The Scales Project, a cross-national dataset on the interpretation of thermal perception scales

Marcel Schweiker et al.*

Thermal discomfort is one of the main triggers for occupants’ interactions with components of the built environment such as adjustments of thermostats and/or opening windows and strongly related to the energy use in buildings. Understanding causes for thermal (dis-)comfort is crucial for design and operation of any type of building. The assessment of human thermal perception through rating scales, for example in post-occupancy studies, has been applied for several decades; however, long-existing assumptions related to these rating scales had been questioned by several researchers. The aim of this study was to gain deeper knowledge on contextual influences on the interpretation of thermal perception scales and their verbal anchors by survey participants. A questionnaire was designed and consequently applied in 21 language versions. These surveys were conducted in 57 cities in 30 countries resulting in a dataset containing responses from 8225 participants. The database offers potential for further analysis in the areas of building design and operation, psycho-physical relationships between human perception and the built environment, and linguistic analyses.

Background & Summary

Occupants have a significant influence on their indoor environment and its energy use through their presence and interactions with the building envelope and control system 1–5. Factors driving occupants-building interactions are linked to either the intention to adjust indoor environmental parameters (e.g. relating to thermal (dis-)comfort), or to non-environmental factors such as leaving the room6. The perception of the thermal indoor environment is one important driving factor for actions, including adjustment of heating or cooling set points, or opening windows6, which can be described by the adaptive principle: “If a change occurs that produces discomfort, people tend to act to restore their comfort”7. Hence, understanding thermal (dis-)comfort is crucial for appropriate design decisions and choosing suitable operation modes in buildings.

According to the widely-used definition by the American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), “Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation”8. Consequently, rating scales are often used for this assessment. Whether a specific set of thermal conditions can be considered comfortable is commonly determined via simple thermal sensation ratings ("cold" to "hot")9. In parallel, additional dimensions of thermal perception are known and applied10; e.g. affective evaluation ("comfortable" to "extremely uncomfortable"), thermal preference ("cooler" to "warmer"), or personal acceptance ("generally acceptable" to "generally unacceptable").

The Scales Project aims at investigating participants’ concept relating to verbal anchors of thermal sensation, thermal comfort, and thermal acceptance scales and to review the validity of existing assumptions (see below) regarding the interpretation of responses on these scales. The dataset consists of data from a large-scale international survey applying a newly developed questionnaire, which asks survey participants to state their perceived distance between the verbal anchors. The questionnaire was applied in 21 language versions. Surveys were conducted in 57 cities in 30 countries resulting in a dataset encompassing responses from 8225 participants (Fig. 1). Because individual inputs are available for each dimension of thermal perception, potential analyses and their statistical power benefit from the within-subject nature of this questionnaire.

*A full list of authors and their affiliations appears at the end of the paper. *email: marcel.schweiker@kit.edu
Following the project’s objective, this dataset can be used to analyse the conceptual relationships between verbal anchors of one scale, or between one or more scales. For example, thermal sensation is most frequently assessed using the seven-point ASHRAE thermal sensation scale, with the verbal anchors ‘cold’, ‘cool’, ‘slightly cool’, ‘neutral’, ‘slightly warm’, ‘warm’, and ‘hot’. A common assumption related to the application of the thermal sensation scale is the assumption of equidistance, meaning the difference between ‘warm’ and ‘hot’ is equal to that between ‘warm’ and ‘slightly warm’. However, research has questioned this assumption 9,11–14. Hence, the applicability of statistical methods relying on them (e.g. linear regression) needs to be questioned. Beyond reviewing the validity of this assumption, the newly developed questionnaire also enables to analyze the influence of different contexts (e.g. language, climate, and season) and characteristics of individuals (e.g. sex). Further assumptions existing for other dimensions of thermal perception, here: thermal comfort and thermal acceptance, can be assessed also.

Another important assumption in the field of thermal comfort to be reviewed through our dataset, postulates that occupants would be satisfied with the indoor thermal conditions, if they chose one of the middle three verbal anchors of the ASHRAE thermal sensation scale (“slightly cool”, “neutral”, or “slightly warm”). In other words, ‘neutrality’ is assumed to be a desired condition. Various studies have shown individual and contextual differences not supporting this assumption9,12,13,15–17. In particular, researchers repeatedly identify a discrepancy in users who declare satisfaction while feeling warm or cool18–21.

In addition, the data can also be used for traditional thermal comfort explorations, with more than 5,031 of the datasets include at least one measurement of indoor temperature. Furthermore, the detailed description and availability of questionnaires, available in multiple languages, can serve as a benchmark for future thermal comfort studies and permit replication to other contexts, for example libraries or offices, or other cohorts such as office workers or older people.

**Methods**

**Questionnaire development and pilot study.** Within the framework of IEA EBC Annex 69, an international and interdisciplinary group consisting of 7 independent research groups in 6 countries (Australia, China, Germany, Korea, Sweden, and United Kingdom) – the initial core group – developed the methods applied in the present paper, based on promising results from an experimental study14. This work included several rounds of face-to-face discussions email conversations as well as an online survey. The details of these discussions together with the description of the methods were submitted and registered to the Open Science Framework (OSF) as a pre-analysis plan (PAP)22. At the time of submission of the PAP, one application of the questionnaire had been conducted, but the corresponding questionnaires were securely stored and untouched until the moment of submission of the PAP.

The initial core group also developed the questionnaire in an English version. Mandarin (with simplified Chinese), German, Korean and Swedish translations were subsequently prepared by native language experts familiar with the concepts used in the questionnaire.

Each group piloted the initial version of the questionnaire according to the following procedure: The questionnaire was applied without further explanation to at least 7 individuals, of which 2 had to be experienced in the field of human thermal comfort. After collecting the questionnaires, researchers discussed with the participants the length of the questionnaire, the clarity of instructions, and issues when filling out the questionnaire. The observations made through these applications were discussed among the core group and reflected in the revised and final versions of the questionnaire.

**Expansion of research group.** After agreeing on a final version of the questionnaire and submitting the PAP, the initial core group reached out to other researchers in the field through existing networks, such as the Network for Comfort and Energy Use in Buildings (NCEUB) (http://nceub.org.uk/), and personal contacts.
Additional researchers had to sign a co-author agreement and guarantee to follow the procedures prescribed for data collection (see below). In case researchers used other languages than the above mentioned, they had to translate the questionnaire into their language following the same procedure as initially applied – including piloting the new language version with at least 7 individuals beforehand. The number of 7 individuals was based on observations by the initial core group during the first pilot phase revealing that the number of issues raised by test participants concerning the questionnaire do not increase substantially with a higher number of initial respondents. In addition, the project leader checked the questionnaire with respect to the formalities. The final consortium consisted of 56 research groups from 30 countries with a total of 94 individual researchers.

**Survey participants.** Respondents were university students attending lectures, because they were expected to have only minor variations in age and activity level, supporting the focus on our targeted contextual differences. It was a requirement that the students had not participated in lectures addressing the concept of human thermal comfort. Each respondent could only participate once.

**Questionnaire.** The questionnaire consists of an introductory page, the two-page main part dealing with the scales and a fourth page addressing the respondents’ background and current thermal state (see all language versions in the online repository sites). The main part used a newly developed free-positioning task, where participants were asked to position the verbal anchors on a straight line (Fig. 2). In the questionnaire scales relating to thermal sensation, thermal comfort and thermal acceptance were investigated. The first questions prompted participants to process each of these scales individually. Later questions addressed the relationship between (1) thermal sensation and thermal comfort; and (2) thermal sensation and thermal acceptance. Verbal anchors were chosen according to ISO 10551. ISO 10551 and many thermal comfort studies also use a preference scale ranging from “prefer cooler” to “prefer warmer”. This scale was not used for this study because pilot studies suggested that this scale tends to be misinterpreted by respondents as also pointed out earlier.

In addition to questions relating to thermal sensation, thermal comfort and thermal acceptance scales (Part 1 of the questionnaire), respondents were asked about their current thermal state and background (Part 2 of the questionnaire). Countries and cities of participants’ origin and residence were collated to identify potential adaptations to climatic conditions at the locations where the questionnaires were administered and where participants were living beforehand. See Online-only Table 1 for a full list of variables included in dataset and their source.

**Survey procedure.** In each country the questionnaire had to be distributed at least twice during two distinct seasons. The requirement for two distinct seasons was lowered for places with only minor variations in outdoor weather conditions throughout the year. Data were collected from a minimum of 100 respondents per country (a minimum of 50 per season).

The following conditions had to be followed for the distribution of the questionnaires:

- **Timing:** at the end or if necessary during classes, when participants had been seated at least 30 minutes
- **Form:** paper-pencil
- **Language:** local language (in case of large groups of foreigners in a country/class (e.g. Chinese in Korea), researchers were free to distribute more than one language version.

On a separate sheet, researchers noted the following additional information:

- **City and Country of survey**
- **Date, start time of distribution and end time of collection**
- **Number of questionnaires distributed**
- **Number of questionnaires received back**
- **Observations made during survey distribution and collection:** e.g. “very high noise levels” or “at day of survey it was unnaturally warm for this time of the year”
- **Classification of season:** This classification was done without any predefined categories and based on individual researchers’ decision. The researchers used terms for seasons according to typical terms used at their location. Future users of this dataset, who may plan to include such variable into their analysis, can decide whether they follow the classifications given in the dataset or create their own classifications e.g. based on prevailing outdoor conditions, the date of application, KG class, or other information.
In addition, researchers acquired data of the outdoor conditions (outdoor temperature and humidity) from close-by weather stations (either owned by the researchers, available to researchers, or using public sources) and optionally recorded the indoor conditions during the distribution period. Despite their significant influence on thermal perception, indoor conditions were made optional for the following two reasons:

For the first, the main purpose of the Scales Project was not that of a classic thermal comfort study aiming at the analysis of the relationship between indoor thermal conditions (and other factors) and thermal perception assessed through thermal perception scales. The main objective of this study was to reveal participants’ understanding and interpretation of verbal anchors on the scales. The assumption was that they were affected by the prevailing conditions such as seasonal differences or immediate outdoor conditions as well as by an individual’s actual thermal state.

For the second, the methodological intention was to maintain a low level of constraints for additional researchers to join this project. Given the aim of a large response rate from a variety of climates and geographical contexts, a decision was made that the availability of measurement equipment should not be a prerequisite for joining. In addition, classical thermal comfort analysis requires the measurement of indoor air temperature, radiant temperature, relative humidity, and air velocity together with the assessment of clothing insulation level. Due to the place of application being university class rooms, temperature distributions in terms of air temperature and also mean radiant temperature could be expected to vary largely among individual positions in a large classroom, e.g. close-by or further away from windows or air outlets. Measuring thermal conditions at each participants’ seat would have required substantial amount of equipment significantly limiting the number of participating researchers.

Therefore, a decision was made to have indoor thermal conditions not mandatory and to focus on the assessment of participants’ self-reported thermal state. Future users of this data set should be aware of the limitations. Those planning to use recorded indoor air temperatures can still use large parts of the dataset, as 5,031 questionnaires include at least one measurement of indoor air temperature.

**Data preparation.** Individual research groups prepared the data from their questionnaires and submitted for each application two files: one containing the data transferred from the questionnaire, one containing the additional information for each application. The positions of the labels drawn in the free positioning task were quantified using a ruler and measuring the distance of the positioned label to the left end of each horizontal line.

Upon reception of a dataset, the project leader validated the dataset by means of an automated script (see section Technical validation). In addition, the project leader made the following adjustments to harmonize the data and added further variables by means of an R script available online23 (see section “Custom code used” below):

**Adjustments:**

- Researchers participating in this study were advised to print the questionnaire, so that each line representing a linear scale was exactly 100 mm long. This would result in measured distances of verbal anchors between 0 mm and 100 mm. However, there were several cases where the printouts were slightly distorted, i.e. shorter or longer. The real length of the lines in the printouts was reported with the information for each application. Based on this information, the measured values were adjusted for the ratio between the real length of the line in the printed version and the prescribed length of 100 mm.
- Date and time formats were harmonized.
- Season descriptions were harmonized.

**Additional variables:**

- KG class: Koeppen-Geiger (KG) classifications were derived for the place of survey (provided by the researcher), and the places of current residence, previous residence, and origin (as stated by the participants). To obtain the KG class for each combination of city and country, the KG world map (Version March 2017) provided for R (http://koeppen-geiger.vu-wien.ac.at/present.htm) was used. This map is based on data from 1986 to 2010 and is the re-analysed KG map with a resolution of 5 arc minutes using the downscaling algorithms25. In order to obtain the KG class automatically, the latitude and longitude were first derived based on Nominatim, the search engine for OpenStreetMap data (http://nominatim.openstreetmap.org), then converted to the pixel number of the map.
- Language type: The verbal anchors differ in their type between languages (see also19). In some languages, e.g. English, two adjectives are used on the cool and warm side of the scale, respectively, e.g. “warm” and “hot.”
- Adaptation level: Depending on the answers to the places of current and previous residence, this variable had the levels: “low”, “middle”, or “high.” The coding was based on the length of residency and the KG classes of current and previous place of living. “Low” denotes that the respondent was living less than a year in the current KG class and that the previous place had a different KG class. “Middle” was assigned to those living 1 to 3 years in the current KG class, but a different one before. All others, i.e. living more than 3 years in the current KG class are “high”.
- Native: The variable native speaker was a binary variable (yes/no) generated. Responses are marked as “yes”, in case the language of the questionnaire is equal to (one of) the language(s) spoken in the country of origin of the respondent. All other responses were marked as “no”.
- Country of residence plausible: Participants reported their country of residence. This record was compared to the country of application noted by the researcher. In case these two countries differed (52 responses), the new variable “Country of residence plausible” was set to “no”, otherwise “yes”.


The variables available in the dataset, including their measurement scale, and levels (if applicable) are presented in Online-only Table 1.

**Ethics and consent.** Ethic approvals were acquired where institutional or national requirements made it necessary, such as the Institutional Review Board’s approval. Informed consent was obtained from all subjects before conducting the survey.

**Data Records**
All data records listed in this section are available from the project page23 on OSF and can be downloaded without an OSF account. The information regarding the cities of current residence, previous residence and origin were removed, as they can serve to identify an individual participant. The R script used for pre-processing the semi-raw data is also available. The data were licensed under a CC0 1.0 Universal license.

**Data structure.** *All Datasets.* File format: comma separated values file (.csv).
These files contain:

- Individual raw datasets without information on cities
  - survData: file containing participant responses
  - survInfo: file containing researcher observations
  - summary reports: Summary report by researcher for each application
- One changelog-File: Record of changes made to raw datasets
- Codebooks for each raw data
- Combined dataset including all information from survData and survInfo file together with additional variables.

**Questionnaires.** File format: Adobe pdf (.pdf).
These files contain the 21 language versions used.

**Data templates.** File format: Microsoft Excel (.xlsx).
These files contain the data templates used for data collection.

**R Scripts.** File format: plain text files (.R)
These files contain the R Scripts used for processing the raw datasets, technical validation, and additional variables.

**Technical Validation**
Incoming datasets were rigorously checked in several steps:

1. Visual inspection of the datasets, whether they comply with the prescribed formats. If not, datasets were send back to researchers.
2. Semi-automated R Script to validate
   
   a. Spelling of country names, city names, and language codes
   b. Whether KG class can be derived automatically (otherwise KG class was added manually)
   c. Whether data points are within the expected range (e.g. relative humidity between 0 and 100%), or one of the available categories (e.g. only one of 7 age groups)
3. Additional checks. After combining all datasets, combinations of data points were validated. For example, it can be expected that the verbal anchors of the sensation scale are drawn in the right order, i.e. from cold to hot. Responses, where the verbal anchors for the sensation scale were not in this order were flagged. In addition, outliers were flagged in case a multi-variate regression analysis detected them as outliers. The project leader informed researchers of those data points being flagged and requested an additional check of the original questionnaire. These validations looking for data consistency revealed that the answer patterns in questions 1a, 2a, and 3a, for 266, 307, and 84 questionnaires, respectively, did not meet the researchers’ expectations. The additional checks showed, that one researcher did not understand parts of the instruction of data entry correctly and repeated the data entry again. In the other cases, only 49, 34, 5 values were not correctly transferred, i.e. in 81.6%, 88.9%, 94%, the data was correctly transferred. In case there were more than 10% of data points flagged per one application, the project leader checked the validity of data entries at a random base based on scans of original questionnaires provided by the submitting researchers.

**Usage Notes**
For further analyses, it is recommended to use the final dataset on OSF and not the individual raw datasets, because revisions by data providers have only be made on the final dataset.

In total, 9111 questionnaires were distributed and 8225 responses collected (90% response rate). Note that the dataset provided consists of all 8225 questionnaires submitted. The authors did not want to exclude any
questionnaire from the dataset based on specific exclusion criteria, e.g. outlier definition or completeness of questionnaire. Future users of the dataset can make their own decisions, which questionnaires they consider as valid or not. Any exclusion criteria from the authors side, would limit the freedom of future users to make such decision.

**Code availability**

R software\(^6\) was used for all steps requiring data manipulation described above in section Data preparation and below in section Technical validation. Custom code was developed for these steps and is made available (see Code availability below). The custom code consists of three main scripts with additional functions loaded when running the scripts.

The first script (ScalesSurv_00_DataPreparationAndChecks.r) contains the steps for initial data screening and calculating additional variables for individual datasets.

The second script (ScalesSurv_01_LoadAllDatasets_compl_final.R) combines individual datasets and harmonizes some factor levels, e.g. changing all season descriptors ‘fall’ to ‘autumn’ for consistency with other descriptors.

The third script (ScalesSurv_02_Prepares_Data_final.R) is used for additional data preparations, such as additional harmonisations and adjustments to individual data points based on the results from technical validation.

All R scripts used for validating incoming data, acquiring climate classifications, and calculating additional variables are available on OSF\(^6\). The R version used for processing the data was 3.5.2 (2019-04-23). The packages used for data preparation and validation were: knitr, gridExtra, grid, ggplot2, panther, xtable, png, kableExtra, reshape2, SparseM, plyr, data.table.

Received: 8 May 2019; Accepted: 16 August 2019; Published online: 26 November 2019

**References**

1. Andersen, S., Andersen, R. K. & Olesen, B. W. Influence of heat cost allocation on occupants’ control of indoor environment in 56 apartments studied with measurements, interviews and questionnaires. *Build. Environ.* **101**, 1–8 (2016).
2. Andersen, R. K. The Influence of Occupants’ Behaviour on Energy Consumption Investigated in 290 Identical Dwellings and in 35 Apartments. In *Proceedings of Healthy Buildings 2012*, Brisbane, Australia (2012).
3. Blight, T. S. & Coley, D. A. Sensitivity analysis of the effect of occupant behaviour on the energy consumption of passive house dwellings. *Energy Build.* **66**, 183–192 (2013).
4. Guerra Santin, O., Itard, L. & Visscher, H. The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. *Energy Build.* **41**, 1223–1232 (2009).
5. Majcen, D., Itard, L. & Visscher, H. Actual and theoretical gas consumption in Dutch dwellings: What causes the differences? *Energy Policy* **61**, 460–471 (2013).
6. Schweiker, M., Carlucci, S., Andersen, R. K., Dong, B. & O’Brien, W. Occupancy and Occupants’ Actions. In *Exploring Occupant Behavior in Buildings* (eds Wagner, A., O’Brien, W. & Dong, B.) 7–38 (Springer, 2018).
7. Nicol, F. & Humphreys, M. A. Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy Build.* **34**, 563–572 (2002).
8. ASHRAE. Standard 55-2017. Thermal environmental conditions for human occupancy. *Am. Soc. Heating, Refrig. Air-Conditioning Eng. Atlanta, USA* (2017).
9. Schweiker, M. et al. Challenging the assumptions for thermal sensation scales. *Build. Res. Inf* **45**, 572–589 (2017).
10. ISO. ISO 10551. Ergonomics of the thermal environment—Assessment of the influence of the thermal environment using subjective judgment scales (2001).
11. Al-Khatri, H. & Gadi, M. B. Collective understanding of ASHRAE thermal sensation phrases among Arab students. In *10th Windsor Conference - Rethinking Comfort* (eds Brotas, L., Roaf, S., Nicol, F. & Humphreys, M.) 357–370 (NCUEB, 2018).
12. Humphreys, M. A., Nicol, F. & Roaf, S. *Adaptive thermal comfort: foundations and analysis*. (Routledge, 2016).
13. Pitts, A. The language and semantics of thermal comfort. In *Windsor Conference: Comfort and Energy Use in Buildings 1–7* (NCUEB, 2006).
14. Fuchs, X., Becker, S., Schakib-Ekbatan, K. & Schweiker, M. Subgroups holding different conceptions of scales rate room temperatures differently. *Build. Environ.* **128**, 236–247 (2018).
15. Mayer, E. Die bisherige Zuordnung von PMV und PPD noch richtig? *KI Luft- und Kältetechnik* **34**, 575–577 (1998).
16. Van Hoof, J. Forty years of Fanger’s model of thermal comfort: comfort for all? *Indoor Air* **18**, 182–201 (2008).
17. Al-Khatri, H. & Gadi, M. B. Investigating the behaviour of ASHRAE, Bedford, and Nicol thermal scales when translated into the Arabic language. *Build. Environ.* **151**, 348–355 (2019).
18. Humphreys, M. A. & Hancock, M. Do people like to feel ‘neutral’?: Exploring the variation of the desired thermal sensation on the ASHRAE scale. *Energy Build.* **39**, 867–874 (2007).
19. Fountian, M., Brager, G. & De Dear, R. Expectations of indoor climate control. *Energy Build.* **24**, 179–182 (1996).
20. Shahzad, S., Brennan, J., Theodosopoulos, D., Calautit, J. K. & Hughes, B. R. Does a neutral thermal sensation determine thermal comfort? *Build. Serv. Eng. Res. Technol.* **39**, 183–195 (2018).
21. Buratti, C. & Rucciardi, P. Adaptive analysis of thermal comfort in university classrooms: Correlation between experimental data and mathematical models. *Build. Environ.* **44**, 674–687 (2009).
22. Schweiker, M. et al. Contextual differences in the interpretation of thermal perception scales – a large-scale international questionnaire study. *Open Science Framework*. [https://doi.org/10.17605/OSF.IO/PS8R7] (2017).
23. Schweiker, M. et al. Contextual differences in the interpretation of thermal perception scales – the data base from a large-scale international questionnaire study. *Open Science Framework*. [https://doi.org/10.17605/OSF.IO/9P2GQ] (2019).
24. Humphreys, M. A., Nicol, F. & Roaf, S. *Adaptive thermal comfort: foundations and analysis*. (Routledge, 2016).
25. Rubel, F., Bragger, K., Haslinger, K. & Auer, I. The climate of the European Alps: Shift of very high resolution Köppen-Geiger climate zones 1800–2100. *Meteorol. Zeitschrift* **26**, 115–125 (2017).
26. R Development Core Team. *R: A Language and Environment for Statistical Computing*. (R Foundation for Statistical Computing, Vienna, Austria, 2012).
27. Mahdavi, A. & Taheri, M. An ontology for building monitoring. *I. Build. Perform. Simul.* **10**, 499–508 (2017).
28. ISO 639-1:2002. Codes for the representation of names of languages—Part 1: Alpha-2 code (2002).
29. EN 15251. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics; German version EN 15251:2012 (2012).
Acknowledgements

This project was conducted under the framework of IEA EBC Annex 69. M. Sch., S.B., and K.S.-E. acknowledge funding by the Heidelberg Academy of Sciences and Humanities within the project “Thermal comfort and pain”. M. Sch. is thankful to Prof. F. Nicol to share the information on participation via NCEUB, Prof. A. Wagner, Prof. G. Vrachliotis, and Dr. M. Krause from Karlsruhe Institute of Technology for their support in distributing questionnaires. A.A.-Z. would like to thank all the students from University of Technology- Iraq/Mechanical Engineering Department, who participated by providing answers to the questionnaire. F.A.-A. and the research related to Jordan was supported by M. Sch. H.A.-K. is thankful to Dalal Al-Khatiri, Noor Alhuda Al-Saqr, and Maryam Al-Bartamani for their contribution in distributing the questionnaires. E. Am. is thankful to Eleni Alexandrou of the National Technical University of Athens for her contribution in distributing the questionnaires. B.C. is thankful to the National Natural Science Foundation of China (No. 51521005 and No. 51678330). C.C. is thankful to National Research Foundation of Korea (No. NRF-2017R1A2B401212) J.-H.C. would like to express gratitude to the USC students who volunteered for the data collection, and a special thanks to Ms. Zhihe Wang, who provided a technical assistance to compile the acquired dataset. S.D.-A. is thankful for the funding support of the TEP-130 R&D group from the US. L.P.E. would like to thank IITM, India for the support and DAAD for the scholarship. G.G. is thankful to Andrés Chico, Freddy Ordoñez, Jesús López (Escuela Politécnica Nacional – EPN), Ricardo Narváez (Universidad Central del Ecuador), Guillermo Soriano (Escuela Superior Politécnica del Litoral – ESPOL), Daniel Quiroz (Universidad Regional Amazónica Ikaíam) and Stalin Guaman (Universidad Regional Amazónica Ikaíam). S.G. would like to thank the Sustainable Energy Research Group (energy.soton.ac.uk) for supporting this work. D.H. is thankful to all the students from Universiti Malaysia Sabah who participated in the present field study. She is also very grateful to all the lecturers who contributed directly and indirectly in the present study. R.T.H. would like to thank Prof. Markus Reppich and Prof. Michael Krupp and all HSA students involved for their support. C.M.H. was supported by Research Council of the UK (EPSRC) and UK Research and Innovation through the Centre for Research into Energy Demand Solutions, grant reference number EP/R035288/1. Q.J. acknowledges the funding by Chalmers Energy Area of Advance and is thankful to Jan-Olof Dalenbäck, Holger Wallbaum, Björn Gross, and Ulrike Rahe. B.K. is thankful for Heatshield, under EU Horizon 2020 grant agreement No 668786 and the Ministry van Defensie (SOLAR V1605). ]Ko. would like to thank Prof. Jorn Toftum for help with translation of the survey questionnaire. A.K. is appreciative of the volunteer work of Yi-Cheng Lei, Eugene Leung, Bentley Rager, Rachel Rimmer, and Kelly Schoenborn. M.C.J.L. would thank for MOST Taiwan and NTCUST to support the funding and measure instruments. L.M.-R. is thankful to Andrés Chico, Freddy Ordoñez, Jesús López (Escuela Politécnica Nacional – EPN), Ricardo Narváez (Universidad Central del Ecuador), Guillermo Soriano (Escuela Superior Politécnica del Litoral – ESPOL), Daniel Quiroz (Universidad Regional Amazónica Ikaíam) and Stalin Guaman (Universidad Regional Amazónica Ikaíam). I.R. is thankful for first year Architecture students of University of Moratuwa who volunteered for the data collection. M.O.K. would want to thank all the students from Imo State University, Owerr and Federal Polytechnic, Nekede who participated by providing answers to the questionnaire. M.O.L. would like to thank Tadeo Neneda and Menelik Tibkabire who helped administer the questionnaires. W.O. would like to thank Prof. Bruce Lonman for his support and all CUHK students involved. The study is supported by General Research Fund, Research Grant Council, Hong Kong (Project code: 14629516) and Vice-Chancellor’s One-off Discretionary Fund of the Chinese University of Hong Kong. A.L.P.A. would like to thank the Civil Engineering students of IFSC who volunteered for the data collection. M.I.R. is appreciative of the volunteer work of Yi-Cheng Lei, Eugene Leung, Bentley Rager, Rachel Rimmer, and Kelly Schoenborn. V.S.'s involvement in the project was partially funded through the Special Study Program provided by The Faculty of Professions, University of Adelaide. D.T. would like to thank Vinnova (Sweden’s Innovation Agency) and her colleagues at the Division of Building Services Engineering for their support.

Author contributions

All authors provided feedback on all steps, especially critical feedback on the paper, and data collection. M. Sch. conceived of the idea (together with S.B. and K.S.), organized the project, wrote the R scripts and the manuscript, contributed to datasets DEKIT, was involved in preparing the English version, translating and piloting the German version and development of methods. A.A.-Z. contributed to datasets IRTIA, was involved in preparing the English version, translating and piloting the Dutch version. A.A.-Z. contributed to datasets DEHSA, was involved in preparing the English version, translating and piloting the Arabic version. H.A.-K. contributed to datasets IRTIA. D.H. contributed to datasets MYUMS, was involved in translating and piloting the Malaysian version. R.T.H. contributed to datasets DEHSA, was involved in preparing the English version, translating and
piloting the German version and development of methods. G.M.H. contributed to datasets GBUOS and GBUCL, was involved in preparing and piloting the English version and developments of methods. Q.J. contributed to datasets SECTH05 and 06. M.J. contributed to datasets GBCOY. R.K. contributed data preparation and checks. J.Ki. contributed to datasets AUSYD, was involved in preparing and piloting the English version and developments of methods. N.K. contributed to datasets AEKUS. B.K. contributed to datasets NLVUA. M.D.K. contributed to datasets IDITB. J.Ko. contributed to datasets DKDTU, was involved in translating and piloting the Danish version. S.K. contributed to datasets INJA1 and INHYD. A.K. contributed to datasets USUOR. R.L. contributed to datasets BR. M.L. contributed to datasets LPWPR, was involved in translating and piloting the Polish version. M.C.J.L. contributed to datasets TWNUT, was involved in preparing the English version, translating and piloting the traditional Chinese version and development of methods. Y.L. contributed to datasets DEHSIA. M.M. contributed to datasets IRKERA. U.M.-O. contributed to datasets NGIMS. L.M.-R. contributed to datasets CLUBBB, was involved in translating and piloting the Spanish (Chile) version. A.M. contributed to datasets DEUKL. F.M. contributed to datasets ITPBA, was involved in translating and piloting the Italian version. J.M. contributed to datasets INJA1 and INHYD. G.M. contributed to datasets UKGSA. J.M.-R. contributed to datasets EC, was involved in translating and piloting the Spanish (Ecuador) version. D.M. contributed to datasets CNTHU, was involved in preparing the English version, translating and piloting the simplified Chinese version and development of methods. B.M. contributed to datasets USUCB. E.N. contributed to datasets HKCHU. M.Ok. contributed to datasets NGIMS. M.Ol contributed to datasets UGNKZ. W.O. contributed to datasets HKCHU. A.L.PA. contributed to datasets BR. A.P-F. contributed to datasets CLUBBB, was involved in translating and piloting the Spanish (Chile) version. I.R. contributed to datasets LKUOM, was involved in translating and piloting the Sinhalese version. G.R. contributed to datasets BR, was involved in translating and piloting the Portuguese version. S.R. contributed to datasets IQUOB, IQTUB and IQNAH, was involved in translating and piloting the Arabic version. C.FR. contributed to datasets USMIT. M.I.R. contributed to datasets USUOR. M.Sa. contributed to datasets IRKERA. K.S.-E. contributed to datasets DEKIT, was involved in preparing the English version, translating and piloting the German version and development of methods. S.Sch. contributed to datasets USUCB. S.Sh contributed to datasets AURML. M.Shk. contributed to datasets IPTCU, was involved in translating and piloting the Japanese version. V.S. contributed to datasets USUCB. S.Su. contributed to datasets IDITB was involved in translating and piloting the Indonesian version. M.Ta. contributed to datasets IRSBU. E.T. contributed to datasets AUUOW. D.T. contributed to datasets SECTH01 to 04, was involved in preparing the English version, translating and piloting the Swedish version and development of methods. P.T. contributed to datasets INJA1 and INHYD. S.T. contributed to datasets INSAL. M.T. contributed to datasets CLUBBB, was involved in translating and piloting the Spanish (Chile) version. J.T. contributed to datasets DEUKL. R.B.T. contributed to datasets NGABU. C.V. contributed to datasets DEBUW. Y.Y. contributed to datasets HKCHU. L.Y. contributed to datasets CNXIA. G.Z-L. contributed to datasets GBCAR. Y.Zhai. contributed to datasets CNXIA. Y.Zhu. contributed to datasets CNTHU, was involved in translating and piloting the simplified Chinese version. Z.Z. contributed to datasets IRSBU and IRTIA, was involved in translating and piloting the Farsi version.

Competing interests
The authors declare no competing interests.

Additional information
Correspondence and requests for materials should be addressed to M. Schweiker.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit http://creativecommons.org/licenses/by/4.0/.

The Creative Commons Public Domain Dedication waiver http://creativecommons.org/publicdomain/zero/1.0/ applies to the metadata files associated with this article.

© The Author(s) 2019

Marcel Schweiker1,2,*, Amar Abdul-Zahra3, Maira André4, Farah Al-Attrash5, Hanan Al-Khatrif6, Rea Risky Alprianti1,7, Hayder Alsaad4,8, Ruchia Amin9, Eleni Ampatzis10, Alpha Yacob Arsano11, Montazami Azadeh12, Elie Azar13, Bannazadeh Bahareh14,

123
6, SE-412 96, Gothenburg, Sweden. 36Faculty of Engineering, Environment and Computing, Coventry University, Gulton road, CV1 2JH, Coventry, United Kingdom. 37School of Architecture, Design and Planning, The University of Sydney, Wilkinson Bldg G04, 2006, Sydney, Australia. 38Training and Performance Optimization, The Netherlands Organisation for Applied Sciences, Kampweg 55, 3769 DE, Soesterberg, The Netherlands. 39Department of Nutrition, Exercise and Sports, University of Copenhagen, 2100, Copenhagen, Denmark. 40Department of Civil Engineering, Technical University of Denmark, Brovej 118, 2800, Kgs, Lyngby, Denmark. 41Centre for Energy and Environment, Malaviya National Institute of Technology (MNIT), JLN Marg, 302006, Jaipur, India. 42Department of Architecture, College of Design, University of Oregon, 1206 University of Oregon, 97403, Eugene, United States of America. 43Department of Interior Design, National Taichung University of Science and Technology, 129, Sec. 3, Sanmin Road, 40401, Taichung, Taiwan. 44Mechanical Engineering, Shahid Bahonar University of Kerman, Jomhouri, 76169133, Kerman, Iran. 45Architecture, Federal Polytechnic, Polytechnic Road, 460262, Nekede, Nigeria. 46Faculty of Architecture, Construction and Design, University of Bio-Bio, Avda Collao 1202, 4081112, Concepcion, Chile. 47Department of Psychology, University of Koblenz-Landau, Fortstraße 7, 76829, Landau, Germany. 48Dipartimento di Scienze dell’Ingegneria Civile e dell’Architettura, Politecnico di Bari, Via Orabona, 4, 70125, Bari, Italy. 49Mackintosh Environmental Architecture Research Unit, Glasgow School of Art, 167 Renfrew Street, G3 6RQ, Glasgow, United Kingdom. 50Institute for Environmental Design and Engineering, University College London, Gower Street, WC1E 6BT, London, United Kingdom. 51Project-team BPE, Cerema, 46 Rue St Théobald, 38081, L’Isle d’Abeau, France. 52Center for the Built Environment (CBE), University of California, Berkeley, 232 Wurster Hall #1800, 94720, Berkeley, United States of America. 53School of Architecture, Institute of Future Cities, Institute of Environment, Energy and Sustainability, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong SAR, China. 54Architecture, Imo State University, Samek Road, 460222, Owerri, Nigeria. 55Faculty of the Built Environment, Uganda Martyrs University, Nkozi, Uganda. 56School of Architecture, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong SAR, China. 57Department of Civil Construction, Federal Institute of Santa Catarina, Av. Mauro Ramos, 950 - Centro, 88.020-300, Florianópolis, SC, Brazil. 58Department of Building Science, University of Bio-Bio, Avda Collao 1202, 4081112, Concepcion, Chile. 59Department of Architecture, University of Moratuwa, 10400, Moratuwa, Sri Lanka. 60Department of Building Physics/Low Energy Buildings, Technical University Kaiserslautern, Paul-Ehrlich-Straße 29, 67663, Kaiserslautern, Germany. 61Departamento de Arquitectura, Facultad de Arquitectura, Urbanismo y Geografía, Universidad de Concepción, Barrio Universitario, Casilla 160-C, 4089100, Concepción, Chile. 62Property, Construction and Project Management, RMIT University, Swanston, 3000, Melbourne, Australia. 63Department of Environmental Studies, Salesian College, 734219, Sonada, Darjeeling, India. 64Department of Construction, Shahid Beheshti University, Evin, 1983969411, Tehran, Iran. 65Sustainable Buildings Research Centre, University of Wollongong, Squires Way, 237, 2500, Wollongong, Australia. 66Division of Building Services Engineering, Department of Architecture and Civil Engineering, Chalmers University of Technology, Sven Hultins gata 6, SE-412 96, Göteborg, Sweden. 67Department of Environmental Studies, Salesian College, 734219, Sonada, Darjeeling, India. 68Department of Architectural Theory and Design, University of Bio-Bio, Avda Collao 1202, 4081112, Concepción, Chile. 69Akademie für angewandte Bewegungswissenschaften gGmbH, Walter-Krause-Str. 11, 68163, Mannheim, Germany. 70Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong SAR, China. 71School of Architecture, Xi’an University of Architecture and Technology, Yanta Road, 710055, Xi’an, China. 72Welsh School of Architecture, Cardiff University, King Edward VII Av., CF10 3NB, Cardiff, United Kingdom.