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# Outdoor thermal comfort and adaptation in severe cold area: A longitudinal survey in Harbin, China

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ABSTRACT

A year-long longitudinal outdoor thermal sensation and comfort survey was conducted in Harbin, which is located in the severe cold area of China. The survey included micrometeorological measurements and a longitudinal questionnaire survey. The thermal comfort and adaptation in severe cold area were investigated. The results of similar studies in other regions were compared with those of this study. In spring, summer, and autumn, "neutral" was the most frequently perceived thermal sensation, while "cold" was the most common sensation in winter. Moreover, "slightly uncomfortable" was the most common thermal comfort feeling in winter. The thermal acceptable range in Harbin was determined to be at 2.5–30.9 °C of physiologically equivalent temperature (PET). The neutral temperatures were 18.7 °C, 20.0 °C, 21.9 °C, and 18.0 °C of PET in spring, summer, autumn, and winter, respectively. The thermal sensation was found to be mostly related to the air temperature. Thermal adaptation existed during the research period, because clothing insulation was found to be negatively related to the air temperature generally. As for the psychological adaptation, expectations and the thermal comfort demand changed with the seasons. The variation of the thermal acceptable ranges, neutral PETs, and PET calibrations of the thermal sensation vote (TSV) of different climate zones indicated that the thermal comfort was affected by the climatic and regional diversity.

## 1. Introduction

Outdoor thermal comfort is a criterion used to assess the environmental liveability of a city. Citizens tend to spend more time in comfortable outdoor conditions. Therefore, outdoor comfort is an important factor in planning and designing urban layout patterns. With the development of the urban micrometeorological technology, the number of studies on outdoor thermal comfort has increased over the last 20 years.

Table 1 summarizes various previous thermal comfort studies conducted in different regions over the last 20 years.

The studies listed in Table 1 have mainly focused on the relationship between thermal sensation and micrometeorological conditions and on the thermal adaptation by using various thermal comfort indices. In the existing outdoor thermal comfort studies, four micrometeorological parameters including air temperature ($T_a$), relative humidity (RH), wind speed ($V_a$), and global solar radiation (G), which influence the heat exchange between human and the outdoor environment, were the primary research focus. Also, a large number of thermal indices have been put forward to describe thermal state. The thermal indices can be used in the following ways to evaluate outdoor thermal comfort: in calculating an acceptable or a comfortable range by thermal indices [11,14,15,20], in analyzing the regression relationship between TSV and thermal indices, and further getting neutral temperatures [4,11,15,17,18,21,23–25], or in determining how certain thermal index values fall into particular TSV scales [11,14,21,26]. Moreover, thermal adaptation is another important factor that affects the thermal comfort. Thermal adaptation includes all measures that people implement consciously or unconsciously in order to improve their thermal comfort [27].

These studies imply that the relationship between thermal sensation and micrometeorological conditions vary greatly because of the complex climatic conditions and the specific thermal adaptation characteristics existing in different climate regions. Moreover, the existing thermal indices had an original scope of application. For example, the widely used thermal comfort index of physiologically equivalent temperature (PET) was originally applied to mid-Western Europe. So, the thermal acceptable range, the neutral temperature described by thermal indies, and the calibration for TSV in a certain climate may not be applicable to another climate. As for thermal adaptation, the first thermal adaptation implementation was directed at indoor thermal

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**Table 1**
Summary of regions, climate, seasons, and primary research contents of outdoor thermal comfort surveys.

| Authors | Year of Publication | Region | Climate | Season | Primary research contents |
|---|---|---|---|---|---|
| Nikolopoulou [1] | 2001 | Ca, United Kingdom | Temperate marine climate | Spring, summer, and winter | 2 |
| Khandaker [2] | 2003 | Dhaka, Bengal | Tropical monsoon climate | July and August | 1 |
| Thorsson [3] | 2004 | Gothenburg, Sweden | Temperate marine climate | July to October | 1, 2, 3 |
| Nikolopoulou and Lykoudis [4] | 2006 | Athens (GR) | Mediterranean climate | All year | 1, 2 |
| | | Thessaloniki (GR) | Temperate marine climate | | |
| | | Milan (I), Fribourg (CH), Kassel (D) | Temperate continental climate | | |
| | | Cambridge (UK) and Sheffield (UK) | Temperate marine climate | | |
| Eliasson et al. [5] | 2007 | Gothenburg, Sweden | Temperate marine climate | January, April, June, October | 1 |
| Nikolopoulou and Lykoudis [6] | 2007 | Athens, Greece | Mediterranean climate | All year | 1 |
| Mayer et al. [7] | 2008 | Freiburg, Germany | Temperate marine climate | Summer | 1, 3 |
| Holst & Mayer [8] | 2011 | Freiburg, Germany | Temperate marine climate | Summer | 1, 3 |
| Oka [9] | 2011 | Philadelphia, USA | Subtropical humid climate | June and September | 1, 3 |
| Lee et al. [10] | 2013 | Freiburg, Germany | Temperate marine climate | July | 1, 3 |
| Cohen et al. [11] | 2013 | Tel Aviv, Israel | Mediterranean climate | All year | 1, 2, 3 |
| Ruiz and Correa [12] | 2015 | Mendoza, Argentina | Temperate continental climate | Summer and Winter | 1, 2 |
| Aljawabra and Nikolopoulou [13] | 2010 | Marrakech, Morocco | Tropical desert climate | Summer and Winter | 1, 2 |
| Lin and Matzarakis [14] | 2008 | Sun Moon Valley, Taiwan, China | Subtropical monsoon climate (hot summer and warm winter climate) | All year | 3 |
| Lin [15] | 2009 | Taichung City, Taiwan, China | Subtropical monsoon climate (hot summer and warm winter climate) | Summer and Winter | 1, 2, 3 |
| Hwang et al. [16] | 2011 | Taiwan, China | Subtropical monsoon climate (hot summer and warm winter climate) | All year | 1, 3 |
| Lin et al. [17] | 2011 | Taiwan, China | Subtropical monsoon climate (hot summer and warm winter climate) | Summer and Winter | 1, 2, 3 |
| Ng and Cheng [18] | 2012 | Hong Kong, China | Subtropical monsoon climate (hot summer and warm winter climate) | November to August | 1, 3 |
| Yin et al. [19] | 2012 | Nanjing, China | Subtropical monsoon climate (hot summer and cold winter climate) | August | 1 |
| Lin et al. [20] | 2013 | Taiwan, China | Subtropical monsoon climate (hot summer and warm winter climate) | Hot and Cold season | 1, 2, 3 |
| Lai et al. [21] | 2014 | Tianjin, China | Temperate monsoon climate (cold climate) | All year | 1, 3 |
| Niu et al. [22] | 2015 | Hong Kong, China | Subtropical monsoon climate (hot summer and warm winter climate) | June | 1, 3 |
| Chen et al. [23] | 2015 | Shanghai, China | Subtropical monsoon climate (hot summer and cold winter climate) | Winter | 1, 3 |
| Zeng and Dong [24] | 2015 | Chengdu, China | Subtropical monsoon humid climate (hot summer and cold winter climate) | August | 1, 3 |
| Liu et al. [25] | 2016 | Changsha, China | Subtropical monsoon climate (hot summer and cold winter climate) | All year | 1, 3 |

1. Relationship between thermal sensation and micrometeorological conditions.
2. Thermal adaptation.
3. Thermal comfort index.