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A path analysis of outdoor comfort in urban public spaces

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ABSTRACT

Research on outdoor comfort generally focuses on the thermal sensation as a substitute for actual comfort. The assessment of outdoor comfort, however, is complex in nature because it involves various contextual settings in open spaces, individuals’ social demographics, and psychological factors. In contributing to the existing literature, this study attempts to extend the modelling framework of outdoor comfort assessment by incorporating physical microclimate, spatial contexts, social demographics and individuals’ subjective perceptions, expectations and preferences. A path analysis is conducted to capture the direct and indirect effects of various factors on comfort using the data collected in a field experiment. Results show that the causal dependency, which is normally simplified in existing studies, can be better illustrated with the indirect effects through mediators. The use of objective indicators and individuals’ subjective factors are fundamental to adequately capture the actual comfort in urban public spaces.

1. Introduction

Research interest in the quality of urban public spaces has dramatically increased in recent years due to the rapid process of migration from rural areas to urban areas. The concentration of city residents and consequent emerging requirements on improving the quality of the urban environment and revitalising the city centre has resulted in the need for sustainable urban development [1–3]. Outdoor public space plays an essential role in shaping urban daily life as being the place for social interaction and various activities, such as culture, entertainment and sport as well as commercial activities [4–6]. The fascinating and vibrant cities should accommodate diverse activities for the people by offering more desirable and attractive public spaces, so people can carry out their activities in relative comfort and safety while interacting, engaging in spectacles and ceremonies, or just simply sitting or waiting [7,8]. Activities in the public realm are highly influenced by microclimate and specified by urban spatial settings. Thus, participants differ in their assessment of comfort. In order to provide valuable insight into the performance of the outdoor built environment, comfort has been a primary measure for public space design and the assessment of its quality [9,10].

Conceptually, thermal comfort has been described as a state of mind, approximating one’s satisfaction with the environment [11]. However, in view of thermal physiology, the neutral thermal sensation is typically used as a substitute for overall comfort [12]. The objective indicators of physical meteorological condition and human physiological status capture measurable and quantifiable attributes well. An individual’s subjective thermal comfort was technically interpreted as an objective quantity when the heat balance between the human body and its surroundings is approached [13]. Over the last few decades, thermal comfort has been measured mainly through heat balance indices, such as Predicted Mean Vote (PMV) [14], Standard Effective Temperature (SET*) [15] and its outdoor update (OUT_SET*) [5,16], Physiologically Equivalent Temperature (PET) [17] and Universal Thermal Climate Index (UTCI) [18], etc. However, most of these indices are limited to the specific steady state with thermally homogenous environments. Regarding outdoor comfort, the related microclimate can hardly remain unchanged and the heat balance of human body and environment is consequently unstable. Therefore, unlike in the steady-state environment, prediction with these indices is not justifiable in transient conditions, especially in outdoor spaces [18]. Moreover, individuals are isolated with a role to only respond to the ambient thermal condition. This underlying postulation does not incorporate the personal indicators like psychological and behavioural aspects. Still, heat balance theory, which substitutes the neutral sensation for thermal comfort, has had a profound influence on outdoor comfort modelling [12,19].

The diverse and complex context of urban public spaces and their
spatial settings with the corresponding microclimate faced by individuals is driving an increasing need for a full understanding of outdoor comfort. Still, people have different perceptions and preferences when they are exposed to different environments, despite having identical thermal balances, as indicated by heat balance theory. In this regard, comfort is an outcome of the interaction between an individual's preferences and perceived opportunities and constraints induced by specific outdoor microclimate and spatial-temporal urban settings within a particular institutional and local context. Over recent decades, many field studies on outdoor thermal comfort have been carried out in different cities and climate zones. Various effects have been identified with respect to microclimatic conditions, participants' psychological factors, experience of outdoor use and layout of urban spaces [4,5,20–23]. Therewith, the significant discrepancy in the results of empirical investigations between heat balance index and on-site interviews triggers the need for systematic modelling and prediction of outdoor comfort. Data related to physical meteorological conditions and subjective psychological and behavioural factors can give a further insight into comfort assessment.

The physiological difference between comfort and thermal sensation was confirmed by experimental investigation a long time ago [24]. As a rational experience, thermal sensation is directed towards an objective world in terms of cold and warm; thermal comfort, on the other hand, is an emotional experience and relative to expectation [25]. Instead of thermal neutrality, an individual's comfort emerges from a desired sensation or satisfaction [26–28]. In contrast to heat balance theory, the mainstreaming of adaptive comfort principles assumes that comfort will derive from the standpoint of adaptation, which is more than a derivative of neutrality state or an outcome of steady-state heat balance [29,30]. Individuals have the ability to be more comfortable through the access to opportunities to modify conditions such as changing clothing or activity level [31]. The “average person” comfort has been specified individually and extended by taking into consideration dynamic, integrated and participatory aspects [31–33]. The postulation that comfort is the physical state of a passive individual recipient has been developed and advanced to the psychological perception derived from their experience, expectation and reaction. The individual’s role is gaining increasing importance, therefore drawing more and more attention within comfort modelling [34]. In addition, comfort has been socially determined and defined by norms and expectations, shifting from one time, place and season to the other. The context-based individual and social factors on thermal perception have been studied through investigation in outdoor spaces, which reveal the specific thermal requirements of the occupants and their relationship with the moderating factors [10,35]. Moreover, the culture and climate that people are used to, their emotional state, visiting purpose and their use of public spaces may potentially also link to individuals' subjective evaluation of outdoor comfort [35–38].

A qualitative method linking thermal and spatial information and people's perceptions has been developed [13]. The divergence between thermal index and actual response in field studies show that an individual's thermal expectation and preference induced by contextual factors are specific to different urban settings and corresponding microclimates. The energy-balance indices may not be universally applicable across contexts [39]. The importance of physical, physiological and psychological influential aspects have been addressed by several empirical in-situ investigations based on either heat balance theory or adaptive approaches [37,39,40]. However, the direct causal relationships between comfort and influences have been modelled without considering psychologically mediated effects. Still, the mechanism of the influence on comfort was simplified as one single step from the triggering factors to direct assessment. Few studies investigate the indirect effects that are different from the cause-effect process [37,41]. Systematically investigating the perceptual mechanism of comfort assessment therefore becomes necessary and critical [42].

Outdoor activities take place in the context of ever-changing and non-uniform physical conditions in terms of microclimate and other environmental elements (e.g. noise, air quality, landscape, lighting, etc.). Adequate consideration should be taken on the perceptual process related to the activities within the spatial-temporal and institutional constraints in urban public spaces. The human dimension of comfort assessment should be particularly well established in urban public spaces because this is where people frequently gather [43]. Thus, the related comfort should be specified as a derivative of an individual's activities within a particular outdoor environment. The actual adaptation to outdoor activities may be affected by the magnitude of individuals' familiarity with the place and experience of microclimate therein [44,45]. From this point of view, we presume that an individual has his/her own cognitive schema, which is related to their expectation and familiarity of the microclimatic and spatial condition in intended public spaces. This insight on participants' responses to comfort derives from the integrated structure of direct and indirect effects, constituting the starting point for a new model. Considering explicitly the role of mediators, in this study, the manifold influencing factors are incorporated systematically to reveal their impacts on comfort assessment. More specifically, a comprehensive path model is formulated to elicit the influential factors and their effective path on outdoor comfort. We examine the effects of mediators using the data collected from a field study in the public spaces of Eindhoven city centre, in the Netherlands.

This paper therefore aims to outline an expanded and integrated conceptual framework that illustrates comfort assessment in non-uniform and unsteady outdoor environments by considering the nature and strength of both direct and indirect influences. The simplified causal relationships are modelled through path analysis discovering the intermediary function of related psychological factors. The path analysis entails the comfort assessment by both physical microclimate conditions and human factors in a structured process (e.g. emotional status, perceived meteorological situations and urban spatial settings). We contend that outdoor comfort cannot be viewed as only a manifestation of neutral status in heat balance, but rather the outcome of a perceptual process associated with respondents’ expectations and preference formed by their outdoor behaviour, thermal experience, socio-demographic characteristics and emotional status, which are influenced by experiences implementing behavioural adjustments and psychological adaptations. Thus, we utilise the acceptability and need satisfaction of outdoor activities as two mediators. The microclimate and other environmental stimuli perceived by individuals are related to the degree of their acceptability and the satisfaction of outdoor activities. As such, the new approach is consistent with the basic premise underlying the development of path analysis to replace the traditional methodology by explicitly taking into account both direct and indirect effects.

2. Methodology

2.1. Field experiment

A series of field studies was conducted in Eindhoven, an industrial city in the south-east part of the Netherlands. This city is categorised as having temperate oceanic climates (Cfb) according to the “Köppen-Geiger” climate classification, which involves a moderate winter and summer. Such data, for a comfort study, are typically collected through two methods of in-situ investigation: automated monitoring and manual survey. A location-based face-to-face interview was considered the best way to provide in-depth information to help understand respondents’ feelings, perceptions, and attitudes in terms of comfort. Accordingly, the questionnaire used in the survey was conceived based on an improved conceptual framework with extended consideration of individuals' demographics and psychological and behavioural aspects.

The specific locations of the survey were elaborately assigned based on the principle of Orthogonal Experiment Design (OED, in order to avoid potential bias caused by spatial settings and functional features of
public spaces [46,47]. Experiment design has been applied in general for multivariate analysis. However, studies on outdoor comfort assessment utilising this approach are scarce. The key task in the experiment design is to find the optimal combination of attribute levels that results in orthogonality and balance. In practice, however, a fractional factorial design is normally used as a full factorial design normally results in a large number of combinations.

In this study, the main factors required in OED related to spatial setting and functional features were selected, which include landscape water or fountain (W), facility for sitting (F), green lawn (G), catering kiosk service (A) and trees or shelter from sun and wind (S). Each factor was set in two levels, resulting in $2^5 = 32$ possible profiles in total. Therefore, optimal combinations of attribute levels were created with resolution III fractional design. Eight representative public spaces in the city centre were selected representing the overall situation (see Table 1). The specific locations are marked on the map, as shown in Fig. 1 with the corresponding picture of the scene.

The typical meteorological variables, such as air temperature, humidity, global temperature and wind velocity, were measured simultaneously. Monitoring sensors were equipped on a tripod and connected with the data-logger and battery according to ISO7726 [48]. To better understand the properties, the range and accuracy of the sensors were specified. Detailed parameters are presented in Table 2. In addition, the values of global temperature, air temperature and wind velocity were used to calculate the mean radiant temperature according to the modified calculation method [49]. For proper execution of the survey, the questionnaire was designed in Dutch and English to avoid language issues. The answer of the rating form was based on a seven-point Likert scales. In particular, for evaluation of an individual’s emotional status, the Positive and Negative Affect Schedule (PANAS) was utilised, which was proposed by Watson (1988). In PANAS, respondents were asked to rate to what extent they experienced each of the 20 effects as described by adjective words (ranging from “not at all” to “extremely”). Half of the presented adjectives are related to positive effects and the other half to negative effects. Besides the rating of thermal sensation, respondents were also asked to evaluate the level of acceptability and need satisfaction of outdoor activity and comfort assessment.

### Table 1

| Specific spot | G | S | A | F | W |
|---------------|---|---|---|---|---|
| S1            | 1 | 1 | 1 | 1 | 1 |
| S2            | 1 | -1| -1| -1| 1 |
| S3            | -1| 1 | -1| 1 | 1 |
| S4            | -1| -1| 1 | -1| 1 |
| S5            | -1| 1 | 1 | -1| -1|
| S6            | -1| 1 | 1 | -1| -1|
| S7            | 1 | -1| 1 | 1 | -1|
| S8            | 1 | 1 | -1| -1| -1|

### Table 2

| Variable                | Model         | Resolution | Accuracy                     |
|-------------------------|---------------|------------|------------------------------|
| Air temperature         | NTC           | 0.01K      | ± 0.05K                      |
| Relative humidity       | HUMITTER 50U  | 0.1%       | ± 3%, 10–90%                 |
| Wind velocity           | CLIMA         | 0.1 m/s    | ± 0.3 m/s rms, $v \leq 5$ m/s|
|                         |               |            | ± 3% rms, $v > 5$ m/s        |
|                         |               |            | ± 5% rms, $v > 50$ m/s       |
| Global temperature      | NTC (in a black ball) | 0.01K | ± 0.05K                      |

Fig. 1. Studied locations and scene.
(Source: maps were downloaded from www.openstreetmap.org, and photos were taken by the authors)
The whole course of data collection ranged from the end of March 2015 to the beginning of April 2015 in ten inconsecutive days without precipitation. With the assistance of 54 Master students from the Department of Built Environment at Eindhoven University of Technology, a series of cross-sectional surveys were carried out along with physical measurements. More than 1000 questionnaire-based interviews were conducted across different locations by randomly recruiting respondents. The portable device with sensors and a data-logger was set up to monitor the physical condition automatically. A scene of the survey is shown in Fig. 2. Some respondents were interviewed while sitting on bench with a monitoring device set nearby. Data on microclimate and noise were collected through the fieldwork. The survey started with a concise explanation of the research purpose. The exact start and end times of the interview were recorded. The duration of each interview was used to synchronise the measurement for the precise average values of variables. In general, respondents spent ten to twenty minutes to complete an interview.

2.2. Path analysis

Path analysis is an extension of multiple regression analysis, which is regarded as a special case of structural equation modelling (SEM) [50,51]. As SEM deals with measured and latent variables, path analysis deals with observed variables only. In this study, path analysis is utilised to estimate the magnitude and significance of hypothesised relationships between comfort and sets of variables related to physical microclimate and individuals’ socio-demographic characteristics, emotional status, expectations and perceptions of microclimate and environment condition, along with relevant behaviour factors.

The dependent variable in the path model is outdoor comfort, which is different from the neutral thermal sensation. Further, we believe that, to conduct activities, individuals need to be involved in active interactions with the urban environment. If the experience of a location does not satisfy the expectation, the individual will continue to adapt themselves. However, if the adaptation is repetitively constrained, the assessment may be negative. Individuals may still be pleased with the experience although the unpleasant experiences accumulated could reinforce that individual’s perception.

The path model aims to overcome the potential shortcoming in conventional models, e.g. linear regressions by transforming the causal influences to direct and indirect effects. These possible relationships and their strength are cornerstones of the comfort perception mechanism, and have to be revealed by path analysis. For example, we postulate that microclimate affects comfort perception through thermal sensation and the acceptability of outdoor activities. The time individuals spend in outdoor environments may have potential impacts on comfort. We assume that there are relationships between the overall outdoor comfort and individuals’ thermal sensation, thermal acceptability and need satisfaction of outdoor activities. In addition, the integrated exogenous influences, such as microclimate condition, individuals’ socio-demographic characteristics, behaviour factors, emotional status and subjective perception of urban settings and corresponding microclimate and environment attributes are also investigated.

The comfort perception is conceptualised as a process in which individuals attempt to adapt themselves and satisfy the particular need in outdoor environments, given a microclimate and perceived spatial-temporal constraints with their own experience. A conceptual structure of the direct and indirect effects on comfort is presented in Fig. 3. Based on the hypothesis, the paths have been set up to include the connections between the endogenous variables and the influences from the exogenous variables. Through existing investigations, we predefine the relationships between comfort assessment and the acceptability and need satisfaction of outdoor activities. In addition, the endogenous variables are impacted by the manifold exogenous variables in terms of place-related attributes (e.g. microclimate condition, environmental stimuli) and human-related factors (e.g. social demographics, preference and perception of environment).

The hypothesised connections are illustrated in Table 3. Having identified the relationships, a maximum likelihood estimation method was used to estimate the parameters.

3. Results

3.1. Descriptive statistics

Based on the data collected in the field study, the descriptive statistics of microclimate conditions are presented in Table 4. The whole fieldwork was conducted at the beginning of spring, which is characterised as a relatively cold thermal condition, having a lowest temperature of 4.2 °C. The wind velocity was up to 3.9 m/s, which is within an acceptable scope. In general, the ranges of air temperature, relative humidity, wind velocity and mean radiant temperature are large, which means the microclimatic condition changes daily and hourly.

In total, we obtained 701 effective samples. The results of the descriptive statistics of socio-demographic characteristics are presented in Table 5. The majority of respondents are aged between 16 and 35. The number of males is slightly higher than the number of females. Most respondents are in good health, with only few reporting indispositions.
A large proportion of respondents have the medium body mass index, ranging from 18.9 to 24.9. In addition, education is mainly distributed in the categories from "intermediate vocation college" to "Master's degree holder". Most respondents are Dutch, while about 23% of the respondents have a foreign nationality.

The descriptive statistics of behaviour-related factors are demonstrated in Table 6. It shows more than half of the respondents walked near to the monitoring devices before they were invited into the survey. Over 60% of the respondents came with transport tools, including bike, car or public transportation, and the rest came by foot. Since all surveys were conducted in public spaces of the city centre (e.g. shopping area, transportation hub), a large proportion of respondents’ visiting frequency is once a week and more (more frequent than “scarcely”). In terms of outdoor duration, most respondents spend less than one hour in outdoor environments and less than 30 min in the studied location. Almost half of the respondents came for the sake of passing by or were in transit for the next trip, and the rest stayed for different purposes, such as social activity, shopping, rest, leisure and other objectives.

### 3.2. Results of the path analysis

The direct and indirect relationships are estimated using the data collected from in-situ measurements and surveys. The correlation of exogenous variables was not allowed in this model. Results of the goodness-of-fit of the path model are listed in Table 7. As demonstrated, this model is testified as a good-fitting model based on the values of the Comparative Fit Index (CFI) and Tucker Lewis Index (TLI), which are
greater than the empirical cut-off criterion [52]. Further, the Standardized Root Mean Square Residual (SRMSR) is far less than 0.08. The value of Root Mean Square Error of Approximation (RMSEA), which measures the discrepancy per degree of freedom, is smaller than the empirical threshold, 0.05. In summary, the structure of the direct and indirect relationships is proved as significant.

As presented in Fig. 4, a majority of the exogenous variables have indirect impacts on comfort assessment through mediators. Still, there are some variables that have both significant direct and indirect effects. Results of the constants are shown in Table 8. The coefficients of all direct and indirect connections are presented in Table 9 with the level of significance (**: p < 0.01, ***: p < 0.05 and *: p < 0.1).

Based on the estimation results, the microclimatic variables, such as air temperature, wind velocity and relative humidity, show significant indirect influence on comfort. However, the mean radiant temperature has no noteworthy effects. In particular, air temperature significantly impacts an individual’s outdoor thermal sensation. The direct relationship between air temperature and the acceptability of outdoor activity was also investigated; however, no evident effect was found. In contrast, relative humidity slightly influences the acceptability of outdoor activity in a negative way but it does not act on thermal sensation. It is reasonable that wind velocity negatively impacts respondents’ thermal sensations and thermal acceptability because the data collection was carried out in the early spring with relatively low average air temperature. In addition, in the context of Dutch historical meteorology, wind turbulence has been always criticised as an annoying phenomenon, especially in the cold and cool seasons. To speak of mean radiant temperature, as a physical meteorological influence, although it is the most decisive determinant in some traditional thermal indices, in this model, only a negligible effect was revealed with a low significant level according to the estimate for both thermal sensation and acceptability.

With regard to socio-demographic characteristics, the influences of age, sex and education level have been demonstrated through the path model. As shown in Fig. 4 and Table 9, a significant negative direct connection was found between age and thermal sensation. In the context of the cold season in Eindhoven, senior interviewees responded to the thermal sensation tending to the colder side, as they may have a narrower range of neutral thermal sensation than younger respondents, and may be more sensitive to any deviation from an optimal environment and express more discomfort through thermal sensation. Nevertheless, we only interviewed individuals between 13 and 85. The influence of age on juveniles and children needs further investigations.

The education level of respondents is confirmed to have only a direct negative impact on comfort perception, while sex has both direct and indirect connections with comfort assessment. The indirect effect is imparted by the mediator of the need satisfaction of outdoor activity. Respondents with a higher education level had a lower comfort level. In addition, the male was inclined to have a more comfortable feeling than the female in an outdoor environment, and felt more satisfaction in outdoor activity. A growing number of studies have found significant differences in thermal comfort between sexes and many field studies showed that females express more discomfort than males, especially in

Table 7
Goodness of fit of the path analysis.

| Chi-Square Test | Value | Degree of Freedom | P- value | SRMR | RMSEA | CFI | TLI |
|-----------------|-------|-------------------|----------|------|-------|-----|-----|
| Value           | 197.614 | 86                | 0.000    | 0.014 | 0.043 | 0.935 | 0.889 |

Table 8
Estimation of the intercepts.

| Intercepts              | Estimate | Standard Error | P-Value |
|-------------------------|----------|----------------|---------|
| Thermal sensation       | 2.339    | 0.816          | 0.004   |
| Acceptability of outdoor activity | 5.892  | 0.963          | 0.000   |
| Need satisfaction       | 1.218    | 0.578          | 0.035   |
| Comfort                 | 1.254    | 0.442          | 0.005   |

Fig. 4. Diagram of path analysis (variation due to error is not included for simplicity).
Table 9
Estimation results of the path model.

|                        | Estimate | Standard Error | P-Value |
|------------------------|----------|----------------|---------|
| **Thermal Sensation on** |          |                |         |
| air temperature        | 0.159    | 0.039          | **<0.001** |
| wind speed             | -0.267   | 0.083          | **<0.001** |
| relative humidity      | 0.004    | 0.007          | 0.586   |
| mean radiant temperature| 0.005    | 0.006          | 0.378   |
| age                    | -0.006   | 0.004          | 0.097   |
| sitting                | 0.263    | 0.114          | **<0.001** |
| standing               | 0.352    | 0.145          | **<0.001** |
| by foot                | -0.308   | 0.113          | **<0.001** |
| by bike                | -0.054   | 0.128          | 0.676   |
| perceived wind speed   | -0.131   | 0.032          | **<0.001** |
| perceived humidity     | -0.058   | 0.031          | 0.059   |
| perceived sunlight     | 0.249    | 0.030          | **<0.001** |
| total outdoor duration | -0.197   | 0.037          | **<0.001** |

| **Acceptability for outdoor activity on** |          |                |         |
| air temperature        | -0.052   | 0.045          | 0.249   |
| wind speed             | -0.263   | 0.095          | **<0.001** |
| relative humidity      | -0.050   | 0.008          | **<0.001** |
| mean radiant temperature| 0.004    | 0.007          | 0.576   |
| prospective thermal sensation | 0.168 | 0.040          | **<0.001** |
| prospective wind speed | 0.060    | 0.037          | **<0.001** |
| perceived opportunity  | 0.076    | 0.035          | **<0.001** |
| perceived wind speed   | -0.065   | 0.039          | 0.095   |
| perceived humidity     | -0.064   | 0.036          | **<0.001** |
| perceived sunlight     | 0.146    | 0.037          | **<0.001** |
| Thermal sensation      | 0.265    | 0.045          | **<0.001** |

| **Need Satisfaction on** |          |                |         |
| sex                     | 0.205    | 0.102          | **<0.044** |
| environmental preference | -0.046   | 0.026          | **<0.001** |
| positive affects        | 0.026    | 0.007          | **<0.001** |
| negative affects        | -0.033   | 0.010          | **<0.001** |
| by foot                 | -0.496   | 0.122          | **<0.001** |
| by bike                 | -0.132   | 0.134          | 0.326   |
| waiting for bus or train| 0.462    | 0.374          | 0.216   |
| resting                 | 1.000    | 0.385          | **<0.001** |
| social activity         | 0.234    | 0.410          | 0.569   |
| shopping                | 0.901    | 0.377          | **<0.017** |
| leisure                 | 0.789    | 0.390          | **<0.003** |
| passing by              | 0.910    | 0.380          | **<0.001** |
| perceived spatial openness| 0.145   | 0.036          | **<0.001** |
| adaptive adjustment     | 0.491    | 0.146          | **<0.001** |
| total outdoor duration  | -0.128   | 0.051          | **<0.012** |
| duration in current place| 0.197  | 0.064          | **<0.002** |
| perceived air quality   | 0.096    | 0.035          | **<0.001** |
| perceived noise         | -0.066   | 0.032          | **<0.041** |
| preference of wind speed| 0.083    | 0.034          | **<0.014** |
| Thermal sensation       | 0.211    | 0.035          | **<0.001** |
| Acceptability of outdoor activity | 0.117 | 0.031          | **<0.001** |

| **Comfort on** |          |                |         |
| sex            | 0.263    | 0.091          | **<0.004** |
| education level | -0.144   | 0.034          | **<0.001** |
| visiting frequency | 0.079  | 0.038          | **<0.001** |
| positive affects | 0.029    | 0.006          | **<0.001** |
| negative affects | -0.032   | 0.009          | **<0.001** |
| prospective thermal sensation | -0.074 | 0.032          | **<0.020** |
| prospective wind speed | -0.101  | 0.028          | **<0.001** |
| perceived air quality | 0.088   | 0.031          | **<0.001** |
| perceived noise    | -0.059   | 0.029          | **<0.040** |
| preference of wind speed | 0.071  | 0.030          | **<0.020** |
| preference of sunlight | 0.048   | 0.029          | 0.097   |
| perceived spatial openness | 0.127  | 0.031          | **<0.001** |
| Thermal sensation  | 0.303    | 0.034          | **<0.001** |
| Acceptability of outdoor activity | 0.130  | 0.028          | **<0.001** |
| Need satisfaction  | 0.246    | 0.032          | **<0.001** |

cool conditions [53], which is similar to the result of the current path analysis. The emotional status of respondents was investigated in the survey by the standard method and represented as positively or negatively affecting comfort. Both emotional aspects were connected with need satisfaction and comfort assessment. Positive effects may increase the satisfaction and comfort, while negative effects may reduce comfort. The preference to urban settings or natural environments was taken into account as a determinant. Respondents who prefer an urban setting are more satisfied compared with those who are keen on a natural scene.

In case of behaviour-related factors, results show that respondents with a motion state of sitting and standing before the interview were inclined to experience a warmer sensation, compared with those who were walking. With regard to the transportation mode, in particular, walking negatively influenced thermal sensation and the need satisfaction of outdoor activities compared with biking and taking private vehicles or public transportation. Biking, as a popular transportation mode for daily life, has no observable difference compared with taking a private automobile or public transportation. Further, the indirect impacts of walking on comfort perception are through thermal sensation and need satisfaction. In addition, in terms of time spent in the outdoor environment, the duration of the whole series of outdoor activities influences both thermal sensation and the need satisfaction. People who spent more outdoor time rated lower thermal sensation and need satisfaction; however, the respondents who stayed longer in the studied public space facilitated their rating of need satisfaction of outdoor activity. The purpose of people's outdoor activity for resting, shopping, leisure and passing positively affects their comfort through need satisfaction. The frequency of visiting was proved to have a positive connection with comfort assessment. People who visited the place more often are in favour of a more comfortable assessment.

We also considered the individuals' perceived microclimate condition, noise and air quality, which play an important role in modelling comfort perception. When respondents perceived higher wind speed and humidity, they reduced their evaluation on comfort. In contrast, higher perceived sunlight positively influences the respondent's comfort. In addition, these influences affect comfort perception through four paths, namely: 1) thermal sensation; 2) acceptability of outdoor activity; 3) thermal sensation and need satisfaction of outdoor activity; and 4) acceptability and need satisfaction of outdoor activity. The individuals' perception of noise negatively impacts the comfort assessment directly and through need satisfaction indirectly. However, the perceived air quality positively influences comfort in both direct and indirect ways. Respondents are more satisfied with better air quality for outdoor activities. In addition, the perceived openness of the public space, as an indicator of spatial setting, positively influences comfort. Through need satisfaction the indirect impact of perceived openness is passed on comfort as well.

Considering that comfort perception may rely on individuals' experience, expectation and preference, our results show that the expected thermal and wind condition have evident connections with the acceptability of outdoor activity and comfort assessment. If respondents expect a warmer outdoor thermal condition, they respond with higher acceptability but a less comfortable feeling. The influence of expected wind speed negatively influences acceptability and comfort assessment. In terms of the impacts of respondents' expectation of thermal and wind condition, individuals who thought the outdoor thermal condition to be warm may have a high acceptability of outdoor activity. However, when they go out and experience an outdoor thermal condition that is colder than their expectation or out of their neutral range, they might respond with a lower comfort perception.

In the case of wind expectation, the situation is different from the thermal condition. Individuals with high wind speed expectation find outdoor activities disagreeable and also degrade their comfort feeling. The effects of the preference of wind speed and sunlight on need satisfaction of outdoor activity and comfort perception are positive and
significant. Since the data collection fieldwork was conducted in a cold season, the preference of sunlight naturally drives up the comfort perception in outdoor environments. In general, people who prefer higher wind speed in general perceive more comfort.

Furthermore, due to the importance of people’s adaptation in existing comfort-related studies, we asked people, based on the actual spatial settings and facilities, whether they did self-adaptation before outdoor activities and what their perceived opportunities of adaptation are in the studied areas. Results signify that the need satisfaction of outdoor activity increases if people adapted before going out. Similarly, if respondents perceive more adaptive opportunities, they would endorse outdoor activities.

4. Conclusion and discussions

Research on outdoor comfort in urban public spaces is of high importance to increase the site attractiveness, people’s outdoor activities, and the quality of life in general. Comfort assessment not only depends on a neutral thermal sensation, but also on the contextual information, service level of infrastructure, and even people’s psychological factors. A proper method to evaluate the actual comfort of individuals is necessary for various stakeholders in urban management, design and planning, in order to improve the existing infrastructure and outdoor environments.

Therefore, to enhance the understanding of comfort assessment in urban public spaces, this paper proposed an extended modelling framework for outdoor comfort by incorporating physical microclimate, social demographical information and individuals’ subjective perceptions, expectations and preferences. A path analysis method is used to examine the direct and indirect effects of various factors on the subjective comfort in urban public spaces using the data collected in a field survey. Although our modelling is based on the context of a Dutch city that is characterised by a temperate ocean climate, the methodology proposed in this paper is generic and applicable in other contexts, e.g. different public spaces, diverse climate zones. This methodology comprises a standard process of field study and path model based on an expanded conceptual framework dealing with complex situations.

The results show that people’s thermal sensation increases in accordance with air temperature but counter to wind speed. The prospective microclimate of outdoor environment in terms of thermal sensation and wind speed influences the acceptability of outdoor activity in a positive way. However, their direct effects on comfort are negative. Individuals who expected a warmer thermal condition and windy outdoor environment had a higher acceptability of being out; in contrast, they form a lower comfort assessment. When the real condition was not approximate to the previous expectations, respondents were more likely to lower their comfort assessment. Moreover, preference of wind positively influences the need satisfaction of outdoor activity and comfort assessment, which indicates that respondents with a preference for windier outdoor conditions were apt to feel more comfort. The preference for sunlight also shows a direct positive effect on comfort.

When respondents initiated prepared for adaptation to outdoor environments, or received more information on the adaptive opportunities approved by the public space spatial settings, they may perceive more comfort. On the other hand, a better acquaintance with a certain space and the positive impression of spatial openness improves an individual’s comfort perception. Hence, the behavioural adaptive preparation for outdoor activities, good understanding of the microclimate and urban settings could influence the acceptance level and satisfaction of outdoor activities, as well as the comfort perception.

Further, we found that the comfort perception was getting worse with the increment of activity duration in the outdoor environment because the thermal sensation and the satisfaction of outdoor activity kept going down. However, the time spent in the public spaces positively influenced the satisfaction, thereby improving the comfort feeling. This may be attributed to the differences in visiting purposes. For instance, people who are immersed in the destination and carry out their own activities may have a higher magnitude of satisfaction. However, the total duration in the outdoor environment normally comprises not only the time of activity in the given public space but also the time for travel and for waiting.

As comfort perception is fundamentally different from the neutral thermal sensation, we speculate that the comfort assessments of respondents are dependent on high motivation, the acceptance of being outdoors, and the satisfaction with outdoor activities. We contend that the direct simplified process from physical condition to comfort perception has to be substituted with an extended framework. Regarding the comfort assessment per se, the majority of participants responded with comfort feeling based on their own condition. If we include the respondents who responded neutrally, neither comfort nor discomfort, into consideration, approximately 81.5% respondents perceived no discomfort in urban public spaces. Thus, to further understand the outdoor comfort issue, more comprehensive data collection and more sophisticated modelling approaches are required. Moreover, the impacts of transportation and urban spatial setting on comfort might be considered in future studies.

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Appendix A. Supplementary data

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References

[1] V. Mehta, Lively streets: determining environmental characteristics to support social behavior, J. Plann. Educ. Res. 27 (2007) 165–187, https://doi.org/10.1177/073945607079497.
[2] K. Lloyd, C. Auld, Leisure, public space and quality of life in the urban environment, Urban Pol. Res. 21 (2003) 339–356, https://doi.org/10.1080/081114032000147995.
[3] J. Anderson, K. Ruggieri, K. Steemers, F. Fluppert, Lively social space, well-being activity, and urban design: findings from a low-cost community-led public space intervention, Environ. Behav. 49 (2017) 685–716, https://doi.org/10.1177/0013916516659108.
[4] S. Thorsson, M. Lindqvist, S. Lindqvist, Thermal bioclimatic conditions and patterns of behaviour in an urban park in Göteborg, Sweden, Int. J. Biometeorol. 48 (2004) 149–156, https://doi.org/10.1007/s00484-003-0189-x.
[5] J. Spagnolo, R. de Dear, A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia, Build. Environ. 38 (2003) 721–738, https://doi.org/10.1016/S0360-1323(02)00209-3.
[6] J. Zacharias, T. Stathopoulos, H. Wu, Microclimate and downtown open space activity, Environ. Behav. 33 (2001) 296–315, https://doi.org/10.1177/001391650132008.
[7] D. Das, Urban quality of life: a case study of Guwahati, Soci. Indicat. Res. 88 (2008) 297–310, https://doi.org/10.1007/s11205-007-9191-6.
[8] S. Jalaladdini, D. Okbay, Urban public spaces and vitality: a socio-spatial analysis in the streets of cypriot towns, Procedia - Soc. Behav. Sci. 35 (2012) 664–674, https://doi.org/10.1016/j.sbspro.2012.02.135.
[9] S. Lenzholzer, N.Y. van der Wulp, Thermal experience and perception of the built environment in Dutch urban squares, J. Urban Des. 15 (2010) 375–401, https://doi.org/10.1080/13574809.2010.488030.
[10] S. Shooshhtaran, I. Ridley, The effect of physical and psychological environments on the users thermal perceptions of educational urban precincts, Build. Environ. 115 (2017) 182–198, https://doi.org/10.1016/j.buildenv.2016.12.022.
[11] Ashrae standard, ASHRAE STANDARD 55-2004 thermal environmental conditions for human occupancy, ASHRAE Stand (2004) 34, https://doi.org/10.1007/s11269-
Y. Peng et al.

Building and Environment 149 (2018) 459-467

011-0203-9 2004.

[12] L. Chen, E. Ng, Outdoor thermal comfort and outdoor activities: a review of research in the past decade, Cities (2012) 118–125, https://doi.org/10.1016/j.cities.2011.08.006.

[13] S. Lenzholzer, W. Klemm, C. Vasiliou, Qualitative methods to explore spatial perception in outdoor urban spaces, Urban Clim (2016), https://doi.org/10.1016/j.uclim.2016.10.003.

[14] P.O. Fanger, Thermal Comfort. Analysis and Applications in Environmental Engineering, (1970).

[15] A.P. Gagge, A.P. Fobelets, L.G. Berglund, A standard predictive index of human response to the thermal environment, ASHRAE Trans (1986) 709–731.

[16] H. Chappells, E. Shove, Debating the future of comfort: environmental sustainability, energy consumption and the indoor environment, Build. Res. Inf. 33 (2005) 32–40, https://doi.org/10.1080/0961321042000527262.

[17] J.F. Nicol, S. Roaf, J.F. Nicol, Rethinking thermal comfort, Build. Res. Inf. 3218 (2017), https://doi.org/10.1080/09613218.2017.1301696.

[18] M.K. Singh, S. Mahapatra, S.K. Atreya, Adaptive thermal comfort model for different climatic zones of North-East Asia, Appl. Energy 88 (2011) 2420–2428, https://doi.org/10.1016/j.apenergy.2011.01.019.

[19] F. Al jawase, M. Nikolopoulou, Influence of hot arid climate on the use of outdoor urban spaces and thermal comfort: do cultural and social backgrounds matter? Intell. Build. Int. 2 (2010) 198–207, https://doi.org/10.3763/inbi.2010.0046.

[20] S. Thorsson, T. Honjo, F. Lindberg, I. Eliasson, E.-M. Lim, Thermal comfort and outdoor activity in Japanese urban public places, Environ. Behav. 39 (2007) 660–684, https://doi.org/10.1177/0013916506294937.

[21] R.L. Hwang, T.P. Lin, R.L. Hwang, Effect of thermal adaptation on seasonal outdoor thermal comfort, Int. J. Climatol. 31 (2011) 302–312, https://doi.org/10.1002/joc.2120.

[22] J. Pick, R. De Dear, An outdoor thermal comfort index (OUT-SET) - part I: the model and its assumptions, Biotemper, Urban Climatol. Turn Millenium, Sel. Pap. From Conf. ICB-ICUC, vol. 99, 2000, pp. 279–283 https://www.researchgate.net/profile/Richard_De_Dear/publication/268983313_An_outdoor_thermalcomfort_index_OUT-SET_Part_I_The_model_and_its_assumptions/links/567a4b6308ae40c0e27e9397.pdf.

[23] P. Höppe, The physiological equivalent temperature - a universal index for the biometeorological assessment of the thermal environment, Int. J. Biotemper. 43 (1999) 71–75, https://doi.org/10.1007/s004840050118.

[24] P. Höppe, Different aspects of assessing indoor and outdoor thermal comfort, Energy Build. 34 (2002) 661–665, https://doi.org/10.1016/S0378-7788(02)00017-9.

[25] Y. Cheng, J. Niu, N. Gao, Thermal comfort models: a review and numerical investigation, Build. Environ. 47 (2012) 13–22, https://doi.org/10.1016/j.buildenv.2011.05.011.

[26] M. Nikolopoulou, S. Lykoudis, Thermal comfort in outdoor urban spaces: analysis across different European countries, Build. Environ. 41 (2006) 1455–1470, https://doi.org/10.1016/j.buildenv.2005.05.031.

[27] M. Nikolopoulou, N. Baker, K. Steemers, Thermal comfort in outdoor urban spaces: understanding the human parameter, Sol. Energy 70 (2001) 227–235, https://doi.org/10.1016/S0038-092X(00)00093-1.

[28] R.L. Hwang, T.P. Lin, M.J. Cheng, J.H. Lo, Adaptive comfort model for tree-shaded outdoors in Taiwan, Build. Environ. Times 45 (2010) 1873–1879, https://doi.org/10.1016/j.buildenv.2010.02.021.

[29] E. Ng, V. Cheng, Urban human thermal comfort in hot and humid Hong Kong, Energy Build. 55 (2012) 51–65, https://doi.org/10.1016/j.enbuild.2011.09.025.

[30] A.P. Gagge, J.A.J. Stolwijk, J.L. Hess, Statistical Design and Analysis of Experiments - Different European countries, Build. Environ. (2007) 867–88, https://doi.org/10.1002/joc.1537.

[31] T.P. Lin, R. De Dear, R.L. Hwang, Effect of thermal adaptation on seasonal outdoor thermal comfort, Int. J. Climatol. 31 (2011) 302–312, https://doi.org/10.1002/joc.2120.

[32] G.S. Brager, R.J. de Dear, Thermal adaptation in the built environment: a literature review, Energy Build. 27 (1998) 83–96, https://doi.org/10.1016/S0378-7788(97)00053-4.

[33] S.Y. Chan, C.K. Chau, T.M. Leung, On the study of thermal comfort and perceptions of environmental features in urban parks: a structural equation modelling approach, Build. Environ. 122 (2017) 171–185, https://doi.org/10.1016/j.buildenv.2017.06.014.

[34] S. Lenzholzer, Research and design for thermal comfort in Dutch urban squares, Ressour. Conserv. Recycl. 64 (2012) 39–48, https://doi.org/10.1016/j.resconres.2011.06.015.

[35] F. Rossi, E. Anderini, B. Castellani, A. Nicolini, E. Morini, Integrated improvement of occupants' comfort in urban areas during outdoor events, Build. Environ. 93 (2015) 285–292, https://doi.org/10.1016/j.buildenv.2015.07.018.

[36] S. Lenzholzer, Engrained experience-a comparison of microclimate perception schemata and microclimate measurements in Dutch urban squares, Int. J. Biotemper. 54 (2010) 141–150, https://doi.org/10.1007/s00484-009-0262-z.

[37] S. Lenzholzer, S. Koh, Immersed in microclimate space: microclimate experience and perception of spatial configurations in Dutch squares, Landsc. Urban Plan 95 (2010) 1–15, https://doi.org/10.1016/j.landurbplan.2009.10.013.

[38] R.L. Mason, R.F. Gunst, J.L. Hess, Statistical Design and Analysis of Experiments - with Applications to Engineering and Science, second ed., (2015), https://doi.org/10.2307/2285468.

[39] E. Johansson, S. Thorsson, R. Emmanuel, E. Krüger, Instruments and methods in outdoor thermal comfort studies - the need for standardization, Urban Clim 10 (2014) 346–366, https://doi.org/10.1016/j.jclim.2013.12.002.

[40] ISO, ISO 7726, Ergonomics of the thermal environment, instruments for measuring physical quantities, Geneva Int. Stand. Organ (1998) ISO 7726:1998 (E). 57 pages.

[41] S. Thorsson, F. Lindberg, I. Eliasson, B. Holmer, Different methods for estimating the mean radiant temperature in an outdoor urban setting, Int. J. Climatol. 27 (2007) 1983–1993, https://doi.org/10.1002/joc.1537.

[42] E.J. Pedhazur, Multiple Regression in Behavioral Research, (1997), https://doi.org/10.2307/2285468.

[43] D. Streiner, Finding our way: an introduction to path analysis, Can. J. Psychol. 50 (2005) 115–122, https://doi.org/10.3763/inbi.2010.0046.

[44] P.M. Bentler, D.G. Bonett, Significance tests and goodness of fit in the analysis of covariance structures, Psychol. Bull. 88 (1980) 588–606, https://doi.org/10.1037/0033-2909.88.3.588.

[45] S. Karjalainen, Thermal comfort and gender: a literature review, Indoor Air 22 (2012) 96–109, https://doi.org/10.1111/j.1600-0668.2011.00747.x.