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ORIGINAL PAPER

Investigating the impacts of shaded outdoor spaces on thermal adaptation and cognitive performance of university students in classroom environments

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Abstract

Shading strategies are effective means to reduce urban risk factors such as the Urban Heat Island (UHI) effect. The influence of shaded outdoor spaces on university students' thermal adaptability and cognitive performance is limited researched. The study aims at evaluating the effect of shaded outdoor spaces upon thermal comfort; and, linking such results upon university students' cognitive performance in a classroom environment with natural ventilation. A case study was conducted with students the ages of 19–22 at Bilkent University in Ankara, during the mid-season in October.

The quantitative microclimatic conditions of the university campus's unshaded/shaded areas and indoor studios were obtained through Physiologically Equivalent Temperature (PET) index. The qualitative evaluation was undertaken by the adaptive model and thermal comfort survey. D2 test of attention was conducted to measure cognitive performance of students.

This study revealed that the shade may increase thermal adaptation with the lowest mean PET of 18.7°C, while the highest mean PET of 33.2°C was obtained in sun-exposed space. Also, experiencing shaded outdoor space contributed to an improvement in concentration performance (CP) of students resulting in the mean CP score of 182.8, while those with sun-exposed outdoor space experience had the mean CP score of 167.6 within studios.

Keywords Thermal adaptation · Cognitive performance · Shaded space · PET · Indoor-outdoor relationship

Introduction

The increase of the Earth's temperature, mainly due to anthropogenic climate change, has played a significant role in thermal comfort in outdoor and indoor environments. Within the consolidated urban fabric, the lack of vegetation increases the heat storage in the ground layer and building materials, contributing to the greater level of air and surface temperature in urban areas compared to the rural surrounding (Oke 1982). The 'Urban Heat Island' (UHI) effect has given high importance to human thermal comfort with ongoing urbanization patterns (de Miranda et al. 2022; Zheng et al. 2022) due to the reduction of living and working productivity (Anupriya 2016), making urban pollution more severe and affecting citizens' health (Leal Filho et al. 2021; Sadeghi et al. 2022). Therefore, human thermal discomfort has become a common concern in the built environment (He et al. 2020; Laue et al. 2022).

Due to the urban morphology, wind and solar radiation are significant factors affecting human thermal comfort and adaptation (Lin et al. 2010; Jin et al. 2020). Solar radiation has the most significant effect on human thermal sensation in outdoor spaces (e.g., Elnabawi and Hamza 2020; Ji et al. 2022). The wind and shade also contribute towards improving thermal sensation and comfort (Abreu-Harbich et al. 2014; Sarhadi and Rad 2020). However, the wind-tunnel effect, especially with

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the shade between two buildings, could result in a cold path (Nugroho et al. 2022). The influence of climatic parameters on thermal perceptions showed variances based upon the thermal environments, with solar radiation dominating in locations exposed to direct sunlight, while wind speed prevailed in spaces where wind speed is increased by building structures (Xie et al. 2022). It is important to analyse how the effects of outdoor microclimatic variables differ based upon outdoor thermal conditions, and relate their impacts to indoor thermal comfort through using quantitative and qualitative thermal comfort approaches, whose limited research is available in the literature.

With regards to the effect of thermal environment, humans tend to adapt themselves to thermal conditions to improve their thermal comfort (Nouri and Matzarakis 2019). Increasing the effect of shading in outdoor spaces is an effective adaptive strategy for human thermal comfort (Mi et al. 2020; Rahman et al. 2020; Ouyang et al. 2020). Shading effects from the architectural elements, vegetation, and other landscape amenities, can decrease the incidence of solar radiation, and sunlight, lower the ground surface temperature and reduce long and short-wave radiation effects (Hwang et al. 2011; Nouri et al. 2018; Jaafar et al. 2022). High temperature in outdoor open spaces leads to thermal discomfort for students due to a lack of shading area (e.g., Abdallah et al. 2020; Lee et al. 2021). The shade from such amenities and vegetation increases thermal comfort and adaptation in spring, summer, and fall (Middel et al. 2016; Liu et al. 2022) and provides more comfortable spaces than outdoor spaces receiving direct sunlight (Manavvi and Rajasekar 2022; Othman et al. 2021) and decreases Physiologically Equivalent Temperature (PET) in summer (Mi et al. 2020). Although the importance of shaded strategies was comprehensively implied in the summer and winter seasons (Yin et al. 2019; Huang et al. 2019), more examinations are needed to be thoroughly undertaken through analysing both PET and thermal responses during mid-seasons.

Regarding shading strategies, ‘staying and seeking a shaded outdoor location’ has been shown as the most preferred adaptive behaviour for improving human thermal comfort in higher temperatures (e.g., Watanabe and Ishii 2016; Sharmin and Steemers 2020). The provision of choice in the built environment considerably affects pedestrian behaviour. The absence of choices for thermal adaptation could cause pedestrians to avoid or stay shorter periods in outdoor environments (Eliasson et al. 2007; Nouri and Costa 2017a). Although outdoor adaptive behaviours have been comprehensively investigated, it is needed to understand how experiencing different outdoor conditions shows difference in indoor behaviours in university indoor settings.

Thermal comfort has been shown as a significant determinant for cognitive performance. Most studies have concentrated on thermal comfort of controlled indoor environments in relation to cognitive performance and productivity of university, primary/secondary school students, and office workers (e.g., Sarbu and Pacurar 2015; Wang et al. 2018; Woo et al. 2022). The change in indoor thermal conditions affect learning performance of students (Kim et al. 2020). Juan and Chen (2022) indicated that the changes in indoor temperature led to considerable difference in human concentration level. Warm discomfort affected negatively performance, while optimum temperature range was indicated between 22°C (slightly cool) and 26°C (a little higher than neutral) temperature values (Cui et al. 2013). However, it is needed to analyse how cognitive performance in indoor settings differ among students with different outdoor thermal experiences to thoroughly understand outdoor-indoor thermal relationship.

Previous studies have well documented the importance of shaded outdoor spaces and thermal comfort through quantitative and qualitative approaches on outdoor and indoor thermal comfort separately. Limited information is available on how experiencing shaded outdoor spaces can affect the outdoor and indoor thermal adaptability of university students. In addition, preceding studies that investigated the relationship between thermal environment and cognitive performance primarily focused on the effect of indoor thermal conditions on cognitive skills. Yet, there is restricted disseminated research on the effects of experiencing outdoor thermal conditions with different shading strategies on the cognitive performance of students in indoor environments.

Considering the Turkish growing and densifying capital city of Ankara, which is a vulnerable city to existing and future heat stress factors, this study was undertaken in the autumn season due to the limited examination of thermal adaptation in literature during mid-seasons. To aid interdisciplinary guidelines on how architects and designers can better approach the learning environments regarding urban morphology, the aim of the study was twofold. The first aim was to evaluate the effect of shaded outdoor spaces upon thermal comfort of university students through evaluation of quantitative aspect with a human bio-meteorological model, and qualitative aspects of thermal comfort with subjective outdoor and indoor thermal comfort questionnaire surveys. The second aim was to link such quantitative and qualitative results of thermal comfort upon university students’ cognitive performance with d2 test of attention (Brickenkamp and Zillmer 1998) in a classroom environment with natural ventilation, resulting in a possibility for providing a more comprehensive understanding of thermal perception by combining both quantitative and qualitative approaches (Shooshtarian et al. 2020).

Materials and methods

Study area

The city of Ankara is located in the Central Anatolia Region of Turkey at 40°N and 33°E, with a climatic Köppen-Geiger (KG) classification of ‘*Dsb*’ which is associated with a snow/cold climate with dry/warm summers (Peel et al. 2007). The newer map of KG for Turkey produced by Yılmaz and Çiçek (Yılmaz and Çiçek 2018) also indicated that Ankara is adjacent to '*Csa*' which identifies warm temperate with dry hot summer, and '*BSk*' which identifies cold semi-arid climate classification. With substantially higher temperature threshold during the summer, KG in the case of Ankara can vary to '*Dsa*' within the depressions of the plateaus (Nouri et al. 2021a). Mean temperatures of Ankara range from 0.2 °C in January to 23.4 °C in July, with an annual average of 11.9 °C. According to the statistics of the Turkish State Meteorological Service in 1991–2020 for seasonal normal in Ankara, average temperature ranges between 0.9 and 2.7°C in winter (Dec, Jan, Feb), 6.7°C and 16.5°C in spring (Mar, Apr, May), 20.6°C and 24.3°C in summer (Jun, Jul, Aug), as well as 7.3°C and 19.6°C in autumn (Sep, Oct, Nov). Average maximum temperature ranges from 4.7 to 7.4°C in winter, 12.2 to 22.8°C in spring, 27.3 to 31.0°C in summer, and 13.0 to 26.5°C in autumn. Average minimum temperature ranges from −2.2 to −0.3°C in winter, 1.9 to 10.5°C in spring, 14.1 to 17.4°C in summer, and 2.7 to 13.1°C in autumn. The annual average precipitation amount is 34.4 mm, with monthly total precipitation ranging from 14.6 mm in August to 51.0 mm in May.

The field investigation was conducted on İ.D. Bilkent University campus given its enclosure of various microclimatic conditions. To provide a particular analytical area within the campus, the Points of Interest (POI) methodology was intended for use within this study (Nouri and Costa 2017b). Two POIs were selected as study areas on the main campus of Bilkent University (Fig. 1 and Fig. S1). POI 1 with the mean Ta of 21.2°C and the mean PET of 18.7°C during the measured period is defined as a shaded outdoor space, located between two buildings that block direct solar radiation and have a probability of wind tunneling effect due to the mass configuration (wide-narrow-wide) (Nugrahanti et al. 2018). The height of the nearby buildings in POI 1 is around 16 m, and the height of the bridge between two buildings measures approximately 4 m from the ground to its lowest point. POI 2 with the mean Ta of 26.5°C and the mean PET of 33.2°C during the measured period is an open square that receives direct solar radiation during the measured period, used as a frequent gathering area for students. Two studios (Studio 1 and Studio 2) with natural ventilation, located in the same direction and on the same floor, were selected as classroom environments (Fig. 1 and Fig. S2). The classroom environments will henceforth be referred to as studios due to not considering classroom and studio the same type of learning environments.

Field study

Quantitative and qualitative aspects of thermal comfort within the outdoor spaces were evaluated through the measurement of microclimatic parameters, a questionnaire survey on human responses, and cognitive performance tasks in indoor settings. This study was carried out in the autumn season as a result of human comfort levels changing considerably due to fluctuations in thermal sensation (Li et al. 2020) being different from many studies investigated in summer and winter season. The field investigations were conducted on the 11th of October 2021 on a sunny day in the autumn season. On this day, the average daily mean and maximum temperature were 6–7°C higher than the seasonal normal in Ankara. The field measurements were conducted between 15:00 and 16:30 local time, symbolic of end of the hotter hours of the day, and the period in which local surface receives and absorbs heat at a greater rate than it can radiate it back to the encircling atmosphere, depending on cloud cover and wind speed. It presents the period with increased vulnerability to indoor temperatures within naturally ventilated buildings in Ankara (Nouri et al. 2021b). The questionnaire surveys and cognitive performance tasks were conducted with undergraduate university students in Interior Architecture and Environmental Design as subjects of the study.

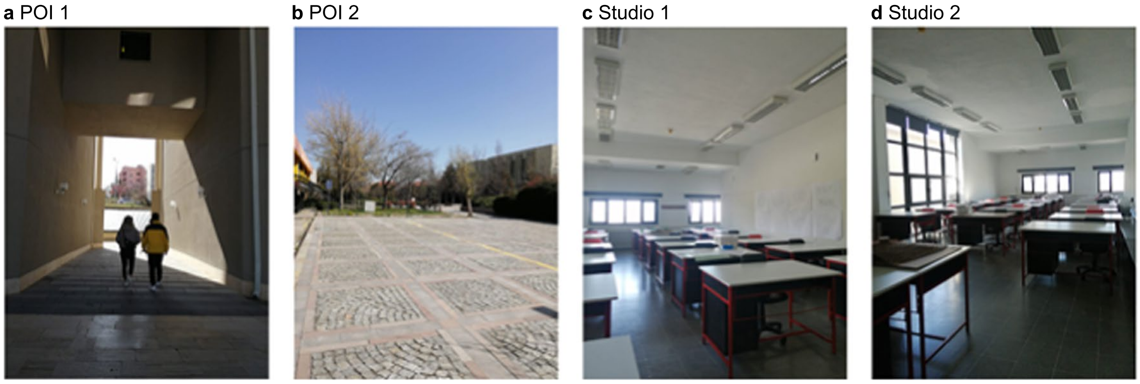

Fig. 1 Photos of the measurement locations: **a** POI 1, **b** POI 2, **c** Studio 1, and **d** Studio 2

Quantitative measurements

In situ outdoor (POI 1 and POI 2) and indoor (studios) measurements of four singular microclimatic variables were measured by the use of the portable Kestrel Heat Stress (KHS) trackers with the temporal resolution of 1 min at a 1.1 m height, equating to the centre of gravity of the human body for standing subjects (ISO 1998) to process into an Energy Balance Model (EBM) index (Höppe 1984, 1999) within this study (Table S1). The importance of these variables in determining the physiological impact on the human bio-meteorological system in consideration of retrieved environmental conditions is the reason for their selection in this study. These variables provide a more comprehensive understanding of the association to human thermoregulation dynamics and the approach to the human body (Höppe 1999).

The four variables retrieved from in situ $KHS_{OUT}/_{IN}$ were outdoor/indoor air temperature (Ta_{OUT}/Ta_{IN}), outdoor/indoor globe temperature (Tg_{OUT}/Tg_{IN}) outdoor wind/indoor air speed (V_{OUT}/V_{IN}, respectively), outdoor/indoor relative humidity (RH_{OUT}/RH_{IN}). In addition to four preliminary microclimatic variables, outdoor/indoor mean radiant temperature ($Tmrt_{OUT}/Tmrt_{IN}$), which is used to measure the radiation fluxes, was calculated in outdoor and indoor measurement sites (Table S2).

Qualitative measurements

This study aimed at determining psychological and behavioural aspects of thermal adaptation in order to strengthen thermo-physiological analysis. Outdoor and indoor questionnaires were distributed to 58 university students. 116 questionnaires, 58 for outdoor (POI 1 and POI 2) and 58 for indoor environments, were collected. The questionnaires consisted of three sections (Table S3):

- The first section gathered demographical information, location in outdoor environment, and clothing insulation according to ASHRAE Standard 55 (2010).
- The second section asked to rate overall thermal comfort vote (OTCV), using a four-level scale (Comfortable, slightly comfortable, slightly uncomfortable, comfortable), as suggested ASHRAE Standard 55 (2010). This section includes the sensation, preference, and comfort votes for air temperature (Ta), wind speed (*V*), and solar radiation (Tmrt). Based on ASHRAE Standard 55 (2010), air temperature sensation vote (ATSV) was evaluated on a seven-point scale (−3, cold; −2, cool; −1, slightly cool; 0, neutral; 1, slightly warm; 2, warm; 3, hot), similarly for thermal sensation vote (TSV) in previous studies (e.g., Wang et al. 2017; Mishra et al. 2017). Air temperature preference vote (ATPV) was rated on a five-point scale (much colder, a bit colder, no change, a bit warmer, much warmer), similarly to Sun et al. (2022). Wind speed and solar radiation sensation vote (WSSV and SRSV) were rated on a seven-point scale (Very low/Very weak, Low/Weak, Slightly low/Slightly weak, Neutral, Slightly high/Slightly strong, High/Strong, Very high/Very strong) as the previous study (e.g., Lin et al. 2015; Wang et al. 2017). For wind speed and solar radiation preference vote (WSPV, and SRPV), a five-point scale was used (Lower/Weaker, A bit lower/A bit weaker, No change, A bit higher/A bit stronger, Higher/Stronger), similarly to previous studies (e.g., Abdallah et al. 2020; Sun et al. 2022). The comfort vote for air temperature, wind speed, and solar radiation (ATCV, WSCV, and SRCV) was evaluated using Yes/No answers.
- The third section adaptive behaviours were divided into two parts, based upon changing their location and adjusting their own thermal state.

Thermal Index (thermo-physiological analysis: PET calculations)

The study referred to the EBM index within the urban and interior contexts to determine the effects of the thermal environment on the human body. The PET index (Mayer and Höppe 1987; Matzarakis et al. 1999), based upon the Munich Energy-balance Model for individuals (MEMI) (Höppe 1993, 1999) was considered an appropriate thermal index in this study. EBM stress classification including the PET presented the highest performing indices relevant to the body-atmosphere balance variety (de Freitas and Grigorieva 2017). Additionally, its unit (°C) makes results more apprehensible (Matzarakis et al. 1999). The PET index is described by the Ta at which, in an indoor context, the human energy budget is sustained by T_{Sk}, core temperature (T_{Cr}), and perspiration rate (PR) is equivalent to those under the assessed conditions. To state human Physiological Stress (PS) thresholds by Matzarakis et al. (1999), the PET was calculated using the biometeorological model RayMan Pro © (Matzarakis et al. 2006, 2007; Matzarakis and Fröhlich 2018). Based upon MEMI, outdoor/indoor air temperature (Ta_{OUT}/Ta_{IN}), outdoor wind/indoor air speed (V_{OUT}/V_{IN}, respectively), and outdoor/indoor relative humidity (RH_{OUT}/RH_{IN}), were retrieved from the in situ $KHS_{OUT}/_{IN}$. To calculate the PET index, outdoor/indoor Mean Radiant Temperature ($Tmrt_{OUT}/Tmrt_{IN}$) was calculated through Tg_{OUT}/Tg_{IN}, retrieved from in situ $KHS_{OUT}/_{IN}$, based on the following equation from the ISO 7726 standard (ISO 1998):

$$\mathrm{Tmrt}_{\mathrm{IN}} = \left[\left(\mathrm{Tg}_{\mathrm{IN}} + 273\right)^4 + \frac{0.25\times 10^8}{\varepsilon}\left(\frac{\left|\mathrm{Tg}_{\mathrm{IN}} - \mathrm{Ta}_{\mathrm{IN}}\right|}{D}\right)^{1/4} \times \left(\mathrm{Tg}_{\mathrm{IN}} - \mathrm{Ta}_{\mathrm{IN}}\right)\right]^{1/4} - 273$$

and

$$\mathrm{Tmrt}_{\mathrm{OUT}} = \left[\left(\mathrm{Tg}_{\mathrm{OUT}} + 273\right)^4 + \frac{0.25\times 10^8}{\varepsilon}\left(\frac{\left|\mathrm{Tg}_{\mathrm{OUT}} - \mathrm{Ta}_{\mathrm{OUT}}\right|}{D}\right)^{1/4} \times \left(\mathrm{Tg}_{\mathrm{OUT}} - \mathrm{Ta}_{\mathrm{OUT}}\right)\right]^{1/4} - 273$$

where D is the globe diameter (0.025 m in this study) and ε is its emissivity (0.95 for a black globe). Tmrt is defined as the uniform temperature in an imaginary enclosure in which the radiant heat transfer from a human body is equal to the heat transfer to the surfaces of an actual enclosure with non-uniform temperatures (ISO 1998). Furthermore, a comparative chart was used to identify the Physiological Stress (PS) grade (Table S4).

Cognitive performance: d2 Test of Attention

The standard version of d2 Test of Attention was used to measure individual cognitive performance of students because its construct and convergent validity were determined to assess attention (Bates and Lemay 2004). The d2 is a one-page paper-pencil and time-limited test that aims at assessing concentration and selective attention (Brickenkamp and Zillmer 1998). The d2 test includes 14 lines with 47 characters, 658 in total. These stimuli contain the letters ‘d’ or ‘p’ with marks above and/or below, with requirement. The test requires participants to cross (/) any letter ‘d’ with two marks for each line within 20 s (Brickenkamp 1962).

Scoring of the d2 test of attention includes the followings: (1) total number of items processed (TN), which is a quantitative measure of performance of all items that were processed, including both relevant and irrelevant ones; (2) errors of omission (E1); (3) errors of commission (E2); (4) total number of errors (E); (5) percentage of errors (E%), (6) a total number of items scanned minus the error (TN-E); (7) concentration performance (CP), which is the sum of items crossed out correctly - E2; (8) the fluctuation rate (FR), which is maximum total items processed in a trial minus minimum total items processed in a trial (Table S5). Similar to studies (e.g., da Silva-Sauer et al. 2022; Woo et al. 2022), the following parameters of the d2 Test of Attention were utilized within this study: TN, E%, TN-E, CP, and FR.

Experimental procedure

The students were divided into 2 groups, Grp 1, and Grp 2, based upon studio environments (Studio 1 and Studio 2, respectively), to experience POI 1 and POI 2 before their break time. In outdoor exposure period, Grp 1 was exposed to POI 1 for 15 min, while Grp 2 was told to spend 15 min in POI 2 because thermal adaptation phase of the body to reach a steady-state was found ~ 15–20 min in previous studies (e.g., Goto et al. 2002; Arens et al. 2006; Wu and Mahdavi 2014). Based upon adaptive thermal comfort theory, one’s perception of thermal comfort is affected by one’s recent thermal experience (Brager and de Dear 1998). After the adaptation phase, outdoor thermal comfort questionnaires were distributed to record their outdoor thermal perceptions. Upon completing the outdoor questionnaire, Grp 1 and Grp 2 moved to the studio environment for indoor exposure period and spend 15 min in their studios. Then, indoor thermal comfort questionnaires were filled in studios and completed the d2 Test of Attention (for approximately 5 min), respectively. Outdoor and indoor microclimatic variables were measured during outdoor and indoor exposure periods and filling in questionnaires and d2 Test of Attention.

Statistical analysis

Distributions with a percentage of thermal responses, descriptive statistics of PET and thermal responses were cross-examined and compared. To interpret the results obtained from in situ $\mathrm{KHS}_{\mathrm{OUT}}/_{\mathrm{IN}}$ the table indicating the mean, minimum and maximum values for measured microclimatic parameters in each site, and Climate-Tourism/Transfer-Information-Scheme (CTIS) (Matzarakis 2014) were used.

Similar to studies (e.g., Wang et al. 2018; Chen et al. 2018; Sharmin et al. 2019), the correlation among thermal responses votes at the ordinal scale, including OTCV, Ta, V, Tmrt sensation, preference, and comfort was determined by Spearman’s rho correlation test to measure the strength and direction of a relationship between two variables (Argyrous 1997), in POIs and studios. An independent *t*-test analysis was conducted to compare parameters of the d2 Test of Attention to measure cognitive performance of students with different outdoor space experiences, similarly to Luo et al. (2016) and Liu et al. (2020).

Results

Personal information analysis

The mean age of the participants was 21 years old with a standard deviation of 1.1 years. The participants were in the age groups of 20–22 years old (84.0%), 18–19 years old (7.0%), and 23 years old (9.0%). 74.0% of the participants were female and 26.0% were male.

Quantitative measurements

Microclimatic parameters in POIs and studios

During the measurement period, Ta_{OUT} in POI 2 (Ta_{OUT}POI 2) was higher with the mean of 26.5°C in comparison to Ta_{OUT} in POI 1 (Ta_{OUT}POI 1) (21.2°C), Studio 1 (22.5°C) and Studio 2 (24.0°C) (Fig. 2). The mean Ta in POI 2 is also considerably higher than the mean Ta value (18.4°C) obtained from AMS (#17130) during the measurement period and average temperature for seasonal normal in autumn season (ranging between 7.3 and 19.6°C). Additionally, the value of V_{OUT} in POI 1 (V_{OUT}POI 1) was 1.0 m/s. The measured RH patterns also presented that the mean RH was almost the same in RH_{OUT} in POI 1 (RH_{OUT}POI 1) (41.0%), RH_{OUT} in POI 2 (RH_{OUT}POI 2) (34.0%), Studio 1 (35.0%), and Studio 2 (33.1%). The highest mean Tg was recorded in Tg_{OUT} in POI 2 (Tg_{OUT}POI 2) (35.3°C) in comparison to Tg_{OUT} in POI 1 (Tg_{OUT}POI 1) (20.2°C), Studio 1 (22.4°C), and Studio 2 (22.5°C). Subsequently, the $Tmrt_{OUT}$ in POI 2 ($Tmrt_{OUT}$POI 2) had the highest mean value with 43.4°C in comparison to $Tmrt_{OUT}$ in POI 1 ($Tmrt_{OUT}$POI 1) (22.0°C), Studio 1 (22.4°C), and Studio 2 (21.4°C) (Table S6).

Thermal comfort analysis through the PET index

PET was determined by the corresponding meteorological parameters within POIs, and studios, with determining metabolic rate of the participants 0.9 clo and 80 W in the RayMan model to analyse the impacts of identified microclimatic variables on the human biometeorological system (Matzarakis et al. 2007). Fig. 3 indicated the variation of the PET in POIs to determine the physiological stress levels during measurement periods. In comparison to the physiological stress grades (Table S4), it was determined that the hottest PET value and physiological stress grade was varied in POI 2, with the mean PET equating to 33.2°C, resulting in 'Moderate Heat Stress.' The lowest mean PET value and physiological stress grade was revealed in POI 1 with the mean PET equating to 18.7°C, indicating 'No Thermal

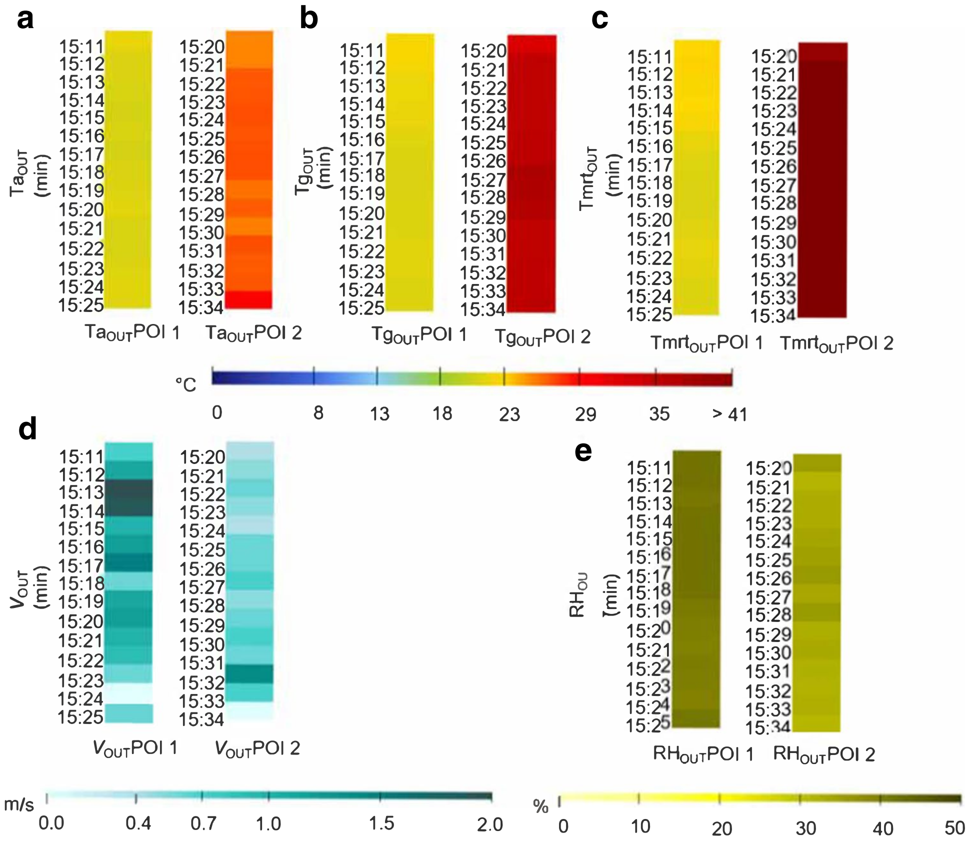

Fig. 2 CTIS diagram of variation results obtained from KHS_{OUT} between 15:11–15:25 for POI 1 and 15:20–15:34 for POI 2: (**a**) Air Temperature, (**b**) Globe Temperature, (**c**) Mean Radiant Temperature, (**d**) Wind Speed, and (**e**) Relative Humidity. Ta_{OUT}, outdoor air temperature; Ta_{OUT}*POI 1*, outdoor air temperature in POI 1; Ta_{OUT}*POI 2*, outdoor air temperature in POI 2; Tg_{OUT}, outdoor globe temperature; Tg_{OUT}*POI 1*, outdoor globe temperature in POI 1; Tg_{OUT}*POI 2*, outdoor globe temperature in POI 2; RH_{OUT}, outdoor relative humidity; RH_{OUT}*POI 1*, outdoor relative humidity in POI 1; RH_{OUT}*POI 2*, outdoor relative humidity in POI 2; V_{OUT}, outdoor wind speed; V_{OUT}*POI 1*, outdoor wind speed in POI 1; V_{OUT}*POI 2*, outdoor wind speed in POI 2

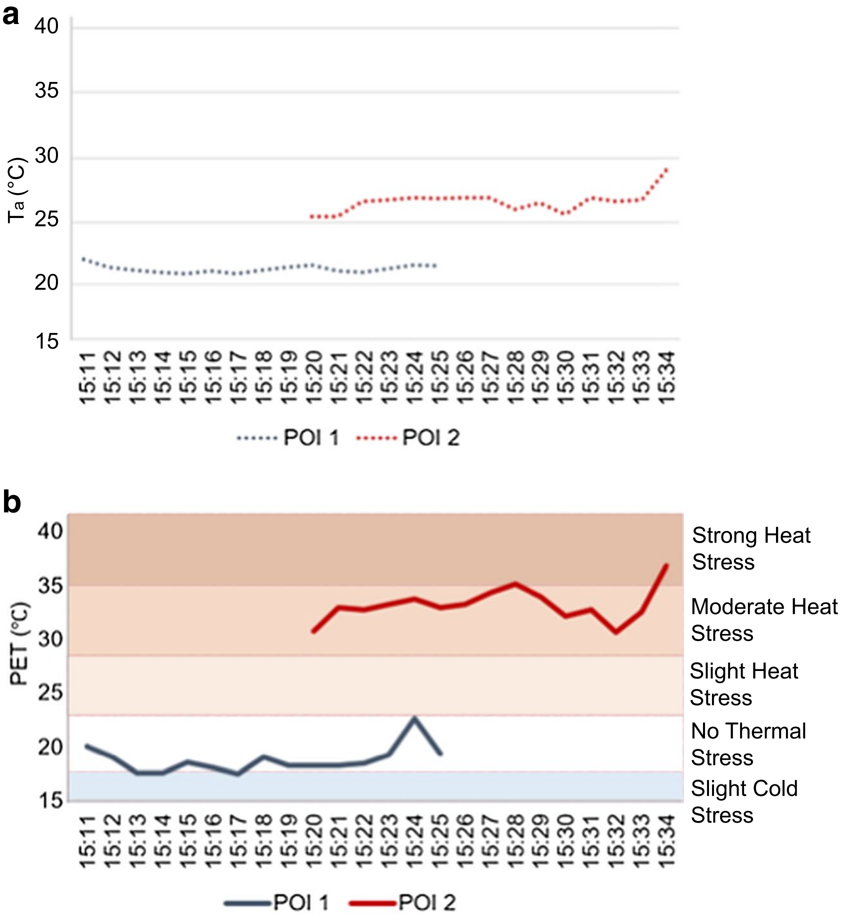

Fig. 3 Variation in POIs: (**a**), Air Temperature, and (**b**), PET with physiological stress grades

Stress'. Studio 1 and Studio 2 resulted in-between 'No Thermal Stress' and 'Slight Heat Stress,' with the mean PET value equating to 23.0°C, and 23.2°C, respectively.

Qualitative thermal responses

Overall thermal comfort

Forty-eight percent of students in POI 1 claimed outdoor OTCV ($OTCV_{OUT}$) condition are 'slightly uncomfortable' (Fig. S3). The votes in POI 2 were almost equally distributed between 'slightly uncomfortable' (31.3%), and 'uncomfortable' (28.1%). Regarding indoor contexts, most students in Grp 1 declared indoor OTCV ($OTCV_{IN}$) 'comfortable' (54.2%), while 'comfortable' (46.9%), and 'slightly comfortable' (43.8%) votes were almost equal percentages in Grp 2.

Air temperature

The results of outdoor ATSV ($ATSV_{OUT}$), ATPV ($ATPV_{OUT}$), and ATCV ($ATCV_{OUT}$) demonstrated a significant difference among POIs (Fig. 4). In $ATSV_{OUT}$, the highest percentage was allocated in POI 1 with 'slightly cool' (36.0%), and 'cool' (32.0%), while in POI 2, most students voted 'slightly warm' (33.3%), and 'warm' (30.3%). For $ATPV_{OUT}$, students, mostly voted 'a bit warmer' (64.0%) in POI 1, while 'a bit colder' (67.7%) in POI 2. Regarding $ATCV_{OUT}$, 76.0% in POI 1 voted 'yes', while the majority in POI 2 voted 'no' (66.7%).

After experiencing POI 1 and POI 2, participants were asked indoor ATSV ($ATSV_{IN}$), ATPV ($ATPV_{IN}$), and ATCV ($ATCV_{IN}$) in studios. In $ATSV_{IN}$, 'neutral' sensation represented the largest group in Grp 1 (37.5%) and Grp 2 (54.5%). In $ATPV_{IN}$, most votes in Grp 1 (50.0%), and Grp 2 (54.5%) were accumulated in 'no change'. Regarding $ATCV_{IN}$, 'yes' votes had the highest percentage in Grp 1 (83.3%) and Grp 2 (87.9%).

Wind speed

The participants were questioned on outdoor WSSV ($WSSV_{OUT}$), WSPV ($WSPV_{OUT}$), and WSCV ($WSCV_{OUT}$) in POIs (Fig. 4). In $WSSV_{OUT}$, the greater percentage in POI 1 were 'slightly high' (51.0%), while the votes were almost equally distributed between 'neutral' and 'very low' in POI 2. Regarding $WSPV_{OUT}$, 60.0% of students in POI 1 voted

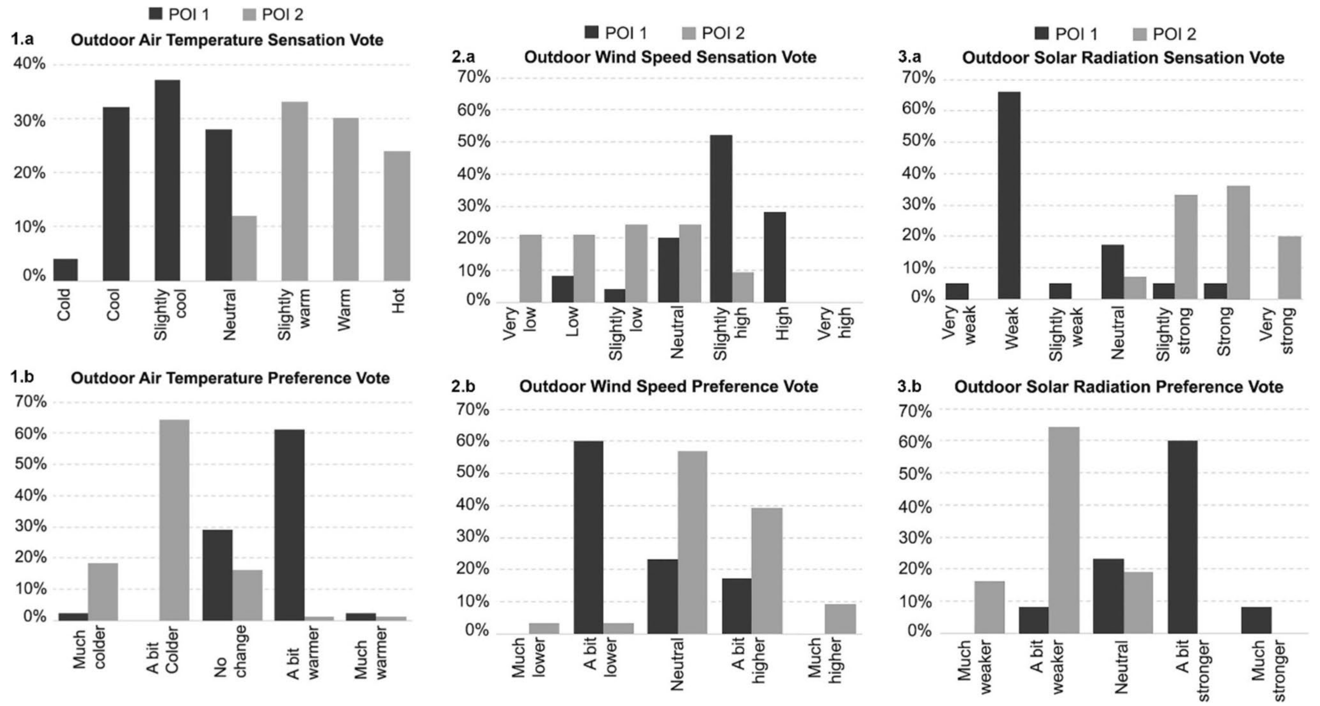

Fig. 4 Distribution analysis of outdoor thermal responses for Ta, *V*, and Tmrt in POIs: (1.a) $\mathrm{ATSV}_{\mathrm{OUT}}$, (1.b) $\mathrm{ATPV}_{\mathrm{OUT}}$, (2.a) $\mathrm{WSSV}_{\mathrm{OUT}}$, (2.b) $\mathrm{WSPV}_{\mathrm{OUT}}$, (3.a) $\mathrm{SRSV}_{\mathrm{OUT}}$, and (3.b) $\mathrm{SRPV}_{\mathrm{OUT}}$

'a bit lower' wind speed, while 'no change' (45.5%) and 'a bit higher' (39.4%) votes indicated the highest proportion. In $\mathrm{WSCV}_{\mathrm{OUT}}$, votes of 'yes' represented the greatest group in both POI 1 (56.0%) and POI 2 (69.7%).

The results from the studios showed 62.5% of Grp 1 and 63.6% of Grp 2 declared indoor WSSV ($\mathrm{WSSV}_{\mathrm{IN}}$) as 'neutral'. In indoor WSPV ($\mathrm{WSPV}_{\mathrm{IN}}$), 'no change' votes demonstrated the greatest group in Grp 1 (79.2%) and Grp 2 (56.3%). For indoor WSCV ($\mathrm{WSCV}_{\mathrm{IN}}$), most students in Grp 1 (83.3%), and Grp 2 (69.7%) voted 'yes.'

Solar radiation

Based upon outdoor SRSV ($\mathrm{SRSV}_{\mathrm{OUT}}$), SRPV ($\mathrm{SRPV}_{\mathrm{OUT}}$), and SRCV ($\mathrm{SRCV}_{\mathrm{OUT}}$), in $\mathrm{SRSV}_{\mathrm{OUT}}$, most students in POI 1 accumulated 'weak' (68.0%), while the votes in POI 2 were almost equally distributed between 'slightly strong' (39.0%), and 'strong' (33.0%). Regarding $\mathrm{SRPV}_{\mathrm{OUT}}$, 'a bit stronger' votes (60.0%) demonstrated the greatest percentage in POI 1, while the majority in POI 2 voted 'a bit weaker' (66.0%). For $\mathrm{SRCV}_{\mathrm{OUT}}$, most participants in POI 1 voted 'yes' (64.0%), while 'no' (66.0%) in POI 2 (Fig. 4).

Participants were questioned about indoor SRPV ($\mathrm{SRPV}_{\mathrm{IN}}$) in studios after experiencing POI 1 and POI 2. The greatest percentage of Grp 1 (50.0%), and Grp 2 (61.0%) was distributed in 'no change' votes. Almost half of the students in Grp 1 (42.0%), however, voted 'a bit stronger.'

Correlation between outdoor and indoor thermal responses

$\mathrm{ATSV}_{\mathrm{IN}}$ showed a significant correlation with only $\mathrm{SRSV}_{\mathrm{OUT}}$ in Grp 1 (r_s=0.411). This revealed that $\mathrm{ATSV}_{\mathrm{IN}}$ tended to increase with the increase of $\mathrm{SRSV}_{\mathrm{OUT}}$. Regarding Grp 2, $\mathrm{ATSV}_{\mathrm{IN}}$ was significantly affected by only $\mathrm{ATSV}_{\mathrm{OUT}}$ (r_s= 0.379), indicating that $\mathrm{ATSV}_{\mathrm{IN}}$ had an increase when $\mathrm{ATSV}_{\mathrm{OUT}}$ increased. Furthermore, $\mathrm{WSSV}_{\mathrm{OUT}}$ in Grp1 was the only variable affecting $\mathrm{WSSV}_{\mathrm{IN}}$ (r_s=0.427). Based upon Grp 2, $\mathrm{ATSV}_{\mathrm{OUT}}$ showed the most significant correlation with $\mathrm{WSSV}_{\mathrm{IN}}$ (r_s=−0.630), followed by $\mathrm{SRSV}_{\mathrm{OUT}}$ (r_s=−0.442). Regarding these results, it demonstrated that $\mathrm{WSSV}_{\mathrm{OUT}}$ tended to increase with the increase of $\mathrm{WSSV}_{\mathrm{IN}}$ in Grp 1, while the decrease of $\mathrm{ATSV}_{\mathrm{OUT}}$ and $\mathrm{SRSV}_{\mathrm{OUT}}$ in Grp 2 (Table S7).

The correlation between $\mathrm{OTCV}_{\mathrm{IN}}$ and outdoor sensation votes was also analysed for Grp 1 and Grp 2. $\mathrm{OTCV}_{\mathrm{IN}}$ only affected $\mathrm{WSSV}_{\mathrm{OUT}}$ in Grp 2 (rs=0.396), indicating that $\mathrm{OTCV}_{\mathrm{IN}}$ had an increase with the increase of $\mathrm{WSSV}_{\mathrm{OUT}}$. Regarding the correlation between sensation and comfort votes, the only correlation was found between $\mathrm{ATSV}_{\mathrm{OUT}}$ and $\mathrm{WSCV}_{\mathrm{IN}}$ in Grp 2 (r_s=−0.383). Furthermore, the results of the correlation between indoor preferences and outdoor sensation votes in Grp 1 and Grp 2 indicated that $\mathrm{ATSV}_{\mathrm{OUT}}$ had the most significant correlation with $\mathrm{WSPV}_{\mathrm{IN}}$ (r_s=0.578), followed by $\mathrm{ATPV}_{\mathrm{IN}}$ (r_s=−0.515) in only Grp 2. This revealed that the increase of $\mathrm{ATSV}_{\mathrm{OUT}}$ led to the increase of $\mathrm{WSPV}_{\mathrm{IN}}$ and the decrease of $\mathrm{ATPV}_{\mathrm{IN}}$ in Grp 2.

Correlation among outdoor thermal responses

The results of correlation among sensation votes showed that only $\mathrm{WSSV_{OUT}}$ showed a significant strong correlation to $\mathrm{ATSV_{OUT}}$ in POI 1 (r_s=−0.606). This revealed that $\mathrm{ATSV_{OUT}}$ tended to decrease with an increase in $\mathrm{WSSV_{OUT}}$. In POI 2, the only variable affecting $\mathrm{ATSV_{OUT}}$ was $\mathrm{SRSV_{OUT}}$ (r_s=0.438), indicating that a higher $\mathrm{SRSV_{OUT}}$ was associated with an increase in $\mathrm{ATSV_{OUT}}$. Given that the strength in the effect of $\mathrm{WSSV_{OUT}}$ in $\mathrm{ATSV_{OUT}}$ in POI 1 was higher than $\mathrm{SRSV_{OUT}}$ in POI 2 (Table S8).

Regarding correlation between sensation votes and overall thermal comfort, $\mathrm{ATSV_{OUT}}$ showed the most significant influence on $\mathrm{OTCV_{OUT}}$ in POI 1 (r_s=0.627), followed by $\mathrm{WSSV_{OUT}}$ (r_s=−0.449*)*, and $\mathrm{SRSV_{OUT}}$ (r_s=0.435*)*. This indicated that $\mathrm{OTCV_{OUT}}$ showed an increase with the increase of $\mathrm{ATSV_{OUT}}$ and $\mathrm{SRSV_{OUT}}$, while the decrease of $\mathrm{WSSV_{OUT}}$. $\mathrm{OTCV_{OUT}}$ in POI 2 was affected by $\mathrm{ATSV_{OUT}}$ (r_s=−0.531) and $\mathrm{SRSV_{OUT}}$ (r_s=−0.442). This revealed that $\mathrm{OTCV_{OUT}}$ tended to increase when $\mathrm{ATSV_{OUT}}$ and $\mathrm{SRSV_{OUT}}$ decreased (Table S8).

Adaptive behaviours

As regards Adaptive behaviours (I), 'having a hot/cold drink' (48.0%) and 'taking off some clothing' (51.5%) were considered the most behavioral adaptive measure in POI 1 and POI 2, respectively. For Adaptive behaviours (II), most students claimed 'being in a more sunny location' (56.0%) in POI 1, and 'being in a more shaded location' (66.7%) in POI 2 as a dominant behaviour choice.

In the following phase, students were asked to choose behavioural preferences in studios after experiencing POI 1 and POI 2. Based upon Adaptive behaviours (I), the results revealed that 'opening windows' was the most preferred behavioural measure of students in Grp 1 (41.7%) and Grp 2 (36.4%). For Adaptive behaviors (II), 'going outdoors' (33.3%), 'no changes' (33.3%) were demonstrated the highest distribution in Grp 1, while 'no change' (51.5%) in Grp 2 (Fig. S4).

The difference in cognitive performance among students with experience of different outdoor shading levels

Independent *t*-test indicated that university students with experience of different outdoor shading levels had significant differences in CP (p = 0.042) and FR (p = 0.041) while there was no significant difference in TN, E1, E2, and E%. CP of students in Grp 1 (M=182.8, σ = 34.3) was higher than students in Grp 2 (M=167.6, σ= 21.0). FR of students in Grp1 (M=16.5, σ = 5.8) was demonstrated to be lower than students in Grp 2 (M=19.3, σ = 4.5) (Table S9).

Discussion

The importance of adaptation to climate change on thermal comfort in warming cities has been considered in different disciplines. However, there is a need for an interdisciplinary approach to associate separated disciplines that have the common goal to minimize the adverse impacts associated with climate change and UHI effects upon urban inhabitants. The results of the study raise the opportunity to establish interdisciplinary bridges between human thermal comfort, interior/landscape architecture, and neuropsychology, based upon quantitative and qualitative aspects of thermal comfort within learning environments. The results should be approached as a wholesome evaluation of the potential positive effects of outdoor shaded spaces. In this study, the focus was undertaken upon those that are conducive to learning environments, and where university students moreover spend long sequential hours within the same interior space. Within this perspective, thermal comfort becomes an important issue for these university environments, whose efficiency must be ensured in an era of climate change.

Comparison of thermal responses against microclimatic conditions

The shade improved outdoor thermal comfort as numerous studies (e.g., Hanafi and Alkama 2017; Chan et al. 2017; Mi et al. 2020) based upon $\mathrm{OTCV_{OUT}}$. To understand the reasons behind this outcome, sensation, preference, and comfort level were analysed for Ta, *V*, and Tmrt, which have been identified as the strongest parameters influencing outdoor thermal comfort (e.g., Lee et al. 2014; Amindeldar et al. 2017; Sarhadi and Rad 2020).

The shade decreased Ta sensation to the cool side with a warmer preference despite feeling comfortable. Experiencing sun-exposed POI led to Ta sensation in warm side with colder preference to have better climatic conditions as Makaremi et al. (2012). The current results about a decrease in Ta sensation in shade are in alignment with earlier studies (e.g., Middel et al. 2016; Othman et al. 2021) despite being conducted in different climatic conditions. Yet, inconsistency remains regarding 'neutral' sensation assumed as the most comfortable thermal condition in shade during spring and autumn seasons (e.g., Hwang et al. 2011; Hadianpour et al. 2018).

The existing literature also recognizes that wind speed is just as, if not more important than air temperature for thermal comfort studies (e.g., Tse et al. 2017; Hou 2018; Xie et al. 2018). Based upon the outcomes, shade significantly increased $\mathrm{WSSV_{OUT}}$ compared to sun-exposed POI. $\mathrm{WSSV_{OUT}}$ in the shade was found to be higher than Othman et al. (2021), which concluded a 'neutral' *V* sensation in higher Ta. Despite the difference, wind speed conditions were satisfied in both spaces although participants preferred lower *V* in the shaded POI.

Solar radiation has been proven to be an important parameter affecting thermal comfort in the outdoor context (e.g., Pearlmutter et al. 2007; Ndetto and Matzarakis 2013; Norton et al. 2015). The current findings indicated that shade decreased Tmrt sensation to 'weak,' but it was preferred to be stronger despite being satisfied. Contrarily, Tmrt sensation in sun-exposed space was founded 'slightly strong' and 'strong', resulting in uncomfortable conditions with 'a bit weaker' preference, showing consistency with Xie et al. (2022) regarding solar radiation as a dominant parameter in sun-exposed spaces.

The comfort level of Ta, and *V* were found more satisfying with 'neutral' sensations with no change preferences in conditions in Studio 1, Studio 2 than in outdoor spaces despite different outdoor shading level experiences. This resulting choice could be linked to the inability of humans to differentiate single parameters since the main cause of the effect is not only associated with singular factors (Matzarakis 2020).

Correlation of thermal responses

Qualitative (i.e., psychological) thermal responses significantly affect thermal comfort apart from quantitative measurements (Fransson et al. 2007; Wang et al. 2017, 2018). Hwang and Lin 2007 revealed that thermal sensation has a relationship with wind sensation and sun sensation in outdoor and semi-outdoor spaces. From another standpoint, the undertaken study revealed that the effects of each measured microclimatic parameter varied based on outdoor condition shading levels. The results confirmed that the only parameter affecting $\mathrm{ATSV}_{\mathrm{OUT}}$ was $\mathrm{WSSV}_{\mathrm{OUT}}$ under the shaded POI, while $\mathrm{SRSV}_{\mathrm{OUT}}$ under the sun-exposed POI with partly similarity with previous studies (e.g., Krüger et al. 2011; Ng and Cheng 2012). Within this study, however, the strength of associations mostly was higher than in these studies. The reasons behind the difference could be a result of conducting in different countries with different KG classifications.

The study illustrated that thermal responses influencing $\mathrm{OTCV}_{\mathrm{OUT}}$ varied depending on the shading levels of outdoor environments. $\mathrm{ATSV}_{\mathrm{OUT}}$ and $\mathrm{SRSV}_{\mathrm{OUT}}$ were important determinants of human comfort under shaded and sun-exposed POIs. $\mathrm{WSSV}_{\mathrm{OUT}}$, however, had a significant influence on $\mathrm{OTCV}_{\mathrm{OUT}}$ under only shaded POI. These findings are not consistent with Wang et al. (2017), indicating no significant relationship among TCV, TSV, and WSV in summer. Wang et al. (2018), however, reported the increase in TCV with the decrease in TSV, and the increase in WSS. The results are confirmed in the shaded POI, while not in the sun-exposed POI within this study. The possible reason for this partly confirmation could be explained with *V* recorded higher in the shaded POI than Wang et al. (2018).

The existing literature continues to highlight the effect of outdoor climatic factors, specifically Ta, on the indoor environment (e.g., Nicol and Humphreys 2010; Humphreys et al. 2013; Adunola 2014). This study's findings were built on a new perspective by analysing the relationship between outdoor thermal responses from different microclimatic conditions and their influence on indoor thermal responses. The relationship varied based upon the experienced outdoor space within the study as a result of what Nikolopoulou and Steemers (2003) refer to as past experience factors. $\mathrm{SRSV}_{\mathrm{OUT}}$ in shaded POI and $\mathrm{ATSV}_{\mathrm{OUT}}$ in sun exposed POI can be the only outdoor parameters influencing positively $\mathrm{ATSV}_{\mathrm{IN}}$, being a partly alignment with the outputs by Humphreys et al. (2013) that the mean of $\mathrm{Ta}_{\mathrm{IN}}$ was dependent on $\mathrm{Ta}_{\mathrm{OUT}}$. $\mathrm{WSSV}_{\mathrm{OUT}}$ in the shade was the dominant subjective measure of $\mathrm{WSSV}_{\mathrm{IN}}$. The study illustrated that only subjective measure of $\mathrm{OTCV}_{\mathrm{IN}}$ was $\mathrm{WSSV}_{\mathrm{OUT}}$ for students exposed to the sun during the outdoor measurement period. The outcomes also showed that $\mathrm{ATSV}_{\mathrm{OUT}}$ can be an important determinant for $\mathrm{WSPV}_{\mathrm{IN}}$ of students with sun-exposed POI experience. Therefore, these outcomes also revealed that qualitative outdoor measures of Ta, *V*, and Tmrt could be a crucial criterion to understand the expectation of university students in an indoor context.

Adaptive behaviours

The study illustrated that thermal adaptation behaviours in the outdoor context show a variation depending upon thermal conditions. The shade could lead to a need for changing the location to a sunnier space. The study confirmed the earlier studies with seeking shade to improve their thermal comfort in sun-exposed spaces with higher Ta (e.g., Martinelli et al. 2015; Watanabe and Ishii 2016; Xue et al. 2021). Since the study was conducted in October, corresponding to the transition from hot season, the students in the sun-exposed space may have perceived almost summer thermal conditions rather than autumn, which could explain their preference for changing location to shaded area. As Nouri et al. (2021a) indicated, maximum Ta value equating to 37.6°C was considerably high for autumn season in Ankara, considering maximum Ta in summer season equated 39.9°C. Further, PET value ranges between 29.1 and 35.0°C with the highest frequency in autumn season, and 35.1 and 46.0°C in summer season at 15:00 local time (Nouri et al. 2023). The outcomes also illustrated that students did not tend to change their location in studio contexts despite different outdoor thermal condition experiences, and 'open windows,' which was the most common thermal adaptive behaviour (Schweiker and Wagner 2016; Kim et al. 2017; Chen et al. 2021).

Comparative analysis of PET and thermal sensation

The study established that the PET/PS levels in selected spaces showed a considerable difference during the measurement period. With regards to comparing physiological and psychological outcomes, the lowest PET values were recorded in the shaded outdoor space with the mean PET equating to 18.7°C, showing the great difference with the mean Ta_{OUT}POI 1 of 21.2°C. The sensation also identified the space as 'slightly cool'. Contrarily, the sun-exposed space with the mean PET equating to 33.2°C in the mean Ta_{OUT} POI 2 of 26.5°C was identified as 'slightly warm' and 'warm' in thermal sensation votes, revealing the highest PET values. Therefore, the study's outputs indicated that the shaded POI reduced the PET due to reduced Tmrt. The reduction of the PET was matched to students expressing 'slightly cool'. In studios, the sensation was determined as 'neutral' in the mean PET value equating to 23.0°C. These results enforced that the sensation of students in the sun-exposed POI was almost identical to the output of the model with PET (Matzarakis and Mayer 1997) (Table S4). The actual sensations of students were revealed to be slightly higher in indoor contexts and to be slightly lower for the shaded outdoor space than those associated with the PET outputs. Apart from comparison between physiological and psychological results, this study also revealed that PET values and Ta_{OUT} in POIs showed a great variance based upon thermal conditions of POIs.

Addition to the PET results, the PS threshold grades varied differently under the shaded and sun-exposed POI. The occurrence of 'Moderate Heat Stress' took place in the sun-exposed POI, while 'No Thermal Stress' was obtained in the shaded POI. These outcomes enforced that even during the autumn season, human thermophysiological thresholds could still vary significantly during the hotter hours of the day because of Tmrt fluctuations between POIs.

Comparison of cognitive performance

Previous studies that have been researched on the relationship between thermal comfort and cognitive performance did not mostly consider the effect of experiencing outdoor space with different thermal conditions on cognitive performance in indoor settings (e.g., Zhang et al. 2019; Barbic et al. 2019). To address such a gap, the current study provided new insight into the differences in cognitive performance in studio environments between students who experienced the shaded and sun-exposed outdoor environment. This study illustrated a significant difference in concentration performance and fluctuation rate between students with experience in shaded and sun-exposed outdoor spaces. These differences were seen in studio contexts where 'neutral' sensation votes were greatly distributed. Therefore, these results indicated experiencing a shaded POI improved concentration performance of students, and decreased fluctuation rate. Earlier studies, however, concluded the best cognitive performance was achieved in 'neutral' (Lan et al. 2010), and 'slightly cool' sensation (Jensen et al. 2009; Lan et al. 2011). The main reason for this difference could be that previous studies were conducted by changing indoor microclimatic conditions, and not considering outdoor space experiences. Thus, the current study showed that experiencing shade had a positive effect on students' cognitive performance in an indoor environment during autumn season.

Study limitations

The outcomes of this study were specifically focused upon the case of Ankara, Turkey. However, the methodology framework could be applied to other regions with different KG classifications to obtain thermal benchmarks of diverse outdoor and indoor spaces. Also, it should be emphasized that the results of the application of the study had some methodological limitations, these being that (1) the study was conducted during a mid-season. Through measuring quantitative and qualitative aspects in other seasons, more relationships between thermal responses could be found, including among seasons; (2) there is the opportunity to expand the measurement period within a future study by conducting the experiments during various times of days to find a diurnal change both in outdoor and indoor contexts; (3) there is a crucial opportunity for a future study in different POI typologies to shed more information upon the effects of outdoor local amenities upon the relationships delineated in this study; (4) the sample size could be enlarged using the established methodology in this study to further explore the results presented by this research; (5) to measure the cognitive performance of university students, different tasks such as Digit Span test and Trier Social Stress Test could provide the opportunity to evaluate more cognitive skills; and finally, (6) because of educational issues, experiment time period for Grp 1 and Grp 2 showed about 10 min difference, thus each group can participate in the experiment in the future study in the same period.

Concluding remarks

This research investigated the impacts of shaded outdoor spaces on thermal adaptation and cognitive performance of university students within studio settings in Ankara, during the autumn season. The findings of the research supported that shaded outdoor spaces improved outdoor thermal comfort and experiencing shaded outdoor spaces increased cognitive performance of university students. The considerable difference in mean Physiological Equivalent Temperature between shaded (18.7°C) and sun-exposed (33.2°C) outdoor spaces demonstrated that shade enhanced the opportunity to consider the different bioclimatic environments on the university campus, and find the different ways for thermal adaptation of students. In shaded outdoor areas, students revealed a greater occurrence of thermally comfortable conditions resulting in the opportunity to improve cognitive performance in indoor studio settings. Furthermore, wind speed in shaded outdoor space was found the most significant parameter influencing outdoor thermal comfort level of students after air temperature, and indoor wind speed sensation. This gives great precedence to considering wind/air speed as a considerable parameter in even learning environments. Based upon sun-exposed outdoor space, solar radiation indicated its noticeable influence on thermal comfort of students after air temperature, considering the adverse impact for thermal adaptation in both outdoor and indoor contexts.

The diversity of the undertaken analyses pointed out the association between outdoor quantitative and qualitative microclimatic parameters and indoor thermal comfort of students. Nevertheless, different outdoor site characteristics, such as shaded and sun-exposed within this study, impacted differently the indoor thermal comfort of students, giving the importance of examination of interior design by considering different outdoor site experiences. With regards to adaptive behaviours in outdoor settings, the preference of students exposed to shaded and sun-exposed spaces for changing their location to the sunnier or shadier areas might indicate the necessity to improve the design of such areas, including for the autumn season. Considerably, the progressive impact of experiencing shaded outdoor areas on concentration performance of students in studio settings indicated that outdoor site-specific characteristics were a critical component that could be considered by architects and designers with respect to both quantitative and qualitative aspects of thermal comfort in outdoor and indoor contexts.

The major contribution of shading strategies with buildings that have the potential of wind tunneling effect because of the mass configuration (wide-narrow-wide) is the reduction of mean radiant temperature based upon the results of this study. Therefore, the building shading strategies with respect to mass configuration can be used as an effective method regarding quantitative and qualitative aspects of thermal comfort to mitigate Urban Heat Island effect within the era of climate change. With this respect, it is recommended to take into consideration of shading strategies with building structures in designing outdoor spaces of learning environments through architectural and urban design interventions to help students adapt to hotter conditions in outdoor environment.

Overall, although thermal comfort studies have been an extensive topic of study within the scientific community, this study builds upon the weaker links between its quantitative and qualitative aspects between indoor and outdoor contexts. Where, moreover, within an era of climate change and rapidly densifying urban fabrics, these contexts continue to be increasingly susceptible to both existing and future heat-related stress factors. The case of Ankara is a typical example of such risk factors and a beacon for the growing need for interdisciplinary practice for different disciplines that share common goals. An example of such goals is the ongoing need to ensure the efficacy of contemporary learning environments, whereby cognitive performance attributed are also investigated and associated with both outdoor and indoor relationships. It can be, moreover, possible to investigate such study in more thermally efficient construction methods, where the thermal resistance of the building shell provides more resistance to outdoor stimuli, considering the increased vulnerability of the building used within this study as a reason for the selection.

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Data Availability All the data and materials used in this research are presented in the figures and tables. Further information is available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate The procedures in this research regarding human subjects (students' psychological evaluations) were conducted with the approval of the Bilkent University Ethics Committee. All authors consented to participate in this research.

Competing interests The authors declare no competing interests.

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