalent Temperature (1999) & THI\(^{11}\), temperature humidity index (1994) & SW\(_{req}\)\(^{26}\), Required sweat rate (1989) \\
 & PET\(^{13}\), Physiological Equivalent Temperature (1999) & THI\(^{11}\), temperature humidity index (1994) \\
 & UTCI\(^{30}\) (2009) & PT\(^{12}\), Perceived Temperature (1997) \\
 & & PET\(^{13}\), Physiological Equivalent Temperature (1999) \\
 & & PHS\(^{28}\), Predicted heat strain(*) (2004) \\
 & & ST\(^{29}\) (2005) \\
 & & UTCI\(^{30}\) (2009) \\
\hline
\end{tabular}
\caption{Main comfort and stress indices proposed by thermal environment literature under chronological order}
\end{table}

In bold letters international standardised indices. (*) In place of SW\(_{req}\) index.
The reliability of temperature-humidity indices

The reliability of temperature-humidity indices (THI) is crucial for understanding and predicting thermal comfort. These indices, such as the Humidex, are used to estimate the perceived temperature felt by the human body. The Humidex is based on the human body's thermoregulatory system and is particularly useful in regions with high humidity and variable temperatures.

The Humidex formula is given by:

\[ \text{Humidex} = t_a + \frac{5}{9}(p_m - 10) \]

where \( t_a \) is the air temperature in °C, \( p_m \) is the mean radiant temperature in °C, \( p_m \) is the mean radiant temperature in °C, \( p_m \) is the mean radiant temperature in °C, and RH is the relative humidity (%).

In Table 3, HD limit values are reported.

Although Humidex was at first formulated for weather forecasts, its use has been extended to the assessment of hot thermal stress in indoor and outdoor environments. As a matter of fact, Santee et al. (38, 39) compared the rectal temperature predicted by a heat-balanced-based thermal model in order to find a statistically significant relationship between the heat index values and the predicted temperature range in which, for a naked subject exposed to quiet air, the human body heat balance equation (1) in the absence of the accumulation term is satisfied, is from 27°C to 30°C:

- the human body is unable to get over the heat accumulation when its temperature exceeds a minimum value of 32°C in the presence of a relative humidity value greater than 75%.

According to these hypotheses, Humidex results as an empirical index formulated under particular hypotheses and under particular climatic conditions (Mild Canada areas) and it is intrinsically unable to take into account the radiative heat flow, the metabolic rate, the air velocity and finally the clothing insulation as well as the heat balance equation (1).

HD calculation is based on a Thom’s index modification and it is expressed through the merely empirical equation:

\[ \text{HD} = t_a + \frac{5}{9}(p_m - 10) \]

where

\[ p_m = 6.112 \left( 10^{0.0174 t_a} \right) \frac{RH}{100} \]

Equation (2) results in an index which appears even more easy than WBGT (effective both indoors and outdoors and taking into account the radiative thermal flow), suggested by ACGIH and by ISO also for a first rough hot stress assessment. In Table 3, HD limit values are reported.

Although Humidex was at first formulated for weather forecasts, its use has been extended to the assessment of hot thermal stress in indoor and outdoor environments. As a matter of fact, Santee et al. (38, 39) compared the rectal temperature predicted by a heat-balanced-based thermal model in order to find a statistically significant relationship between the heat index values and the predicted
rectal temperature, finding a good correlation between HD values and the predicted rectal temperature under hot stress conditions. On this point of view, several Italian reports on the unexpected death related to the heat waves of summers 2003 and 2004\(^40\), \(^41\) correlate highest HD values with the danger of death. This custom has been very recently adopted by European Commission all the more because in a special document called “Pan European Assessment of weather driven natural risks” a HD limit value of 35°C for reducing excessive hot risks has been proposed\(^42\). In the recent past the Occupational Health Clinics for Ontario Workers Inc. (OHCOW) created a “Humidex Based Heat Response Plan” (HBHRP) briefly summarized\(^43\) in Table 4, that translated the WBGT limit values into Humidex values and developed recommended responses for each Humidex range. This plan was developed as a tool to help workplaces as most find using the WBGT complicated and expensive. On the other hand the Canadian Centre for Occupational Health and Safety (CCOHS) states\(^44\): « When the humidex rating is in the 40–45°C range, most people would it uncomfortable. However, many kinds of work must be restricted when the humidex is above 45°C ». Moreover Use and Occupancy of Buildings Directive of the Treasury Board of Canada\(^45\) makes use of Humidex as effective parameter for the thermal comfort in office accommodations considering as unsatisfactory a Humidex value, based on indoor microclimatic measurements, beyond 40°C.

Assuming that a strong strain level or even the risk of death under hot conditions in the presence of high temperature and humidity values (incipient heat stroke) is almost a trivial consequence, two questions take place:

- both thermal stress and comfort assessment can be carried out ignoring the physiological response of subject to the thermal environment?
- using a bioclimatic index in conditions different from those in which it has been formulated can lead to a reliable assessment of both outdoor and indoor thermal environment?

In order to answer to these questions this paper deals with a comparison between the thermal environment assessment carried out according to ISO standards and the Humidex index. Analyses through a special software designed according to International Standards of the field has been carried out\(^34\) trying to highlight the presence of any structural lacks due to a so simplified formulation\(^14\), \(^15\), \(^46\).

### Methods

The comparative analysis of the same thermal environment assessment by means of HD and standardised indices/procedures above quoted, in two different ways has been carried out:

1. **by means of an indirect evaluation** (for both comfort and stress situations) aimed to evaluate the “limit situations” corresponding to an assigned value of the mean radiant temperature, the air velocity, the metabolic rate, the clothing insulation and, in case of PHS, the vapour permeability of clothing required for the assessment of the evaporative heat flow at the skin surface\(^28\).

2. **by means of a direct evaluation** (only for comfort situations) of the same thermal environment starting from a reasonable set of microclimatic and subjective parameters;

As a consequence, two special computer programs have been designed:

- the former, for each HD value, returns correspond-
ing \((t_a, \text{RH})\) couples;

- the latter, upgraded in accordance to the regulations in force\(^4\), allows the calculation of \((t_a, \text{RH})\) couples corresponding to:
  a. a required value of PMV according to ISO 7730;
  b. a required value of WBGT according to ISO 7243;
  c. the overall amount of sweat and the final rectal temperature evaluated in accordance with PHS method inspiring ISO 7933 and for eight-hours of continuous work\(^5\). In order to make easy the interpretation of the assessment, temperature-humidity limit values on special psychrometric charts have been reported, allowing the definition of safe working areas\(^6\).

\(^4\)ISO 7933 Standard requires the comparison between the limit values of produced sweat and the rectal temperature and those predicted by PHS model.

\(^5\)Numerical evaluations have been carried out settling, when necessary, some variable. In particular:

- since HD index has been validated under of mild Canada’s summer situations static clothing insulation value at 0.60 clo has been chosen\(^7\).
  Moreover, according to ISO 9920 and ISO 7730, both movements and pumping effect on the clothing insulation have been take into account resulting in dynamic clothing insulation values reported in Table 5;

- metabolic rate values have been chosen in the range corresponding to a light activity according to ISO 8996\(^8\) as reported in Table 6;

- in not uniform environments the mean radiant temperature value at most greater than 10°C with respect to the air temperature has been chosen;

- quiet air, freely drinking acclimatised subjects

### Table 5. Dynamic clothing insulation values as a function of the metabolic rate used for thermal comfort\(^20\) and hot stress\(^20\) assessment

<table>
<thead>
<tr>
<th>Metabolic rate M (met)</th>
<th>Static clothing insulation (I_{cl} ) (clo)</th>
<th>Dynamic clothing insulation (I_{cl,dyt} ) (clo)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ISO 7730</td>
<td>ISO 9920</td>
</tr>
<tr>
<td></td>
<td>ISO 7733</td>
<td>ISO 7933</td>
</tr>
<tr>
<td>1.4</td>
<td>0.60</td>
<td>0.57</td>
</tr>
<tr>
<td>1.8</td>
<td>0.60</td>
<td>0.55</td>
</tr>
<tr>
<td>2.8</td>
<td>0.60</td>
<td>-</td>
</tr>
</tbody>
</table>

\(v_a = 0.10 \text{ m/s.}\)

### Table 6. Metabolic rate values suggested by ISO 8996 as a function of the subject activity\(^46\)

<table>
<thead>
<tr>
<th>Class</th>
<th>Average metabolic rate with range in brackets, (met)</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Resting, sitting at ease.</td>
<td>1.1 (0.95 ÷ 1.2)</td>
</tr>
<tr>
<td>1</td>
<td>Light manual work (writing, typing, drawing, sewing, book-keeping); hand and arm work (small bench tools, inspection, assembly or sorting of light materials); arm and leg work (driving vehicle in normal conditions, operating foot switch or pedal). Standing drilling (small parts); milling machine (small parts); coil winding; small armature winding; machining with low power tools; casual walking (speed up to 2.5 km/h).</td>
<td>1.7 (1.2 ÷ 2.2)</td>
</tr>
<tr>
<td>2</td>
<td>Sustained hand and arm work (hammering in nails, filing); arm and leg work (off-road operation of lorries, tractors or construction equipment); arm and trunk work (work with pneumatic hammer, tractor assembly, plastering, intermittent handling of moderately heavy material, weeding, hoeing, picking fruits or vegetables, pushing or pulling lightweight carts or wheelbarrows, walking at a speed of 2.5 km/h to 5.5 km/h, forging).</td>
<td>2.8 (2.2 ÷ 3.4)</td>
</tr>
<tr>
<td>3</td>
<td>Intense arm and trunk work; carrying heavy material; shovelling; sledgehammer work; sawing; planning or chiselling hard wood; hand mowing; digging; walking at a speed of 5.5 km/h to 7.0 km/h. Pushing or pulling heavily loaded hand carts or wheelbarrows; chipping castings, concrete block laying.</td>
<td>4.0 (3.4 ÷ 4.5)</td>
</tr>
<tr>
<td>4</td>
<td>Very intense activity at fast to maximum pace; working with an axe; intense shovelling or digging; climbing stairs, ramp or ladder; walking quickly with small steps; running; walking at a speed greater than 7.0 km/h.</td>
<td>5.0 (&gt; 4.5)</td>
</tr>
</tbody>
</table>
have been finally assumed in the hot environments assessment.

We need to highlight that this compared assessment in a range of subjective and physical parameters resulting in a Humidex value in the range from 20°C to 55°C has been carried out. As a consequence the assessment of comfort situations dealt with microclimatic situation with PMV values in the range [-0.50 ÷ 0.50], typical of class (B) environments.

Results and Discussion

Hot environments

The Humidex reliability reported for the assessment of hot environments as well as severe hot climatic conditions has been checked by comparing limit curves compatible with eight hours of continuous work obtained according to WBGT index and PHS model. Such analyses for two metabolic rate values typical of a light activity (M=1.4 and 1.8 met) and only one typical value of moderate activity (M=2.8 met) have been carried out (see Table 5).

Curves depicted in Fig. 2A clearly demonstrate that, in uniform environments (t_a=t_r) and for light metabolic rates (M=1.4 met), HD index generally exhibits a restrictive behaviour with respect to both WBGT and PHS. Moreover, concerning ISO and ACGIH layouts, WBGT lim=29°C exhibits a dual behaviour in the 40 ≤ HD ≤ 45 area:

- below t_a=36°C, WBGT limit curve is above HD=40 limit curve: HD index appears more restrictive than WBGT;
- over t_a=36°C, WBGT limit curve is below HD=40 limit curve: WBGT appears more restrictive than HD.

On the contrary, if the evaluation of the working situation is carried out by means of PHS method, actually the thorough method for stress assessment in hot environments, up to t_a=40°C a less restrictive than HD evaluation is revealed; as a matter of fact D_lim,PHS limit curve is always over HD=45 limit one. On the contrary hand, over 40°C, PHS assessment becomes more restrictive than HD so that PHS limit curve falls in the 40 ≤ HD ≤ 45 area: as a consequence a microclimatic situation judged as certainly dangerous by PHS method, is ambiguously interpreted by Humidex as only greatly uncomfortable. It is noteworthy highlighting that, according to our previous results in this range the different slope of the limit curve is related to the different protection criterion.

Depending on the acclimatisation and according to ISO 7933), whereas at lower temperature (and high humidity) the ineffectiveness of thermoregulation by perspiration avoids the body cooling with the consequent overcoming of maximum allowable value of the rectal temperature (38°C) due to the highest heat accumulation.

These results appear just a little bit surprising especially taking into account Humidex Based Heat Response Plan. As a matter of fact the HD=37 limit curve depicted in Fig. 2A, corresponding to the maximum index value consistent to a continuous working situation (see Table 4) is always below WBGT_lim=29°C limit curve; therefore the whole microclimatic situations between WBGT_lim=29°C and HD=37 (or HD=39) curves would be assessed as dangerous on the base of HD approach.

The singular behaviour of HD index with respect to WBGT and PHS methods highlighted in uniform environments, has been also verified in environments characterised by t_a ≠ t_r (i.e. in sheet metal factories, hot forming, engine rooms, mines or in the presence of radiation or outdoor situations). According to data reported in Fig. 2B, in each microclimatic condition the WBGT_lim=29°C curve is always below both HD=37
and HD=39 curves. Therefore, even in the presence of so low metabolic rate (M=1.4 met), Humidex index results in an evaluation even less restrictive than WBGT, which, according to ISO 7243, appears an useful index only for a rough assessment. As a consequence, a dangerous microclimatic condition is misinterpreted by HD as only uncomfortable.

A similar behaviour occurs also when the environment assessment is carried out by means of PHS rational method: in fact at above 34°C, PHS 8-h limit curve falls in the 30 ≤ HD ≤ 39 area. This means that microclimatic conditions over 34°C and at low humidity are considered only as slightly uncomfortable (or not so dangerous on the base of above quoted HBHRP) whereas on the base of PHS approach, are inconsistent with 8 h of continuous work due to the overcoming of the maximum allowable dehydration.

Data reported in Fig. 3A show that a light increase of the metabolic rate (from 1.4 to 1.8 met), consistent with a light activity yet, results in the shifting downward of 8-h limit curve provided by PHS (WBGT limit value is always 29°C for M=1.8 met). This occurrence on one hand makes WBGT more strict than PHS in the temperature range 32 ÷ 38°C, and on the other one returns a very ambiguous assessment of the working situation through HD, especially under not-uniform situations (Fig. 3B) where both WBGT and PHS limit curves fall down in microclimatic conditions assessed by Humidex as only slightly uncomfortable.

Figure 4 finally reports the hot stress assessment results in typical conditions for a medium metabolic activity (M=2.8 met), t_r= t_a (Fig. 4A) and t_r ≠ t_a (Fig. 4B). These graphic data further demonstrate the full disagreement between assessment criteria suggested by the existing regulations and Humidex index. In these particular conditions it is possible find microclimatic conditions evaluated comfortable by HD whereas they could be practically lethal if assessed by means of both WBGT and PHS.

**Moderate indoor environments**

In order to compare the assessment of a moderate indoor environment by means of PMV and HD index, in Table 7 both PMV and HD values for an uniform environment (t_r= t_a) under typical summer clothing situations and for two light activity metabolic rates are reported.

Table 7 data analysis seem to lead to contrasting
results:

- PMV and HD appear in good agreement only in a narrow range of temperatures: 22.5°C ÷ 25.5°C for M=1.4 met and 20.0°C ÷ 24.0°C for M=1.8 met; moreover, if comfort temperature range predicted by HD is 6.0°C, PMV shows a reduced comfort temperature range: 3.0°C (4.0°C) at 1.4 met (1.8 met);
- the agreement in the thermal comfort assessment is obtained at higher temperature values (at 1.4 met) while at lower temperature, PMV appears more restrictive than HD;
- an improved agreement at lower temperature is possible only by increasing the metabolic activity, but this occurrence results in the shifting of the maximum comfort temperature to lower values (from 25.5°C at 1.4 met to 24.0°C at 1.8 met).

These results clearly demonstrate the inability of HD index in a reliable assessment of comfort situations at lower temperatures, probably due to its formulation under mild hot climatic outdoor conditions.

A more in-depth comparative analysis of the same environment, also taking into account the combined effect of the air temperature, the mean radiant temperature and the humidity, has been carried out. Results on special psychrometric charts, provided with upper and lower comfort curves in accordance with PMV and HD, in Figs. 5 and 6 are reported. Before showing these results we like to highlight that under typical indoor environment situations, the comparative analysis in the humidity ratio range 30 ÷ 70% has been discussed. The reasons of this choice are easy: below humidity level of 30% mucous membranes start to dry up with the consequent reduction of the body defences towards germs and bacteria; on the other hand over 70% become to be important the allergenic factors and the superficial condensate formation responsible for moulds making worse the indoor air quality.

As clearly shown in Fig. 5A, corresponding to typical summer office conditions (M=1.4 met, Icl=0.60 clo), Humidex index appears unable in a reliable assessment of thermal comfort in every microclimatic condition. As a matter of fact, the comparison between comfort curves required for the B-class by ISO 7730 (PMV= ±0.50) and those required by Humidex (HD=20 and HD=29) results in a perfect agreement only in filled areas.

On the contrary, outside filled areas, that is in more “cool-humid” and in “warm-dry” conditions, microclimates judged as comfortable by HD, appear absolutely uncomfortable on the base of the PMV index. Moreover, Fig. 5A curves highlight a dual behaviour:
below 22.5°C and for RH ≥ 30% HD provides a less prescriptive assessment whereas, over 23.5°C and for RH ≥ 50%, the opposite occurrence has been revealed. This phenomenon is not surprising if we take into account that, unlike PMV, Humidex index exhibits a high sensitivity with respect to relative humidity. Anyway, inconsistencies in comfort assessment outside typical PMV comfort areas, require a more in-depth assessment of the work situation in order to avoid the onset of stress microclimatic conditions (i.e. |PMV| > 1.0) which by means of special cold or heat stress indices have to be investigated.

As far as a little increase of the metabolic rate effect is concerned, data reported in Fig. 5B more clearly show an improved agreement with PMV at lower temperature, while at higher temperature a significant discrepancy has been observed. This occurrence appears just a little surprising since only a slight increasing of the metabolic rate in the light activity range results in a different evaluation of the same thermal environment. On the other hand a metabolic rate value of 1.8 met is typical of several indoor situations, as laboratory assistants, teachers and secretaries, respectively.

In order to highlight the different contributions of radiative and convective “subject-environment” heat transfer phenomena on the thermal environment assessment, two radiant temperature values have been investigated: $t_r = t_a + 3.0°C$ and $t_r = t_a + 5.0°C$ very likely situations in the presence of windows. Iso-PMV curves shown in Fig. 6 deal with the effect of the difference between the air temperature and the mean radiant temperature ($t_a$ ≠ $t_r$). The width of filled areas depicted in Fig. 5 clearly highlight that the increase of ($t_r - t_a$) difference results in a progressive worsening of the agreement between PMV and HD revealed in uniform environments (see Fig. 5). Such occurrence is the trivial consequence of the HD formulation: Humidex index takes into account only two (relative humidity and air temperature) out of four environmental parameters affecting the equation (1) ignoring both air velocity and mean radiant temperature as well as subjective parameters.

**Conclusions**

The comparative assessment of the thermal environment carried out in accordance with the International Standard in force and Humidex has shown a substantial disagreement between the two approaches both for the hot stress (indoor and outdoor) and comfort (indoor) assessment. Particularly, concerning the assessment of hot extreme environments, obtained results have highlighted that the simplified HD formulation results in an ambiguous assessment of the working situation, or, what is worse, in underestimating the workplace dangerousness especially for light metabolic rates and in dry conditions. Concerning moderate environments, Humidex provides a good estimation of thermal comfort only in a narrow range of thermohygrometric conditions (i.e. higher temperature and summer conditions or lower temperature and winter conditions) and at lowest metabolic activity since it is unable to take into account the clothing insulation effect, the metabolic activity changes and the presence of temperature non-uniformities.

Therefore bioclimatic indices like Humidex, although very easy to be interpreted, can be used only by media to give more useful information about kind of clothing to choose before going out, particularly the clothing most likely to provide thermal comfort or avoid a excessive hot sensation. In other situations (thermal comfort in buildings or thermal stress induced by the combination between the microclimate and the particular work activity) their use should be strongly restricted, since they loudly fail when used out of their narrow validation range as well as they do not take into...
account the physiological response of the subject to the thermal environment. On this point of view rational methods suggested by ISO Standards (PHS, PMV) offer a more reliable assessment although a special software is always required. In a further paper the compared analyses here discussed will deal with more promising indices as UTCI, based on a rational approach and validated in a widest range of microclimatic conditions.

**Symbols**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>W/m²</td>
<td>Convective heat flow</td>
</tr>
<tr>
<td>C_res</td>
<td>W/m²</td>
<td>Respiratory convective heat flow</td>
</tr>
<tr>
<td>DI</td>
<td>°C</td>
<td>Thom Index</td>
</tr>
<tr>
<td>E</td>
<td>W/m²</td>
<td>Evaporative heat flow at the skin</td>
</tr>
<tr>
<td>E_res</td>
<td>W/m²</td>
<td>Respiratory evaporative heat flow</td>
</tr>
<tr>
<td>ET*</td>
<td>°C</td>
<td>New effective temperature</td>
</tr>
<tr>
<td>Dlim,PHS</td>
<td>min</td>
<td>Duration limited exposure according to PHS approach</td>
</tr>
<tr>
<td>HD</td>
<td>°C</td>
<td>Humidex index</td>
</tr>
<tr>
<td>I_cl</td>
<td>m²K/W, clo</td>
<td>Clothing insulation</td>
</tr>
<tr>
<td>I_cl,dyn</td>
<td>m²K/W, clo</td>
<td>Dynamic clothing insulation</td>
</tr>
<tr>
<td>IREQ</td>
<td>m²K/W, clo</td>
<td>Required clothing insulation</td>
</tr>
<tr>
<td>M</td>
<td>W/m², met</td>
<td>Metabolic rate</td>
</tr>
<tr>
<td>PHS</td>
<td>-</td>
<td>Predicted Heat Strain</td>
</tr>
<tr>
<td>p_s</td>
<td>hPa</td>
<td>Saturated water vapour pressure</td>
</tr>
<tr>
<td>PMV</td>
<td>-</td>
<td>Predicted Mean Vote</td>
</tr>
<tr>
<td>R</td>
<td>W/m²</td>
<td>Radiative heat flow</td>
</tr>
<tr>
<td>RH</td>
<td>%</td>
<td>Relative humidity</td>
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<tr>
<td>S</td>
<td>W/m²</td>
<td>Body heat storage rate</td>
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<td>Air temperature</td>
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<td>°C</td>
<td>Operative temperature</td>
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<td>°C</td>
<td>Rectal temperature</td>
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<tr>
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<td>°C</td>
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<td>m/s</td>
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<tr>
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<td>W/m²</td>
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<tr>
<td>w_a</td>
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<td>Humidity ratio</td>
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<td>WBGT</td>
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<tr>
<td>WBGTlim</td>
<td>°C</td>
<td>Limit wet-bulb globe temperature</td>
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**References**

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