Building and Environment 261 (2024) 111760

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Investigating the transient conditions of "Sabat" space and its influence on pedestrian sensations during thermal walks. Algiers' Casbah case study

Sabah Ali Smail [a,b,*], Noureddine Zemmouri [a], Moussadek Djenane [a], Marialena Nikolopoulou [b]

[a] LACOMOFA laboratory, Department of Architecture, University of Mohamed Khider, Biskra, 07000, Algeria
[b] Kent School of Architecture and Planning, University of Kent, Canterbury, CT2 7NR, UK

ARTICLE INFO

Keywords:
Walkability
Lift-up design
Fatigue sensation
Alliesthesia
Semi-outdoor
Resilient comfort

ABSTRACT

Cities are already witnessing the impacts of climate change. Prolonged heat exposure have a direct effect on pedestrians' thermoregulatory system, causing serious heat-related issues in the form of fatigue and thermal exhaustion. While the human body is capable of maintaining heat balance, excessive heat exposure combined with increasing heat loads can deteriorate the thermoregulatory process which leads to discomfort. Walkability is one of the significant challenges for climate change mitigation. Balancing the dichotomy of walking to mitigate climate change, and mitigating climate change to walk emphasizes the importance of promoting resilient walkability. In this context, the term "resilience" is used to highlight the need to design urban spaces able to adapt to increased urban heat, enabling pedestrians to tolerate and recover from discomfort conditions. This study investigates the potential of the "Sabat", a traditional semi-outdoor space with lift-up design, and its distribution in generating transient thermal aeraulic conditions, and reducing fatigue sensation, hence, supporting a positive walking experience. Thermal walks have been conducted in Casbah of Algiers during temperate and hot weather conditions, in the context of uphill walking. Results revealed the alliesthesial effect of cool-shaded and ventilated Sabats to reduce fatigue sensation, which was confirmed by the significant correlation at lag-(-1) ($r = 0.504$, $p < 0.001$). Findings shed light on the importance of maintaining dynamic alliesthesia to create modulated restorative opportunities and offer starting point for hypothesizing broader trends for future implementation of Sabat design in modern cities.

1. Introduction

1.1. Climate change and walkability

Cities are already experiencing the effect of climate change, especially in the Mediterranean region where significant temperature increase is being observed. Large cities are expected to witness a temperature increase of 1.5 °C by mid 21st century [1]. This trend is further exacerbated in dense urban areas and is expected to reach up 5 °C temperature increase based on unchanged current greenhouse emission [1].

Walkability is one of the significant challenges for climate change mitigation. Walking, as the easiest and free from of urban mobility, presents a variety of advantages on health and the urban microclimate. However, reducing car-dependency requires comfortable and healthy walkable environments. Weather significantly impacts the walking experience [2] and pedestrians' satisfaction to decide to walk [3], and it is suggested that comfort and pleasurability are among the essential walking needs [3,4]. Balancing the dichotomy of walking to mitigate climate change on the one hand, and mitigating climate change to walk on the other hand, emphasizes the importance of promoting resilient walkability.

1.2. Temperature increase and thermal exhaustion

Temperature rise is affecting both the microclimate and the people, resulting in more frequent hot days, heatwaves, and prolonged warm conditions. Consequently, outdoor activities and pedestrian's well-being are threatened. Extreme temperatures can cause a multitude of physiological and psychological risks. Prolonged exposure, especially for extremes of heat, have a direct effect on pedestrians' thermoregulatory system, causing serious heat-related issues in the form of thermal exhaustion, cardiovascular stress and heat stroke [5]. Direct solar radiation significantly effects pedestrians heat thermoregulation balance

* Corresponding author. BP 145 RP, Biskra 07000, Algeria.
E-mail addresses: sabah.alismail@univ-biskra.dz, S.Ali-Smail@kent.ac.uk (S. Ali Smail).

https://doi.org/10.1016/j.buildenv.2024.111760
Received 1 April 2024; Received in revised form 12 June 2024; Accepted 19 June 2024
Available online 20 June 2024

and could include significant heat loads for continuous periods of exposure under clear sky conditions [6]. Daily walking is more affected by heat stress compared to activities such as running or cycling, highly due the extended periods of exposure [7]. Moreover, the longer the walking activity is, the higher the physiological demands [8]. The human body experiences additional thermal loads when walking uphill, since it produces twice as much heat as walking downhill [9]. Such conditions are likely to results in uncomfortable and unhealthy environments, and more importantly, a concerning rise in heat related morbidity and mortality [10–12]. Adaptation becomes a critical factor in the ability to sustain the walking activity and prevent fatigue.

1.3. Climate resilient approach

Resilience stands for the ability to absorb a major shock with the capacity of effective recovery and normal continuity [13]. Promoting resilient walkability, in the context of urban climate, stands for the ability to ensure both dualities, exposure and protection from unsatisfactory weather conditions to increase both tolerance and adaptation to environmental risks, i.e., solar radiation. Outdoor comfort should be adjusted to a wider range of climate conditions and should include factors such as thermal adaptation and recovery, especially when considering the walking activity. In this context, the term resilience is used to highlight the need to design urban spaces able to adapt to increased urban heat, enabling pedestrians to tolerate and recover from discomfort conditions.

The experience of walking is associated to diversity as it is a dynamic movement within urban spaces. Environmental diversity in urban areas plays an important role in providing adaptive possibilities to enable tolerance and recovery form thermal stress [14–21]. Such approach could be associated with the concept of “alliesthesia”. Cabanac (1979) [22] introduced alliesthesia as the change in pleasure sensation in response to external stimulus. This change depends on the nature and intensity of the stimulus, and individuals inner state. As such, a stimulus is pleasant when it facilitates in restoring the inner state [23,24]. Although this may not reduce the totality of heat exposure, it is the most effective approach to enhance pedestrians’ comfort by adopting behavioral and configurational transients that would enhance the resilience and adaptability of urban areas.

1.4. The Sabat space

The “Sabat” space is a type of semi-outdoor space. The term “Sabat”, originated from Arabic (ar: ساباط) [25], referring to a device that allows the creation of additional space attached to a building’s first floor and bridging the public right-of-way, resulting in a room bridging the street [25] (Fig. 1). Due to its dual functions, the term “Sabat” could refers to two distinct spaces. First, it refers to the space above the passage, functioning as an indoor architectural feature which is the origin of its creation. Second, it denotes the covered passage at street level formed by the extended space above the street, which is the subject of our research.

Architecturally, Sabat is a “lift-up” building design [26,27] at ground level within the street corridor, resulting in a short semi-covered space, known as “covered passage” [28–30] or “roofed alley” [30,31], limited by the opposite buildings, offering protection from sun exposure and precipitation while maintaining natural air flow. Such configuration allows for only two opposite openings (Fig. 2.(1)), in contrast to the arcade (Fig. 2.(2)) which is distinguished from the Sabat with additional frontal openings.

1.4.1. Historical background

Elements above the street, Sabats, were one of the essential urban elements found in most cities in the Islamic word [32]. However, such configuration were also widely spread in Persian architecture [30,31, 33] and in non-Muslim countries such as Greece, Southern Italy, Spain and Portugal [32], with similarities in using covered passage between historical cities in North Africa and those in the Puglia and Calabria regions of southern Italy [25]. Bessim Hakim in his book stipulates that such similarities are results of common routes of Byzantine and Islamic urban rules and their diffusion in the Mediterranean regions, and that Islamic urban rules evolved from existing practices in the region [25]. Design attributes of such space differ in relation to climate, cultural

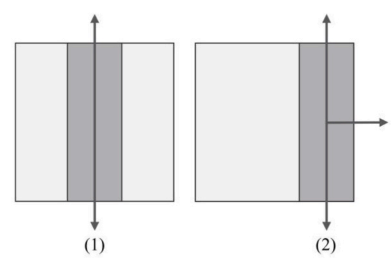

Fig. 2. The difference between the Sabat (1) and the arcade (2) in terms of the horizontal openings’ number. Dark grey represents the coverage area, light grey represents the building, and the segments show the direction of the openings.

Fig. 1. Examples of Sabats in the Mediterranean region, in Algiers’s Casbah (a) Algeria, Ostuni (b) and Bari (c) in Italy; demonstrating the extended room above the street, resulting in a covered passage. (source: Author, 2022).

background and urban rules [25,30,31]. The scope of our research is held on Sabat design in the Mediterranean climate conditions, focusing on Algiers Casbah. Although studies have investigated the use of semi-outdoor spaces for both indoor and outdoor environment [34–36], the Sabat space is poorly researched, as its design is no longer in use in modern urbanism, hence lacking investigations approaching its potential in climate resilient strategy to support walking activity.

1.4.2. Sabats and under street pathways

Traditionally, sometimes owners of adjacent buildings decide to build Sabats along the street, resulting in a continuous Sabats forming a tunnel effect above the street [25]. However, it is important to distinguish Sabat, in current research, from under street pathways (tunnel or subways) since they differ predominantly in ground level placement which has direct influence on the thermal-aeraulic conditions, as well as user experience, length of exposure and distribution. The Sabat with its lift-up design at ground level is directly exposed to external environmental conditions, which results in variable wind speeds, allowing air to flow through freely [30]. In the case of underground placement, wind speeds and air distribution would be difficult to predict, expected to be generally poor, depending on ventilation system, depth, length and design [37].

1.5. Aim and objectives

The Sabat should not only be viewed as a source of shade and it is important to investigate how the outdoor activities are influenced by its presence in the Mediterranean climate. As such, this study investigates the potential of Sabat space in generating transient thermal aeraulic conditions, along with the dynamic changes in pedestrians walking experience - mainly thermal sensation, wind sensation, thermal pleasure and fatigue sensation-during thermal walks in Algiers Casbah. The aim is to investigate the potential of Sabat in reducing fatigue sensation, hence, supporting a positive walking experience.

2. Thermal walk methodology

Several studies highlighted the importance of pedestrian-centered approach to better understand the dynamic influence of the built environment on pedestrians walking experience [38–43] as it is crucial in understanding how to create suitable walkable environment. Following the pedestrian-centered approach, thermal walks allow for more comprehensive understanding of the simultaneous interaction between the individuals and the non-steady conditions of their surrounding environment. Previous thermal walk studies have focused on the thermal sensation of pedestrians [17,18,20,21,44–47]. In addition to the variations in thermal sensation, this study investigates thermal pleasure and fatigue sensation of pedestrians as they walk by transient conditions in two different walking routes of different Sabat distributions. The changes of pedestrians' fatigue sensation in relation to transient conditions when passing by Sabats is the main focus.

2.1. Study area

The study has been carried out in Casbah, the historical city of Algiers and a UNESCO world heritage site since 1992. Casbah is located in north Algeria (36°47′00″N, 3° 03′37″E) at 107 m, in proximity to the Mediterranean Sea. According to Köppen–Geiger, Algiers has a Mediterranean warm temperate climate (Csa) with humid-hot summer and mild winters [48]. The prevailing winds come from the north-east in summer and from the north-west in winter.

The historical city has been shaped by a variety of influences. Despite serious threats of physical decay due to lack of maintenance, today's Casbah still preserves its Islamic-Ottoman architectural and urban significance. The old city is characterized by dense urban fabric, pedestrian-only narrow and staired streets, and noticeable presence of covered passage at street level (Sabat), especially in its upper residential part. Fig. 3 shows different Sabats in Algiers Casbah which are identifies based on field investigation. All Sabats have one to three rooms build above the street, and are characterized by narrow width, low height and short coverage areas, with few exceptions of combined Sabats forming a tunnel effect at street level.

Thermal walks included a walking experience questionnaire and simultaneous mobile monitoring of thermal aeraulic conditions within two preselected walking routes in the upper Algiers' Casbah. It included a total of 16 assessment points of covered passages (Sabat) and non-covered streets. Since Casbah is known for its staired street character, walking uphill was the selected direction for the current study to investigate the least satisfied conditions for the walking activity (Fig. 4).

2.2. Assessment stops

The assessment points were selected to cover a variety of Sabat spaces depending on their orientation, distribution and design attributes within two different walking routes. The choice of the measurements' position was coordinated with the simultaneous environmental monitoring and pedestrians dynamic experience in motion. The measurements inside the Sabat were taken in the middle, to best capture pedestrian's actual sensations after entering the Sabat space. Conditions outside the Sabat were only captured through measurements in the middle of each street segment, with the sensors protected from direct solar exposure. The two selected walking routes have the same starting point and end differently in the direction of uphill walking to investigate the least favorite walking conditions. They both differ in terms of Sabat distribution (number and position), and are characterized by similar aspect ratio. Route 1 has a total of 350-m walking distance with 191 stair steps. It constitutes of 9 street segments and 7 Sabat spaces, of which two are located in the first part and 5 at the second half of the walking route. Route 2 has a total of 300-m walking distance and 186 stair steps. It constitutes of 6 street segments and 4 Sabat spaces located in the first half of the walking route.

2.3. Meteorological conditions

Table 1 presents the weather conditions of the days when the winter and summer surveys were conducted. The weather during winter survey was characterized by moderate air temperature (mean of 19.87 °C) of which the first day was the warmest with 20.69 °C. Relative humidity was relatively high reaching up to 84 %. Wind speed at 10 m height fluctuated between 2.95 m/s and 1.08 m/s, with most wind coming from the west. The summer survey was characterized by significant higher air temperatures and relative humidity, at 53.34 °C and 71 % respectively, while wind speed fluctuated significantly from 7.96 m/s to 2.45 m/s, which could be explained by the prevailing sea breeze in close proximity.

2.4. The mobile thermal aeraulic measurement

A portable weather station was tailored for the mobile measurements, consisting of the digital multifunction Testo 480 described in Table 2. The vane probe, the humidity (Rh) and temperature (Ta) probe were fixed on a camera tripod at a height of 1.40 m while the wind speed (Ws) probe was extended to reach 1.70 m height, representing the average height of a walking person. The humidity and air temperature probe was kept on the shaded part of the walking route to avoid direct solar radiation exposure. The vane probe was well fixed in the tripod away from obstructions (including moving pedestrians) that could disrupt airflow to ensure the most accurate measurement. To orientate the sensor towards the wind direction, the vane was carefully rotated in the first 30 s, to capture the highest value, before it was then fixed, and values were recorded each minute during the 7-min stop.

The weather data were recorded from 13 h to 16 h within an interval

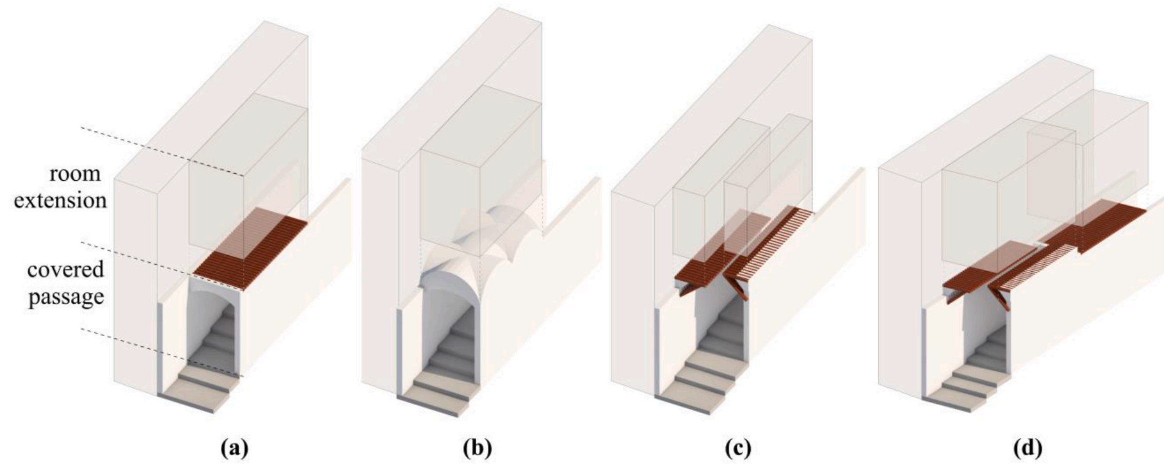

Fig. 3. Algiers Casbah's Sabat types. The overhead structure of the covered passage varies and could be made of wooden beams (a) or groin vault (b). Sometimes, two extended corbels end-up colliding as demonstrated in (c) forming a covered passage. Composed Sabat (d). (Source: Author, 2024).

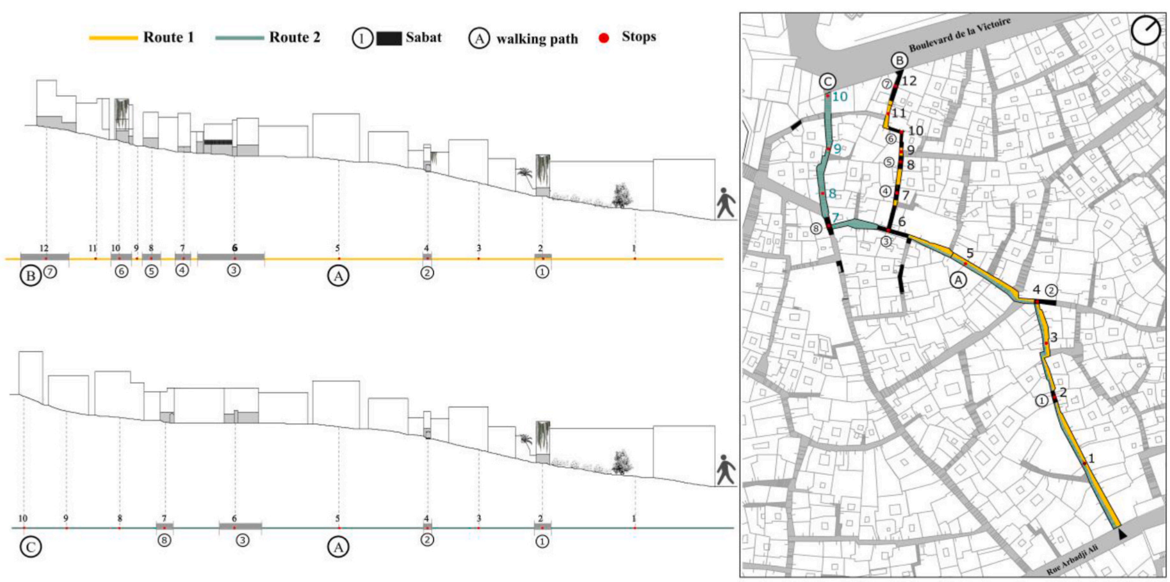

Fig. 4. Thermal walks in two preselected walking route 1 and route 2. Stairs count is represented for both walking routes in addition to the position and distribution of the Sabat spaces.

Table 1
Weather data during winter and summer surveys: air temperature (Ta), relative humidity (Rh), wind direction (Wd), and Wind speed (Ws).

date	Ta(°C)	Rh (%)	Wd	Ws (m/s)	Sky coverage (%)
25 Dec 22	20.69–18.63	55–70	W	2.95–1.52	0.00
26 Dec 22	20.12–17.87	55–65	W	3.35–3.36	0.38
27 Dec 22	19.15–16.91	60–84	NW	2.17–3.31	0.03
28 Dec 22	19.39–17.67	57–70	W	1.91–1.17	0.14
31 Dec 22	20.03–18.8	51–61	S	1.08–1.45	0.00
22 July 23	31.23–29.72	62–72	N	7.96–7.60	0.51
23 July 23	35.34–33.95	42–27	N/NW	2.45–3.42	0.51

Table 2
Instruments used for the mobile measurement surveys: air temperature (Ta), relative humidity (Rh), wind speed (Ws), and surface temperature (Ts).

Data	Instrument	Accuracy
Ws	vane probe (Ø 16 mm) with telescope (960 mm)	± (0.2 m/s +1 % of m.v.) (0.6–40 m/s)
Ta	Humidity and temperature probe (Ø 12 mm)	±0.2 °C (+15 to +30 °C) ±0.5 °C (remaining range)
Rh	Humidity and temperature probe (Ø 12 mm)	± (1.0 %RH + 0.7 % of m.v.) 0 to 90 %RH
Ts	Waterproof surface probe with widened measurement tip (Ø 6 mm)	−60 to +400 °C

of 1h50 and 7-min 'stopping time' [19,21]. Data analysis was based on the mean value of the last 3-min assessment. It included a total of 16 assessment points of covered (Sabat) and non-covered streets.

2.5. The walking experience - questionnaire

A total of 30 adult participants aged between 20 and 45 years old (11 male/19 females) agreed to participate through an online Call of research participants. The winter walks consisted of 20 participants and the summer walks consisted of 10 participants. Each walk consisted of 1–3 participants, who were advised to provide individual, quick and conscious response at each survey point. The questionnaire comprises of point-to-point evaluation to capture the variation in pedestrian sensation within the transient conditions, in addition to retrospective evaluation at the middle and end of the walk (A, B and C in Fig. 4) to capture the overall experience. The first part of the questionnaire included general participant information, i.e., age, gender, familiarity with study area and clothing. The second part, presented in Table 3, was designed to cover the dynamic change in thermal sensation (TSV) using the ASHRAE seven-point scale; wind sensation (WSV), varying from calm to windy; thermal pleasure from unpleasant to pleasant; and fatigue sensation rated with two different nine-point scales from refreshed to tired and rested to fatigued.

At the center of the walking experience, an emotional process is affected by different levels of appraisal of internal and external factors, resulting in affective experiences described by Russell (1984) [49] with two dimensions. Valence represents positive to negative subjective feelings or attitudes towards an emotion-eliciting stimulus (pleasant – unpleasant). Arousal (activation), describes the level of which subjects are influenced by the surrounding environment. Recent studies argued that descriptive dimensions such as thermal sensation are not sufficient to capture the complete thermal experience since they only describe the state of the weather and not the pedestrian experience [50–52]. Fatigue is defined by Ream and Richardson [53] as a physical or mental exhaustion characterized by a temporary reduction in power following a prolonged activity. Fatigue sensation is considered in this study as an affective dimension, characterized by valence (refreshed-tired) and a degree of activation (rested-fatigated) according to Russell (1984) affective model, and was rated according to the Swedish short measure scale of affective state [54].

2.6. Data analysis

Collected data was processed and analyzed using IBM SPSS version 29.0.0.0. Meteorological data was analyzed based on the mean values, while subjective data was analyzed based on the median values. All subjective data expressed a good alpha reliability test ($\alpha = 0.694$ to $\alpha = 0.853$). Descriptive statistics were used to show the variation in thermal aeraulic conditions between route 1 and route 2 and between Sabats and non-covered stops. Since the data exhibited non-normal trends (normality distribution histograms) non-parametric Kruskal Wallis test was used to detect the variance in the thermal aeraulic conditions among Sabats and non-covered stops; and the variance in walking experience among path A, B, and C. TSV, WSV, thermal pleasure and fatigue sensation were analyzed for correlation with the thermal aeraulic conditions and stairs using Spearman Rho correlation test and scatter plot. Autocorrelation and cross-correlation were plotted to analyze alliesthesia. The selection of the statistical test was guided by Yaffee & McGee [55], Pallant [56] and Sage Research Methods Datasets [57].

3. Results

3.1. Sabat's transient conditions

The variations in the meteorological measurements revealed the significance of Sabat design, distribution and orientation within the street in generating transient conditions. Fig. 5 represents the thermal aeraulic variations along the two walking routes. The figure includes graphs of the mean measured meteorological data during winter (A) and summer (B). The graphs are combined with street and Sabat morphological determents: orientation, Sky view factor (SVF), height to width ratio (H/W), Sabats section and coverage area. Kruskal Wallis boxplots in Fig. 6 present the statistical variance in thermal aeraulic conditions between total assessed Sabats and non-covered streets during winter (Fig. 6(a,b)) and summer (Fig. 6(c)) conditions.

As expected, the most significant variations are observed after walking from non-covered streets, with moderate to high SVF and H/W ratio, to Sabats with fully obstructed SVF and deep shaded section (Fig. 5). Ta was lower inside Sabats during winter ($H(1) = 6.353$, $p < 0.05$) and summer ($H(1) = 8.415$, $p < 0.05$) (Fig. 6(a)). The trend was further noticeable during the summer survey in Sabat 3, 4, 5 and 6 where Ta was found below 32 °C, similar to indoor room-like temperatures. Ta reached up to 25 °C during winter and 40 °C during summer in non-covered stops with open section and high degree of visible sky (stop 1 and 10 in route 2 and stop 11 in route 1). The largest Ta fluctuation is observed at Sabat 1, where the variations in SVF and H/W were important. Another large fluctuation is found at Sabat 3 and Sabat 7, where the variation in SVF is moderate but the coverage area of both Sabats is important. During winter, Sabat 7 was the warmest among Sabats due to its north-west orientation and its location between a narrow street and a wide main street from the northern side. The marginal exposure to direct sun exposure between 1 p.m. and 4 p.m. when the sun is low results in significant heat storage. The vertical enclosure of Sabat resulted in slower heat release through convection which results in warmer air temperature [34], suggesting that Sabats exposed to direct solar exposure tends to trap heat, leading to higher temperature during winter conditions.

Ground temperature and wall temperature were significantly lower in all measured Sabats ($H(1) = 8.064$, $p < .05$), ($H(1) = 6.904$, $p < .05$) (Fig. 6(c)), respectively, in comparison to that of non-covered stops especially in open section streets with high SVF. Inside Sabats, ground temperature was marginally close to Ta with the exception of Sabat 3 to Sabat 6 where ground temperature was below Ta and reached 26 °C in the absence of access to direct solar exposure.

Ws reached up to 1.8 m/s inside Sabat 1, 3 and 4 during summer, and up to 1 m/s during winter survey inside Sabat 1 and 7, while was below 0.2 m/s in stop 5 and Sabat 6 (Fig. 5). Similar to Ta, the most significant Ws variations were observed at Sabat 1 and Sabat 7 when passing from open street section with high SVF and high Ta to fully obstructed Sabat with lower Ta, and which align with the prevailing winds direction. Ws also increased at the deep shaded Sabat 3 which is situated within a two-street intersection south-west/north-west.

Despite the observed variations, Kruskal Wallis revealed no significant difference in Ws ($H(1) = 1.34317$, $p > 0.05$) during winter (Fig. 6(a)). Ws exhibited a large distribution downward the bottom of the boxplot while the median shifted to the upper part, indicating a large distribution among Sabat spaces (Fig. 6(a)). An increase in Ws is observed at each Sabat followed by a decrease in non-covered, with the exception of Sabats oriented north-west (Sabat 4, 5, and 6) where Ws decreased and reached its lowest value at Sabat 6. The close positioning of the Sabats and the short-exposed areas in-between may contributed to reduced Ta variations and decreasing the Ws. Focusing on Sabat 1, 2, 3, 7, and 8, to demonstrate the impact of Sabat's position, Ws significantly varied between Sabat and non-covered stops ($H(1) = 6.617$, $p < 0.05$) (Fig. 6(b)), which suggest the influence of orientation and position of Sabats on wind variation.

During summer, Kruskal Wallis revealed a significant difference despite the presence of Sabat 3, 4, 5 and 6 in the input data. Overall, wind variations were higher during summer which could also be explained by the variations in meteorological data and the sea breeze effect during the hot season. Another explanation could be attributed to

Table 3
Walking experience Questinnaire

TSV and WSV	**Indicate how you feel the environment at the moment:** Cold; Slightly cold; Cool; Neutral; Warm; Slightly hot; Hot Calm; Breezy; Gentle breeze; Slightly windy; Windy
Thermal pleasure	**De you feel the actual weather to be pleasant or unpleasant?** Unpleasant; Slightly unpleasant; Indifferent; Slightly pleasant; Pleasant
Fatigue sensation	**How would you rate your current physical condition?** Refreshed - Rested – 1 2 3 4 5 6 7 8 9 – Tired - Fatigated

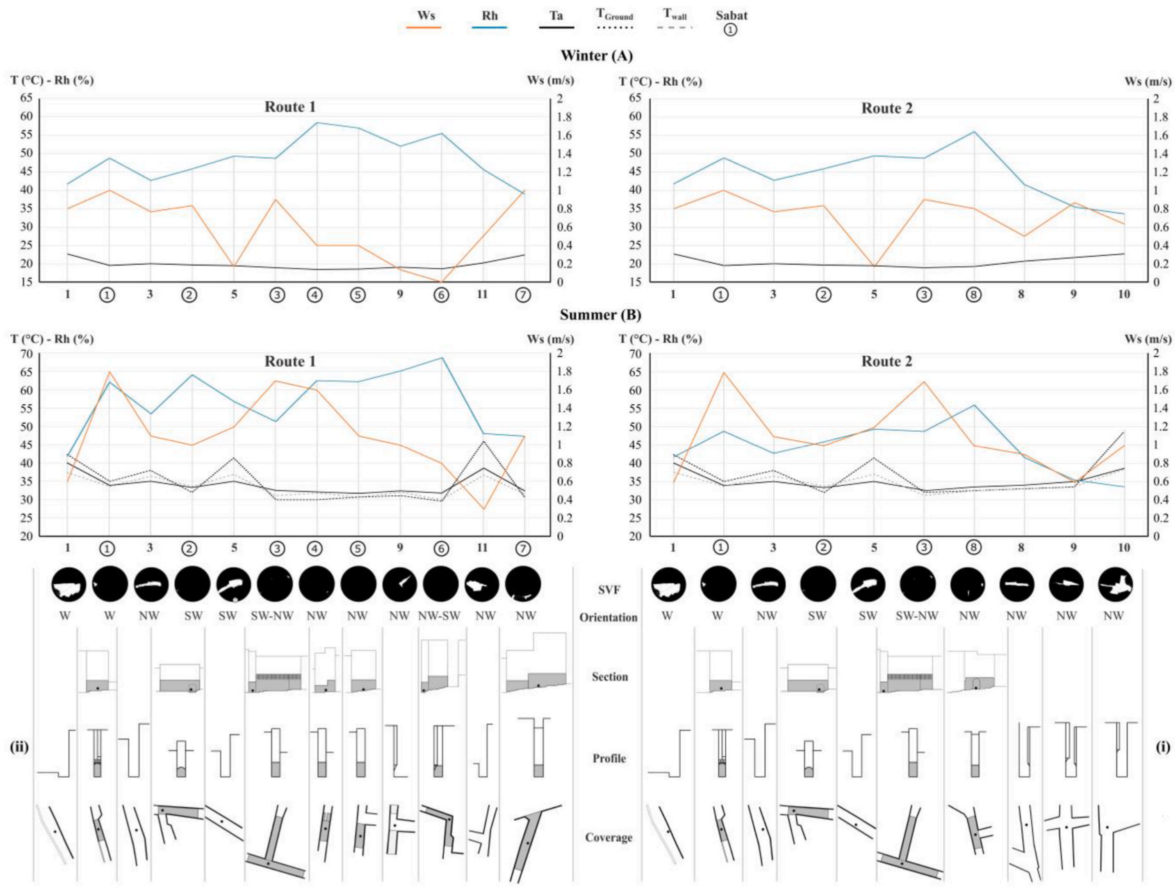

Fig. 5. Mean variations of Ta, T_{ground}, T_{wall} and Rh (on the right Y axe) and Ws (on the left Z axe) recorded during winter (A) and Summer (B) mobile measurements. (i) and (ii) show the spatial variations of the Sabats and non-covered stops, mainly SVF, orientation, H/W, Sabat section and coverage area in route 1 and route 2.

by the higher variation in ground temperature during the summer season. Fig. 5 shows that a reduction in ground temperature within Sabats was consistently accompanied by an acceleration in Ws, and conversely, high ground temperature in non-covered stops is consistently followed by lower Wind speed. Additionally, slight variations in ground temperature result in a small variation in Ws. Moreover, no variations in Ta and ground temperature do not yield significant changes in Ws (Sabat 4 to Sabat 6 in route 1; Sabat 8 to stop 9 in route 2). Such results suggest that wind acceleration may also be associated with significant difference in ground temperatures.

Rh is found significantly higher inside Sabats ($H(1) = 5.835$, $p < 0.05$) during warm winter survey while there is no significant different during the hot summer conditions ($H(1) = 2.162$, $p > 0.05$).

3.2. *Sabat effect on pedestrians' walking experience*

The influence of the transient thermal aeraulic conditions generated by Sabats, especially in the second part of route 1, has a significant impact on subjects' walking experience. Fig. 7 shows the clustered bar medians of fatigue sensation, pleasure, TSV and WSV recorded during winter and summer thermal walks. Fig. 8 presents graphs of the variations in fatigue sensation, pleasure, TSV, and WSV, during winter (Fig. 8(A)) and summer (Fig. 8(B)) thermal walks. As stairs exacerbate, the figure is combined with Sabat distribution to highlight the potential influence of Sabat on pedestrians' sensations in relation to stairs count (Black line).

3.2.1. *Winter conditions*

In the first part of the walk (path A), high values of TSV were observed along non-covered stops with moderate Ta followed by immediate TSV improvement when walking by the following shaded Sabat with reduced Ta and refreshing effect of the wind acceleration, therefore enhancing thermal pleasure (Fig. 7). Moreover, each increase in WSV inside Sabat was followed by immediate increase in pleasure. Slow gradual increase in fatigue was observed, however, the increase was slowed upon passing by Sabats (Fig. 8).

The transition toward Shaded and ventilated Sabat significantly improved TSV and pleasure and offered short-term recovery from fatigue at Sabat 3 (5/9 to 4/9). In the second part of route 1 (path B), TSV slightly increased to "indifferent" in stop 9, passing by Sabat 4, 5 and 6. Here, increased TSV could be explained by the reduction in Ws and marginal change in Ta (Fig. 5), in addition to the accumulated thermal load of climbing stairs. However, pedestrians' pleasure and fatigue sensation did not appear to be associated with TSV, and the shaded Sabats offered more chance to gradually recover from fatigue (4/9 to 3.5/9) at the end of the walk (Fig. 8(A)). TSV significantly increased in route 2 (path C) and ranged between "slightly hot" and "hot" when walking non-covered street due to increased Ta and the additional thermal load of stairs climbing. In the absence of Sabats, pleasure significantly decreased to "unpleasant" with significant increase in fatigue sensation (4/9 to 7/9) at the end of the walk (Fig. 8(A)). additionally, there was a 0.3 difference in air temperature between Sabat 7 in route 1 and Stop 9 in route 2 (Fig. 5), however, participants voted Sabat 7 as "warm" and Stop 9 as "hot" indicating a possible influence of past thermal experience (route 2) and psychological adaptation (route 1) on the actual Thermal sensation.

3.2.2. *Summer conditions*

The influence of staired streets and elevated Ta is further evident on pedestrians' fatigue sensation in the absence of Sabats in route 2 (Fig. 7).

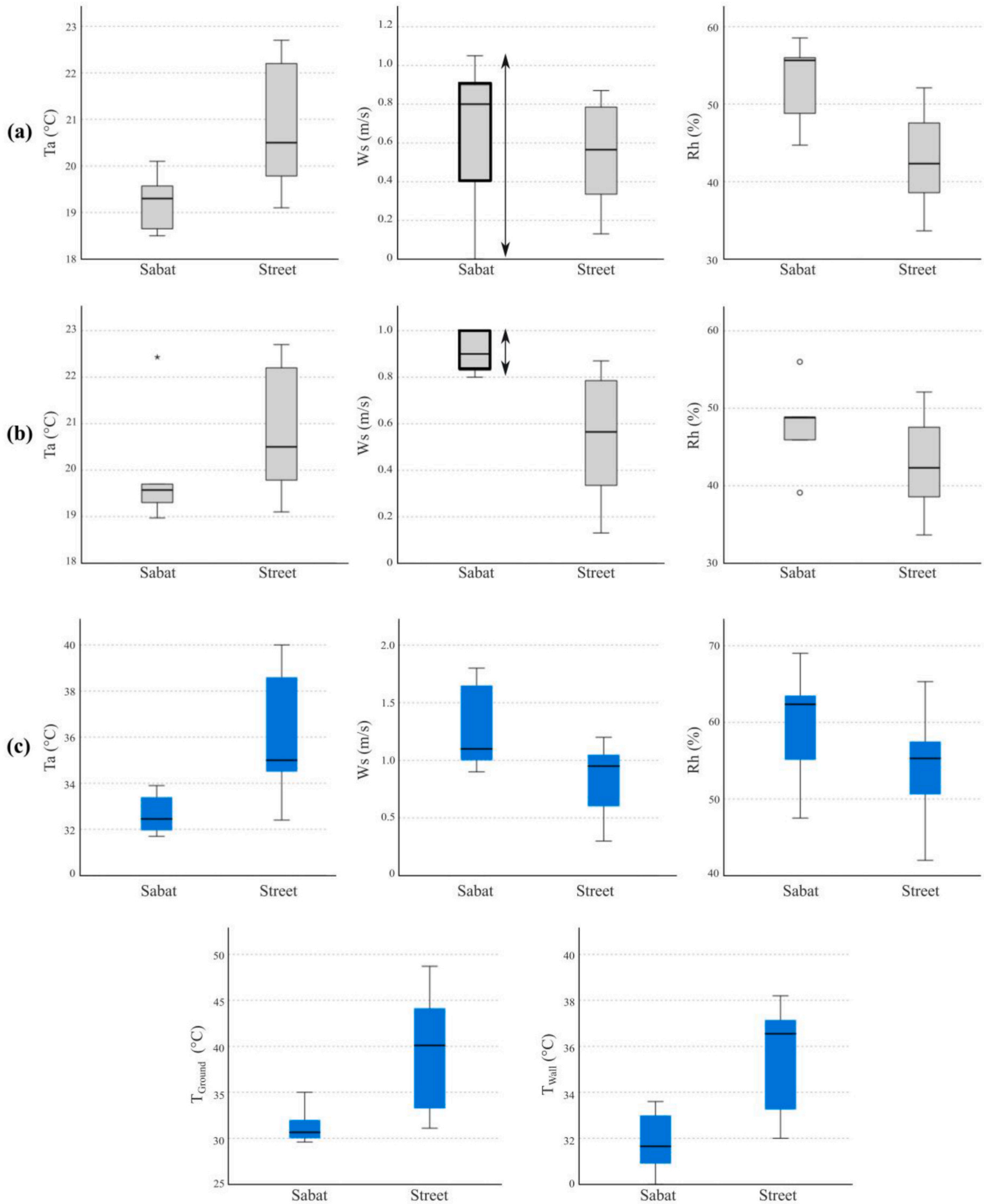

Fig. 6. Kruskal Wallis Boxplots showing distributions in Ta, T_{ground}, T_{wall}, Ws and Rh at Sabats and non-covered stops during the winter (a) and summer (c) measurements. (b) shows Kruskal Wallis boxplots results, focusing only on Sabat 1, 2, 3, 7, and 8.

In the first part of the walk (path A), higher TSV was recorded in the beginning of the walk which reached "slightly hot" in non-covered stops. TSV immediately dropped after passing the following Sabat (Sabat 2 and 3). Similarly, pleasure ranged from "indifferent" to "unpleasant" with higher TSV and low Ws before rapidly improving after reaching Sabat 3 (Fig. 8(B)), simultaneously with increased WSV due to deep shaded passage with increased Ws (Fig. 5). In the second part of route 1 (path B), subjects gradually recovered from fatigue after passing two attached Sabat (stop 9) and reached a steady state toward the end of the walk (Sabat 7). However, fatigue significantly increased with the progress of walking route 2 (path C), simultaneously with rapid increase of TSV raging from "slightly hot" to "hot" with the majority of "unpleasant" sensation occurring at the last non-covered street (Fig. 8(B)).

3.3. Pedestrian sensations among different walking paths A, B and C

Kruskal-Wallis results revealed significant difference in the walking experience among the 3 walking paths A, B and C, which is further demonstrated by the boxplots in Fig. 9. During the winter thermal walks (i), there was no significant difference in fatigue sensation between path

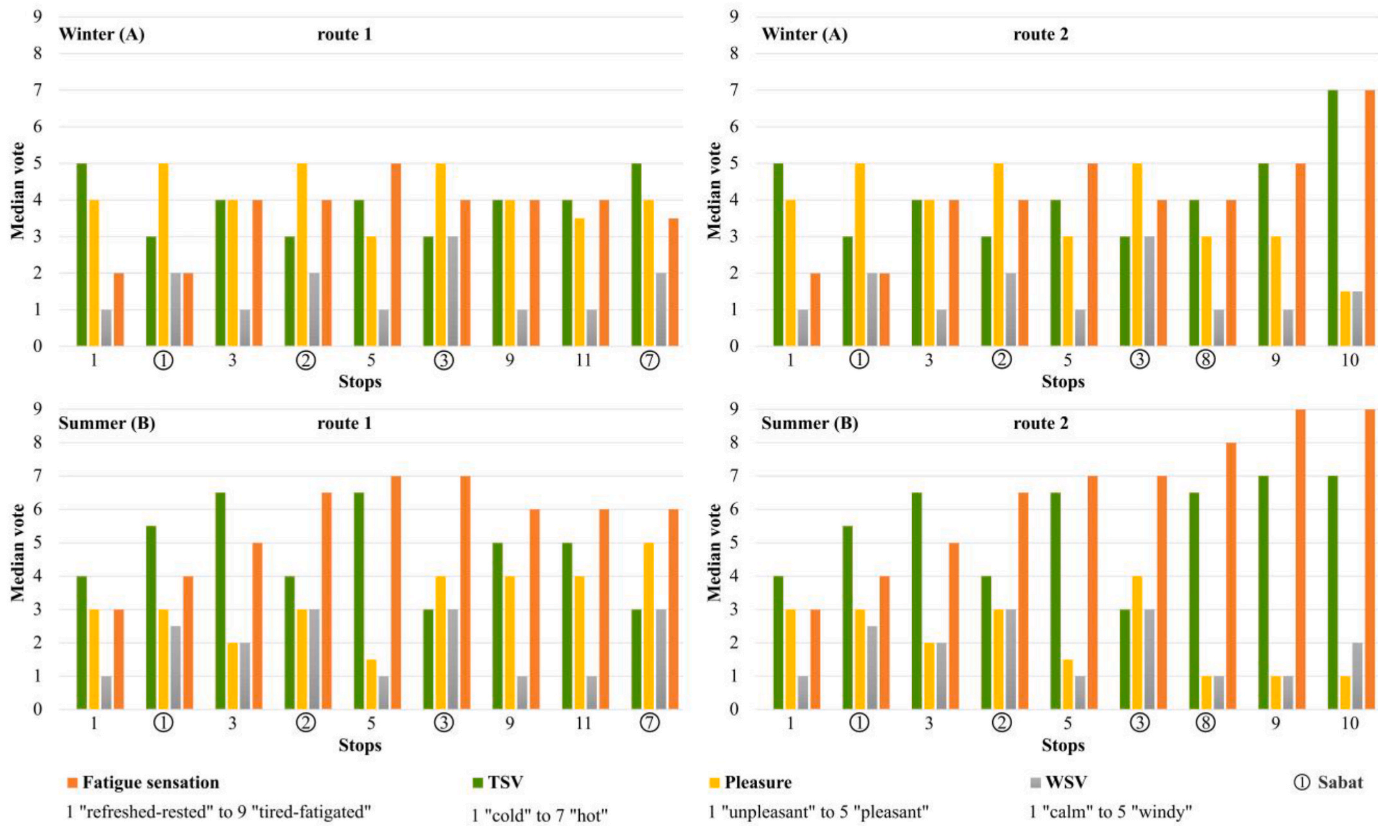

Fig. 7. Clustered bar median of fatigue sensation, pleasure, TSV and WSV in route 1 and route 2 during winter (A) and summer (B) thermal walks. Circled stop numbers represent Sabats.

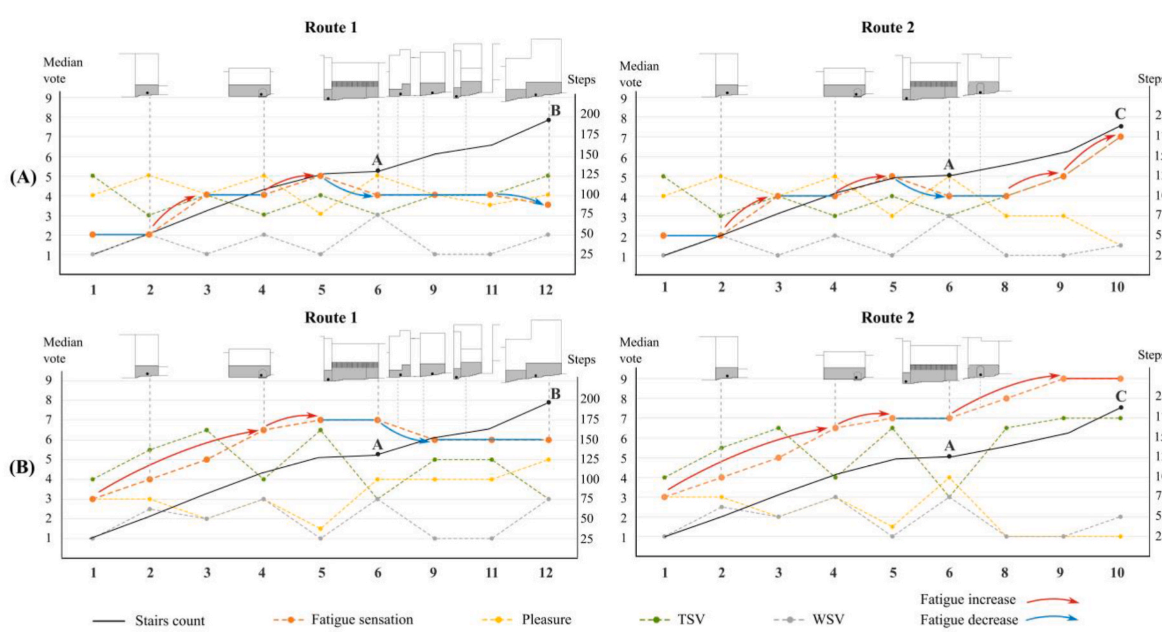

Fig. 8. Changes in fatigue sensation, pleasure, TSV and WSV in relation to Sabat distribution and stairs count in route 1 and route 2 during winter (A) and summer (B) thermal walks. A, B, and C represent the walking paths.

A and B ($Z = 1.458$, $p > 0.05$, Bonferroni corrected $p > 1.00$). However, fatigue was significantly higher at the end of route 2 (Path C) and was significantly higher than path A and B of route 1 ($Z = -17.187$, $p < 0.001$, Bonferroni corrected $p < 0.001$), ($Z = -18.646$, $p < 0.001$, Bonferroni corrected $p < 0.001$), respectively. The boxplots (i) in Fig. 9 show a small reduction of the interquartile range of fatigue in path B in comparison to path A, suggesting a potential of fatigue recovery. Similarly, path B was attributed with significant lower TSV and higher pleasure in comparison to path C, while there was no significant difference with path A. Path C was voted as the most unpleasant with

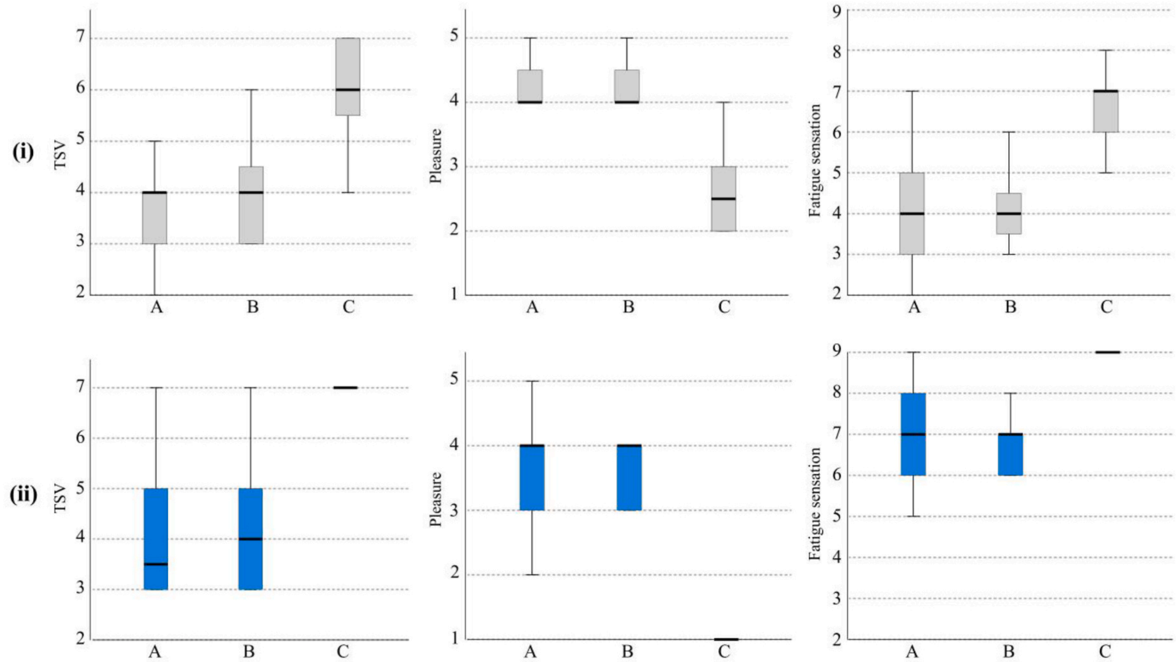

Fig. 9. Kruskal-Wallis boxplots of fatigue sensation, pleasure and TSV along path A, B, and C during winter (i) and summer (ii) thermal walks.

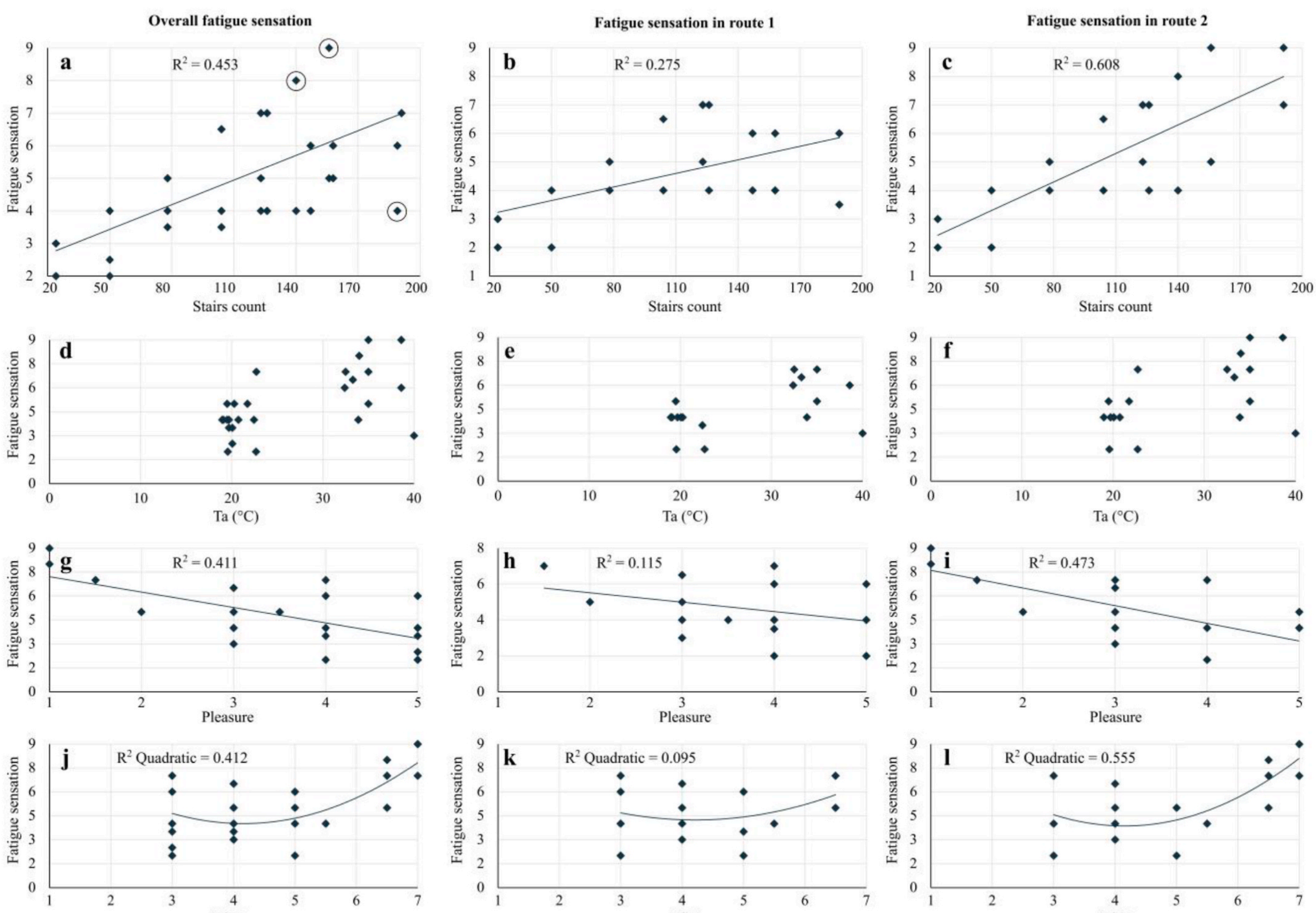

Fig. 10. Scatter plot correlation of overall fatigue sensation, fatigue sensation in route 1 and fatigue sensation in route 2 with stairs count, Ta, pleasure and TSV (a–l).

significant higher level of TSV in comparison to A and B.

During the summer thermal walks (ii) (Fig. 9), fatigue was significantly higher in C (route 2) and was significantly higher than path A and B ($Z = -9.150$, $p < 0.004$, Bonferroni corrected $p < 0.011$), ($Z = -9.700$, $p < 0.05$, Bonferroni corrected $p < .05$) respectively. There was no statistical significance between A and B ($Z = 0.550$, $p > 0.05$, Bonferroni corrected $p > 0.05$). However, the boxplot of A presents a large dispersion of the interquartile range, while the boxplot of B shows a smaller and skewed dispersion toward the first quartile suggesting a fatigue reduction (Fig. 9). Pleasure and TSV in C significantly differ from A and B. Path B was attributed with significant Lower TSV and higher Pleasure in comparison to path C.

Fatigue was significantly higher during the summer survey as indicated in Figs. 7 and 8. Fatigue sensation increased with the gradual increase of the stairs count in route 2. However, the presence of stairs with the progress of walking route 1 did not appear to increase fatigue. Such findings suggest that the presence of Sabats in the second part of the route 1 contributed to offer recovery conditions. This implies a possible delay effect of transient thermal aeraulic conditions of Sabats, as pedestrians walk, on instant fatigue sensation.

3.4. *Correlation analysis*

3.4.1. *Overall fatigue*

The scatter plot in Fig. 10(a) illustrates a moderate positive linear relationship between stairs count and overall increased fatigue ($R^2 = 0.453$; Spearman Rho $\rho = 0.660$, $p < 0.001$, $N = 36$). That is, as the number of walked steps increases with time, there is a high tendency for pedestrians to experience more fatigue. However, it is important to note a few outliers, specifically starting from the second part of the walk which could be associated with the difference in Sabat distribution of the two walking routes. The presence of such outliers' patterns introduces the variability in the relationship between stairs-climbing and fatigue sensation and highlight the impact of Sabats presence in this relationship. Both pleasure and TSV moderately correlates with fatigue ($\rho = -0.568$, $p < 0.001$, $N = 36$; $\rho = 0.428$, $p < 0.05$, $N = 36$) respectively. Pleasure's scatter plot confirms a negative linear relationship ($R2 = 0.411$), while TSV's reveals a weak positive relationship (Fig. 10(g–j)). Spearman Rho correlation showed a significant positive relationship of Ta with fatigue ($\rho = 0.4530$, $p < 0.05$, $N = 36$). However, Scatter plot does not display a linear relationship (Fig. 10(d)) suggesting a non-linear relationship. Such finding indicates the significance of exposure duration on fatigue sensation.

3.4.2. *Fatigue during winter and summer*

Fatigue sensation is found to vary among temperate and hot microclimate conditions. During winter, fatigue strongly correlates with stairs ($\rho = 0.840$, $p < 0.000$, $N = 18$), with moderate negative correlation with pleasure ($\rho = -0.610$, $p < 0.05$, $N = 18$). However, during summer, fatigue only correlates with stairs ($\rho = 0.734$, $p < 0.001$, $N = 18$). The correlation between fatigue sensation and stairs is slightly higher during winter conditions. During summer, the reduced correlation coefficient of stairs could be explained by the additional thermal loads related to elevated temperature exposure. Such findings suggest that fatigue sensation is associated to both the physical activity (uphill walking) and the microclimate conditions contributing to the higher thermal load on the human body.

3.4.3. *Fatigue in two different walking routes*

In route 1, both scatter plot and Spearman Rho show no significant correlation of fatigue with stairs count ($R^2 = 0.275$; $\rho = 0.205$, $p > 0.05$, $N = 18$) (Fig. 10(b)). The increasing number of stair count within the walk does not appear to have any influence on fatigue sensation in the presence of Sabats. Conversely in route 2, scatter plot and Spearman Rho reveal a moderate positive relationship between stairs and fatigue ($R2 = 0.608$; $\rho = 0.767$, $p < 0.001$, $N = 18$) (Fig. 10(c)). Moreover, the influence of Ta is only significant in route 2 ($\rho = 0.483$, $p < 0.05$, $N = 18$). Similarly, TSV and pleasure tend to only have significant correlation with fatigue in route 2 ($\rho = 0.619$, $p < 0.05$, $N = 18$; $\rho = -0.644$, $p < 0.05$, $N = 18$) respectively (Fig. 10(I, l)).

Overall, in non-covered streets with ascendant stairs count, the walking experience is negatively impacted. The combination of the physical exertion involved in climbing stairs and prolonged exposure to elevated temperatures and solar radiation lead to the accumulation of thermal loads, heightening thermal sensation, and lowering the overall pleasure. In such conditions, the thermal regulatory mechanism operates to offset heat production induced by physical activity, along with heat gain through convection and radiation, ultimately contributing to an increased sensation of fatigue. In the presence of transient conditions generated by Sabats within the walking route, the walking experience is not impacted by the ascendant stairs count. Short-term exposure to shaded passages with increased wind speed tends to offer recovery conditions, which relieves the thermal regulatory system of the accumulated thermal loads. This, in turn, would enhance tolerance for the physical activity, including stair-climbing. Such findings reveal the significance of Sabats in reducing thermal exhaustion produced by both uphill walking and prolonged heat exposure, highlighting the potential of thermal alliesthesia.

3.4.3.1. *Transient conditions effect on thermal pleasure.*

During winter, in route 1, thermal pleasure strongly correlates with WSV ($\rho = 0.805$, $p < 0.05$, $N = 9$) while there is no significant correlation with TSV and stairs count. However, in route 2, the association is only significant with STV ($\rho = -0.886$, $p < 0.001$, $N = 9$). In the case of transient thermal aeraulic conditions, thermal pleasure was associated with WSV and did not show significant correlation with TSV. This suggests that in transient conditions, pedestrians' thermal pleasure is more sensitive to variation in Wind speed.

3.5. *Analyzing alliesthesia*

The autocorrelation function (ACF) and partial autocorrelation (PACF) are time series statistical analysis that reveal the covariance in a series between one observation and another observation, indicating a potential correlation in the same series k lags away [55]. Cross-correlation analysis on the other hand, reveals the functional correlation between an input series and an output series over time, where both the input and the output series are time series, revealing how changes in the output series is affected by changes in the input series. In this study, ACF and PACF are used to analyze whether there is a significant influence of previous fatigue sensation (lagged value) on instant fatigue sensation, indicating the effect of past experience. Additionally, Cross-correlation analysis is used to analyze the time lag effect of stairs count on fatigue sensation. This analysis investigates whether the increase in fatigue sensation tends to move together (instant) or follow (lag) the movement of ascending stairs count, assessing for a delayed effect. The latter aims to reveal the alliesthesial potential of short-term Sabat exposures on reducing fatigue sensation.

3.5.1. *Autocorrelation of fatigue sensation in two different walking routes*

Fig. 11 shows that significant autocorrelations were found for both walking routes as the autocorrelations were within 95 % confidence interval. ACF of fatigue in route 1 revealed a significant positive autocorrelation at lag-1 ($r = 0.746$, $p < 0.001$) and lag-2 ($r = 0.442$, $p < 0.001$). Such results indicate that there is a significant effect of previous fatigue sensation of previous two survey points (4–8 min before) on the instant fatigue sensation. This was later confirmed by a significant PACF autocorrelation which reveals a direct positive correlation between instantaneous and previous fatigue sensation. As fatigue sensation gradually decreased in route 1 (Fig. 8), results imply the significant influence of previous experience, walking by Sabats within the street, in

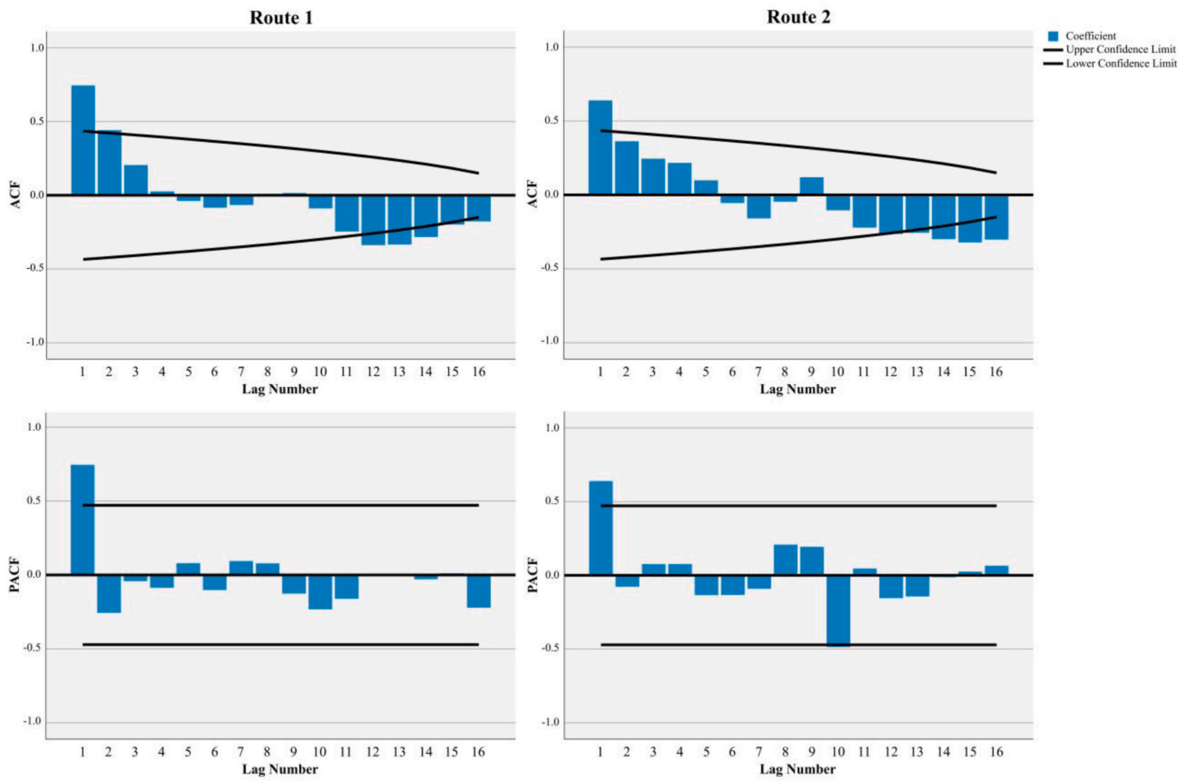

Fig. 11. Autocorrelation (ACF) and partial autocorrelation (PACF) of fatigue sensation in each walking route. The solid lines indicate the 95 % confidence interval, used to determine whether the null hypothesis is rejected. The bars indicate the autocorrelation coefficient at each lag number.

developing a level of recovery which contributed to reduce fatigue sensation. Such findings confirms the potential effect of past experience in introducing a delayed effect of actual conditions. ACF of fatigue in route 2 revealed a significant positive autocorrelation at lag-1 ($r = 0.640$), indicating a significant effect of previous fatigue sensation (2–5 min before) on actual fatigue. This was also confirmed by the significant PACF autocorrelation. This time, fatigue sensation gradually increased in route 2 (Fig. 8), suggesting an accumulative effect of previous fatigue sensation on actual fatigue sensation.

3.5.2. *Delayed response the fatigue sensation*

Both ACF and PACF were characterized by rapid attenuation suggesting stationarity, thus, allowing for cross-correlation analysis. More information about stationarity are provided in Ref. [55]. Cross-correlation analysis was conducted to examine the delayed effect of stairs on fatigue sensation while walking route 1 and route 2 (Fig. 12). Cross-correlation results show that there is a significant correlation at lag-(0), indicating that fatigue sensation is highly correlated with instantaneous increase in stairs count.

In route 1, results also indicate a significant correlation at lag-(-1) ($r = 0.504$, $p < 0.001$) (Fig. 12), suggesting that changes in fatigue sensation also respond after a short time lag to changes in stairs count. This implies a delayed response to fatigue sensation when subjects pass by frequent shaded cooling Sabats, and that the history of exposure affects subjects 'actual experience of fatigue. Here, this delay response to stairs count confirms the impact of thermal alliesthesia in providing short recovery, thus reduced fatigue sensation in presence of Sabats. The Sabat space, with the coverage it provides, results in shaded and ventilated spots that may provide recovery experiences. For route 2, a higher significant correlation at lag-(0) implies that a prolonged

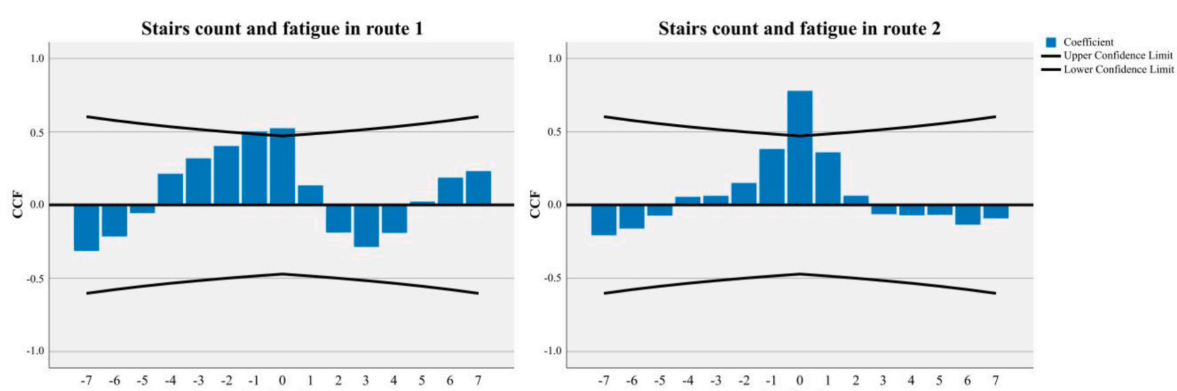

Fig. 12. Cross-correlation (CCF) between stairs count and fatigue sensation in route 1 and route 2. The solid lines indicate the 95 % confidence interval, used to determine whether the null hypothesis is rejected. The bars indicate the autocorrelation coefficient at each lag number.

exposure to the same environmental conditions may induce additional thermal loads since subjects were continuously climbing staired street with continuous heat exposure.

4. Discussion

Findings demonstrated the potential of Sabat, a covered passage at street level, in generating wind acceleration despite the compact urban layout of Casbah, and its potential in reducing fatigue sensation, hence supporting a positive walking experience. This section offers insights into the importance of Sabat as an urban design allowing for cool-shaded and ventilated spots for the walking activity **(4.1)**, and its significance in supporting resilient walkability **(4.2)**. It also discusses the broader implications **(4.3)** as well as the limitations and future work **(4.4)**.

4.1. The Sabat as a cool-shaded and ventilated spot

The wind channeling effect inside Sabat allowed for providing cool-shaded and ventilated spots for the walking activity. This can be attributed to the combined effect of thermal surface heating and aeraulic mechanical forces. Thermal heating plays an important role in controlling wind flow within urban areas [58,59]. Shaded Sabats with low ground temperature contribute to generate different air pressures. Low air temperatures inside Sabat result in high air pressure, in contrast to low wind pressure resulting from higher air temperatures in non-covered stops. The transient pattern of shaded Sabat and exposed streets creates horizontal temperature variations, leading to wind pressure differences. The latter causes air to move from high-pressure areas to areas of lower pressure, thus generation wind acceleration. On the other hand, when wind moves through narrow passages between buildings, it tends to accelerate due to the channeling effect [60]. In case of lift-up configuration, such as the Sabat, the mechanical nature of the wind flows at high speed through the lift-up void openings. However, Sabat 4, 5, and 6 exhibited the lowest wind speed despite following the same orientation of the prevailing winds (Fig. 5). This could be explained by the short distance between the 3 Sabats and the low height of the void underneath (2 m). Such results align with Chew and Norford [61]. They suggested that a 2 m void height is insufficient to channel wind speed while a void height of 4 m is sufficient for maintaining high pedestrian-level wind speeds along the street, while and there was no significant difference for further increase 4–6 m. These findings suggest that for short distance between Sabats, wind flow may be slowed down by the downwash effect from the windward face of downstream Sabat in comparison to the first one. Although single low Sabat may allow wind acceleration, the wind flow may lose its momentum at the nearest opening of the following Sabat.

Limited air circulation in addition to excessive heat at pedestrian level are major issues for outdoor activities, especially in compact urban areas. The lift-up design has been widely adopted in building design in southern China and southern Asia [26] as recent studies highlighted the potential of void created at (1–3 m above the ground level) in creating local cooling spots for pedestrian activities [26,27,61,62]. These studies have demonstrated its benefits in providing wind amplification and shading breaks which provides optimal microclimates for the walking activity. In presence of Sabats, thermal pleasure strongly correlated with WSV ($\rho = 0.805$, $p < 0.05$, $N = 9$) while there was no significant correlation with TSV and stairs, suggesting that in transient conditions pedestrian thermal pleasure is more sensitive to variation in wind speed. As such, the Sabat design would present a significant solution to improving weak wind condition in dense cities at the pedestrian level by providing cool-shaded and ventilated spots along the walking route, especially during the hot season.

4.2. The role of Sabat in supporting resilient walkability

An environment that is enriched with diverse conditions provides more adaptive opportunities, thereby enhancing the walking experience. Our study highlights the significance of rhythmic Sabats in enhancing environmental diversity. Such urban design would enhance pedestrians' resilience to outdoor discomfort, hence supporting resilient walkability.

When passing by frequent shaded and ventilated Sabats, the influence of transient conditions was significant in instantly improving thermal pleasure and gradually reducing fatigue sensation (Fig. 8) despite the presence of stairs. Such findings reveal the role of Sabats in creating restorative experiences within a walking route. Adaptive opportunities and the potential to reduce thermal discomfort are highly associated with the changes in thermal sensation [46,63]. Moreover, people response to a physical stimulus also depends on psychological factors such as history of exposure and perceived control [63,64]. Physical adaptation implies the changes in the physiological responses resulting from short frequent exposures to Sabats' pleasant conditions, leading to a gradual decreased thermal strain. The coverage of the Sabat offered a degree of protection over the outdoor conditions leading to decreased levels of "physiological stress" [65]. Such increase in adaptive capacities can offer opportunities to experience alliesthesia [22] which enhances of the capacity to recover [66], thus building self-resilient comfort.

Walking is known to improve health and improve fatigue as it can boost feeling of energy and reduce blood pressure. However, as the results demonstrated, uphill walking within prolonged exposure to discomfort conditions (solar exposure) is shown to increase fatigue sensation. It has been shown that short durations of activity followed by short active recovery increases the feeling of energy and decreases the feeling of fatigue [67]. The use of Sabats, as cool-shaded and ventilated breaks, would reduce the impact of long walks and prolonged discomfort exposure, therefore encouraging resilient walkability.

4.2.1. Association between thermal alliesthesia and fatigue recovery

Fatigue recovery provides a framework to understand the affective benefits associated with environmental diversity. Previous studies have demonstrated that the meteorological conditions induce a delayed response to human thermal sensation during the walking activity [17,68,69] and that thermal pleasure is strongly associated to restorative opportunities [65]. This study presented a novel method of investigating pedestrian walking experience by introducing fatigue sensation as an affective dimension to measure thermal discomfort. Cross-correlation analysis (Fig. 12) confirmed the delayed effect of passing by Sabats and revealed the association of thermal alliesthesia in reducing fatigue sensation. A continuous exposed environment may negatively affect thermal experience since pedestrians are continuously exposed to solar radiation in addition to stairs climbing, which lead to accumulative thermal loads (negative alliesthesia), hence increasing fatigue sensation. In more diverse environment, short exposures to shaded and ventilated Sabats offered a higher potential for pedestrians to seek restorative experiences (positive alliesthesia), hence reducing fatigue sensation.

4.3. Broader implications

The current work highlighted the importance of supporting environmental diversity in designing outdoor climate-resilient strategies, as in a more diverse environment, especially in dense cities, rhythmic and short exposures to shaded and ventilated spaces have higher potential for pedestrians to seek restorative experiences. Our findings expand on previous literature about alliesthesia and shed light on the importance of maintaining frequency and rhythm along with alliesthesia to create modulated (dynamic repetition) restorative opportunities. The number, duration and frequency of exposures to positive alliesthesia along with pedestrian's tolerance level invites further investigation.

The careful implementation of Sabat design is crucial in creating adaptive and restorative opportunities for resilient walking facing the current climate change conditions. At Algiers historical city scale, such findings could encourage city planners to prioritize the urgent restoration and conservation of damaged Sabats. In the context of new urbanism, such design could be integrated into the development of future dense and walkable cities' extension within the 15-min city framework. Reaching various amenities within a 15-min walkable distance necessitates the improvement of heat resilience capacity [70]. Incorporating the Sabat design would not only enhance heat resilience through its restorative qualities but also significantly contribute to other aspects of the 15-min city concept. Its implementation could expand beyond environmental benefits, fostering social and economic features. The covered passage could also be a place of services and social interaction, i.e. coffee shops, book store, resting spots, etc., enhancing land use diversity, and proximity to amenities. This will ensure livable, resilience and walkable communities.

Further investigations are imperative to understand the thermal aeraulic behavior of these covered passage and in different climate conditions, as well as its influence on different pedestrians' affective qualities such as sense of security. This holistic approach is necessary for determining optimal implementation of the Sabat design in modern urbanism, while considering global cultural differences.

4.4. Limitations and future work

The study sheds light on how traditional urban spaces can play a pivotal role in adapting with current climate change challenges. However, there are also limitations in relation to the sample size and user groups, as well as the equipment employed for the surveys.

(1) Given the small sample size and narrow age group of participants, the vulnerability of the elderly to fatigue is not discussed, although fatigue has been found to be an important feature for activity restriction for older people [71]. Additionally, thermal walks were conducted for only two days in the summer due to the heat wave conditions especially during the survey hours from 13 h to 16 h, in addition to the difficulties encounters due to the challenging terrain conditions. However, summer thermal walks supplemented the initial results from winter thermal walks to account for the influence of transient conditions during extreme temperatures. To overcome the limitation of small sample size during summer conditions, the analysis was conducted on the overall experience during both seasons and differentiating for each walking route. The findings from this constrained sample provide valuable insights in constructing hypotheses for further work, incorporating larger and more diverse age groups in different urban configurations, climate and terrain conditions., i.e., down-hill walking and flat terrain walking.

(2) To overcome the vane probe sensitivity, the vane probe was well fixed in the tripod away from obstructions (including moving pedestrians), and was carefully rotated in the first 30 s, to capture the highest value, before it was then fixed to ensure the most accurate measurement. Acknowledging the limitations of the vane's sensitivity, current data invite utilizing more sophisticated equipment to validate and refine these initial findings.

Air temperature was measured by TESTO 480 which was always positioned in the shaded part of the non-covered stops to avoid any influence from solar radiation. However, a radiation shield should be used in the future to eliminate potential interference of solar radiation. To overcome this limitation, surface temperature measurements were incorporated during the summer surveys to offset the effect of solar radiation on wind speed, providing supporting data along with air temperature. More importantly, the main findings of the potential of Sabat to support a positive walking experience and the association of thermal alliesthesia with fatigue reduction in presence of Sabats are found to be independent of the microclimate data. Thus, the limitation associated with air temperatures does not introduce bias into this study's main findings.

(3) While the measurements were limited inside Sabats, it is important to emphasize that these measurements are preliminary and indicative in nature. They provide valuable first-hand insights into the environmental conditions experienced along the Sabat. Detailed measurement of Sabats (outside, beginning, middle and end) are required in future work to quantify the thermal aeraulic behavior and performance of such configuration.

5. Conclusions

The current work offered novel and primary understanding on the significance of creating rhythmic cool-shaded and ventilated Sabat design on reducing the fatigue sensation and the importance of dynamic alliesthesia in urban restorative design strategies. Specifically, it investigated the potential of the Sabat design, a traditional semi-outdoor space at ground level with lift-up design serving as short covered passages, in generating transient conditions, along with their influence on pedestrians' walking experience in the context of uphill walking in Mediterranean cities, the case of Algiers Casbah.

The main conclusions are summarized below:

(1) The Sabat design and distribution were found to significantly generate transient thermal aeraulic conditions within street corridors. Conditions inside Sabats were characterized by lower air and ground temperatures and higher wind speeds compared to non-covered street. Notably, the lift-up design effectively accelerated the flow of air inside the Sabat. This could be attributed to the difference in ground temperatures and the aeraulic mechanical force of air flow in narrow passages, with respect to orientation, distribution and design attributes of the Sabat (height, length and width).

(2) The dynamic thermal experience of walking through frequents Sabats positively influenced pedestrians' affective state, in the context of pleasure and fatigue sensation. The distribution of such short interval conditions along the street provided rhythmic, restorative breaks, effectively reducing the sensation of fatigue. Hence the significance of the combined effect of shade and wind in elevating thermal strains.

(3) More importantly, different Sabats distributions had different influence on pedestrians' walking experience. Sabats located at the second part of the route were more efficient to reduce fatigue in route 1, while Sabats in the first part of the walking route had no significant influence in reducing fatigue toward the end of route 2. Such findings indicate the importance of rhythm and distribution on the one hand, and the implications of subjects' exposure and levels of tolerance on the other hand.

(4) Additionally, the significance impact of short past thermal experience on pedestrian's fatigue sensation at lag-2 ($r = 0.442$, $p < 0.001$) (4–8 min) was demonstrated and validated by the delayed fatigue sensation despite uphill walking at lag-1 ($r = 0.640$). This reveals the implication of positive thermal alliesthesia in providing short restorative conditions, gradually reducing fatigue sensation in short rhythmic intervals of cool-shaded and ventilated passages (Sabats).

The current research provides insights for improving the walking experience in traditional cities with similar context to Algiers Casbah, while offering a valuable starting point for hypothesizing broader trends for future implementation of Sabat design in modern cities. Such interventions could ensure that all urban areas, including historical cities, benefit from restorative design strategies, which can promote social equity and inclusiveness in city planning.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Sabah Ali Smail: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Noureddine Zemmouri:** Writing – review & editing, Supervision, Conceptualization. **Moussadek Djenane:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Marialena Nikolopoulou:** Writing – review & editing, Supervision, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The authors are grateful for the opportunity offered by the University of Kent to host the main author as visiting staff and ensuring a successful research collaboration.

References

[1] A. Revi, D. Satterthwaite, F. Aragón-Durand, et al., Urban areas in climate change 2014: impacts, adaptation, and vulnerability, Part A: Global and Sectoral Aspects (2014), https://doi.org/10.1017/CBO9781107415379.
[2] A. Forsyth, What is a walkable place? The walkability debate in urban design, Urban Des. Int. 20 (2015), https://doi.org/10.1057/udi.2015.22.
[3] M.A. Alfonzo, To walk or not to walk? The Hierarchy of walking needs, Environ. Behav. 37 (2005), https://doi.org/10.1177/0013916504274016.
[4] R. Ewing, S. Handy, Measuring the Unmeasurable: urban design qualities related to walkability, J. Urban Des. 14 (2009), https://doi.org/10.1080/13574800802451155.
[5] C. O'Malley, P.A.E. Piroozfarb, E.R.P. Farr, J. Gates, An investigation into Minimizing urban heat island (UHI) effects: a UK perspective, Energy Proc. 62 (2014), https://doi.org/10.1016/j.egypro.2014.12.368.
[6] B. Nielsen, K. Kassow, F.E. Aschengreen, Heat balance during exercise in the sun, Eur. J. Appl. Physiol. Occup. Physiol. 58 (1988), https://doi.org/10.1007/BF00636625.
[7] H. Otani, M. Kaya, A. Tamaki, et al., Combined effects of solar radiation and airflow on endurance exercise capacity in the heat, Physiol. Behav. 229 (2021), https://doi.org/10.1016/j.physbeh.2020.113264.
[8] P.N. Ainslie, I.T. Campbell, J.P. Lambert, et al., Physiological and metabolic aspects of very prolonged exercise with particular reference to hill walking, Sports Med. 35 (2005), https://doi.org/10.2165/00007256-200535070-00006.
[9] A. Johnson, M. Benjamin, N. Silverman, Oxygen consumption, heat production, and muscular efficiency during uphill and downhill walking, Appl. Ergon. 33 (2002), https://doi.org/10.1016/S0003-6870(02)00031-5.
[10] L. Kleerekoper, M. van Esch, T.B. Salcedo, How to make a city climate-proof, addressing the urban heat island effect, Resour. Conserv. Recycl. 64 (2012), https://doi.org/10.1016/j.resconrec.2011.06.004.
[11] M. Li, S. Gu, P. Bi, J. Yang, Q. Liu, Heat waves and morbidity: current knowledge and further direction-a comprehensive literature review, Int. J. Environ. Res. Publ. Health 12 (2015), https://doi.org/10.3390/ijerph120505256.
[12] A. Fikfak, K. Lavtižar, J.P. Grom, et al., Study of urban greenery models to prevent overheating of parked vehicles in P + R facilities in Ljubljana, Slovenia, Sustainability 12 (2020), https://doi.org/10.3390/su12125160.
[13] R. Leichenko, Climate change and urban resilience, Curr. Opin. Environ. Sustain. 3 (2011), https://doi.org/10.1016/j.cosust.2010.12.014.
[14] A. Potvin, Movement in the Architecture of the City a Study in Environmental Diversity, Doctoral dissertation, University of Cambridge, 1996, https://doi.org/10.17863/CAM.31085.
[15] M. Nikolopoulou, K. Steemers, Thermal comfort and psychological adaptation as a guide for designing urban spaces, Energy Build. 35 (2003), https://doi.org/10.1016/S0378-7788(02)00084-1.
[16] C. Chun, A. Tamura, Thermal comfort in urban transitional spaces, Build. Environ. 40 (2005), https://doi.org/10.1016/j.buildenv.2004.08.001.
[17] K.K.-L. Lau, Y. Shi, E.Y.-Y. Ng, Dynamic response of pedestrian thermal comfort under outdoor transient conditions, Int. J. Biometeorol. 63 (2019), https://doi.org/10.1007/s00484-019-01712-2.
[18] S. Liu, N. Nazarian, M.A. Hart, et al., Dynamic thermal pleasure in outdoor environments - temporal alliesthesia, Sci. Total Environ. 771 (2021), https://doi.org/10.1016/j.scitotenv.2020.144910.
[19] Q. Qi, Q. Meng, J. Wang, P. Ren, Developing an optimized method for the 'stop-and-go' strategy in mobile measurements for characterizing outdoor thermal environments, Sustain. Cities Soc. 69 (2021), https://doi.org/10.1016/j.scs.2021.102837.
[20] Y. Dzyuban, D.M. Hondula, J.K. Vanos, et al., Evidence of alliesthesia during a neighborhood thermal walk in a hot and dry city, Sci. Total Environ. 834 (2022), https://doi.org/10.1016/j.scitotenv.2022.155294.
[21] Z. Peng, R. Bardhan, C. Ellard, K. Steemers, Urban climate walk: a stop-and-go assessment of the dynamic thermal sensation and perception in two waterfront districts in Rome, Italy, Build. Environ. 221 (2022), https://doi.org/10.1016/j.buildenv.2022.109267.
[22] M. Cabanac, Sensory pleasure, Q. Rev. Biol. 54 (1979), https://doi.org/10.1086/410981.
[23] R. de Dear, Revisiting an old hypothesis of human thermal perception: alliesthesia, Build. Res. Inf. 39 (2011), https://doi.org/10.1080/09613218.2011.552269.
[24] M. Cabanac, Physiological role of pleasure, Science 173 (1971), https://doi.org/10.1126/science.173.4002.1103.
[25] B.S. Hakim, Mediterranean urban and building codes: origins, content, impact, and lessons, URBAN Des, Int 13 (2008), https://doi.org/10.1057/udi.2008.4.
[26] Y. Du, C.M. Mak, J. Liu, et al., Effects of lift-up design on pedestrian level wind comfort in different building configurations under three wind directions, Build. Environ. 117 (2017), https://doi.org/10.1016/j.buildenv.2017.03.001.
[27] Q. Xia, X. Liu, J. Niu, K.C.S. Kwok, Effects of building lift-up design on the wind environment for pedestrians, Indoor Built, Environ. Times 26 (2015), https://doi.org/10.1177/1420326X15609967.
[28] S. Missoum, Alger à l'époque ottomane, la médina et la maison traditionnelle, 2003. Edisud.
[29] F.H. Arrar, D. Kaoula, M.E. Matallah, et al., Quantification of outdoor thermal comfort levels under sea breeze in the historical city fabric: the case of Algiers Casbah, Atmosphere 13 (2022), https://doi.org/10.3390/atmos13040575.
[30] H. Jafari Sharami, S.J. Hosseini, Theoretical framework of the Isfahani style: inspiring sustainable aspects of a vernacular urban development, Frontier. Architect. Res. 13 (2024), https://doi.org/10.1016/j.foar.2023.12.008.
[31] F. Akrami Abarghuie, R. Javadi, E. Mirabi, et al., Experience of urban thermal pleasure: a qualitative study to the understanding of thermal-scape quality, Cities 131 (2022), https://doi.org/10.1016/j.cities.2022.104022.
[32] B.S. Hakim, Revitalizing traditional towns and heritage districts, ArchNet-IJAR: International Journal of Architectural Research 1 (3) (2007), https://doi.org/10.26687/archnet-ijar.v1i3.26.
[33] P. Keshtkaran, Harmonization between climate and architecture in vernacular heritage: a case study in yazd, Iran, Procedia Eng. 21 (2011), https://doi.org/10.1016/j.proeng.2011.11.2035.
[34] M. Sinou, K. Steemers, Urban semi-enclosed spaces as climate moderators. Proceedings of PLEA 21th, 2004.
[35] C.-Y. Wen, Y.-H. Juan, A.-S. Yang, Enhancement of city breathability with half open spaces in ideal urban street canyons, Build. Environ. 112 (2017), https://doi.org/10.1016/j.buildenv.2016.11.048.
[36] Y.-H. Juan, A.-S. Yang, C.-Y. Wen, et al., Optimization procedures for enhancement of city breathability using arcade design in a realistic high-rise urban area, Build. Environ. 121 (2017), https://doi.org/10.1016/j.buildenv.2017.05.035.
[37] C. Liu, A. Li, C. Yang, W. Zhang, Simulating air distribution and occupants' thermal comfort of three ventilation schemes for subway platform, Build. Environ. 125 (2017), https://doi.org/10.1016/j.buildenv.2017.08.036.
[38] K. Nagara, Y. Shimoda, M. Mizuno, Evaluation of the thermal environment in an outdoor pedestrian space, Atmos. Environ. 30 (1996), https://doi.org/10.1016/1352-2310(94)00354-8.
[39] S.H. Ameli, S. Hamidi, A. Garfinkel-Castro, et al., Do better urban design qualities lead to more walking in Salt Lake City, Utah? J. Urban Des. 20 (2015) https://doi.org/10.1080/13574809.2015.1041894.
[40] M. Johansson, C. Sternudd, M. Kärrholm, Perceived urban design qualities and affective experiences of walking, J. Urban Des. 21 (2016), https://doi.org/10.1080/13574809.2015.1133225.
[41] S. Dadpour, J. Pakzad, H.R. Khankeh, Understanding the influence of environment on adults' walking experiences: a meta-synthesis study, Int. J. Environ. Res. Publ. Health 13 (2016), https://doi.org/10.3390/ijerph13070731.
[42] A. Bornioli, G. Parkhurst, P.L. Morgan, Affective experiences of built environments and the promotion of urban walking, Transport. Res. Part A Policy Pract. 123 (2019), https://doi.org/10.1016/j.tra.2018.12.006.
[43] P. Cambra, F. Moura, How does walkability change relate to walking behavior change? Effects of a street improvement in pedestrian volumes and walking experience, J. Transport Health 16 (2020), https://doi.org/10.1016/j.jth.2019.100797.
[44] A. Chokhachian, K. Ka-Lun Lau, K. Perini, et al., Sensing transient outdoor comfort: a georeferenced method to monitor and map microclimate, J. Build. Eng. 20 (2018), https://doi.org/10.1016/j.jobe.2018.07.003.
[45] S. Lenzholzer, W. Klemm, C. Vasilikou, Qualitative methods to explore thermo-spatial perception in outdoor urban spaces, Urban Clim. 23 (2018), https://doi.org/10.1016/j.uclim.2016.10.003.

[46] C. Vasilikou, M. Nikolopoulou, Outdoor thermal comfort for pedestrians in movement: thermal walks in complex urban morphology, Int. J. Biometeorol. 64 (2020), https://doi.org/10.1007/s00484-019-01782-2.

[47] Y. Zhang, J. Liu, Z. Zheng, et al., Analysis of thermal comfort during movement in a semi-open transition space, Energy Build. 225 (2020), https://doi.org/10.1016/j.enbuild.2020.110312.

[48] M. Kottek, J. Grieser, C. Beck, et al., World map of the Köppen-Geiger climate Classification updated, Meteorol. Z. 15 (2006), https://doi.org/10.1127/0941-2948/2006/0130.

[49] J.A. Russell, U.F. Lanius, Adaptation level and the affective appraisal of environments, J. Environ. Psychol. 4 (1984), https://doi.org/10.1016/S0272-4944(84)80029-8.

[50] J. Nakano, Evaluation of thermal comfort in semi-outdoor environment, Build. Eng. 110 (2003).

[51] T. Parkinson, R. de Dear, Thermal pleasure in built environments: physiology of alliesthesia, Build. Res. Inf. 43 (2015), https://doi.org/10.1080/09613218.2015.989662.

[52] S. Liu, N. Nazarian, J. Niu, et al., From thermal sensation to thermal affect: a multi-dimensional semantic space to assess outdoor thermal comfort, Build. Environ. 182 (2020), https://doi.org/10.1016/j.buildenv.2020.107112.

[53] E. Ream, A. Richardson, Fatigue: a concept analysis, Int. J. Nurs. Stud. 33 (1996), https://doi.org/10.1016/0020-7489(96)00004-1.

[54] D. Västfjäll, T. Gärling, Validation of a Swedish short self-report measure of core affect, Scand. J. Psychol. 48 (2007), https://doi.org/10.1111/j.1467-9450.2007.00595.x.

[55] R.A. Yaffee, M. McGee, Introduction to Time Series Analysis and Forecasting with Applications of SAS and SPSS, Academic Press, 2001.

[56] J. Pallant, SPSS Survival Guide Manual, sixth ed., vol. 6, Open University Press, 2016.

[57] Time series cross-correlations and the USDA feed grains database (1876–2015), in: Sage Research Methods Datasets Part 1, SAGE Publications, Ltd., 2017, https://doi.org/10.4135/9781473995765.

[58] J.-J. Kim, J.-J. Baik, Urban street-canyon flows with bottom heating, Atmos. Environ. 35 (2001), https://doi.org/10.1016/S1352-2310(01)00135-2.

[59] X. Xie, C.-H. Liu, D.Y.C. Leung, Impact of building facades and ground heating on wind flow and pollutant transport in street canyons, Atmos. Environ. 41 (2007), https://doi.org/10.1016/j.atmosenv.2007.08.027.

[60] T. Stathopoulos, H. Wu, C. Bédard, Wind environment around buildings: a knowledge-based approach, J. Wind Eng. Ind. Aerod. 44 (1992), https://doi.org/10.1016/0167-6105(92)90028-9.

[61] L.W. Chew, L.K. Norford, Pedestrian-level wind speed enhancement with void decks in three-dimensional urban street canyons, Build. Environ. 155 (2019), https://doi.org/10.1016/j.buildenv.2019.03.058.

[62] J. Weng, B. Luo, H. Xiang, et al., Effects of bottom-overhead design variables on pedestrian-level thermal comfort during summertime in different high-rise residential buildings: a case study in chongqing, China, Buildings 12 (2022), https://doi.org/10.3390/buildings12030265.

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

[64] J. Spagnolo, R. de Dear, A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia, Build. Environ. 38 (2003), https://doi.org/10.1016/S0360-1323(02)00209-3.

[65] K. Lyu, R. de Dear, A. Brambilla, et al., Restorative benefits of semi-outdoor environments at the workplace: does the thermal realm matter? Build. Environ. 222 (2022) https://doi.org/10.1016/j.buildenv.2022.109355.

[66] M. Schweiker, Rethinking resilient comfort– definitions of resilience and comfort and their consequences for design, operation, and energy use. 11th Windsor Conference, 2020.

[67] D.C. Monroe, N.H. Gist, E.C. Freese, et al., Effects of sprint interval cycling on fatigue, energy, and cerebral oxygenation, Med. Sci. Sports Exerc. 48 (2016), https://doi.org/10.1249/mss.0000000000000809.

[68] W. Ji, B. Cao, M. Luo, Y. Zhu, Influence of short-term thermal experience on thermal comfort evaluations: a climate chamber experiment, Build. Environ. 114 (2017), https://doi.org/10.1016/j.buildenv.2016.12.021.

[69] N. Al Sabbagh, Walkability in Dubai: Improving Thermal Comfort, Open University, UK, 2017, https://doi.org/10.21954/ou.ro.0000eb18. Thesis dissertation.

[70] Y. Wang, B.J. He, C. Kang, et al., Assessment of walkability and walkable routes of a 15-min city for heat adaptation: development of a dynamic attenuation model of heat stress, Front. Public Health (2022), https://doi.org/10.3389/fpubh.2022.1011391.

[71] T. Egerton, S.F.M. Chastin, D. Stensvold, et al., Fatigue may contribute to reduced physical activity among older people: an observational study, J. Gerontol. 71 (2016), https://doi.org/10.1093/gerona/glv150.