Establishing a global database for outdoor thermal comfort survey: A pilot study of standardisation of methodology

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Abstract: In the last two decades, studies of subjective thermal comfort have been widely conducted in the urban environment, covering different cultures and climatic regions. However, shortcomings can be observed mainly with respect to protocols used in terms of assessment scales of thermal perception, calculated thermal indices and instrumental setup used for micrometeorological measurements. Such data may vary considerably across studies due to constraints at field sites and the availability of instruments, making it difficult for inter-comparisons between studies and climatic regions, calibrations of thermal indices and a true understanding of people's thermal perception in outdoor settings. There is a need for standardisation of methodology and guidance for conducting field surveys in outdoor spaces with implications on climate-sensitive urban design, public health measures and adaptation of humans to a changing climate. The objective of this pilot study is to develop a standard methodology for outdoor thermal comfort surveys towards the creation of a worldwide outdoor comfort database. The progress of this pilot study is reported in this paper and future developments are also introduced.

Keywords: Up to five

1. Introduction

Climatic effects on the comfort of building occupants have been widely studied in the last few decades (Olgyay, 1963; Givoni, 1976; Nicol and Raja, 1996) and it was found that climatic effects are associated with the health and well-being, as well as productivity and living quality of building occupants (Huntington, 1945). Olgyay (1963) pointed out the constituents of the physical environment act directly upon human body which tends to achieve biological equilibrium through physical and psychological reactions. Hence, human comfort is determined by the energy exchange between human body and the climatic environment of the surroundings, which aims to achieve the "comfort" conditions as defined by integrating climatic variables such as temperature, humidity, air movement and radiation.

The shorter time spent (e.g. in the range of minutes) in the outdoor environment also influences the thermal exposure. Höppe (2002) suggested that the steady-state assumption of indoor thermal comfort does not provide realistic assessments for outdoor settings. His previous study based on the Instationary Munich Energy-Balance Model (Hoppe, 1989) showed that thermo-physiological parameters such as skin and core temperatures take at least one hour in outdoors to achieve the steady-state level. The complex outdoor environment also creates large variations in thermal conditions that the outdoor space users are exposed to. Lau et al. (2019a) showed that subjective thermal sensation changes considerably when pedestrians travel outdoors and suggested that the environmental conditions exposed have a lag effect on thermal perception of pedestrians. Therefore, the assessment of human thermal comfort in outdoor environment requires a different methodological framework and analytical approach in order to address the distinctive relationship between subjective thermal sensation and environmental conditions experienced by outdoor space users.

1.1. Subjective assessment of the thermal environment

Human thermal comfort is generally studied by using questionnaire surveys to obtain a subjective assessment of the thermal conditions that the respondents are exposed to. There are a wide range of subjective assessment scales for the thermal environment, including perceptual or affective, global or localised, instantaneous or covering certain period of time (ISO 10551, 2019). The object of judgement also varies from the environment to the person of assessment, from general conditions to specific components such as temperature and air movement, from permanent to temporary situation. The ISO 10551 provides five subjective judgement scales to describe a person's thermal state, including thermal perception, thermal comfort, thermal preference, personal acceptability and personal tolerance. The ASHRAE Standard 55 (2017) also provides a scale for thermal perception (commonly known as the ASHRAE 7-point scale) and thermal acceptability (Table 1). However, these standards were not designated for general outdoor conditions and their applications in previous studies vary considerably for local context.

Table 1. Protocols for subjective perception of thermal environment (Johansson et al., 2014).

Parameter	Standard	Interview question and measurement scale
Thermal sensation or perception	ISO10551	'How are you feeling now?' 7 Point scale: cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2) and hot (+3) 9-point scale: above plus 'Very cold' (-4) and 'Very hot' (+4) (mainly for use in extreme environments)
	ASHRAE	'What is your general thermal sensation?' 7-Point symmetrical thermal perception scale (equal in wording to the ISO 10551)
Thermal comfort (affective evaluation)	ISO10551	'Do you find this environment…?' 4-Point: comfortable (0) as the point of origin followed by slightly uncomfortable (1), uncomfortable (2), very uncomfortable (3)
Thermal preference	ISO10551	'Please state how you would prefer it to be now' 7-Point: much cooler (-3), cooler (-2), slightly cooler (-1), neither warmer nor cooler (0), a little warmer (+1), warmer (+2) and much warmer (+3)
Personal acceptability	ISO10551	'On a personal level, this environment is for me…' Two-category statement: acceptable rather than unacceptable (0) and unacceptable rather than acceptable (1) Continuous scale: clearly acceptable, just acceptable, just unacceptable and clearly unacceptable
Personal tolerance	ISO10551	'Is it…?' 5-Point: perfectly tolerable (0), slightly difficult to tolerate (1), fairly difficult to tolerate (2), very difficult to tolerate (3) and intolerable (4)

Currently there are no standard guidelines for subjective assessment of the outdoor thermal environment, so the use of questions and measurement scales vary across studies. The ASHRAE 7-point scale was commonly used (Krüger and Rossi, 2011; Lau et al., 2019b) while 5-point (Nikolopoulou and Lykoudis, 2006; Metje et al., 2008) and 9-point scales (Kántor et al., 2012) were also used in some studies. There is usually a middle point in the assessment scale, but the terms used to describe this middle point include "neutral", "comfortable", "neither cool nor warm" and "acceptable". The assessment of other meteorological components, such as solar radiation, air movement and humidity, was also used in some studies (Stathopoulos et al., 2004; Villadiego and Velay-Dabat, 2014; Lau et al., 2019b). Moreover, the personal state of thermal comfort (affective evaluation) and thermal preference was sometimes included in the thermal assessment (Oliveira and Andrade, 2007; Ng and Cheng, 2012). The inconsistencies in subjective scales and wordings used lead to possible errors in comparison between the results of different studies.

Personal factors such as gender, body weight, and skin colour were also found to be associated with the subjective assessment of the thermal environment (Krüger and Drach, 2017). It suggested possible variations in thermo-physiological adaptation to the thermal environment. Previous studies also suggested that human behaviour is another determinant of thermal perception (Knez and Thorsson, 2006) while reason for visit and cultural background were widely regarded as psychological mechanism of thermal adaptation in outdoor environment (Nikolopoulou et al., 2001). However, these factors were not addressed by all the studies and the methods of assessment need to be standardised to produce more accurate and reliable results.

1.2. Thermal comfort indices for the outdoor environment

More than 100 different thermal indices have been developed to describe the heat exchange between human body and its surrounding environment (Błażejczyk et al., 2012). Energy balance model of human body was developed and widely used in the 1970s to 1980s, with a number of biometeorological indices developed for the assessment of thermal stress and strain (Höppe, 1997). One of the commonly used indices was Predicted Mean Vote (PMV) which provides a practical and easily programmable heat balance model of human body (Fanger, 1970). It has since been a widely adopted biometeorological index to describe the predicted mean thermal perception under indoor conditions. Pickup and de Dear (2000) developed a physiologically valid outdoor comfort index (OUT_SET*) by adapting the indoor comfort index SET* to outdoor settings. This involves an estimation of the amount of solar radiation absorbed by the human body and hence determine an outdoor mean radiant temperature.

The Munich Energy-balance Model for Individuals (MEMI) was later developed to incorporate individual heat fluxes, body temperatures, sweating rates and skin wettedness into the assessment of the thermal conditions of the human body in a physiologically relevant way (Höppe, 1984). It also forms the basis of the Physiological Equivalent Temperature (PET) which is defined as “the air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed (Höppe, 1999, p.71). PET has been used in studies of outdoor thermal comfort in different climates and urban settings (Lin, 2009; Ng and Cheng, 2012; Krüger, 2017).

Another commonly used thermal index which has been widely used in the last decade is Universal Thermal Climate Index (UTCI). UTCI is defined as “the air temperature which would produce under reference conditions the same thermal strain as in the actual thermal environment” (Błażejczyk et al., 2010). It is therefore a one-dimensional quantity which represents the human physiological reaction to the actual thermal conditions defined by multiple dimensions. It was developed based on the UTCI-Fiala model which was adapted to predict human responses to outdoor climate conditions. The model also considers behavioural adjustments of the clothing insulation with outdoor air temperature as well as the effect of air movement, walking speed and clothing’s thermal and evaporative resistances (Havenith et al., 2011). UTCI has been widely used in the assessment of outdoor thermal environment (Bröde et al., 2012; Krüger et al., 2017; Oh et al., 2019).

1.3. Micrometeorological measurements

The measurement of micrometeorological conditions is an integral part of outdoor thermal comfort studies since it provides observed data for comparing to subjective thermal perception. Oke (2006) presents a set of guidelines for meteorological observations in urban areas while ISO 7726 (1998) and ASHRAE Handbook of Fundamentals (ASHRAE, 2017) also provide a description of instruments that suit thermal comfort measurements for indoors. However, additional considerations are necessary for the exposure of instruments, the measurement of wind speed, and the estimation of mean radiant temperature (Tmrt; Johansson et al., 2014).

Temperature and humidity sensors may be affected by radiation sources like solar radiation and heated urban surfaces, leading to overestimation of the air temperature. As such, shielding and ventilation are required to minimise the radiative exchange between the instrument and its surroundings and avoid the accumulation of warm air around the probe. Cheng et al. (2012) argued that the radiation shield may not be sufficient to prevent overestimation of air temperature so correction to the results may be required. Wind speed is also an important variable in the assessment of thermal comfort and the type of sensors may affect the accuracy of measurements. Two-dimensional anemometers are commonly used but the turbulence in outdoors may result in an underestimation of actual wind speed.

T_{mrt} is a critical variable in the assessment of thermal comfort, particularly during warm and sunny weather conditions (Mayer and Höppe, 1987) since it represents the aggregated short- and long-wave radiation fluxes in the surroundings that a human body is exposed to (Johansson et al., 2014). It can be determined by two common approaches, namely integral radiation measurements with the inclusion of angular factors and global thermometer combined with measurements of air temperature and wind speed (Thorsson et al., 2007). The large variations in the use of instruments cause inconsistencies and issues in comparison between studies.

1.4. Objectives of the study

The present study aims to: (1) prioritise the elements of outdoor thermal comfort studies such as subjective thermal sensation, affective evaluation of thermal comfort, thermal preference for better understanding of human thermal comfort at international level; (2) develop an internationally recognised standard methodology for conducting field studies of outdoor thermal comfort; and (3) establish a database of outdoor thermal comfort surveys by collating existing data from studies conducted in different climates. The methodological framework of this study was presented, and the progress of this study was also reported in this paper. Future developments of this study are also introduced.

2. Data Acquisition

2.1. Identification and acquisition of relevant data sources

At the preliminary stage, a literature review was conducted to identify relevant data sources for the inclusion in the database. Articles indexed in journal databases such as PubMed, Web of Science, Scopus and SpringerLink were retrieved and shortlisted for relevance, using relevant keywords including (but not limited to) “outdoor thermal comfort”, “human thermal comfort”, “thermal perception”, “thermal assessment”, “outdoor environment” and “questionnaire survey”. The authors of relevant studies were contacted for their interest in contributing to the database. At the same time, contribution to a pilot study was called in the newsletter of the International Association for Urban Climate in mid-2019 (http://www.urban-climate.org/wp-content/uploads/IAUC072.pdf).

Data obtained from shortlisted studies have to fulfil the following criteria in order to be included in the database. A template, consisting of unit of measurement, code names, and coding conventions, was provided for data contributors.

- Data should be collected from field surveys and experiments conducted in semi-outdoor or outdoor environments.
- Metadata of the study are required, including (but not limited to) dates of questionnaire survey and micrometeorological measurements, number of samples, climate zone and background climatic information, and types of urban settings (with pictures of study site, when available).
- Both subjective (questionnaire survey) and instrumental (micrometeorological measurement) data are required and they should be simultaneously collected to obtain the right-here-right-now response from the respondents.
- The questionnaire survey should consist of subjective assessment of the thermal environment, metabolic rate and clothing level of the respondents, immediate thermal history (if any), biometric information, and demographic background of the respondents.
- The micrometeorological measurements should include four fundamental parameters for calculating thermal comfort indices, namely air temperature, humidity, air movement, globe temperature (or three-dimensional measurements of radiation fluxes for calculating mean radiant temperature, T_{mrt}). Technical specifications of instruments/sensors and detailed instrumental settings will also be required.
- Raw data are required, i.e. not from processed or published data. However, data must have been published in peer-reviewed journals or conference papers. Therefore, publication metadata should be provided. Coding of the data should also be clearly defined by data contributors.

2.2. Study areas and climatic background

In this pilot stage, 11 studies were included in this pilot study with three studies from Europe (Szeged, Warsaw and Athens), two studies from South America (Guayquil and Curitiba), two studies from Australia (Melbourne), and three studies from Asia (Hong Kong) (Figure 1). They cover different background climates according to the Köppen-Geiger's climate classification (Kottek et al., 2006), ranging from Group A (tropical climate), Group B (dry climate), Group C (temperate climate), to Group D (continental climate), so this pilot study provides a variety of physiological acclimatisation and psychological adaptation. A total of 21,254 data entries were obtained. Details of the data sets are listed in Table 2.

2.3. Collection of field data

The study sites of all surveys were public spaces commonly visited, including public squares, pedestrian streets, urban parks, university campuses, and residential districts. Structured questionnaires were administered to study people's subjective assessment of the thermal comfort conditions while micro-meteorological measurements were simultaneously performed. Questionnaire surveys were conducted in summer for all studies and in winter for six studies, with seven of them covering transitional seasons. In Guayaquil, surveys were conducted in wet and dry seasons due to the insignificant seasonal differences in air temperature.

Figure 1. Locations of the studies included in the pilot stage.

Table 2. Details of the studies included in the pilot stage.

Study	Study Area	Latitude, Longitude	Climate Zone	Season	Survey Location	Survey Days	Time Period	Sample Size
ARMI16	Tempe, United States	33.42° N, 111.94° W	Bwh	1,2,3,4	Campus		07h-19h	1284
ATKO12	Szeged, Hungary	46.25° N, 20.14° E	Dfb	1,2,3	Park, square, street		10h-18h	5288; 517
CHLA17	Melbourne, Australia	37.81° S, 144.96° E	Cfb	2	Park		09h-16h	3293
ERJO18	Guayaquil, Ecuador	2.19° S, 79.89° W	Aw	1,2	Arcade, square, park, waterfront		11h-20h	544
ESYU19	Hong Kong	22.32° N, 114.17° E	Cwa	2,4	Park		07h-17h	454
KALI13	Warsaw, Poland	52.23° N, 21.01° E	Dfb	1,2,3,4	Square		11h-16h	818
KAPA13	Athens, Greece	37.98° N, 23.73° E	Csa	2,3,4	Square, street		11h-22h	1706
SASH16	Melbourne, Australia	37.81° S, 144.96° E	Cfb	1,2,3	Campus		09h-17h	1023
EDNG12	Hong Kong	22.32° N, 114.17° E	Cwa	2,4	Park, Residential, Street		07h-19h	2674
KELA18	Hong Kong	22.32° N, 114.17° E	Cwa	2	Park, Residential, Street		10h-17h	1998
EDKR11	Curitiba, Brazil	25.43° S, 49.27° W	Cfb	2,3,4	Street, Square, Crossroads		10h-16h	1655

2.3.1. Micro-meteorological measurements

Field measurements of micro-meteorological conditions included air temperature (T_a; °C), relative humidity (*RH*; %) and wind speed (*v*; ms^{-1}) in all studies. Measurements of thermal radiation, in terms of globe temperature (T_g; °C) and/or global solar radiation, were also conducted for the estimation of mean radiant temperature (T_{mrt}; °C). Sensors were placed close to the respondents with the same exposure to solar radiation and at about 1.1 m above ground surface in most cases, which corresponds to the average height of the centre of gravity of a standing man (Mayer and Höppe 1987).

Table 3 presents the summary statistics of the meteorological variables measured in the 11 studies. Due to the diversified climatic background, there are large variations in air temperature. Apart from Study 4 and 10 which were conducted in the tropical region (Guayaquil, Ecuador) and sub-tropical region (Hong Kong) in summer. Maximum air temperature was over 30°C with Study 1 up to 43.4°C (Tempe, Arizona).

Table 3. Summary of the meteorological conditions of the studies.

Study	**ARMI16**	**ATKO12**	**CHLA17**	**ERJO18**	**ESYU19**	**KALI13**	**KAPA13**	**SASH16**	**EDNG12**	**KELA18**	**EDKR11**
Air Temperature (°C)											
Max	43.4	38.0	40.6	34.3	35.7	30.0	39.3	34.5	38.7	38.9	30.7
Mean	24.8	21.4	24.9	29.1	23.4	12.0	25.1	22.0	26.9	33.3	19.9
Median	25.7	21.1	23.7	28.8	22.4	12.5	25.2	21.5	26.2	33.1	20.2
Min	10.2	6.9	15.8	25.5	11.9	-6.7	7.1	12.2	11.6	29.8	6.4
Std Dev	8.5	6.3	5.2	2.2	7.1	11.1	8.6	5.1	5.7	1.5	5.5
Relative Humidity (%)											
Max	40.2	82.1	99.9	73.1	87.8	85.8	79.4	80.9	86.3	89.3	93.2
Mean	23.3	39.7	56.4	63.3	70.3	55.6	50.4	49.2	62.3	63.7	56.4
Median	20.0	37.5	61.1	64.8	74.1	54.8	48.1	49.8	63.3	63.1	56.3
Min	11.0	14.8	14.6	49.2	45.8	25.2	22.6	18.0	28.7	45.6	23.5
Std Dev	9.5	12.6	17.1	6.7	10.8	15.5	14.2	12.2	11.0	7.7	12.9
Wind Speed (m/s)											
Max	/	4.22	3.70	2.77	2.18	1.90	9.33	6.27	6.85	3.21	3.28
Mean	/	1.16	1.25	1.13	0.69	0.73	0.81	1.63	1.15	0.97	1.14
Median	/	1.06	1.09	1.02	0.65	0.76	0.64	1.48	0.97	0.94	1.07
Min	/	0.10	0.00	0.44	0.00	0.00	0.25	0.19	0.03	0.07	0.00
Std Dev	/	0.54	0.72	0.48	0.47	0.37	0.74	0.81	0.77	0.42	0.56
Mean Radiant Temperature (°C)											
Max	85.8	70.9	77.2	78.9	77.6	86.9	44.7	51.0	79.3	81.2	72.3
Mean	39.8	33.2	46.7	47.9	31.1	20.1	28.1	28.2	34.8	39.8	31.3
Median	34.2	30.5	48.6	47.0	30.5	16.3	30.4	27.5	31.4	34.4	27.2
Min	0.3	2.7	8.8	24.5	14.4	-13.0	8.5	9.7	2.5	29.8	9.8
Std Dev	18.5	13.3	14.6	14.9	8.7	19.7	9.5	9.0	13.2	10.0	13.9
Physiological Equivalent Temperature (°C)											
Max	70.7	53.9	55.6	51.1	48.4	/	43.9	42.1	43.8	/	45.5
Mean	32.2	23.1	31.8	35.9	25.0	/	25.0	21.1	25.8	/	21.7
Median	29.7	22.9	32.0	34.9	27.3	/	26.0	20.5	26.7	/	20.5
Min	5.3	3.6	11.8	24.0	10.6	/	1.7	7.4	2.9	/	3.6
Std Dev	14.0	8.4	8.2	7.2	8.3	/	10.0	7.0	7.9	/	9.0
Universal Thermal Climate Index (°C)											
Max	51.9	45.2	46.2	43.8	/	34.1	39.3	37.9	45.2	44.7	37.6
Mean	27.8	23.8	30.2	34.2	/	13.7	25.7	19.9	29.4	37.5	22.5
Median	26.5	24.1	30.5	33.6	/	13.9	26.9	19.7	28.8	37.0	21.9
Min	6.3	-0.6	14.5	24.6	/	-13.9	3.0	-3.6	9.8	34.0	5.0
Std Dev	9.6	6.5	5.6	4.7	/	12.9	8.9	7.3	7.4	2.0	6.9
Number	1284	5805	3293	544	454	818	1706	1023	2674	1998	1655

Thermal comfort indices are important to provide an objective assessment of the thermal environment. As pointed out by de Dear (1998), there are potential sources of "noise" in the thermal comfort indices since different versions of computer algorithms may have been used to calculate such indices. In order to avoid these inconsistencies, three thermal comfort indices commonly used by outdoor thermal comfort studies, namely PET and UTCI, were calculated from the raw data of micrometeorological measurements acquired from data contributors.

The software RayMan (Matzarakis et al., 2007) and BioKlima (Błażejczyk, 2011) were used to calculate PET and UTCI, respectively. RayMan is developed for the calculation of short- and long-wave radiation fluxes on the human body. It takes into account the complex geometry of urban structures and can be applied in urban planning and street design. The output of the model includes Tmrt for the assessment of the urban bioclimate by using thermal comfort indices such as PMV, PET, SET*. BioKlima consists of different methods of bioclimatic studies and provides easy calculations of more than 60 various biometeorological and thermophysiological indices. The mandatory inputs of meteorological variables include air temperature, relative humidity, globe temperature, wind speed, metabolic rate and clothing level (thermal insulation). Personal factors such as height and weight can also be included for the calculation of the thermal comfort indices.

2.3.2. Questionnaire surveys

Structured questionnaires were conducted to obtain information about subjective assessment of the thermal environment, as well as personal parameters and behaviours, usage of outdoor spaces. Although the overall content of the questionnaires was adjusted to local contexts, this pilot study focuses on the subjective assessment of the thermal environment.

Table 4 describes the thermal assessment scales used in the 11 studies included in this pilot stage. Eight studies adopted the ASHRAE 7-point scale for the respondents to report their thermal sensation vote (TSV). It was originally designed for indoor studies but has been widely used for outdoor studies in the last two decades (Spagnolo and de Dear, 2003; Knez and Thorsson, 2006; Lin et al., 2009; Lau et al., 2018). Previous studies used this scale to correspond to the PET categories particularly developed for Central Europe (Matzarakis and Mayer, 1996; Matzarakis et al., 2009). In three of the studies (ARMI16, ATKO12, and ERJO18), two additional votes ('very cold' and 'very hot') were used to represent the wider range of thermal conditions in the outdoor environment. In particular, the respondents in Szeged were asked to report TSV on a 9-point scale with a 0.1 increment.

The respondents were also asked to report their affective evaluation of overall thermal comfort in seven studies, though different evaluation scales were used. ARMI16 used a 4-point unipolar scale with three levels of uncomfortable votes and one class of comfortable vote. ATKO12 and SASH16 used a 7-point symmetric scale while ESYU19 adopted a similar scale without a 'neutral' option. KAPA13 applied a 5-grade symmetric scale while EDNG12 and KELA18 adopted this scale with the middle vote denominated.

Preference to the current thermal conditions was also asked in most of the studies (except EDNG12). All of them adopted symmetric scales with a neutral option. Seven studies used three classes to represent 'want warmer', 'remain unchanged' and 'want cooler' (McIntyre, 1980). ARMI16, ESYU19, EDKR11 applied seven classes from 'much cooler' to 'much warmer'. Thermal acceptability was only asked in three studies with a 6-point symmetric scale without a 'neutral' option adopted by ESYU19. SASH16 and KELA18 used two classes to represent ‘acceptable rather than unacceptable’ and ‘unacceptable rather than acceptable’. In addition, only three studies asked the perception of different meteorological parameters (such as wind, humidity and solar radiation).

Table 4. Thermal assessment scales used in the 11 studies.

Study	Thermal Sensation	Thermal Comfort	Thermal Preference	Thermal Acceptability	Perception Vote	Remarks
ARMI16	9-point	4-point (0 to -3)	7-point (-3 to +3)	N/A	N/A	
ATKO12	9-point	7-point (-3 to +3)	3-point (-1 to +1)	N/A	WSV, SSV, HSV	TSV is on 9-point scale with 0.1°C increment
CHLA17	7-point	N/A	3-point (-1 to +1)	N/A	N/A	
ERJO18	9-point	N/A	3-point (-1 to +1)	N/A	N/A	
ESYU19	7-point	6-point (-3 to +3)	7-point (-3 to +3)	6-point (-3 to +3)	N/A	
KALI13	7-point	N/A	3-point (-1 to +1)	N/A	N/A	
KAPA13	7-point	5-point (-2 to +2)	3-point (-1 to +1)	N/A	N/A	
SASH16	7-point	7-point (-3 to +3)	3-point (-1 to +1)	2-point (0 or 1)	N/A	
EDNG12	7-point	4-point (-2 to +2)	N/A	N/A	WSV, SSV, HSV	
KELA18	7-point	4-point (-2 to +2)	3-point (-1 to +1)	2-point (0 or 1)	WSV, SSV, HSV	
EDKR11	7-point	4-point (0 to -3)	7-point (-3 to +3)	2-point (0 or 1)	N/A	

2.4. Data harmonisation

Subjective thermal perception is often compared to objective micrometeorological measurements in order to understand the subjective-objective relationship of thermal assessment. As different assessment scales (e.g. number of points on the scales) were adopted by previous studies, there is a need to harmonise the datasets obtained from different studies.

In this study, the method proposed by Dawes (2002) was adopted to rescale the data obtained by different assessment scales since it produces similar mean and variance values. For instance, the data obtained from 9-point scale were rescaled by applying a rescaling factor to reduce the spread from nine to seven classes. The rescaled data were evaluated against the original data based on the mean, standard deviation, kurtosis and skewness values.

3. Analytical Procedures

3.1. Identification of key elements in outdoor thermal comfort surveys

Subjective assessment of the thermal environment includes thermal perception, thermal comfort (affective evaluation), thermal preference, personal acceptability and tolerance (ISO 10551, 2019). Data before and after harmonisation will be tested among subjective assessment and objective measurements for the sensitivity in thermal assessment (Task 5).

The non-parametric Spearman's rank correlation coefficient will be used to determine the correlations among subjective assessment and objective measurements, which indicates the significant elements in thermal assessment with respect to micrometeorological conditions that the respondents are exposed to.

Linear regression analysis will then be conducted to investigate the relationship between both original and binned values of meteorological variables and thermal comfort indices. Linear models will be developed to examine how well subjective thermal assessment can be predicted from observed meteorological measurements.

The models will be validated using two approaches. Firstly, studies from similar climatic regions or similar urban settings will be divided into training and validation datasets. This ensures the applicability of the models in a relatively consistent climatic and environmental conditions. Secondly, the entire datasets will be randomly divided into training (80%) and validation (20%) datasets in order to evaluate the overall predictability of the linear models. The parameters identified will be included in the draft standard methodology which will be further tested by selected research teams in different climatic regions.

3.2. Testing of the draft standard methodology

The key elements identified in Task 5 will be included in the draft standard methodology which will consist of subjective thermal assessment and micrometeorological measurements. The testing of the draft standard methodology will be conducted in selected countries by corresponding research teams in order to test its feasibility and identify if there are any issues or difficulties.

The questionnaire surveys will include the assessment scales and elements determined by the linear models in Task 5 to form the subjective part of data collection. At the same time, the instrumental settings will also be provided for testing the draft standard methodology. The testing will be conducted in different seasons in order to examine the applicability of the draft methodology in both extreme and transitional conditions. The target sample size is 100 responses per round in order to maintain sufficient samples to compare between different studies and refine the methodology if necessary.

3.3. Establishment of the online database

Based on the findings obtained in Tasks 3-5, the key elements of human thermal comfort in outdoors will be identified and used in establishing the online database. Browser-based applications will be used since it has readily available and easy-to-use visualisation and user interface. Open-source JavaScript libraries will be used to visualise the data based on the data analysis conducted in Task 5. The primary focus of the database is to provide information about the conditions that are perceived as comfortable so that the users such as urban planners and designers can take into account these conditions in their practices.

Four types of information will be included in the database. First, subjective assessment of thermal comfort will be provided to indicate how people perceive their thermal comfort under specific conditions. Second, the corresponding meteorological conditions will be provided in order to allow users to understand what conditions are required to achieve thermal comfort. Third, demographic information will be included for any specific use or design of outdoor spaces. Finally, the urban settings where the data were collected will be specified.

During the process of development, a website with online forum will be established to provide an online platform for communication between researchers and contributors. The questions or issues encountered during the process will be shared and data contributors can answer or raise any questions they concern. This online platform can also engage potential users during the development process in order to maximise the applicability of the online database.

4. Way Forward

The primary objective of developing this global database for outdoor thermal comfort survey is to provide the empirical basis for establishing outdoor thermal comfort models by understanding the influential elements of human thermal comfort in the outdoor environment. However, the content of the database has a large potential beyond this due to the large amount of high-quality field data that can be used to explore the issues regrading human thermal comfort in the outdoor environment. The followings are some examples of potential applications of this global database.

The database provides numerous possibilities for developing empirical relationships between different assessment scales of subjective thermal perception. Human thermal comfort research has been using a wide range of subjective assessment scales, for example, the seven-point ASHRAE thermal sensation scale, thermal acceptability and preference assessment. The database therefore provides a platform for evaluating the assumptions behind different assessments and the applicability in outdoor settings.

The contextual effects were studied in some previous work but there have been no comprehensive understandings of how these effects influence subjective thermal perception in different climates. Therefore, there are opportunities for researchers to investigate the characteristics of the outdoor environment and their relationship with human thermal comfort of pedestrians and users of outdoor spaces. Urban planning and design professionals can be informed with the findings and they can enhance the design of outdoor spaces in order to encourage their usage, which in turn has implications on human health and well-being, as well as energy consumption of buildings.

Since the data provided by researchers have been previously published in peer-reviewed academic journals and undergone the process of quality check, they are reliable and ready to use for scientific and design work. The database also allows professional practitioners to extract relevant information for their design. For example, design professionals can acquire the understanding of thermal comfort requirements for specific urban contexts and climatic regions without conducting the field work themselves.

The long-term goal of the database is to establish a standard methodology for conducting outdoor thermal comfort research. The draft version of the standard methodology provided in the later stages of the development of the database allows robust testing of the methodology. It also facilitates comparison of results between different climatic regions and urban settings in order to enhance the understanding of outdoor thermal comfort. This potentially contributes to the discussion of the difference between indoor and outdoor studies, which has been widely discussed in the last two decades.

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