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Evaluation of Qualitative Variables Affecting Thermal Comfort in Outdoor Spaces in Line with Sustainable Design Thinking (Case Study: Naqsh-e Jahan Square, Isfahan)

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Abstract

Attention to human-centered features in architectural design to create levels of physical, functional and psychological comfort, in line with attention to environmental and energy consumption management approaches, is nowadays considered an important and growing movement towards the definition of sustainable architecture. Thermal comfort is a significant subset of this attention which can be examined in two physiological and psychological aspects and is defined as "the condition of mind that expresses satisfaction with the thermal environment". With the assumption that "people are not inactive in environmental conditions", this study seeks to evaluate the qualitative human-centered factors affecting thermal perception by examining the possibility of redefining the upper and lower limits of thermal comfort temperature in the environmental conditions of open spaces with the aim of improving the global standard temperature and minimizing and managing energy consumption. It is based on library studies and field observations whose data were collected using a questionnaire from the visitors to Naqsh-e Jahan Square in Isfahan in the cold season and appropriate solutions were presented after the results had been analyzed using SPSS 26. Results indicated that the architectural response to thermal comfort is influenced by qualitative and human-centered approaches, and adaptation and alliesthesia play a significant role in defining the acceptable human thermal environment and comfort temperature, which does not necessarily conform to the Design limits set by global standards and where calculations are not merely quantitative and can be redefined depending on qualitative characteristics in Line with sustainable Design thinking.

Keywords

Thermal Comfort, Qualitative Variables, Human-Centered Approaches, Naqsh-e Jahan Square, Sustainable Design Thinking.

Introduction

Architectural Design can be defined as a special thinking type or a subset of *problem-solving* (Heath,1984). Based on the Sustainable development approach, this response should be explained to correspond to sustainable Design thinking capacities with the goal of preparing users' thermal comfort. In modern architecture, the focus on the importance of outdoor thermal comfort has been forgotten in contrast with traditional architecture. This topic has its own unique identity suitable to Iranian traditional buildings and behavior and finds its definition in passive design solutions. It is human-oriented and is defined in different scales; from residential yards to an urban square or plazas.

Based on the fact that people are not passive in an ambient condition if the outdoor space gives the users the chance to adapt thinking and compatibility with the built environment, they can choose or manage a more acceptable part(s) in that ambient, according to the condition: May shadow or may sunlight can be chosen, they may spray water across their yard or may sit near a fountain in an urban square to relax. This matter has given a creative response to the provision of human comfort. If this comfort does not exist in a thermal environment, it can be replaced with other parameter(s) to prepare adaptation for the human and his/her built environment and also it can provide thermal sensation with satisfaction to make the environment acceptable (Mortaheb & Heidari, 2015). There is a specified definition for thermal comfort that is called the state of perception in which %80 of people are satisfied with their environment and it is defined as *Good*, not too cool, not too hot (Thevenard & Humphries, 2005). We can explore thermal comfort from two points of view:

a. Physical/ Physiological, which is mostly based on quantitative approaches and is the first challenge to discover in this field.

b. Psychological, qualitative approaches which in recent decades have been the new concern to consider.

In these two approaches, adaptation theory is the main topic to discover which includes clothing level, metabolic rate, … suitable to a person based on his/her expectation, experience, and cognition for *personal control*. Qualitative approaches are really important subjects which have roots in psychological thermal comfort which require more analysis and research because people have different perceptions of an environment. Human response to a physical impulse does not have direct relation to its scale but to his/her cognition. Therefore, psychological parameters have an impact on a space's thermal perception and the changes that happen there. The qualitative approaches are specifically human-oriented and are not related to any other species. On the other side, it has the potential to impact architectural design approaches and energy consumption management. These effects are not specifically related to quantitative parameters and physical measurements. By considering these approaches, the thermal comfort range can be redefined. By considering this topic, useful dimensions can be presented related to medical science and architecture combined with surrounding natural features, buildings or built environment, psychological requirements, and human physical health (Fabbri, 2015). This research has been carried out in the open space of Naqsh-e Jahan Square of Isfahan to analyze thermal comfort with psychological approaches. The open space has been chosen because of people's intentions. Open spaces by any scale should include comfortable conditions, especially thermal comfort, otherwise, they will transfer to lifeless atmospheres (Men'am, 2012).

Literature Review

At the beginning of quantitative studies, Fanger proposed the classical concept to describe thermal perception and named it *thermal comfort*. He described thermal comfort as human satisfaction with the thermal environment and used this explanation to define the concept of *Predicted Mean Vote (PMV)*, which considers thermal comfort a physiological index. This model is also used to estimate the predicted percentage of dissatisfaction (PPD) index. This equation is an attempt to create measurable indices of metabolism, clothing, air temperature, mean radiant temperature (MRT), air flow and humidity (Fanger, 1970).

Although psychological issues play an important role in the concept of thermal comfort, they were long ignored, as was criticized first by Auliciems (1981) and later by other researchers (Westerberg & Glaumann, 1990-91; Nikolopoulou et al., 2001; Thorsson et al., 2004). In the 1990s, a second approach developed as an extension of Fanger's model was called the adaptive model. The adaptive model is based on three interrelated factors: physiological, behavioral and psychological aspects (Humphreys & Nicol, 2002). Although this model takes into account the psychological factors, it is based on closed-room climate studies; it does not comprehensively deal with external environmental conditions, nor does it measure thermal comfort indices for external environments.

The psychological factors influencing thermal comfort have recently received more attention in research. For instance, the momentary thermal *Actual Sensation Vote* by those who visit public spaces has been investigated by means of interviews carried out throughout Europe and compared to the values derived from measurements. This revealed that people in different countries show a great variation in what they consider comfortable temperatures (Nikolopoulou & Steemers, 2003; Nikolopoulou & Lykoudis, 2006). Other studies on psychological issues that influence thermal experience have focused on the relation between thermal comfort and the personal make-up of those who visit open spaces, such as their places of origin and their cultural differences (Knez & Thorsson, 2006; Thorsson et al., 2007; Knez et al., 2009). Sanda Lenzholzer also conducted a study on the perceptual schemas of public spaces to investigate their role in thermal comfort and microclimate experience to examine the necessity of designing building groups to solve the *perceived* versus *real* problem. He compared the results of climate measurements with the subjective results of the participants in the study and found inconsistencies. The analysis showed that people overestimated the effect of wind. Therefore, this study suggested that these more salient situations play a role in the microclimate schemata that people develop about urban places. From the researcher's point of view, this negative bias in the experience of wind can create a negative image of the public space and prevent people from using it, thus leading to the general neglect of that space (Lenzholzer & Van der Wulp, 2010). Nasir et al. explained the approaches related to perception and adaptation in the category of thermal comfort of open spaces and identified the effects of climatic factors and personal approaches on the evaluation of the feelings of visitors to the urban park. They concluded that the thermal adaptation of the interviewees from the physiological and psychological perspectives indicates the importance of sustainable urban parks for continued use by future communities (Nasir et al., 2012; Rupp, 2015) conducted a comprehensive study by which they reviewed 466 articles on thermal comfort from 2005 to 2015. The findings of their study highlighted the importance of the adaptive thermal comfort models complementary to the classical Fanger's model. That study showed that there was scant research on open spaces. Rupp confirmed that multidisciplinary communication with psychologists, physiologists, sociologists, and philosophers can be helpful in developing an integrated research approach. Holistic and combined methods may contribute to a better understanding of thermal sensation, perception and comfort in physiological, psychological and social dimensions (Rupp, 2015).

Ruiz and Correa (2015) conducted a field study to investigate the perception of people on the sidewalks of open space in the city of Oasis in order to evaluate thermal comfort in two seasons, winter and summer. To select the adaptive model, they plotted fourteen multiple linear regressions and used them as the basis of the studies. Using interview and observation methods, Inavonna et al. (2018) investigated the thermal comfort and behavior of citizens in the open urban space. In addition to physical characteristics and the physiological perspective, they studied the psychological perspective and behavioral and social characteristics in relation to the environment. Lenzholzer and de Vries (2020) developed a new model to extend the previous models of thermal perception in outdoor spaces and combine them with new knowledge and extract perspectives for future research and methods. It was assumed that the physical realm shaped the thermal sensation to a large extent. Therefore, it was placed at the beginning of the cause-and-effect chain of thermal perception and was described as distinct from the psychological realm. They achieved a new model that encompassed the psychological factors as well. From their perspective, the inclusion of psychological factors in such models can provide a more accurate prediction of thermal perception in specific environmental settings.

However, developing such models requires much research on environmental psychological factors to finally build a solid evidence base (Lenzholzer & de Vries, 2020).

Here is the list of some important research in Iran about thermal comfort: Heidari (2019) in his book *Thermal Adaptation in Architecture (The First Step in Saving Energy Consumption)* refers to field research related to thermal comfort in Iran and adaptation indexes. He has defined the final formula for thermal comfort for Iran. It seems that this research is a bible about thermal comfort and adaptation theory related to Iran climates. Mortaheb (2016) in his book *Energy Saving Pattern in Housing Architecture* has explored architectural design approaches with respect to adaptive opportunities, thermal comfort, and behavioral role in personal control. In an article (Zabetian & Kheiroddin, 2016), did a comparative study about psychological adaptive experiences in thermal comfort perception in urban open spaces. Amindeldar et al. in their research analyzed the impact of individual variables (age, gender) and climate (air temperature, solar radiation, and airflow speed) on thermal comfort in open spaces (Amindeldar et al, 2017). Zabetian and Kheiroddin (2018) researched the role of thermal comfort perception in people's behavioral patterns in cold and warm seasons; they found out, despite the absence of thermal comfort conditions in two squares, one of them is more crowded and people there could adapt themselves with that condition. Zabetian and Kheiroddin (2018), in another research, discovered that people with reasons that came off the levels of the sense of place, can adapt themselves to the thermal comfort condition, otherwise, leave the place. Majidi and Heidari (2019) have defined two thermal formulas:

1. Outdoor temperature

2. monthly average temperature to determine the comfort temperature in four different open spaces in Isfahan. (Table 1), summarizes some of the studies conducted in the last three years are given.

Table 1: *Studies related to the impact of qualitative factors on thermal comfort in the last three years*.

Author(s)	Year	Title	Abstract
Su, Y., Wang, C., Li, Z., Meng, Q., Gong, A., Wu, Z., & Zhao, Q.	2024	Summer outdoor thermal comfort assessment in city squares—A case study of cold dry winter, hot summer climate zone	Human thermal perception varies with climate. The Dwa climate zone covers vast areas. Conducting outdoor thermal comfort (OTC) studies here would benefit energy efficiency and the economy. However, since OTC research methods are not standardized, different research methods hamper comparing studies in the Dwa climate. This paper aims to determine the summer OTC of typical Dalian squares in the Dwa climate. Dalian is located in the cold A zone (2A) of the China Building Climate Division. The thermal environment of three typical squares was field-measured, and a questionnaire survey of the residents was conducted. 33.2 % of Dalian residents evaluated the thermal environment as neutral, and 39.3 % considered it comfortable. And psychological perception and physical perception were not the same. Multiple methods were used to calculate outdoor thermal benchmarks and calibrate thermal stress for three thermal indexes, SET*, PET, and UTCI. Furthermore, PET, with a prediction accuracy of 25.3 %, was determined to be the best indicator applicable to Dalian in the summer. Finally, a comparison of studies under the Dwa climate zone, including Tianjin and Harbin, reconfirmed the mobility of the human thermal zone. These findings are precious and can contribute significantly to ensuring the sustainability of the outdoor environment.
Xu, T., Yao, R., Du, C., Li, B., & Fang, F.	2023	A quantitative evaluation model of outdoor dynamic thermal comfort and adaptation: A year-long longitudinal field study	The understanding of human outdoor thermal comfort demand and thermal adaptation contributes to sustainable urban design as well as city resilience in the context of human health and wellbeing. Humans' past thermal experience influence their outdoor thermal comfort. However, the quantitative relationship between the past thermal experience and outdoor thermal comfort is still not clear. This study aims to reveal quantitative relations of the impact of people's past thermal experience on adaptive thermal comfort and to develop a new outdoor adaptive thermal comfort model. A year-long longitudinal questionnaire survey along with a combination of outdoor thermal environment campaigns was carried out in Chongqing, China. It began on August 15, 2020, and finished on August 19, 2021. Through the analysis of 2240 valid responses to the questionnaire survey, the outdoor thermal adaptation characteristic and dynamic thermal comfort evaluation of the respondents were revealed. The results show that the quantified temperature of past outdoor thermal experience is the quadratic correlation with the thermal sensitivity coefficient and deviation constant, and the linear correlated with outdoor thermal demands. Based on the quantitative analysis, a new outdoor adaptive thermal comfort model has been developed as a function of the exponentially weighted sum of historical mean air temperature series (MeanTrm). The outdoor adaptive thermal comfort zones by 80% and 90% satisfactions thereby have been first drawn based on the Universal Thermal Climate Index (UTCI). The study developed a methodology for the evaluation of dynamic outdoor thermal comfort which can be used for different climate regions.

Niu, J., Xiong, J., Qin, H., Hu, J., Deng, J., Han, G., & Yan, J.	2022	Influence of thermal comfort of green spaces on physical activity: Empirical study in an urban park in Chongqing, China	The thermal comfort of green spaces, an important factor affecting physical activity, is the premise of outdoor physical exercise. Currently, the way in which thermal comfort influences outdoor physical activities is not fully understood. This study aimed to investigate the effect of thermal comfort in green spaces on the participants' attendance, duration, metabolic rate, and frequency of physical activity during hot summer. We used questionnaire surveys and activity records to evaluate physical activity, and numerical simulations to reproduce the thermal environment in five green spaces in an urban park in Chongqing, China. Thermal comfort was evaluated by physiological equivalent temperature (PET) and thermal sensation vote (TSV). Results showed that: 1) Attendance showed a double peak in shaded spaces, and a single peak in less shaded spaces that offered activity facilities. 2) The hourly average activity duration reached its maximum (37 min) at PET was 30.46 °C. Large areas of tree-shaded squares and pavilions, and fitness trails were more conducive to longer durations of outdoor activity. 3) PET negatively affected the hourly per capita metabolic rate (R2 = 0.9321). Metabolic rate was barely affected by the PET of older adults over the age of 65 years. 4) TSV was inversely proportional to frequency. Well-shaded spaces and spaces that provide activity facilities could increase the activity frequency. These results may serve as a reference for designing improved green spaces that can promote outdoor exercise while safeguarding health.
Meili, N., Acero, J. A., Peleng, A., Manoli, J., Burlando, P., & Fatichi, S.	2021	Vegetation Cover and plant-trait Effects on Outdoor Thermal Comfort in a Tropical City	An increase in urban vegetation is an often proposed mitigation strategy to reduce urban heat and improve outdoor thermal comfort (OTC). Vegetation can alter urban microclimate through changes in air temperature, mean radiant temperature, humidity, and wind speed. In this study, we model how street tree and ground vegetation cover and their structural, optical, interception, and physiological traits control the diurnal cycle of OTC in different urban densities in a tropical city (Singapore). For this purpose, we perform a variance-based sensitivity analysis of the urban Eco hydrological model UT&C. Model performance is evaluated through a comparison with local microclimate measurements and OTC is assessed with the Universal Thermal Climate Index (UTCI). We find a pronounced daily cycle of vegetation effects on UTCI. Tree cover fraction is more efficient in decreasing UTCI during the daytime, while a higher vegetated ground fraction provides more cooling during the night. Generally, increasing vegetation cover fractions do not deter OTC, except in certain urban densities during some periods of the day. An increase in tree and ground vegetation fractions provides a higher average UTCI reduction compared to a change in vegetation traits (0.9 – 2.9 °C vs. 0.7 – 1.1 °C during midday, 10-month average). The increase in humidity related to plant transpiration prevents further reduction of UTCI. However, the choice of vegetation traits enhancing tree transpiration can decrease UTCI during hot periods. These results can inform urban planners on the selection of vegetation amount and traits to achieve feasible OTC improvements in tropical cities.

Theoretical Foundations

Environmental psychology is a set of laws that deal with the interaction between people, the built environment, and the natural environment (Lindenberg et al., 2012), customs, values and social and cultural standards. According to Robert Gifford, this is a mutual influence, where the person changes the environment and his behavior and experiences are changed by the environment (Gifford, 2013). People's feelings and behavior are affected by the interaction between things in the environment of which humans are aware at every moment (Shahcheraghi & Bandarabad, 2020). An important approach to the concepts of environmental psychology is the further explanation of thermal perception, as proposed by several researchers, as well. In relation to thermal comfort, this may include all adaptive processes that people go through to improve the correspondence between their environment and their needs. Some of these processes, such as changes in the volume of blood flow on the skin surface, sweating in the heat and shivering in the cold occur unconsciously. However, changing clothes, body posture and activity level, using thermal controllers, and moving between different thermal environments are conscious activities used to provide thermal comfort (Parson, 2014). In such a framework, the adaptation opportunities can be divided into three different categories: physical, physiological and psychological (Nikolopoulou et al., 2001). Physical adaptation encompasses all the changes that a person makes in order to adapt themselves to the environment or change the environment based on their needs. Therefore, we can identify two different types of reactive and interactive adaptation. The effect of physical adaptation can be evaluated numerically. A person may adjust their range of temperature by 6 K (McIntyre, 1980) or reduce their net metabolic heat by 10% by reducing cold beverages (Baker & Standeven, 1996).

In addition, this information can be integrated into a physiological model to explicitly show the effect of such measurements on the theoretical PMV. Physiological adaptation refers to changes in physiological responses resulting from frequent exposure to a stimulus that leads to a gradual decrease in pressure caused by such an encounter.

In relation to the thermal environment, this is called physiological adaptation. A change in the physiological thermoregulation system over a period of several days or weeks in response to exposure to an environmental thermal stimulus, which is called acclimatization, leads to new changes in the body's self-control system. Physiological change may also be genetic, meaning that genetic changes occur in a period beyond the lifetime of a person or group in an environment with thermal stimuli. Such a mechanism is very important in severe environments, but it is not particularly important in the current study. Regarding the issue of psychological adaptation, which is the focus of this study, Auliciems (1981) points out that psychological adaptation cannot be directly observed because invisible characteristics cannot be easily described and evaluated. He describes psychological adaptation as a change in perception and reaction to sensory information in the environment based on people's previous experiences and thermal memory. Different people perceive the environment in different ways and their response to a physical stimulus depends on their information for a specific situation rather than the magnitude and size, of the stimulus. Therefore, psychological factors affect the thermal perception of a space and the changes that occur in it (Nikolopoulou & Steemers, 2003). In this regard, environmental psychology studies show that characteristics such as building configuration, color, green space, building materials etc. strongly affect human experience and behavioral response and can define guidelines for design. Therefore, related knowledge about how the spatial environment affects thermal perception is very important (Lenzholzer, 2010; Vasilikou, 2014; Klemm et al., 2015).

The spatial environment including dimensions, proportions and materials can be changed through design interventions, while personal factors in thermal perception such as people's clothing, mood, etc. are fixed and cannot be changed. Thus, understanding how spatial environments affect thermal perception is very important and generalizable to design patterns to study the relationship between spatial characteristics and thermal perception, we need to extend the current methods and develop new qualitative methods beyond the current ones. Open spaces, whether in the form of squares or parks, are familiar places for everyone, and so are our associations with them (Nikolopoulou & Steemers, 2003). Different environments of an urban open space include objective stimuli and their resulting subjective perceptions. Environmental stimuli include physical thermal conditions and personal physiological conditions, which can be based on calculations and quantitative research methods, and the subjective perception of environmental stimuli deals with the momentary and then long-term thermal perception of humans, which is considered a psychological approach and a qualitative research method. In another study, the authors investigated the role of the physical characteristics of the space and its effect on thermal comfort, and in this article, an attempt is made to address the concept of Alliesthesi. The term alliesthesia was proposed by Cabanac as a combination of *esthesia (meaning sensation) and allios (meaning changed)* and describes the observation that *the pleasure or displeasure of a sensation is not stimulus bound but depends on internal signals*. While Cabanac already mentioned thermal stimuli, it was only later that the relevance of alliesthesia was shown for the field of thermal comfort in buildings. The concept of alliesthesia describes that a person that is, for example, in a thermal state above thermal neutrality would perceive a cold stimulus – leading towards thermal neutrality– as pleasant (Cabanac, 1971; Candido et al., 2016).

Related to alliesthesia, de Dear (2011) describes comfort as *the hedonic tone or pleasantness of the stimulus (like versus dislike)* and uses in his own studies a scale ranging from *very unpleasant* to *very pleasant* for its assessment (Parkinson & de Dear, 2016). In the continuation of this research, the role of qualitative components *adaptability* and *alliesthesia* in thermal sensation and creating thermal comfort will be investigated.

Methodology

Lenzholzer et al. (2018) suggest the use of quantitative and qualitative methods in thermal perception studies, which often confirm a good correspondence and a significant relationship between two data sets and build a relationship between objective measurement and qualitative and subjective reality. Heidari and Sharples (2002) investigated how to conduct thermal comfort field research according to the method proposed by Nickel (1993), who considered three levels for thermal comfort studies (Heidari & Sharples, 2002).

In the first level, the researcher usually has a simple measurement of a variable such as air temperature - over one or more consecutive days - and the measurement may be associated with a simple question as well. This level mainly emphasizes data collection from effective variables. The second level is characterized by measuring environmental variables including air temperature, Curie temperature, airflow, etc. The researcher obtains all or some of the variables and collects data via a questionnaire with greater frequency than the first level based on thermal sensation using the ASHRAE Thermal Sensation Scale, Bedford's Thermal Comfort Scale and McIntyre's three- or five-point Thermal Preference Scale. The third level is associated with the measurement of environmental variables, the type of clothing, the amount of activity and others, which are mainly related to the interviewee's behavior in the environment. It should be noted that the selection of such variables depends on the research plan and the researcher. The focus of this study was on the characteristics related to psychological adaptation. Since behaviors are influenced by various factors other than thermal perception, it is impossible to obtain data about these sources through inference.

Based on Lenzholzer et al.'s (2018) perspective, we need interviews to investigate momentary preferences related to thermal perception, because only participants can express those experiences orally. Interviews (structured or semi-structured) can be conducted face-to-face or with the *thermal-perceptual notebook* in which respondents record their thermal perception of other factors as they experience it. Therefore, in addition to providing the questionnaire to the interviewees, we tried to read the questions and some answers to them and record their responses based on their recorded voices- with their consent. According to Nickel (1993), as many as one hundred complete questionnaires, which can use the longitudinal sampling method - completion of the questionnaire by a limited number of interviewees while they repeat the answers to the same questionnaire in several different time intervals and measure the environmental variables at each turn- or using the transverse sampling method- progression from one person to another to complete the questionnaire by a larger number than the longitudinal method and simultaneous measurement of environmental and specific variables, is considered sufficient for analysis. We used the transverse sampling method and the third level in January 2022. Part of the research results is presented in this article.

Study Area

The study area is Naqsh-e Jahan Square in Isfahan. The city of Isfahan is located in the center of Iran with a longitude of 51° 39' and 40'' E and latitude of 32° 38' 30'' N with a mean height of 1580 meters above sea level. Its climate is of the cold semi-desert type, that is, with cold winters and hot summers (Deputy of Planning, Information Technology of Isfahan Municipality, 2019; Meteorological Organization of Isfahan Province, 2019).

Like a gemstone in Isfahan City, Naqsh-e Jahan Square attracts many visitors for many reasons, including its variety of uses and functions as well as its environmental conditions, location and aesthetics, which make it a safe haven for its users.

Figure 1: *Perspective of Naqsh-e Jahan Square in Isfahan.*

The attraction of this square has its roots in the relative introversion of the complex in the heart of the city (which Design thinking from a climatic response to the strengths and weaknesses of the design platform) and architectural responses in using dimensions and proportions and establishing color harmony in various artificial materials and natural landscapes in greenery and the use of the water element and the play of light and shadow as well as attention to wisdom and philosophy. All these respond to diverse approaches with interdisciplinary engineering intelligence. Naqsh-e Jahan Square is a place frequented by citizens for various things more in the role of a participant than a mere observer. It is a space where familiar and unfamiliar people with various nationalities, races, ages, genders and social statuses get together and communicate with one another far from the noise and tensions of the city. From another perspective, Naqsh-e Jahan Square may be considered an exterior space compared to the house, because is a public urban space. However, because of its confinement and high spatial quality, it is also considered both a place and an internal space, attracting lots of visitors and making the city of Isfahan a memorable place. The identity and meaning of Naqsh-e Jahan Square create a sense of belonging (Ansari, 2014). As a distinct architectural place, Naqsh-e Jahan Square has unique characteristics that create an aesthetic experience for people as a text, an artwork and even a myth, and it also acts as an inspiring model for architects and city planners (Panjtani et al., 2017).

Therefore, we chose to perform the human-centered studies of this research on this square and evaluate it from the thermal space, comfort and adaptation perspective, believing it to be a lively space frequented by citizens, a rich place that indicates the identity of Isfahan city and is rooted in the sensations, perceptions and knowledge of its audience, and a tourist attraction which will leave every visitor an unforgettable experience.

Findings

On 4 days from January 3rd, 7th, 11th and 15th in the three different periods of *morning to noon*, *noon to afternoon* and *afternoon to evening* with a mean temperature of 12 °C, a sample size of 100 visitors to Naqsh-e Jahan Square were asked with a questionnaire and their responses were analyzed using SPSS 26 software. It should be noted that there was a larger number of questionnaires, but we eliminated those with uncertain, ambiguous or illegible responses, regardless of their content. The table below presents the mean monthly temperature of January 2021 along with the ten-year statistics of this month (from 2008 to 2018).

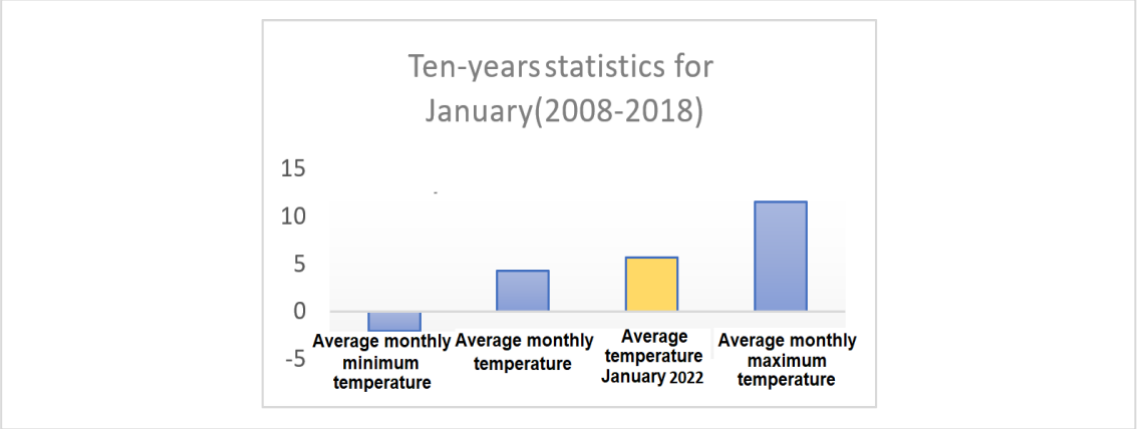

Figure 2: *Comparison of the temperature range of January in the 10-year average and the average of January 2022 (Source: Meteorological Organization of Isfahan Province, 2022).*

Using the equation proposed by Majidi and Heidari (2019) for comfort temperature calculation and based on the mean monthly outdoor temperature, which is 5.7 °C according to the monthly statistics given by the National Meteorological Organization, we achieved the comfort temperature of 15.9 °C for users in the outdoor space. According to the studies conducted by Majidi and Heidari, given this monthly temperature, the neutral (comfort) temperature will not be lower than 15.9 °C. The graph below shows the comfort temperature obtained from the studies of Humphreys, Auliciems and de Dear (this equation is based on the monthly temperature of 5.7 °C in January and is approved in the temperature range of 5°C to 30°C) and Heidari (equation to measure the comfort temperature of Iran). The important point in Graph 2 is that all the obtained comfort temperatures indicate that the current temperature, according to the current equations, is lower than the comfort temperature and the comfort range does not apply to the *no building* feature. As said before, creating a correspondence between qualitative variables and numbers creates a good correspondence and significant relationship between two data sets and establishes a relationship between objective measurement and qualitative and subjective reality. We used SPSS 26 software for descriptive analysis (frequency tables and graphs) in this study to explain the demographic characteristics, the main items of the questionnaire, the indices of the questionnaire and related analyses including analyzing the normal distribution of the data and performing one-sample t-tests to test the hypotheses and used independent two-sample t-tests to validate the data and compare independent groups in their thermal sensation. The questionnaire was defined based on thermal sensation using the ASHRAE Thermal Sensation Scale, the Bedford's Thermal Comfort Scale as shown in the table below. The analytical graph obtained based on thermal sensation and consisting of 52% women and 48% men is as follows:

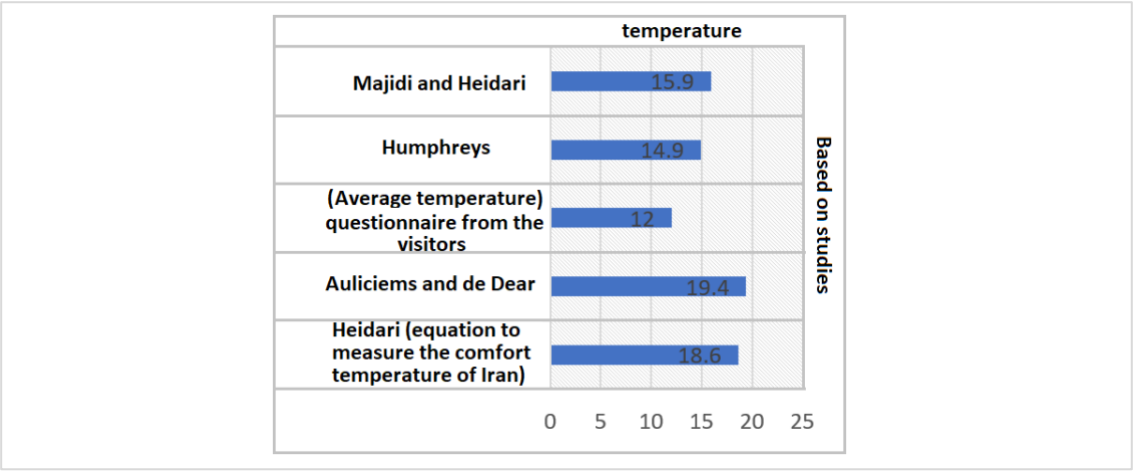

Figure 3: *Comparison of comfort temperature based on researchers' studies and average temperature on visiting days (Source: Authors).*

Table 2: *Corresponding numbers considered for the questionnaire Based on ASHRAE and Bedford Standards (Source: Authors).*

ASHRAE	Warm	Slightly Warm	Neutral	Slightly Cool	Cool
Numerical Equivalent	+2	+1	0	-1	-2
Bedford	Too Hot	Comfortably Warm	Comfortable	Comfortably Cool	Too Cool

Based on the ASHRAE Standard 55, thermal sensation, with numbers between +1 and -1, is in the acceptable temperature range and the comfort range is defined for at least 80% of the visitors. Based on the analysis of the questionnaire, 43% of the respondents consider the current temperature conditions to be *neutral*, while more than 80% of these visitors are within the *comfort* range (suitable, slightly cold or slightly hot).

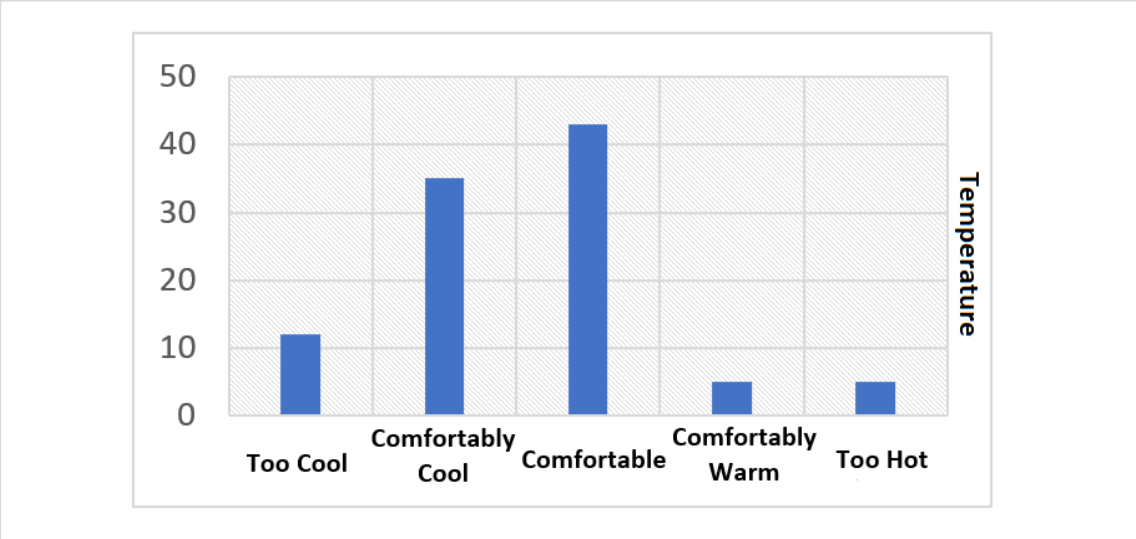

Figure 4: *Thermal sensation Based on questionnaires (Source: Authors).*

According to the ISO standard, the highest level of thermal comfort satisfaction related to PMV is between -0.5 and +0.5. Therefore, given the current conditions and the correspondence of the results with the standards, the mean thermal sensation of the participants was achieved using the t-test by defining the null hypothesis with the proposition that the mean thermal sensation of the visitors to Naqsh-e Jahan Square is equal to -0.5 (as a base). After examining and confirming the normality of data distribution, given that the significance level in this test is equal to 0.527 and greater than 0.05 (t = 0.63, DF = 99), it can be said that at the 5% error level, the mean thermal sensation of the visitors to Naqsh-e Jahan Square in Isfahan is -0.5, which is within the slightly cold but comfortable range and the ISO Standard range. Based on the one-sample t-test, the thermal preference and the correspondence created between the qualitative and quantitative variables, it is possible to determine the (dis)satisfaction level of clients in the face of the predicted men's thermal vote and the determined range in the thermal sensation of *slightly cold but comfortable*. In other words, if the majority of the respondents prefer a change in the current temperature, it will be reflected in their mean opinion corresponding to McIntyre's three-point scale, and if they consider the same temperature and range to be acceptable and satisfactory, they will not seek a change in the temperature. We examined the normal distribution of the data and achieved (sig (0.235)>0.05). With a 95% confidence level, we can say that the visitors to Naqsh-e Jahan Square consider *a slightly cold but comfortable temperature range* to be acceptable and they do not prefer to change it (t = 1.95, DF = 99). Another noticeable issue is related to people's expectations. There are a few cases where thermal conditions deviate from what people experienced in the past, which may cause differences in people's opinions or even lead to their complaints because expectations of momentary perception and their short-term experience related to the time scale change.

According to the research conducted, the interviewees' view of the weather temperature conditions relative to their expectations in the winter season is as follows: 21% of the users consider the thermal space conditions to conform to their expectations. Considering the expectation factor based on the season, relying on mental schema, people's experience and thermal space are only acceptable for this number of the visitors under study. An independent two-sample t-test was used to examine the mean thermal sensation of the groups that expected and did not expect such temperature conditions. After confirming the normality of the data distribution based on Levene's test (sig (0.147)>0.05), the equality of the variances of the two groups expecting and not expecting the normality of the temperature conditions was confirmed. Considering the P-value (sig (0.043) <0.05), the hypothesis of equality of the mean thermal sensation of the two groups is rejected with a 95% confidence level.

Therefore, it can be stated that the expectation of temperature conditions based on the cold season causes changes and differences in people's thermal sensations. In the next analysis, if people's thermal sensation is separated based on their experience of the environment, it can be said that 52% of the visitors with the *neutral* thermal sensation, based on their previous experience, think that the environment should be slightly colder, 31% of them think that the environment should be completely colder, and the rest of the visitors consider the temperature of the environment suitable enough. Most of the visitors (over 45%) with the *slightly cold* thermal sensation consider the thermal environment suitable based on their experience, more than 37% (13 out of 35 visitors) think that the environment should be slightly colder than what it is now. 8.5% of the visitors think that the environment is slightly hotter and the same amount of them think that the environment is completely colder. Based on their previous experience, 80% of the visitors with the slightly hot thermal sensation think that the environment should be slightly colder while the rest think that the conditions are suitable enough. Based on their previous experience, 80% of the visitors with the hot thermal sensation think that the environment should become completely colder while the remaining 20% think that the conditions are suitable enough. 50% of the visitors with the cold thermal sensation consider the environment temperature to be suitable based on their experience, 25% think that it is slightly hotter, more than 16% think that it is slightly colder, and the rest think that the current thermal environment is completely colder.

In addition to the duration of the experience (momentary or long-term) and the effect of different time scales on human perception, the spatial and material characteristics of the environment also affect thermal perception. For instance, short-term weather conditions shape momentary thermal perception, but the accumulated weather experience can lead to long-term perception (Lenzholzer et al., 2018). Based on this view and assuming that short-term experience is related to memory and seems to be responsible for changes in people's expectations from one day to the next (Knez et al., 2009), we used the independent two-sample t-test to examine the alignment of experience and expectation, the thermal experience of two independent groups who expected and did not expect the current temperature conditions. To create a numerical correspondence with qualitative concepts like that created for thermal sensation and preference and evaluate the thermal environment based on the audience's experience, the numbers corresponded with the number zero if they considered the conditions suitable based on their experience, with numbers 1 and 2 if they thought that it should be slightly hotter and hotter, and with the negative sign of these numbers in the opposite state (slightly colder and colder). By confirming the assumption of the equality of variances of the two groups using Levene's test, (sig (0.534)>0.05), We can say with a 95% confidence level that the mean thermal experience of the visitors to Naqsh-e Jahan Square in Isfahan are the same no matter they expected such temperature conditions or not, and that they wanted the environment to be slightly colder due to the winter season. Due to their short-term experience of accepting or not accepting the temperature conditions of the current thermal environment, they have an attitude towards the thermal environment based on their previous experience and think that it should be slightly colder to correspond with the winter season. We also need to analyze alliesthesia, which is a relatively complex concept that involves the response of people in the moment based on the location and time, and probably topics related to phenomenology and attention to topics such as the sense of place, seasonal conditions and other variables.

It is used to describe the pleasant or unpleasant feeling resulting from an increase or decrease in the deviation from a certain point in the adjusted variables. Since this study is specific to the winter season, it asked the question of whether the hot or the cold season was more pleasant. Among the respondents, 41% chose the hot season and 23% chose the cold season. The rest found both seasons pleasant with no difference. By analyzing the responses based on thermal sensation and thermal preference, we can conclude that all the people who made no difference between hot and cold seasons have neutral (67%) and slightly cold thermal sensation (34%), and 97% of them prefer no change in the temperature conditions. The dominant sensation of those interested in the hot season (37%) is *slightly cold* 34% of these visitors have the *neutral* thermal sensation and 29% have the *cold* thermal sensation. As many as 80% of the people voted for slightly hotter weather whereas the rest voted for no change in the current temperature conditions, which seems normal given the current temperature conditions, expectation from the cold season and people's interest in the hot season. None of those interested in the cold season feel the environment temperature as *cold*. 34% of the people have a *slightly cold* thermal sensation.

The rest, equal to 22%, have a neutral, slightly hot and hot thermal sensation. The thermal preference of all those interested in the cold season is the colder temperature conditions, which seems normal considering expectations from the cold season, the interest of these visitors and the current temperature conditions. A general analysis of the two graphs shows that for all visitors with similar interests in both seasons, the current temperature conditions are within the comfort range and scale range of 0 to -1. 71% of those interested in the hot season are in the comfort range (0 to -1). Considering the definition of thermal comfort and this number which is less than 80%, this group cannot fall in the thermal comfort conditions. Therefore, their interest and satisfaction in the thermal sensation and the effective role of season-based alliesthesia in them are confirmed. For those interested in the cold season who have a comfort range from +1 to -1, it can be said that with an error rate of less than 5%, 80% of them are in thermal comfort conditions.

Discussion and Conclusion

Comfort conditions are considered to be conditions where the environmental conditions are *neutral*, i.e. people feel neither hot nor cold. However, it is increasingly believed that a variable environment is preferable to a steady one because the latter environment is not tolerable. Although the mean temperature of the interview days was lower than the comfort temperature given in the equations, the visitors to Naqsh-e Jahan Square are in the acceptable range of thermal comfort, and although the current temperature conditions are lower than the neutral temperature and global equations, they are not acceptable, satisfactory and preferable over temperature change - based on the cold season. The reasons for this can be partly related to the adaptation theory.

Visitors to Naqsh-e Jahan Square may experience a different thermal sensation, which is not the same between the two groups due to their expectations which are based on their short- or long-term experience and factors related to their perceptual schemata or thermal background, leading them to consider the environmental temperature conditions acceptable or unacceptable. The experience factor with two approaches of short-term experience (for example: experience from here and now or the last few days) and long-term experience (for example, the experience of the past years or childhood in the elderly) - which may be far from expected with respect to the current non-linear weather changes - and also the influence of various related factors such as achieving perceptual schemata from short-term and long-term experiences, thermal background and factors such as the experience of others can pose challenges for this factor in terms of separation of experiences. Previous experience is not dependent on place as much as it is a variable brought by people to that space. However, some measures can be taken to influence experience, especially the short-term experience. From the authors' point of view, the role of short- and long-term experience in this research cannot be separated in the *expectation* factor, because apart from these factors, many other factors such as long- and short-term thermal background also affect the expectation factor, and each of these factors can be related to long-term experience or mental schemata.

What is considered in the proposition about the effect of people's expectations on thermal sensation is that the role of experience in any form and state is proportional to the time scale, and this scale can have a different effect for each person in the short or long term.

If we accept Kenz et al.'s (2009) view, the expectation factor can be considered to be influenced by short-term experience, and if it is assumed that the respondents have declared their opinion regarding the suitability or the need for higher or lower temperature conditions based on their long-term experience, this study also confirms the consistency of short- and long-term experience. From the point of view of the researchers, it does not seem necessary to compare the two concepts of thermal adaptation and thermal correlation and both factors can be important for describing and interpreting thermal comfort and the reasons for different sensations and perceptions between individuals, but the observed season-based alliesthesia proposed by Lai (2014) and Yao et al. (2018) (that the thermal sensation *slightly hot* is considered the most comfortable sensation in the cold season) is not confirmed in the general view of the participants in this study, and the thermal sensation *slightly cold* in the winter season is considered the most comfortable sensation of visitors to Naqsh-e Jahan Square in Isfahan, and the concept of adaptation is confirmed.

These visitors are in the comfortable range because of the adaptation factor, but it can be said that considering the division of the visitors into two groups interested in cold and hot seasons based on the season-based alliesthesia, the group interested in the cold season is in the comfortable range. Therefore, the pleasantness of the season-based conditions, even if the expectations and thermal preferences of the people are not met, can place them in the comfort range. Thus, from this point of view, the concept of season-based alliesthesia is confirmed for visitors to Naqsh-e Jahan Square. Studies on human multisensory perception and the concept of *alliesthesia* show that the signs of one sense may influence the perception of a different sense. These cases highlight the importance of human subjective variables in thermal comfort research, arguing that focus on people not only as recipients of multiple exchanges of radiation in outdoor spaces with the aim of achieving balance through their internal thermoregulation process, but also active participation with the perception of this thermal process is the core of this approach and this new perspective can provide a complementary model and explain the importance of qualitative factors in thermal perception in outdoor spaces.

From the point of view of the authors, all the variables including the examined ones along with the quantitative factors related to the environmental conditions and other qualitative factors, in a final correlation and depending on the internal state of the person, create the audience a response based on their outcome at the moment of their responding to thermal comfort. It can be said that attention and evaluation of alliesthesia based on season and place can redefine the temperature range defined for the comfort range in relation to each person (or group) and their characteristics. Confirming this research on a larger scale or attention to further details about the hot and cold seasons conducting analyses in different climates and exploring the characteristics of each region will help localize the equation of thermal comfort according to qualitative approaches and subjective variables and require further specialized researches in Line with sustainable Design thinking.

This Qualitative Variables Affecting thermal comfort must be used as Design Thinking. Such a strategy that architects designed and used by people to overcome the hot and cold weather, is called increasing the adaptation. Adaptation theory says that people should be active in their thermal comfort, but the question is whether this opportunity is given to them or not. For more details look at Figure 4. If we assume that the temperature is on the vertical axis, in the picture, you see two parallel lines with a horizontal axis between them that is blue. We read this area *status quo of the architecture*, the state of the comfort condition that the building provides without any change. The sine curve that the two lines are cut off, creates two stressful areas, out of the parallel lines, which have a large area under the curve (e.g. thermal pressure is high.) If the distance between two lines becomes more, the opportunity of adaptation increases and the thermal pressure range reduces. Finally, if the distance includes the minimum and maximum of the curve, we can say that the opportunity of adaptation in complete, and users can control the environmental condition.

Traditional architecture of Iran has a lot of awesome examples of having the opportunity of adaptation for the users. Yard, basement floor, garden, water and various rooms, all provide good compatibility. Thus, the design of the building and its components have to provide some sort of opportunity of personal control for the users.

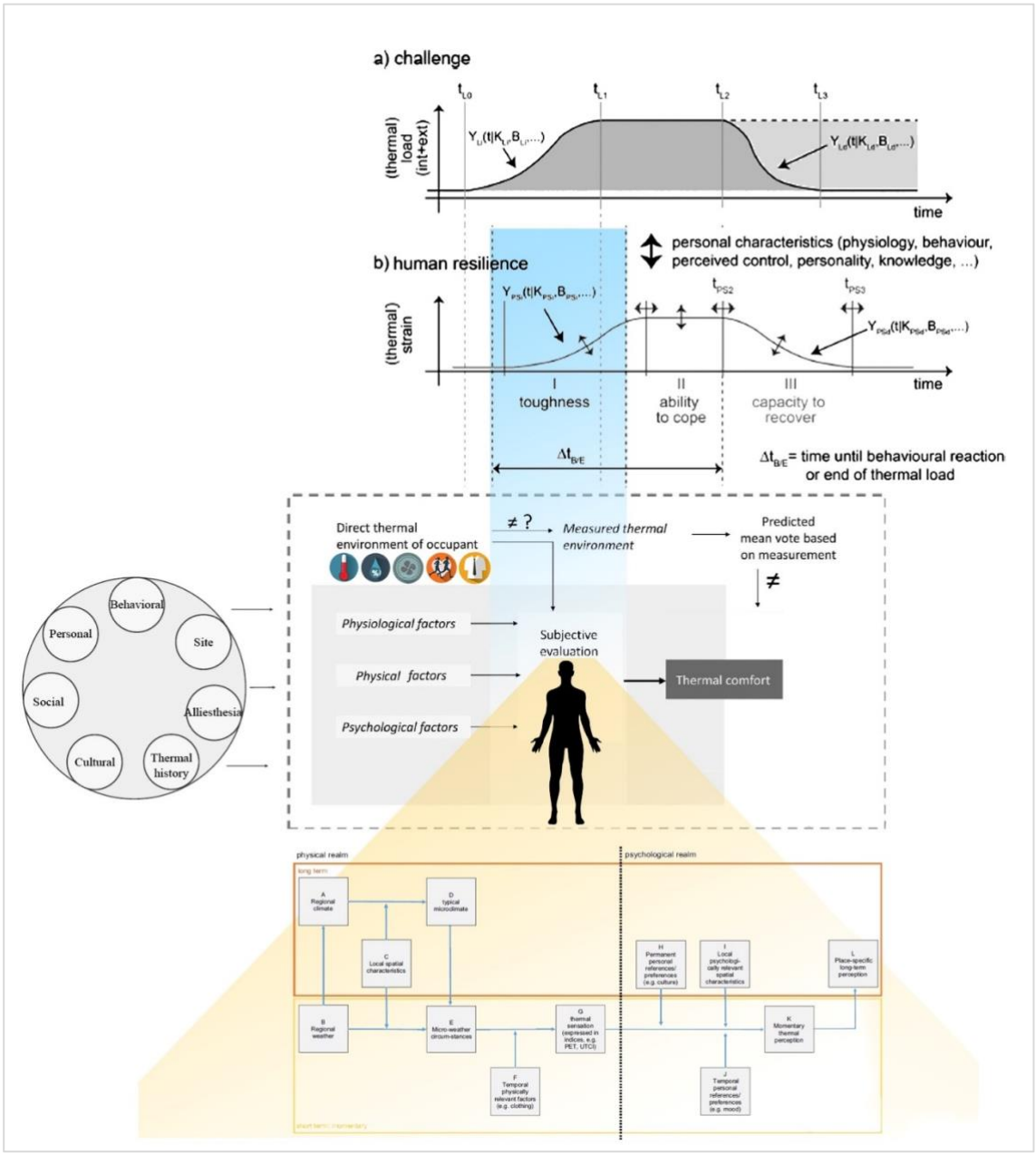

Figure 5: *Explanation of the components affecting thermal, perception, aligned with human flexibility in defining Thermal comfort in line with sustainable design thinking (Source: Retrieved from Schweiker (2022), Lai et al. (2020), Lenzholzer & de Vries (2020)).*

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