Outdoor thermal condition and people’s exposure time - A case study of cold climate

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Abstract

Outdoor thermal condition is one of the important factors for people’s exposure time. This article is the results of a field study had been done in the mid winter 2010 – 2011 in Sheffield, UK. The aim is to find out the relationship between climatic condition, architectural design and peoples behavior. Two outdoor thermal indices that are appropriate for cold condition are used to explain the cold stress situation. To have the related information, the weather data is collected by a mobile Kestrel weather station that is designed for outdoor events. At the same time the people’s behavior is observed according to different activities. Special attention is performed to disables, children and elders that are more sensitive to thermal condition. The results show that outdoor thermal indices such as UTCI (universal thermal climate index), WCET (wind chill equivalent temperature) and THI (Temperature Humidity Index) have not the same explanation for the same cold stress conditions. Other result is that people’s outdoor exposure time is related to outdoor thermal situation but some psychological adaptation factors such as expectation and exciting condition will cause them to come out in spite of bad thermal situation. Architectural design will play an important role to modify thermal condition.

Keywords: outdoor thermal condition, thermal index, exposure time, psychological adaptation.

Introduction

Outdoor events in cold climates are completely related to thermal condition. Providing tolerable thermal condition is one of architects’ responsibilities in design procedure. Outdoor thermal indices are introduced to help architects making appropriate decisions in design procedure. This article is trying to examine the accuracy of two main indices for cold stress condition that are Universal Temperature Climate Index (UTCI), Wind Chill Equivalent Temperature (WCET) and Temperature humidity index (THI) by field study. Micro analysis of people’s behavior in outdoor spaces is used to find out the relation
between thermal condition and other personal factors that may affect people’s behavior in cold conditions.

1- Research history

To help architects and designers for better decision making in design procedure, some thermal indices are provided for thermal prediction according to climatic condition. The first group of thermal outdoor indices is based on thermal stress model. Cold stress indices such as Wind chill Index (WCI) and Wind Chill Equivalent Temperature (WCET) are prepared for cold conditions. The second group of thermal outdoor indices are prepared base on heat budget model. They are capable to evaluate both cold and hot conditions such as Perceived Temperature (PT), Temperature Humidity Index (THI), and Universal Thermal Climate Index (UTCI).

1-1. Wind Chill Equivalent Temperature (WCET)

The wind chill equivalent temperature (also called the wind chill index, the wind chill factor, or just plain wind chill), is the temperature required under no-wind conditions that will equal the cooling effect of the air (the actual air temperature) and the wind on an average size, nude person in the shade. Moisture content of the air, visible moisture on the skin or clothing, presence of sunshine, clothing, and physical activity are not considered (Osczevski & Bluestein, 2005; Aerographer/Meteorology, 2008).

NOAA, National Weather Service of USA website has provided an online calculator for new wind chill index (NOAA, 2013 December) (Equation 1)

New Wind chill Index = 13.12 + 0.6215 T - 11.37 (V^{0.16}) + 0.365 T (V^{0.16})  \tag{Equation 1}

Where $V =$ wind speed (km/h) and $T =$ temperature (Celsius). Winds need to be above 4.8 km/hr and below 177 km/hr. Temperatures need be to above -50°C and below 10°C.

The wind chill index does not take into account the effect of sunshine. Bright sunshine may reduce the effect of wind chill (make it feel warmer) by 6 to 10 units. Bright sunshine can make you feel as much as ten degrees warmer (Shitzer, 2007). Online calculation for WCET is done according to different wind speeds (Tahbaz, 2011). The hazardous WCET (-25°C and -35°C) is calculated for important limits of wind speed such as 1.4 m/s and 5 m/s (10 m/s gust), that are the lowest and highest acceptable wind speed in urban spaces respectively (Table 1).
**Table 1. Air temperature calculation for WCET thermal zones (Tahbaz, 2011)**

<table>
<thead>
<tr>
<th>WCET</th>
<th>Thermal sensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10 to 0</td>
<td>low cold stress</td>
</tr>
<tr>
<td>-25 to -10</td>
<td>moderate cold stress</td>
</tr>
<tr>
<td>-35 to -25</td>
<td>heavy cold stress</td>
</tr>
<tr>
<td>Less than -35</td>
<td>extreme cold stress</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>air temp C</th>
<th>wind speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>38</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WCET</th>
<th>wind speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>wind speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>-10</td>
<td>-7</td>
</tr>
<tr>
<td>-4</td>
<td>-2</td>
</tr>
<tr>
<td>-25</td>
<td>-21</td>
</tr>
<tr>
<td>-16</td>
<td>-13.5</td>
</tr>
<tr>
<td>-35</td>
<td>-29.5</td>
</tr>
<tr>
<td>-24</td>
<td>-21</td>
</tr>
</tbody>
</table>

1-2. **Universal Thermal Climate Index (UTCI)**

Some of outdoor indices are prepared base on heat budget model. They are capable to evaluate both cold and hot conditions such. The Universal Thermal Climate Index (UTCI)\(^1\) is one of these indices that provide an assessment of outdoor thermal environment in bio-meteorological applications based on the equivalence of the dynamic physiological response predicted by a model of human thermoregulation, which was coupled with a state-of-the-art clothing model (Bröde, et al., 2010). The purpose of the Universal Thermal Climate Index (UTCI) is to inform the public of how the weather feels, taking into account factors such as wind, radiation and humidity. In order to help the general public to relate directly to the UCTI, it is proposed that this index should be on the temperature scale (e.g. in degrees Celsius) (Richards & Havenith, 2007; COSTAction730, n.d.). The operational procedure, which is available as software from the UTCI website (Wojtach, 2014), showed plausible responses to the influence of humidity and heat radiation in the heat, as well as to wind speed in the cold and was in good agreement with the assessment of ergonomics standards concerned with the thermal environment.

UTCI will be calculated online at [http://www.utci.org/utcineu/utcineu.php](http://www.utci.org/utcineu/utcineu.php) (Wojtach, 2014). It takes into account all climatic factors: air temperature (-40°C < \(T_a\) < +45°C), mean radiant temperature (-10K < \(T_{mrt}\) - \(T_a\) < +40K), relative humidity (5% < rh < 95%),

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\(^1\) - The UTCI is the completion of another index called Perceived Temperature (PT). The perceived temperature PT in the dimension °C is the air temperature of a reference environment in which the perception of heat and/or cold would be the same as under the actual conditions (Staiger, et al., 1997; Jendritzky, et al., 2000). In the reference environment the wind velocity is reduced to a slight draught, and the mean radiant temperature is equal to the air temperature (for example, an extensive forest). The water vapor pressure is identical with the actual environment as far as it is not reduced by condensation (Jendritzky, 2002). Perceived heat and cold is computed by means of the comfort equation by Fanger (1970) which is based on a complete heat budget model of the human body (Fanger, 1970).
wind speed \((1.1 < V_r < 17.6 \text{ m/s})\) and human factor of cloth insulation \((0.4 < \text{clo} < 2.6)\) and activity of walking \(4 \text{ km/h (2.3 MET or 135 W/m}^2\) (Jendritzky, 2004).

Table 2 shows the thermal zone categories of UTCI. Using the formula of UTCI and above categories the main thermal zones for outdoor spaces is drawn on psychrometric chart (Fig 2).

<table>
<thead>
<tr>
<th>UTCI C°</th>
<th>Thermal category</th>
</tr>
</thead>
<tbody>
<tr>
<td>bellow – 40</td>
<td>Extreme cold stress</td>
</tr>
<tr>
<td>– 40 to – 27</td>
<td>Very strong cold stress</td>
</tr>
<tr>
<td>– 27 to –13</td>
<td>Strong cold stress</td>
</tr>
<tr>
<td>– 13 to 0</td>
<td>Moderate cold stress</td>
</tr>
<tr>
<td>0 to + 9</td>
<td>Slight cold stress</td>
</tr>
<tr>
<td>+ 9 to +26</td>
<td>No thermal stress</td>
</tr>
<tr>
<td>+ 26 to + 32</td>
<td>Moderate heat stress</td>
</tr>
<tr>
<td>+ 32 to + 38</td>
<td>Strong heat stress</td>
</tr>
<tr>
<td>+ 38 to + 46</td>
<td>Very strong heat stress</td>
</tr>
<tr>
<td>above + 46</td>
<td>Extreme heat stress</td>
</tr>
</tbody>
</table>

1-3. Temperature Humidity Index (THI)

Temperature Humidity index (THI) is another index that takes into account wet and dry bulb temperature. It was developed by Thom 1959 and can be applied to locations that are both shaded and protected from the wind (Thom, 1959; Yilmaz, et al., 2007). Although THI is used originally to determine the discomfort due to heat stress, it has been extended over a wider range of conditions that refers to cold stress. The optimum of THI occurs between 15°C and 20°C, and that is the basis for defining comfortable conditions. Below a THI of 15°C, evaporation takes away heat from the body thus requiring defense against cooling and increasing thermogenic mechanisms are required to combat increasing cold stress. The THI is secured by a simple linear adjustment applied to the average of the simultaneous dry-bulb and wet-bulb temperature (Unger, 1999). The equation 2 for THI using air temperature \(t\) and humidity \(f\) is: [39]

\[
\text{THI (°C)} = t-(0.55-0.0055f)(t-14.5)  \tag{Equation 2}
\]

Where \(t\) = air temperature measured in degrees Celsius and \(f\) = the relative humidity (Unger, 1999). The thermal categories of the THI are defined as table 3.
Table 3. THI thermal categories (Kyle, 1994)

<table>
<thead>
<tr>
<th>THI °C</th>
<th>Thermal category</th>
</tr>
</thead>
<tbody>
<tr>
<td>below – 40</td>
<td>Hyperglacial</td>
</tr>
<tr>
<td>– 39.9 to – 20</td>
<td>Glacial</td>
</tr>
<tr>
<td>– 19.9 to – 10</td>
<td>Extremely cold</td>
</tr>
<tr>
<td>– 9.9 to – 1.8</td>
<td>Very cold</td>
</tr>
<tr>
<td>– 1.7 to + 12.9</td>
<td>Cold</td>
</tr>
<tr>
<td>+ 13 to +14.9</td>
<td>Cool</td>
</tr>
<tr>
<td>+ 15 to + 19.9</td>
<td>Comfortable</td>
</tr>
<tr>
<td>+ 20 to + 26.4</td>
<td>Hot</td>
</tr>
<tr>
<td>+ 26.5 to + 29.9</td>
<td>Very hot</td>
</tr>
<tr>
<td>above + 30</td>
<td>Torrid</td>
</tr>
</tbody>
</table>

2- Research Method

To be able to work with these indices and have a comparison opportunity, the thermal zones in Table 1, 2 and 3 are converted on psychrometric chart. Using these psychrometric charts, the collected microclimate data of the field study in the cold city of Sheffield in UK could be interpreted related to outdoor thermal condition.

2-1. Humidity, Air Movement and Sunshine Effect in cold Condition

In cold conditions air movement has a great effect on thermal sensation. By increasing the air speed in temperatures less than 5°C the chill wind effect happens and lowers the effective temperature\(^2\). If clothing were to get wet, the cooling effect would be greater than that predicted by WCET model and the chance of hypothermia would be greater. Fig 1 shows that by increasing the air speed from 1.4m/s to 5 m/s (10 m/s gust), the thermal zone will lower one level.

Sunshine, even in a cold winter day, can make a difference in the thermal sensation. Bright sunshine can make person feels as 6-10°C warmer as advised in the "new" wind chill chart (NWS USA, 2001; Environment-Canada, 2001). The effect of sunshine is much more pronounced at low wind speeds and gradually diminishes as wind speed intensifies and its effects become dominant (Shitzer, 2007).

In wet, windy conditions, someone wearing inadequate clothing can become hypothermic in quite mild temperatures (Heat-Stress, 2008). Activity is an important factor in such conditions. This can be very important because when there is high clothing insulation the range of metabolic rates which are within the band between sweating and shivering is reduced so there is a danger of sweating and creating thermal bridges in the clothing.

\(^2\) - Effective temperature is a comfort index or scale that takes into account the temperature of air, its moisture content, and movement (Medical Dictionary, 2002).
Unfortunately none of the indices related to cold conditions, did study the relation between high activity levels and clothing. Fig 1, 2, 3 and 4 shows cold stress thermal zones of WCET (Wind Chill Equivalent Temperature), UTCI (Universal Thermal Climate Index), THI (Temperature Humidity Index) and PT (Perceived Temperature)\(^3\) respectively.

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Figure 1. WCET Index - Effect of wind speed on thermal zones on psychrometric chat in low temperatures (Tahbaz, 2011)

Figure 2. UTCI - Thermal zones on psychrometric chart in cold condition (Tahbaz, 2011)

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\(^3\) - Although perceived temperature is no longer in use, here it is compared with other indices in cold condition to show its differences.
2-2- The Method of the Field data collection

Microclimate field data are collected in the critical cold condition of the year (midwinter), in populous pedestrian walkways in the city center of Sheffield. The important places in the way such as outdoor coffee shops or restaurants, public building entrance or plaza, passages and walkways are chosen as the point of data collection.
The field data are collected by a mobile Kestrel personal weather station data logger WS-4500 (Fig 5) that is able to collect the data of several meteorological elements such as temperature, humidity, wind speed, biometric pressure, altitude and an internal compass to indicate magnetic north of the observed location4. The range and accuracy of the data elements are shown in the right side of Fig 5. This instrument is capable to be used for weather monitoring for mountaineering or other outdoor events that climatic conditions play a major role (Kestrel-catalog).

One Kestrel is fixed in a place collects data each 30 minutes as a reference point to represent the local climate. Another Kestrel is moving in the path of observation collects data each 30 seconds to show the microclimate changes in different outdoor places. Using outdoor thermal indices to interpret these data, the thermal condition of observed places are defined on psychometric chart provided for each index (Fig 1, 2, 3 and 4). Sikron software (Tahbaz & Amini Behbahani, 2011) is used to accelerate the process of data transfer to psychometric chart.

![Figure 5. Kestrel portable weather station data logger WS-4500 (Kestrel-catalog)](image)

People’s behaviour in different thermal condition, is recorded by taking appropriate photos. Special attention is paid to the children, elderly and disables as the most sensitive people to thermal condition. Behavior is identified by clothes, activities, foods and length of exposure time in each condition. Comparison between people’s behavior and thermal condition predicted by outdoor indices will help to determine two subjects. One is the definition of thermal cold stress according to people outdoor behavior, second is the validity of each index to define the thermal condition.

To control the intervening factors affecting the observation method, the collected data of moving Kestrel weather station as the microclimate representative, is compared with three other climate data in three levels: 1- the meteorology data of the city in a long term period as the representative of the meso-climate, 2- the meteorology data of the observation days as the representative of the city climate, 3- the collected data of the reference point (the fixed Kestrel weather station) as the representative of the local climate. Comparing the long term meteorology data with the weather data of the chosen days will show the condition of the observation days as ordinary, cold or hot days. Comparing the weather data of the observation days (city short term climate) with the

4 - The accuracy of each of its primary measurements was individually calibrated and tested against standards traceable to the National Institute of standards and Technology (NIST) or calibrated intermediary standards (Certificate of Conformity).
data of reference point will show the changes of the local climate according to the urban construction. Comparing the data of the reference point with the data of the observation points (moving Kestrel weather station) will show the microclimate changes according to the architectural design of the outdoor public spaces.

Constructed condition of the observed palaces is considered as the modifier of the local and microclimate situation by providing appropriate sunshade or sunlit place, leeward or windward place. These conditions will show the thermal modification ability of the architectural design.

3- Field study

To have a wide knowledge of climate condition of the case study city a brief explanation of its climatic condition is provided.

Sheffield in United Kingdom is located at 53°23′N 1°28′W. It is a geographically diverse city nestles in a natural amphitheatre created by several hills and the confluence of five rivers. The city's lowest point is just 29 meters above sea level near Blackburn Meadows, while some parts of the city are at over 500 meters. However, 79% of the housing in the city is between 100 and 200 meters above sea level. The climate in Sheffield is generally temperate. The Pennines range of mountains and hills to the west of the city can create a cool, gloomy and wet environment, but they also provide shelter from the prevailing westerly winds, casting a "rain shadow" across the area. Between 1971 and 2000 Sheffield averaged 824.7 millimeters of rain per year; December was the wettest month with 91.9 millimeters and July the driest with 51.0 millimeters. July was also the hottest month, with an average maximum temperature of 20.8°C. The average minimum temperature in January and February was 1.6°C. Since 1960, the temperature has never fallen below −9.2°C (wiki/Sheffield, 2014). Table 3 shows the conventional climatic condition of the city in long term period from 1981-2010.

Table 4. Sheffield long term climate data (MetOffice, 1981-2010; wiki/Sheffield, 2014)

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Record high °C (°F)</td>
<td>(13.9)</td>
<td>(17.6)</td>
<td>(23.3)</td>
<td>(23.9)</td>
<td>(24.8)</td>
<td>(27.6)</td>
<td>(29.9)</td>
<td>(32.1)</td>
<td>(35.4)</td>
<td>(37.4)</td>
<td>(39.9)</td>
<td>(42.2)</td>
<td>(86.2)</td>
</tr>
<tr>
<td>Average high °C (°F)</td>
<td>(6.6)</td>
<td>(7.1)</td>
<td>(7.9)</td>
<td>(8.8)</td>
<td>(12.5)</td>
<td>(16.1)</td>
<td>(18.8)</td>
<td>(21.1)</td>
<td>(23.4)</td>
<td>(26.0)</td>
<td>(27.7)</td>
<td>(29.3)</td>
<td>(80.6)</td>
</tr>
<tr>
<td>Average low °C (°F)</td>
<td>(1.9)</td>
<td>(1.7)</td>
<td>(3.3)</td>
<td>(4.8)</td>
<td>(7.5)</td>
<td>(10.5)</td>
<td>(12.7)</td>
<td>(12.4)</td>
<td>(10.3)</td>
<td>(7.5)</td>
<td>(4.5)</td>
<td>(2.3)</td>
<td>(43.9)</td>
</tr>
<tr>
<td>Record low °C (°F)</td>
<td>(−9.2)</td>
<td>(−8.3)</td>
<td>(−6.5)</td>
<td>(−3.9)</td>
<td>(−0.7)</td>
<td>(1.4)</td>
<td>(3.9)</td>
<td>(4.2)</td>
<td>(1.9)</td>
<td>(−4.1)</td>
<td>(−6.2)</td>
<td>(−9.2)</td>
<td>(15.4)</td>
</tr>
<tr>
<td>Precipitation mm (inches)</td>
<td>(63.4)</td>
<td>(60.4)</td>
<td>(63.4)</td>
<td>(65.5)</td>
<td>(63.8)</td>
<td>(75.6)</td>
<td>(56.0)</td>
<td>(63.3)</td>
<td>(63.8)</td>
<td>(81.2)</td>
<td>(79.4)</td>
<td>(86.7)</td>
<td>(32.8)</td>
</tr>
<tr>
<td>Avg. rainy days (1.0 mm)</td>
<td>(13.4)</td>
<td>(16.6)</td>
<td>(12.2)</td>
<td>(10.3)</td>
<td>(9.6)</td>
<td>(9.1)</td>
<td>(9.9)</td>
<td>(9.9)</td>
<td>(12.7)</td>
<td>(12.8)</td>
<td>(13.8)</td>
<td>(13.0)</td>
<td>(131.6)</td>
</tr>
<tr>
<td>Mean monthly sunshine hours</td>
<td>462</td>
<td>468</td>
<td>111.9</td>
<td>120.0</td>
<td>179.5</td>
<td>199.5</td>
<td>165.0</td>
<td>106.2</td>
<td>90.7</td>
<td>53.7</td>
<td>40.0</td>
<td>1,444.9</td>
<td></td>
</tr>
</tbody>
</table>

3-1- Meso and local climate in the days of observation

To show the thermal situation of the city according to outdoor thermal indices, the psychrometric charts of outdoor indices are generated by SIKRON software (Tahbaz &
Amini Behbahani, 2011) and Weather Data of Sheffield available at EnergyPlus website (EnergyPlus, 2014) is drawn as pschrometric and table calendar climatic needs.

SIKRON software helps to show thermal condition on each index according to main heat or cold stress zones. Rainbow colors are chosen to show ocular outdoor thermal condition. Red colors refer to “extreme” and “very strong” heat stress\(^5\) that may cause “heat stroke”\(^6\). Orange and yellow colors refer to “strong” and “moderate” heat stress that may cause “heat exhaustion”\(^7\). Green colors refer to “no thermal stress”. It means that long term exposure\(^8\) in outdoor is tolerable or pleasant. Light blue colors refer to “slight” cold stress\(^9\) that will feel cool. Dark blue, light and dark purple colors refer to “moderate cold stress”, “strong”, “very strong” and “extreme cold stress” that may cause “hypothermia”\(^10\) and “frostbite”\(^11\). Thermal conditions are distinguished visually and easily by using these colors. Fig 6 shows the charts’ legend. Fig 7 shows the long term hourly climate condition of Sheffield on UTCI index.

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5. Heat stress: The physiological strain caused by an increase in core body temperature above safe levels where the individual is at risk of overheating (CasellaCel, 2014).

6. Heat stroke - Defined by a body temperature of greater than 40.6 °C (105.1 °F) due to environmental heat exposure with lack of thermoregulation. Symptoms include dry skin, rapid, strong pulse and dizziness (OSHA, 2008; Heat_stroke, 2014).

7. Heat exhaustion - Can be a precursor of heatstroke; the symptoms include heavy sweating, rapid breathing and a fast, weak pulse (OSHA, 2008; Heat_illness, 2014).

8. Heat exposure limits are based on some set of assumed physiological, personal, and environmental conditions (CasellaCel, 2014).

9. Cold strain disorders include hypothermia (abnormally low body temperature) and frostbite (CasellaCel, 2014)

10. Hypothermia is defined as a core temperature of the body less than 35 degrees Celsius (cold stress (CDC, 2014).

11. Frostbite is the freezing of some part of the body. Fingers, toes, and even whole arms and legs can be lost as a result of frostbite (CDC, 2014). At or below 0 °C (32 °F), blood vessels close to the skin start to constrict, and blood is shunted away from the extremities via the action of glomus bodies. The same response may also be a result of exposure to high winds (Frostbite, 2014).
3-2- Field data collection

Field study observations were done in the fall and winter 2010-2011 in Sheffield to examine the thermal definition of different outdoor indices in real condition. The study shows the local people’s reaction to cold weather. The results will help to clarify which of the outdoor indices is more appropriate for cold climate.

To compare the short term and the long term weather data of the city, the hourly data of the meteorology station of the observed days, and the local data gathered by Kestrel weather station are compared with the average data of long term meteorology on psychrometric chart of UTCI index. Fig 8 shows that in the observation days of 2010-2011 in Sheffield at daytime the weather is warmer and dryer than ordinary winter days, at night it is a little dryer.
4- Microclimate of the Observed Places

Comparison the meteorology data with the data of the fixed Kestrel in the reference point and the portable Kestrel in outdoor places shows the relationship between city climate, local climate and micro climate. To find out the relationship between outdoor thermal condition and people’s behaviour, a field study research has been done in some days of Nov, Dec and Jan 2010 – 2011 in Sheffield city centre. Different thermal situations were observed in day and night. The results of the data collected in observed outdoor places shows that meteorology station as the city climate has the coldest condition. It is in the slight cold stress zone in calm condition and moderate thermal stress in windy situation according to UTCI index (Fig 9). Fixed data logger as the local climate is warmer than city climate but in the same thermal zone. Portable data logger as the microclimate is one level warmer than local and city climate.

21 Nov 2010 Afternoon – calm condition

![Image](image1)

21 Nov 2010 Afternoon – windy condition

![Image](image2)

Figure 9. Comparison of the climatic condition of the city climate, local climate and micro climate of the observed places

4-1- Slight Cold Stress Condition

In the observed places in the city centre, in afternoon of 21 Nov 2010 that was light up ceremony, according to UTCI index thermal condition is in slight cold stress in calm condition (Fig 9). Presence of population in one of the main squares of the town has caused 3°C temperature increase from 5°C to 8°C (Fig 10). Temperature increase and excitement of the ceremony may be the reason of presence of children and elderly (Fig 11). In windy situation the wind chill will cause effective temperature decrease from 5°C to 2°C (Fig 10 left) and thermal condition will decrease one level from slight to moderate cold stress (Fig 10 right). By the way happiness of Christmas and availability of winter plays associated with hot drinks and food, has prepared an appropriate condition for long term presence in winter cold night (Fig 11).
Figure 10. Presence of population caused 3°C temperature increase in light up ceremony.

Figure 11. Presence of elderly and children wearing supporting warm clothes in exciting afternoon event.

Comparing indices of WCET, UTCI, THI and PT shows that according to UTCI, thermal condition is in slight cold stress zone. WCET shows no cold stress in calm situation and low cold stress in windy places. THI shows thermal situation in cold zone. PT shows thermal condition is in low cold stress except for populous places that the temperature will be modified to comfort condition (Fig 12).
4-2- Moderate cold Stress Condition

In the afternoon of 27 Nov 2010 the thermal condition in the observed places is in higher moderate cold stress zone while local climate is in the lower moderate cold stress zone (Fig 13). In the windy places such as large squares and street canyons, wind chill will cause effective temperature decrease from -2°C to -7°C that made long term presence difficult (Fig 14).

27 Nov 2010 Afternoon

Figure 12. Comparing indices of UTCI, WCET, THI and PT, 21/11/2010

Figure 13. Thermal condition of the observed places – no windy
Windy areas such as open wide places, large squares and street canyons may cause lower moderate cold stress condition. They are not appropriate for long term outdoor presence. Few people were seen passing fast (Fig 15).

In bus stations and some other popular places, structures such as booths have prepared wind and rain shelter with appropriate situation for longer exposure time (Fig 16 point M, P and O). In addition in the places with appropriate facilities such as hot drinks and foods, presence of young people is obvious (Fig 17). In spite of that sit in outdoor for eating is not tolerable (Fig 18). Sometime excitement of outdoor event may cause young people to wear fewer clothes that are not appropriate for that cold stress condition (Fig 19). It
seems psychological adaptation\textsuperscript{12} make moderate cold stress condition tolerable for short exposure time. Nikolopoulou and Steemers (2003) reported that only 50\% of the subjective comfort evaluation can be related to the variation in objective microclimatic conditions. The remaining 50\% could be psychological adaptation that is related to how natural the urban space feels, expectations, experience (short- and long-term), time of exposure, perceived control and environmental simulation\textsuperscript{13}.

![Figure 16. Microclimate condition in windy and wind shelter condition](image1)

![Figure 17. Wind shelter structures prepare better thermal condition for long term exposure](image2)

\textsuperscript{12} - A psychological adaptation, also known as evolved psychological mechanism (EPM), is evolved human or animal behavior resulting from evolutionary pressures (Barrett & Kurzban, 2006). EPM’s are ongoing processes in their emotions and intellect, that help individuals with their well being whether it’s through their mental state of mind or in culture (Medical-Dictionary, 2014).

\textsuperscript{13} - Several investigation have highlighted that human comfort level depends on objective and subjective parameters. Objective parameters include Meteorological parameters (temperature, wind speed, relative humidity and solar radiation) and Skin temperature (forehead and hand temperature). Subjective parameters include Personal parameters (human activity, clothing level, age, origin) and adaptation and acclimatization (preference, expectation, acceptability, habituation) (Metje, et al., 2008).
In Fig 20 the indices are compared related to the data in the night of 27 Nov 2010. According to outdoor thermal indices, UTCI shows these conditions in moderate cold stress. WCET show it in low cold stress in calm situation and moderate in windy places. According to THI all the observed places are in the lowest border of cold stress condition and increasing of humidity will cause very cold condition. PT Index shows all the observed places in low cold stress condition even with higher wind speed (5 m/s). In these indices there is no difference between high and low moderate cold stresses while people behavior shows meaningful change in such situations. Therefore cold stress indices need to be better modified for lower thermal zones to prepare more accurate prediction related to wind speed and humidity.
4-3- Slight to Moderate Cold stress Condition

In afternoon of 28 Nov (Fig 21) and day of 1 Dec 2010 (Fig 22), by air temperature above zero, many children and elderly were present in the city centre. Windy condition causes effective temperature decrease to wind chill -2˚C. In spite of that children and elderly people have long term presence by wearing hat, gloves, shawl and boots. Live music, winter plays, hot drinks and food helps for better toleration to thermal condition (Fig 23).

Figure 21. Observation points in afternoon of 28/11/2010
Figure 22. Observation points in the day of 1/12/2010

Figure 23. Long term exposure time using appropriate clothing, hot drinks and food in winter entertainments

Excitement is a psychological stimulus to bring people outdoor even in slight cold stress condition. For example in snow days, lots of people come out to enjoy snow plays (Fig 24). Sunshine areas and wind shelters are architectural strategies to provide better microclimate condition for long term outdoor presence.
Figure 24. Excitement of winter events will make more psychological adaptation

Long exposure time for shopkeepers and pitchman is done in their booths by some warmers. Long term outdoor eating is possible in wind shelter places. Presence of children, disables and elders is possible by the help of more facilities such as cover on baby carriage or wearing clothes with more thermal resistance values (Fig 25).

The relationship between indoor and outdoor places is important according to thermal shock that may happen to people walking in and out in cold condition. This study shows that indoor public places with short term stay such as banks, shops and trams are not much warmer than outdoor. In most of these places temperature is around 14-15°C that is less than indoor comfort zone (Fig 26 left “C1”). This helps human body to adapt easier with cold outdoor condition in short term stays between indoor and outdoor. In indoor places with long term stay, such as coffee shops, the indoor temperature is fixed to 20-22°C that is indoor comfort zone (Fig 26 right “1G”).
This study shows that in air temperature above or around 0°C (-0.5°C to +0.5°C) thermal condition is more tolerable than -2°C, therefore more children and elderly people are seen in outdoor areas. Comparison between outdoor thermal indices shows that WCET is in low cold stress zone and UTCI is near higher bound of moderate cold stress zone. THI shows thermal condition in cold stress zone and PT shows it in low cold stress even with higher wind speed (Fig 27). It seems these indices need to provide better sensitive assessment of human thermal sensation in moderate and slight cold stress condition.

4-3- No Cold Stress Condition

In conditions of no cold stress in 15 Jan 2011 with temperature more than 12°C, the city centre is full of population and many long term activities are happening. Presence of
many children, elderly and disable people is a visible evidence of tolerable thermal condition (Fig 28 and 29).

Figure 28. Presence of population in no cold stress condition

Figure 29. Some observation points in 15 Jan 2011

In the pictures of 15 Jan 2011 (Fig 28 and 29) it is obvious that people are in tolerable thermal condition and most of them even some children do not wear supporting warmer clothes such as gloves, shawl and hat. According to Fig 30, UTCI shows the temperature more than 12°C in no cold stress zone. THI shows it in the zone between cold and cool condition. WCET and PT do not show good sensitivity to temperatures more than 5°C. This research shows meaningful difference between 5°C (slight cold stress) and 12°C (no cold stress) in people’s outdoor behaviour. It seems that UTCI has better definition for cold thermal condition with better sensitivity for thermal stress definition.
Conclusion

Observations of people’s behavior in several days of cold period in autumn and winter of 2010-2011 shows that the temperature more than 12°C in no cold stress zone is adequate for long term outdoor presence for most people. The temperature around 5-8°C is in slight cold stress where long term outdoor presence of people is done by some facilities such as warm clothes and hot drinks and foods. The temperature around zero (-0.5 to 0.5°C) is in slight to moderate cold stress zone depending on windy conditions. In such situation long term outdoor presence depend on the excitement events and architectural strategies such as sunlit areas and wind shelter structures. Supporting clothes as gloves, shawl and hat helps children and elderly to enjoy outdoor events. The temperature less than -2°C with wind chill decrease to -6°C is a critical condition for long term exposure especially for children, elderly, disables and most of the time only young people are seen outdoor. It is called moderate cold stress according to UTCI and WCET in windy condition.

This research shows that among indices that are prepared for outdoor cold stress condition, THI that is sensitive to humidity is not sensitive enough to cold conditions. WCET is more appropriate for very cold situations and is not sensitive to temperatures more than 5°C. PT (the old version of UTCI) shows better sensitivity to temperatures around -5°C and 5°C that are important borders for moderate and slight cold stress respectively according to people’s behaviour. UTCI has good congruence with outdoor thermal behavior of people for temperatures around zero and around 12°C that are important borders for slight cold stress and no thermal stress conditions respectively.

Although WCET and UTCI have better definition for thermal cold stress zones, they need to prepare more sensitive explanation for temperature changes in moderate and slight cold stress zone. It seems that UTCI have good potential to become modified for cold conditions by adding enough sensitivity to humidity therewith wind speed in cold conditions.

References


