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Transient thermal aeraulic conditions and walkability of in-between spaces. Case of Mediterranean streets.

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Dedication

To my father,

To my mother,

To my brother and sisters.

To all those I hold dear.

Acknowledgment

First, I would like to express my gratitude to Allah the almighty who guided me through this path and gave me the courage and patience to complete this humble dissertation

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Abstract

The effects of climate change are rapidly emerging in urban areas. Today's Mediterranean cities, Algeria included, are the most vulnerable to draught, increased frequency of heatwave and prolonged warm conditions, impacting both the climate, outdoor activities and public health. The vulnerability of the Mediterranean populations to heat-related risks is alarmingly increasing. Consequently, outdoor activities, walking in specific, and pedestrian's well-being are threatened.

Walking activity is more affected by heat stress due to the prolonged exposure in addition to metabolic heat production from the physical activity of walking. Although individuals are capable of sustaining heat balance, increasing heat loads from solar exposure and metabolic heat production can severely deteriorate the thermoregulatory process. During the walking activity, the body stores heat due to an imbalance between heat gain and heat and in absence of adequate heat mitigation devices, thermal exposure may be 'uncompensable' when the human body is enabled to offset the required heat loss, resulting in continuous heat accumulation and increase core temperature. Continuous imbalance in heat storage and heat dissipation could result in significant heat related issues such as fatigue, heat exhaustion, to life risking cardiovascular stress and heat stroke.

The extent of which these risks are to increase in the near future is dependent on the adaptive strategies and resilience of the Mediterranean cities to offset the consequences of global warming. While walking is the most impacted by the climate change, it could play a significant role in reshaping its intensity. Walkability is essential in promoting sustainable cities facing the climate change, however, walking is significantly impacted by the microclimate. Reconciling the dual challenge of addressing walkability to mitigate climate change, and mitigating climate change to walk emphasizes the significance of promoting resilient walkability. To this end, resilience highlights the need to design urban spaces able to adapt to rising urban heat, allowing pedestrians to tolerate and recover from discomfort conditions. The use of adaptive spatial configurations can enhance environmental diversity, ensuring a wide range of climate-resilient solutions that could play an important role in providing comfortable and resilient walking experience by enabling tolerance and recovery form thermal stress.

The aim of this study is to gain a better knowledge of how environmental diversity influence the walking experience with the aim of gaining insights of how to create climate-resilient street configuration able to enhance pedestrian's resilience and walking experience. This study investigates transient thermal aeraulic conditions and walkability of In-between spaces within the Mediterranean streets, in the Context of Algiers Casbah. specifically, the current study focuses on the "Sabat", a traditional in-between space at ground level serving as short-covered passages in Algiers Casbah, that is also widely spread in the Mediterranean region, and its distribution in generating transient thermal aeraulic conditions, and its potential in supporting a positive walking experience.

Walkability is addressed from a pedestrian-centered approach, investigating the influence of environmental diversity on the dynamic walking experience. Thermal walks were carried out in Casbah of Algiers during winter and summer conditions, in the context of uphill walking. Mobile meteorological measurements were conducted inside Sabats and non-covered streets within two walking routes with different Sabats distribution to undergo comparative analysis. Simultaneously, dynamic changes of pedestrians' subjective experience were recorded, mainly pleasure and fatigue sensation. Overlaying and cross-analyzing environmental monitoring and subjective pedestrian responses through statistical analysis made it possible to describe variations, detect variance and correlational relationships as well as tracking the lag effect between changes in environmental conditions and changes in pedestrian's experience.

The obtained results reveal a significant correlation between transient thermal aeraulic conditions and reduced fatigue sensation despite up-hill walking, hence a positive walking experience. Such findings highlight the importance of supporting in-between spaces in designing climate-resilient outdoor spaces. They provide valuable insights for enhancing the walking experience in traditional cities with similar context to Algiers Casbah. A strategic implementation of Sabat design would be crucial in creating adaptive and restorative opportunities for resilient walking amidst climate change challenges. These interventions can extend resilient design strategies to all urban areas, including historical cities, promoting social equity and inclusiveness in city planning as well as creating urban environments that are not only walkable but also culturally resonant.

Key words

Thermo-aeraulic conditions; Transient conditions; Walkability; walking experience; in-between spaces; Mediterranean streets; Algiers Casbah; Sabat; Alliesthesia.

ملخص

تتجلى آثار تغير المناخ بسرعة في المناطق الحضرية. مدن البحر الأبيض المتوسط اليوم، بما في ذلك الجزائر، هي الأكثر عرضة للجفاف، زيادة وتيرة موجات الحرارة، وارتفاع درجات الحرارة لفترات طويلة، مما يؤثر على الأنشطة الخارجية والصحة العامة. تتزايد بشكل مقلق هشاشة سكان البحر الأبيض المتوسط تجاه المخاطر المتعلقة بالحرارة. وبالتالي، فإن الأنشطة الخارجية، والمشي ورفاهية المشاة مهددة .تتأثر نشاطات المشي بشكل أكبر بسبب الإجهاد الحراري بسبب التعرض المتواصل للحرارة بالإضافة إلى إنتاج الحرارة الأيضية من النشاط البدني للمشي. على الرغم من قدرة جسم الإنسان على الحفاظ على التوازن الحراري، فإن زيادة الأحمال الحرارية الناتجة عن التعرض للشمس وإنتاج الحرارة الأيضية يمكن أن تضر بشكل كبير بعملية التنظيم الحراري. أثناء نشاط المشي، يخزن الجسم الحرارة بسبب عدم التوازن بين اكتساب الحرارة وفقدانها، وفي غياب وسائل التخفيف الحراري المناسبة، قد يصبح التعرض الحراري "غير قابل للتعويض" عندما يعجز الجسم البشري عن تعويض الحرارة المفقودة، مما يؤدي إلى تراكم مستمر للحرارة وزيادة درجة حرارة الجسم الداخلية. يمكن أن يؤدي هذا التوازن المستمر بين تخزين الحرارة وتبديدها إلى مشكلات حرارية خطيرة مثل التعب، والإجهاد الحراري، وأزمات القلب والأوعية الدموية التي تهدد الحياة الافراد.

تعتمد درجة زيادة هذه المخاطر في المستقبل القريب على استراتيجيات التكيف ومرونة مدن البحر الأبيض المتوسط في مواجهة عواقب الاحترار العالمي. بينما يعتبر المشي أكثر الأنشطة تأثراً بتغير المناخ، إلا أنه يمكن أن يلعب دوراً مهماً في إعادة تشكيل شدته. إن القدرة على المشي أمر أساسي في تعزيز المدن المستدامة التي تواجه تغير المناخ، ومع ذلك، فإن المشي يتأثر بشكل كبير بالمناخ المحلي. إن التوفيق بين التحدي المزدوج لمعالجة قابلية المشي للتخفيف من تغير المناخ، والتخفيف من تغير المناخ للمشي، يبرز أهمية تعزيز قابلية المشي المرنة. ومن أجل ذلك، يبرز مفهوم المرونة الحاجة إلى تصميم المساحات الحضرية القادرة على التكيف مع ارتفاع درجات الحرارة في المدن، مما يسمح للمشاة بتحمل الظروف غير المريحة والتعافي منها. يمكن أن يعزز استخدام التكوينات المكانية التكيفية التنوع البيئي، مما يضمن مجموعة واسعة من الحلول المقاومة للمناخ التي يمكن أن تلعب دوراً مهماً في توفير تجربة مشي مريحة ومرنة من خلال تمكين التسامح والتعافي من الإجهاد الحراري.

هدف هذه الدراسة هو فهم كيفية تأثير التنوع البيئي على تجربة المشي بهدف الحصول على رؤى حول كيفية إنشاء تكوينات شوارع مرنة للمناخ تعزز مرونة المشاة وتجربة المشي. تدرس هذه الدراسة الظروف الحرارية المتغيرة وحركية المشي في المساحات بين المباني داخل شوارع البحر الأبيض المتوسط، في سياق قصبة الجزائر العاصمة . بشكل خاص، تركز الدراسة الحالية على " الساباط "، وهو مساحة تقليدية بينية على مستوى الأرض تعمل كمسارات مغطاة قصيرة في القصبة الجزائرية ، وتوزيعها في توليد ظروف حرارية متغيرة ، وإمكاناتها في دعم تجربة مشي إيجابية.

يتم تناول قابلية المشي من خلال نهج يركز على المشاة، مع التحقيق في تأثير التنوع البيئي على تجربة المشي الديناميكية. تم إجراء مشي حراري في قصبة الجزائر خلال فصلي الشتاء والصيف، في سياق المشي في المنحدرات. تم إجراء قياسات جوية متنقلة داخل الصبَاط والشوارع غير المغطاة ضمن مسارين مشيين مع توزيع مختلف للساباط لإجراء تحليل مقارن. في الوقت نفسه، تم تسجيل التغيرات الديناميكية في تجربة المشاة الذاتية، بشكل رئيسي الإحساس بالمتعة والإرهاق. سمح تحليل البيانات البيئية ورصد الاستجابات الذاتية للمشاة من خلال التحليل الإحصائي بوصف التباينات، واكتشاف التباين والعلاقات الترابطية، وكذلك تتبع تأثير التأخير بين التغيرات في الظروف البيئية والتغيرات في تجربة المشاة.

كشفت النتائج التي تم الحصول عليها عن ارتباط كبير بين الظروف الحرارية العابرة والإحساس بتقليل التعب على الرغم من المشي في المنحدرات، مما يؤدي إلى تجربة مشي إيجابية. تبرز هذه النتائج أهمية دعم المساحات بين المباني في تصميم المساحات الخارجية المقاومة للمناخ. وتوفر رؤى قيمة لتحسين تجربة المشي في المدن التاريخية ذات السياقات المماثلة قصبة الجزائر. يكون تنفيذ استراتيجيات تصميم الساباط بشكل استراتيجي أمراً حاسماً في خلق فرص تكيفية واسترجاعية للمشي المرن في ظل تحديات تغير

المناخ. يمكن لهذه التدخلات أن تمد استراتيجيات التصميم المقاومة للمناخ إلى جميع المناطق الحضرية، بما في ذلك المدن التاريخية، مما يعزز العدالة الاجتماعية والشمولية في تخطيط المدن، بالإضافة إلى خلق بيئات حضرية ليست فقط قابلة للمشي بل ومتصلة ثقافياً أيضاً.

الكلمات المفتاحية

الظروف الحرارية الهوائية؛ الظروف المتغيرة ؛ قابلية المشي؛ تجربة المشي؛ المجالات البينية ؛ شوارع البحر الأبيض المتوسط؛ قصبة الجزائر؛ الساباط ؛التقلب الادراكي

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Cross-correlation (CCF)

General introduction

1.1 Background

While sustainable development trends are rising, levels of walking in modern cities are on the decline. Cities are already encountering the challenges arising from the climate change, particularly in the Mediterranean region, where significant temperature increases have been observed. This warming trend is not uniformly distributed worldwide as long-term warming trends are situated within the 40°-70° North latitude, making the Mediterranean region the most effected (and hot spot) (Kum et al., 2014). As a result, Mediterranean cities, including Algeria coastal cities, are especially vulnerable to drought, increased frequency of heatwave and prolonged warm conditions. These changes significantly impact climate, outdoor activities, and public health. Mediterranean countries have long been known for their mass tourism due to the quality of the outdoor life and joyful mild climate most of the year. However, The Mediterranean climate zone witnessed a significant shift during the past century. Research indicated a significant displacement of climate zones in Algeria and revealed an alarming prediction of the disappearance of the temperate climate zone along with a rapid expansion of the hot desert zone and contraction of fully humid and hot summers (Zeroual et al., 2018). Coastal Mediterranean cities and high-density urban centers, such as Algiers, are among those most likely to be affected (Cramer et al., 2018).

The vulnerability of the Mediterranean populations to heat-related risks is alarmingly increasing. Consequently, outdoor activities, walking in specific, and pedestrian's well-being are threatened. Extreme temperatures and prolonged exposure have a direct effect on pedestrians' thermoregulatory system, causing serious heat-related issues. Daily walking is more affected by heat stress due to the prolonged exposure in addition to metabolic heat production from the physical activity of walking. Within the progress of the walk, the body stores heat due to an imbalance between heat gain and heat loss (Kenny et al., 2017) and in absence of adequate heat mitigation devices, thermal exposure may be 'uncompensable' when the human body is enabled to offset the required heat loss, resulting in continuous heat accumulation and increase core temperature (Gagnon et al., 2018). Environmental conditions such as high humidity and low air velocity could even worsen the heat dissipation process. High humidity, terrain and exercise could significant impair an individual's ability to dissipate heat resulting in a continuous heat storage. Continuous imbalance in heat storage and heat dissipation could result in significant heat related issues such as fatigue, heat exhaustion, to life risking cardiovascular stress and heat stroke (Kenny et al., 2017)(O'Malley et al., 2014).

The extent of which these risks are to increase in the near future is dependent on the adaptive strategies and resilience of the Mediterranean cities to offset the consequences of global warming. walkability is one of the significant challenges for climate change mitigation. While walking is the most impacted by the climate change, it could play a significant role in reshaping its intensity. Walking has long been recognized as the most free and green mode of transportation and has been recognized as the foundation of the sustainable city for its multi-disciplinary benefits (Forsyth et al., 2008; Moura et al., 2017). Walking is essential in promoting sustainable, environment friendly and livable environment and improving walking environment can significantly influence walking behavior and encourage walking activity(Cambra et al., 2020). On the other hand, reducing cad-dependency requires comfortable and healthy walkable environments. Walking is significantly associated to microclimate conditions and pedestrians' experience. The street geometry plays a crucial role in favoring or hindering the walking activity and thermal stress could impact walking experience and indirectly reduce walkability (Lee et al., 2020). However, the measurement of pedestrian comfort in the context of walking is not straightforward as several factors intervene such as exposure patterns, terrain topography and pedestrians' attributes along with the psychological aspects such as pedestrian satisfaction and experience. Duration and quality of walking experience is more influence by pedestrian's thermal experience than by the microclimate conditions per se (Nikolopoulou et al., 2001).

Reconciling the double-sided challenge of promoting walkability to mitigate climate change while adapting the urban environments to support a comfortable walking experience emphasizes the importance of fostering resilient, climate-adaptive strategies that sustain walkability. Training individuals to build resilience along with providing resilient heat mitigation strategies is required more than ever. Promoting resilient walkability, in this context, highlight the need to design urban spaces able to adapt to increased urban heat, enabling pedestrians to tolerate and recover from discomfort conditions. The use of adaptive spatial configurations can enhance environmental diversity, ensuring a wide range of climate-resilient solutions that could play an important role in providing adaptive possibilities to enable tolerance and recovery form thermal stress (Nikolopoulou et al., 2003). A diverse thermal environment is highly to be more responsive, inclusive and attractive to walk and interact (Chatzipoulka et al., 2020) offering pedestrians ‘freedom of choice’ and therefore increasing satisfaction levels (Steemers et al., 2009).

The arrangement and articulation between the urban elements is crucial in creating environmental diversity. These variations within a walking route could be attributed to several street geometry characteristics such as the degree of enclosure, density and coverage and land cover. Shading elements and in-between spaces such as ‘Sabats’ and arcades are of a significant influence since their degree on enclosure significantly impact solar radiation and wind flow according to its position within the streets. In-between spaces are those intermediate space in which the indoor and outdoor climates are modified without mechanical control system and in which individual may experience the dynamic effect of this changes. The use of ‘Sabats’ and arcade is widely spread in traditional Mediterranean cities. Such elements provide significant source of shade and temporal protection from the severity of outdoor conditions. Although studies have investigated the use of in-between spaces for both indoor and outdoor environment (Juan et al., 2017; Sinou et al., 2004; Wen et al., 2017), 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.

Gaining a deeper understanding of how the physical environment conditions influence the walking experience can lead to the creation of more pedestrian-friendly environments. In this study, the goal of environmental diversity extends beyond offering choices between alternatives; it also involves designing gradually rhythmic and adaptive environments. While this approach may not entirely eliminate heat exposure, it remains the most effective method for improving pedestrian comfort to enhance pedestrians’ comfort by adopting behavioral and configurational transients that would enhance the resilience and adaptability of urban areas. The broader focus of the current study is held on investigating the influence of thermal-aeraulic diversity of in-between spaces on pedestrian walking experience in Mediterranean cities and its potential in supporting resilient walkability, in the context of Algiers Casbah.

1.2 Problem statement

The influence of climate on hindering or enhancing the walking experience is well-recognized. In Mediterranean cities like Algiers, the impact of climate conditions, particularly during the hot seasons, has intensified in recent years. This is especially evident as extreme heat and high humidity have become more pronounced and prolonged. In addition to climate, Algiers' walking experience, as several coastal and hilly Mediterranean cities, is also impacted by the factor of topography, including sloped and staired streets. Thus, adaptation becomes a critical factor in the ability to sustain the walking activity and prevent physical exhaustion and other heat-related illness.

On the other hand, the Sabat -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 covered passage- is a significant type of in-between space that is widely spread in traditional Mediterranean cities, such as the case of Algiers' Casbah- should not only be viewed as a source of shade and it is important to investigate how the walking experience is influenced by its presence.

To this end, the current study focuses on exploring climate-resilient solutions addressing both present and future walkability challenges posed by climate and urban environments, in the context of Mediterranean cities. Specifically, it examines 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- hence supporting a positive walking experience. As such, the current work addresses the following research question:

- **What is the influence of transient thermal aeraulic conditions of in-between spaces, the Sabat design, within street on pedestrian's walking experience?**

That is to investigate the influence of Sabats within the street on generating transient thermal aeraulic conditions; and the influence of these conditions on the dynamic changes of pedestrians' subjective experience.

1.3 Hypothesis

To answer the research question, the current work is grounded on the significance of environmental diversity in enhancing the outdoor environment and the outdoor activities. The assumptions are based the influence of walking experience in triggering future walking intention. As such, it is suggested that:

- The presence of in-between spaces, the Sabat type, within the street generates transient thermal aeraulic conditions that differ from those of the street, which may positively influence pedestrian's walking experience, mainly thermal sensation, wind sensation, thermal pleasure and fatigue sensation.

The main hypothesis could be presented in subparts for better understanding:

- Thermal aeraulic conditions inside the Sabat space differ from those of surrounding non-covered streets generating transient conditions.
- Depending on its distribution, these conditions have positive influence on walking experience, mainly fatigue sensation, thermal pleasure, thermal sensation and wind sensation.

1.4 Aim and objectives

The present study investigates walkability from the user experience's perspective with the goal of improving the walking environment. The study's findings are expected to improve the urban design in order to reduce pedestrian discomfort and promote a better walking experience, especially in hilly cities such as Algiers where outdoor discomfort is generated by both the climate and the topography. Following the research question and the stated assumptions, the current research' aim could be addressed as follows:

- Understand the influence of the Sabat, a type of in-between space, in generating transient thermal aeraulic conditions, therefore enhancing environmental diversity.
- Understand the influence of the Sabat transient conditions, with different distributions within the street in supporting a positive walking experience.
- Investigate to potential of the Sabat design as a climate-resilient solution for both the microclimate and the walking activity
- At a broader spectrum in the context of Casbah and the Mediterranean cities, the aim is to reintroduce the Sabat space as a vernacular urban design that is able to provide sustainable solutions for current and future challenges of the climate change.

1.5 Conceptual analysis

The figure .1. visually presented the conceptual framework allowing for a comprehensive understanding of how the present work translated the research related concepts intro dimensions and factors which were fundamental in framing the research question and structuring the hypothesis into measurable variables. In the context of the current work factors were grouped as independent variables related to street and Sabat morphology, intermediate variables related to the interaction between the microclimate and spatial diversity, and dependent variables related to pedestrian's dynamic walking experience. Here, the intermediate variables serve as dependent variable in investigating the transient conditions, and serve as independent variable when investigating pedestrians' walking experience.

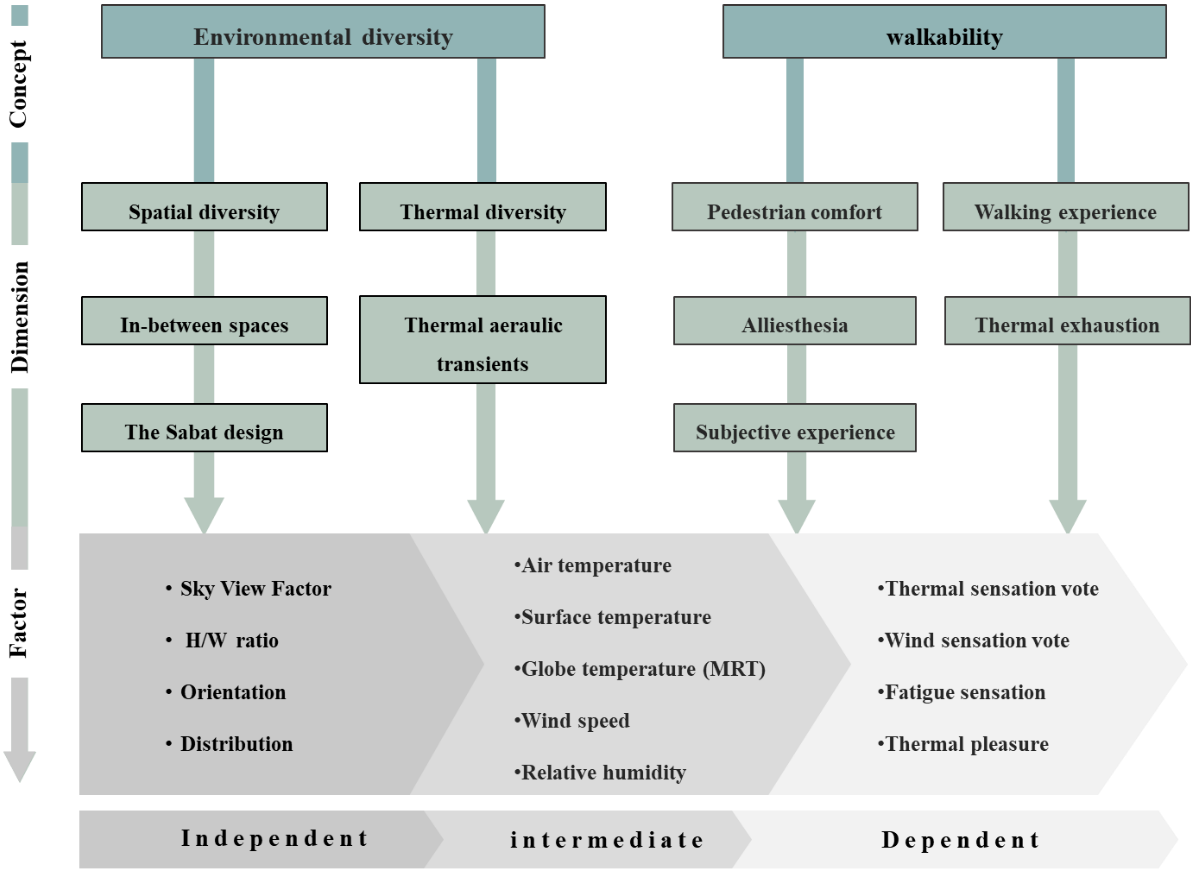


Figure 1: Conceptual framework

1.6 Overview of the methodology

To achieve the research aim, current study developed a mixed research methodology to provide both a theoretical and practical knowledge on walkability and environmental diversity. The methodology follows thermal walks framework (Vasilikou et al., 2013) and is structured as described below:

- Theoretical Literature Review: The review focuses on two main aspects: The implications of climate change on pedestrians and the walking experience, identified as the core problem statement on the one hand; and the potential of environmental diversity and in-between spaces in introducing a new shift in outdoor comfort standard for the aim of providing a better knowledge on potential resilient urban design solutions on the other hand. Moreover, the literature review focus on recent studies using the thermal walk methodology to investigate the influence of transient conditions on pedestrian's dynamic experience.

- Field investigation consists of multiple on-site pre-walks and field observation of the study area addressing the overall accessibility (quality of streets and Sabats), topography and stairs pattern, identification of Sabats and their design attributes, along with pedestrians' walking flow. The aim was to preselect two walking routes with similar street morphology, walking flow, and stairs count, along with different Sabat characteristics and distributions.
- Environmental monitoring consists of point-to-point mobile micrometeorological measurements of air temperature, globe temperature, surface temperature, wind speed and relative humidity during 6 days of winter (2022) and summer (2023) conditions in two walking routes with different Sabat distributions. Additionally, fish eye captures were taken at each assessment stops along with distance-laser measurements of streets' height to width ration and Sabats proportions (height, above the roof height, openings dimensions, length and width of the covered area)
- Human monitoring consists of on-site walking experience questionnaire survey simultaneously with the environmental monitoring. The aim is to record the changes in pedestrians dynamic experience during the instant and retrospective monitoring of their affective state, fatigue sensation and pleasure, thermal and wind sensations, additionally to analyzing alliesthesia.
- Statistical analysis were conducted by overlaying and cross-analyzing environmental monitoring and subjective pedestrian responses for the aim of describing simultaneous or delayed variations, detect variance and correlational relationships as well as tracking the lag effect between changes in environmental conditions and changes in pedestrian's experience, while allowing for comparison between two walking routes with different Sabat distribution

1.7 Thesis structure

The research is structured into two main sections: an introductory chapter, followed by eight chapters and a comprehensive conclusion. The first section presents the theoretical framework, offering essential background on the research area through an extensive literature review. The second section is predominantly practical, detailing the methodology, data analysis, and results. This section concludes with a discussion that summarizes the key findings, explores their broader implications, and suggests areas for future research. An overview of the structure is presented below:

Introductory chapter

Thich chapter provides a comprehensive introduction to the presented research by providing an overview of the research field, the problem statement and hypothesis. The chapter clearly states the aim and objectives of the research along with the assumptions while providing a visual demonstration of the followed conceptual framework and research methodology.

Part 1: The theoretical framework

The theoretical part addresses concisely the problem statement related to the climate and walkability in the first chapter, while it demonstrates the stated hypothesis throughout a detailed literature review on environmental diversity, in-between spaces and transient thermal aeraulic conditions, with the focus on a concise literature review recent studies applying thermal walks methodology in the second chapter. The third chapter provide a brief historical background of the Mediterranean cities to provide a comprehensive review on similarities of using the Sabat spaces, a type of in-between, within several traditional Mediterranean cities, with the focus held on Algiers' Casbah case study.

Chapter 01: climate and walkability

The first chapter delve into the main issues related to climate changes impacts on cities and pedestrians' heat related risks. The chapter highlights the significance of increased temperature and solar radiations on pedestrian's well-being in the context of thermal exhaustion in Mediterranean cities. Additionally, the chapter provides a comprehensive review on walkability and walking experience and its relationship with outdoor comfort. The aim is to highlight the significant impact of climate change on walkability and the importance of promoting resilient strategies.

Chapter 02: Environmental diversity, in-between spaces and pedestrians' dynamic experience

The second chapter provides background information on environmental diversity and its relationships with the walking experience. It demonstrate in influence of spatial diversity in relation variations in street morphology and in-between spaces in generating transient environments at street level with the focus on the thermal aeraulic transients. Moreover, the chapter includes an overview background on recent literature on pedestrians' dynamic subjective sensation in transient conditions and its relevance with adaptation and 'alliesthesia'. The chapter concludes with literature reviews of existing studies investigating transient conditions and analyzing thermal alliesthesia in the context of thermal walks methodology.

Chapter 03: The Sabat space in the Mediterranean cities: Algiers Casbah case study

The final chapter of the theoretical framework provides a historical overview of the Mediterranean region during around the middle age and the influences that led to the spread of the Sabat space in the Mediterranean cities. The chapter focuses later on the historical background of Algiers Casbah highlighting its relation to different influence from the Mediterranean region. The chapter presents at the different types and distributions of existing Sabats along with providing map of Sabat distribution in Casbah which will serve as the corpus of the study.

Part two: Methodological framework and results analysis

Chapter 04: Methodology: Algiers Casbah thermal walks

The methodology chapter provides detailed demonstration of the field investigation of Casbah thermal walks. The chapter present a general overview of the Casbah study area in terms of climate and accessibility, and micrometeorological conditions. The selected walking route along with the selected Sabat are graphically presented in details. The methodological chapter present as well the mobile micrometeorological measurement protocol and includes concise description of the measurement protocol and specifications of the used measurement tools. Moreover, this section provides the protocol followed to investigate pedestrians' dynamic experience by providing detailed questionnaire survey. This chapter also provide an overview of the data analysis statistical tests using mainly IMB SPSS.

Chapter 05: Transient thermal aeraulic condition and pedestrian walking experience

this chapter focuses on reporting the environmental monitoring during winter and summer surveys. Initially, it provides descriptive data of the different variations in microclimate data during both weather conditions. It demonstrate the results from the statistical analysis of variation and correlation while providing comparative analysis between Sabat spaces and non-covered street in addition to the difference in transient patterns between winter and summer conditions. The chapter also includes discussion of the analysis on a separate section and expand upon the background knowledge and literature review of chapter 02 to explain the variations trend.

The second section reports on the result and main findings of the walking questionnaire survey. It provides descriptive statistics of the questionnaire results in both seasonal conditions in parallel to the simultaneous micrometeorological measurements. These descriptive statists offers an overview of the dynamic change in pedestrians sensations along with the variations in the meteorological data. This section also reports on the statistical test of correlation and variation. Furthermore, this section highlight the significant findings from the cross-correlation analysis on analyzing alliesthesia. Following reported results, this section expand upon the provided literature review in chapter 01 and chapter 02, mainly fatigue recovery, tolerance and alliesthesia, and confirm the assumptions of the introductory chapter, highlighting the significant of the Sabat design in providing restorative experiences, hence supporting a positive walking experience.

The general Conclusion

Conclusion, limitations, broader implication and future work

This section builds upon the key findings from chapters 6 by exploring their broader implications. It examines how Sabat spaces can be implemented within the framework of 15-minute cities, offering recommendations for future applications in both traditional and modern urban settings. Additionally, the section acknowledges the limitations of the research methodology and explains the steps taken to mitigate potential bias. Finally, it summarizes the research's most significant findings and emphasizes the importance of further exploration in future studies.

Part 1: Theoretical framework and background

Chapter 1: Climate and Walkability

1.1 Introduction

The climate change is manifesting through alarming consequences impacting individual’s health and well-being. Cities are already living the consequences of climate change and taking actions become urgent in order to mitigate its intensity. This first chapter is a demonstration of the research problem inspiring the current research. The strategic location of the Mediterranean region and its temperate weather made the Mediterranean cities and populations the most vulnerable to the alarming temperature increase and frequent heatwaves. Consequently, outdoor activities such as walking are threatened by significance heat-related risks, mainly heat exhaustion, fatigue, and cardiovascular stress. The current chapter examines the current state of climate change in the Mediterranean region and its implications for public health and walkability. It highlights the adverse effects of temperature increase and heat exposure on disturbing the human body’ energy balance and heat accumulation. Heat exhaustion and fatigue is further triggered by the activity of walking during prolonged exposure to heat exposure, in addition to inadequate shading and steep topography. Individuals must adapt to current and future impacts of the global warming. To this end, walkability is a critical factor influenced by global warming and could significantly reshape the its magnitude. In the context of outdoor comfort, fostering a more resilient walking strategy would play a key element in facing current and future global warming challenges. Within the framework of urban resilience, enhancing walkability through adaptive strategies can play a pivotal role in addressing the challenges posed by global warming.

1.2 Climate and pedestrians in the Mediterranean region

1.2.1 Mediterranean climate overview

Temperature and precipitation are the main variables influencing climate variability. Koppen (1936) established 31 different climate classes based on variability of temperatures and precipitations levels (Kottek et al., 2006). Climate zone classes according to Köppen are identified based on three-letter scheme: the first upper case letter indicated the vegetation group; the second lower case letter represents the precipitation distribution and the last lower-case letter indicated the seasonal temperature variations (Kottek et al., 2006).

The Mediterranean climate is located between about 30° and 45° latitude north and south of the Equator (Spano et al., 2003). The main climate in the Mediterranean region is characterized by cool, wet winters and a warm temperate (C) dry summer (s) with warm (b) to hot (a) summer conditions depending on its location and proximity to the Mediterranean Sea, therefore, it is divided into the Csa and Csb subtypes according to Köppen climate classification (Kottek et al., 2006). The temperature differences during summer and winter seasons primarily depends on the proximity to the sea as coastal cities experience higher temperatures during cold seasons and inland cities experience hotter conditions during the summer, in addition to temperature changes related to elevation differences (Spano et al., 2003). The continuous variations of cold and humid winters followed by a hot and dry summers defines the Mediterranean seasonality making the region highly attractive to outdoor activities (Allam et et., 2019). The complex topography, coastline and vegetation cover of the region, and the large area of the Mediterranean see has a significant impact on moister and storms formation, resulting in a variety of climate types and great spatial variability (Filippo Giorgi et al., 2008). During summer, high pressure and descending motions dominate, resulting in dry conditions over the southern region (Filippo Giorgi et al., 2008).

1.2.2 Vulnerability of the Mediterranean region

Cities are already experiencing the effect of climate change, especially in the Mediterranean region where significant temperature increase is being observed. The long-term climate change impact are being experienced within the short timeframe of human influence (Kum et al., 2014). Mediterranean countries have long been known for their mass tourism due to the quality of the outdoor life and joyful mild climate most of the year. However, Today's Mediterranean cities are the most vulnerable to heatwave episodes and prolonged warm conditions. Temperatures in the Mediterranean region have increased faster than the global average (Lionello et al., 2014). Large cities are expected to witness a temperature increase of 1.5°C by mid 21th century (Revi et al., 2014).This trend is further exacerbated in dense urban areas due to the effect of urban heat island (UHI), and is expected to reach up 5°C temperature increase based on unchanged current greenhouse emission (Revi et al., 2014). Research on climate change, in the context of the Mediterranean region, has indicated alerting consequences of the climate change both on the climate characteristics and public health. It has been shown that the Mediterranean region, Algeria included, is witnessing a significant decrease in precipitation which is estimated to reach up to 15-30% (Zeroual et al., 2018). The warming trend is not evenly distributed worldwide as long-term warming trend are located within the 40°-70° North latitude, making the Mediterranean region the most effected due to its geographical location (Kum et al., 2014). The Mediterranean region, due to its location between arid (Sahara) and wet (northern Europe) regions, made it the most vulnerable region to climate change. The Mediterranean region is located in the transitional zone between the arid climate of North Africa and the temperate and rainy climate of central Europe (Filippo Giorgi et al., 2008) and it is influenced by the interactions between mid-latitude and sub-tropical circulation regime, in addition to the complex morphology of mountain chains and large Mediterranean Sea area contrasts, and a dense and growing human population and various environmental pressures (Cramer et al., 2018; Linares et al., 2020). Consequently, being influenced by the interactions between mid-latitude and tropical processes, making the Mediterranean region a prominent "Hot spot" to future climate change projection as indicated by the Regional Climate Change Index (RCCI) developed by (Giorgi, 2006). The RCCI is a comprehensive index developed to indicate the most responsive region to climate change, identified as 'Hot-spots' (F Giorgi, 2006).

Algeria-specific trends

There has been a significant shift in the Mediterranean climate zone during the past century. The displacement of climate zones in Algeria was investigated for the period from 1951 to 2098 (Zeroual et al., 2018) and they revealed an alarming prediction of the gradual disappearance of the temperate climate (Cf) zone following a very dry desert climate expansion (BWh). Results showed that the long-term trend of the 'BWh' hot desert zone is characterized by an abrupt significant expansion that is accompanied by a contraction of the warm temperate climate, fully humid with hot summer 'Cfa'. The increase in Bwh surface area is influenced by temperature increase, while the contraction of the Cfa is influenced by decreasing precipitation and is explained by the drought that affected coastal Algeria during that decade (Zeroual et al., 2018). Moreover, results indicated a significant rise of 1-1.25°C warming trend in Algeria from 1901 to 2020 (Zeroual et al., 2018) Similar trend is highlighted across the literature in relation to the Mediterranean region during the 20th century. such changing conditions are life threatening, specifically in countries such as Algeria, where the temperate climate area, even though representing 7% of the total surface, it is home to 75% of the population, 70% of all ovine livestock and 55% of the grain production on the country (Zeroual et al., 2018). These conditions would present heat-related risks on public health which are already been pointed out in different Mediterranean cities.

1.2.3 Extreme temperature events

Research revealed the significant impact of climate change on the Mediterranean region, consisting of an alarming increase in temperatures especially in the summer seasons, which would likely to cause greater extreme temperature events, hence heat-related health risks (Giorgi et al., 2008).

Global warming is significantly threatening public health through extreme heat, cold, drought, floods and storms. climate change is affecting vulnerable sectors and populations including elderly people, low income individuals and those with chronic diseases.

The vulnerability of the Mediterranean populations to heat health related risks is alarmingly increasing. Health related risks has long been impacted by temperature exposure, which has been enhanced by the climate change trends (Linares et al., 2020). Mediterranean cities are undergoing a warming trend with prolonged and warmer summers and increased frequency of heat waves (Linares et al., 2020). An annual mean temperature increase in the Mediterranean region of 1.4°C above the global mean warming has been reported (Linares et al., 2020). Recorded rate of temperature increase in the Mediterranean region surpasses global trends, as annual mean temperature are 1.4°C above late-nineteenth-century levels during summer seasons (Fig,1), followed by a significant rise of 0.4°C of Mediterranean Sea surface (Cramer et al., 2018). As such, the warming of Mediterranean region is expected to surpass global rate by 25% in the future, with a larger trend in summer warming at a pace of 40% larger than the global, of which coastal Mediterranean cities and high-density urban centers are among the areas most likely to be impacted (Cramer et al., 2018).

Issues of temperature increase are largely exacerbated due to the overlap of Urban Heat Island phenomenon (UHI), i.e., the increase in temperatures in built-up areas compared to the rural surroundings (Di Bernardino et al., 2023; Oke, 1987). The UHI is known to be caused by various factors such as anthropogenic heat production, materials of high heat absorption and retain, poor ventilation quality due to high building density, low sky view factor impacts on solar radiation absorption, and poor green areas, therefore, reduces the livability of outdoor spaces due to discomfort issues and health threats, in addition to higher energy consumption (Di Bernardino et al., 2023).

1.2.4 Health related risks

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. The main health risks, in the context of the current study, are related to the temperature increase. Heat related health deficiencies are primarily caused by the incapacity of the human body to dissipate heat resulting from excessive extreme temperatures for a prolonged period (Cramer et al., 2018) .Heatwaves can enormously impact large populations for short periods, inducing cumulative physiological stress and intensifying heat-related death rates globally (Linares et al., 2020). Between 2030 and 2050, climate change is expected to cause approximately 250,000 additional deaths per year, from malnutrition, malaria, diarrhea and heat stress alone (WHO, 2019). Heavy heat waves occurred in different Mediterranean countries namely Italy, Spain and Portugal, where heat-related death-troll reached 5000 people (Bouchama, 2004). Athens, Barcelona and Rome had witnessed the deadliest extreme weather events in the period of 1991-2015 which led to thousands of premature deaths caused by extremely reported hot temperatures (Linares et al., 2020). The 2003 heatwave marked an exceptional death record of 14.800 during the 9 days of extreme temperatures, in addition to thousands of individuals sustaining severe neurological damages (Bouchama, 2004). The 2003 marked death rate surpassed 20 times that of the 1995 Chicago heat wave and two time that of the USA in last two decades (Bouchama, 2004). The extent of which these risks are to increase in the near future is dependent on the adaptive strategies and resilience of the Mediterranean cities to offset the consequences of global warming through adaptation of the urban environment and individuals' environmental resilience. Climate change mitigation and adaptation is imperative as they are double fold solution from both health and environmental perspectives.

1.3 Temperature increase impacts on walking

Extreme temperatures can cause a multitude of physiological and psychological risks during the walking activity. 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 (O'Malley et al., 2014). Direct solar radiation significantly effects pedestrians heat thermoregulation balance and could include significant heat loads for continuous periods of exposure under clear sky conditions (Nielsen et al., 1988). Daily walking is more affected by heat stress compared to activities such as running or cycling, highly due the extended periods of exposure (Otani et al., 2021). Moreover, the longer the walking activity is, the higher the physiological demands (Ainslie et al., 2005). The human body experiences additional thermal loads when walking uphill, since it produces twice as much heat as walking downhill (Johnson et al., 2002). Such conditions are likely to results in uncomfortable and unhealthy environments, and more importantly, a concerning rise in heat related morbidity and mortality (Fikfak et al., 2020; Kleerekoper et al., 2012; M. Li et al., 2015). Adaptation becomes a critical factor in the ability to sustain the walking activity and prevent fatigue.

1.3.1 Thermal regulatory mechanism

The human body is in constant heat exchange with the outdoor environment through convection, conduction, evaporation and radiations (Gagge et al., 2010). Thermoregulatory mechanism is important to ensure human activities in various environmental conditions (Romanovsky, 2018).

Walking individuals encounter two sources of heat: the one produced by the process of metabolic heat production due to walking activity, the second one is gained from outdoor exposure. The human body produces heat by means of metabolism, and exchange heat with the environment mainly by radiation and convection (Romanovsky, 2018)**.** The most efficient way for the body to lose heat is by evaporation of body fluids, during which the body's thermal regulatory mechanism consistently works to maintain balanced core (internal) temperature (37°C) when thermal disturbances occur (Hensen, 1990a). That is to say any internal disturbance resulting from internal heat production resulting from exercise, such as walking, or external disturbance resulting from environmental heat or cold exposures (Hensen, 1990a). Using physiological, autonomic or behavior means, human body can survive exposures to a wide range of environmental temperatures (-100°C - 2000°C) while maintaining relatively constant core temperature Tb of being 37°C (Hensen, 1990a; Romanovsky, 2018). However, the thermoregulation system is asymmetric as high core temperatures poses significantly greater risks than low ones (Romanovsky, 2018).

1.3.2 Thermal defenses against heat exposure

During walking activity and outdoor heat exposure, the human body uses several thermoregulatory effectors, called thermal defense, as responses to regulate core temperature (Romanovsky, 2018). External disturbances are instantly sensed by skin thermoreceptors, enabling the thermoregulatory system to act rapidly before the disturbances impact the body core temperature. Notably, skin thermoreceptors respond to temperature as well as to the rate of temperature variation (Hensen, 1990a).

The thermal defenses during heat exposure can alter heat dissipation from the body during a short period (Nagashima et al., 2018). Walking activity or passive heat exposure could result in heat imbalance, increasing positively the rate of body heat storage. Pedestrians, while walking, constantly encounter significant thermal challenges due to the considerable threats of excess heat exposures (Mora et al., 2017 in Romanovsky, 2018), in addition the physical activity of walking. In exposure of heat, significant redistribution of blood and heat to skin results in core expansion due to the expansion of the homogeneous area of high temperature inside the body to the periphery (called shell) (Romanovsky, 2018).

Main heat physiological defenses are Cutaneous vasodilatation and sweating (Romanovsky, 2018). these physiological responses are 'corrective' as they are mostly triggered after changes in core temperature or skin temperature or both and could affect one or more of the heat exchange mechanism between the body and the environment, of which conduction, convection, radiation, and evaporation are the main processes (Romanovsky, 2018). Ambient temperature, air velocity, air humidity are of the main physical factors, among others, determining heat exchange with the environment (Romanovsky, 2018).

1.3.2.1 Cutaneous vasodilation

The skin represent a powerful boundary between the environment and internal body. The expansion or contraction of the thermal gradient within skin blood flow is important for heat loss during heat exposure or physical activity (Francisco et al., 2018). During heat exposure, skin temperature begins to increase, reducing the gradient for heat transfer between the core tissues and the environment, hence increasing the internal temperature. The rise in core temperature results in increased skin blood flow that is mediated by cutaneous active vasodilation (Francisco & Minson, 2018). In absence of sweat, skin blood flow transfers heat to the periphery where it can be dissipated via convection (Francisco & Minson, 2018).

1.3.2.2 Sweat evaporation

Continuous exposure to heat causes linear rise in body temperature with significant rise in sweat and water loss (Gagnon et al., 2018). Sweating is the most efficient thermal defense for individuals with significant potential heat loss ensured by sweat evaporation (Gagnon et al., 2018). It is controlled by core temperature when skin temperature is constant, and by skin temperature when core temperature is constant (Gagnon et al., 2018).

Walking activity and prolonged heat exposure constitute significant thermal challenges to human regulatory mechanism. Walking could require high levels of metabolic heat production, of which about 70% is liberated as heat which must be evacuated (Gagnon et al., 2018). Additionally. heat gain from overexposure is generated when ambient temperature exceeds skin temperature (Gagnon et al., 2018) (Gagge and Gonzales, 1996 in Gangnon & Crandall, 2018). In order to attain heat balance during a thermal challenge, sweat evaporation must evacuate the thermal loads resulting from the combination of metabolic heat production and dry heat exchange from heat exposure (Gagnon et al., 2018). Sweat evaporation from skin or lungs is the most powerful solution to evacuate body heat, and is the only mechanism to proceed when air temperature is higher that skin temperature (Romanovsky, 2018). In high humidity environment, sweating becomes inefficient as an evaporative mechanism, and it will only increase thermal conductance on the skin (Gagnon et al., 2018). Moreover, in a study comparing dry and evaporative heat loss in different air velocities, results indicated that that higher air velocity results in relatively higher evaporative heat loss (Gagnon et al., 2018) (Fig.1.1).

1.3.3 Heat accumulation and discomfort

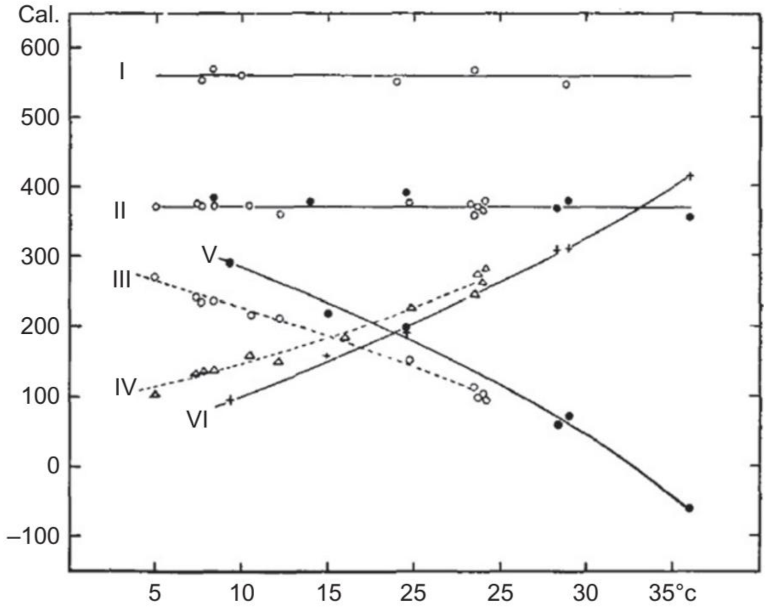


Figure 1.1: heat production (I), total heat loss (II), dry heat exchange (III and V) and evaporative heat loss (IV and VI) for conditions of low (dashed lines, III and IV) and high (solid lines, V and VI) air velocity as a function of air temperature (x-axis) during exercise performed at a fixed intensity (Gagnon et al., 2018).

during the beginning of the walk, the amount of heat dissipation would be lower than the that of heat production, and with the progression of the walk, the accumulated heat produced requires time to dissipate, therefore affecting thermal comfort (Jia et al., 2022). during walking activity, the increased heat production contributes to elevate the heat dissipation rate in order to prevent dangerous elevations in tissue temperature, which is further increased by the additional heat gain during heat exposure (Kenny et al., 2017). As the walking activity continues, the body stores heat due to an imbalance between heat gain and heat loss (Kenny et al., 2017). Here, thermal exposure may also be 'uncompensable' when sweat evaporation becomes enable to offset the required evaporation for heat loss, therefore, the body remains in continuous heat accumulation and increase core temperature (Gagnon et al., 2018) .

Two main raisons could affect thermal heat balance causing heat accumulation. Sweat production during a thermal defense is closely related to the evaporation needed for heat balance. Environmental conditions such as high humidity and low air velocity could significantly impact sweat evaporation as they directly influence water vapor pressure gradient between skin surface and the surrounding environment (Gagnon et al., 2018). Another factor is when the combined effect of metabolic heat production and heat exchange exceeds the body's maximum sweat threshold/capacity (Gagnon et al., 2018). For instance, a dry climate and with high air velocity maximizes the sweat evaporation while high humidity and low air velocity conditions reduce the environment's evaporative capacity which causes sweat dripping as sweat rate increases.

1.3.4 Heat exhaustion and fatigue

As a consequence of temperature increase, more people are experiencing heat-related risks, mainly heat exhaustion and fatigue. Prolonged exposure to hot environments in addition to prolonged walking activity could significantly overpass the body's thermoregulatory mechanism to cool its body temperature, resulting in heat storage and heat exhaustion. While the human body is able to tolerate and adapt to heat loads, internal and external, there are threshold of tolerance to thermal loads. Walking during extreme temperatures, children, elderly people and those with chronic health conditions have less tolerance to heat, hence, higher chances to experience heat exhaustion even during short exposure to hot environments (Kenny et al., 2017). Continuous imbalance in heat storage and heat dissipation could result in significant heat related issues, ranging from mild, e.g., heat rash, cramps, fatigue, to moderate, e.g., heat syncope, heat exhaustion, to life risking illness e.g., heat stroke (Fig.1.2) (Kenny et al., 2017).

Fatigue is defined by Ream and Richardson (1996) as a physical or mental exhaustion characterized by a temporary reduction in power following a prolonged activity (Ream et al., 1996). Heat fatigue could be defined as the process leading to a reduction in the maximal capacity to maintain heat balance, leading to the inability to maintain a required physical task (Smirmaul et al., 2013). Heat related fatigue, or exhaustion, is the result of heat accumulation, where the amount of heat loads, associated to heat exposure and increased metabolic heat production related to exercise, are superior to that of heat loss and is characterized by an elevation in body temperature 37°C and 40°C (Kenny et al., 2017). High humidity, terrain, absence of adequate shade and resting spots, could significant impair the pedestrian's ability to dissipate heat resulting in a continuous heat storage. Depending on the temperature and humidity of the environment, in addition to the intensity of the walk (walking, climbing, running, heavy lifting, etc), it would take about 45 minutes to heat balance and dissipate heat (Kenny et al., 2017). Moreover, Prolonged heat exhaustion, if the body temperature is not regulated, can results is significant heatstroke (Al Mahri et al., 2018).

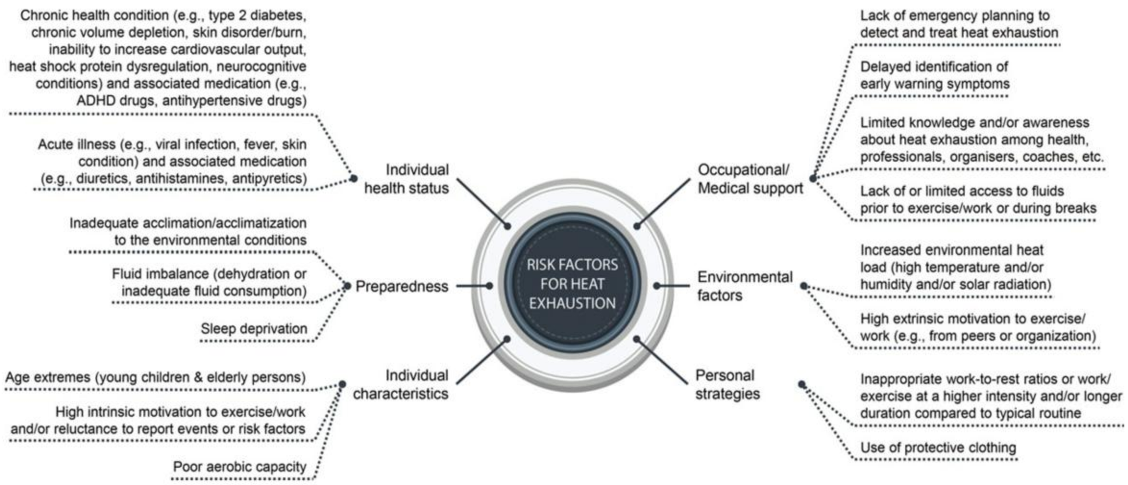


Figure 1.2: Risk factors of heat exhaustion (Kenny et al., 2017)

Heat fatigue and exhaustion are more frequent during prolonged exposure and activity, especially in hot environment and extremes of heat (Abdel-Ghany et al., 2013). Walking activity in hot environments, individuals are at a major risk of experiencing imbalanced physiological parameters such as increased heart rate, body temperature, and blood pressure and sweat production (Fang et al., 2019). Continuous imbalance in these physiological parameters, in addition to heat accumulation, the human body can severally encounter heat-related disorders such as heat stroke, heat cramps and fatigue (Fang et al., 2019). These heat-related risks are to increase in hot environment and prolonged heat exposures, therefore walking activity in absence of adequate recovery conditions would negatively impact pedestrians' health. To this end, outdoor environment need to be designed in order to provide heat adaptation solutions while offering possibilities to train individuals to absorb and recover from heat accumulation during the walking activity. Ensuring instant reduction in heat load sources, such as shading breaks, water fountains or windy spots, can immediately manage heat exhaustion (Kenny et al., 2017). Outdoor comfort evaluations need to correctly adjusted taking into accounts the dynamics of the outdoor activities and the dynamic changes in pedestrians' walking experience.

The perception of fatigue could also be related to the psychological perceived effort for task completion (Lam et al., 2021). Investigating fatigue sensation, as a result of heat exposure during the walking activity, should receive more attention in outdoor comfort studies. A recent study investigating the short-term physiological and psychological adaptation during summer conditions, results indicated that perceived fatigue is significant in predicting outdoor thermal sensation and thermal comfort during walking activity and exercise. and highlighted the role of fatigue on influencing thermal adaptation (Lam et al., 2021). Therefore, it is suggested that perceived fatigue should be extended to outdoor thermal comfort studies during the walking activity (Lam et al., 2021).

1.4 Walkability and walking experience

1.4.1 What is Walkability

In the context of urban planning and urban design, walkability is defined as the extend of which the built environment promotes walking by providing pedestrian's comfort, safety and connectivity with varied destinations within an affordable distance, time and effort (Southworth, 2005). A walkable environment should support walking for utilitarian purposes as well as for pleasure, recreation and health (Southworth, 2005). The term "walkability" has widely spread across different research fields in the past two decades, and is still an up-to-date research domain due its complexity. Walking has long been recognized as the most free and green mode of transportation and has been recognized as the foundation of the sustainable city for its multi-disciplinary benefits (Forsyth et al., 2008; Moura et al., 2017). Walking is essential in promoting sustainable, environment friendly and livable environment and improving walking environment can significantly influence walking behavior and encourage walking activity (Cambra et al., 2020).

1.4.2 Benefits of walking

1.4.2.1 public health

As a result of significant decline in walking rates worldwide and its consequences on long-term health issues, urban planners and transportation specialists began emphasizing the importance of soft urban mobility and overall city sustainability. walking was earlier introduced in the field of public health, and later transportation, urban planning and urban design for its significant benefits as a health-enhancing physical activity and a green travel mode (Lee et al., 2006). walking has since been recognized as a key component of efficient, accessible, equitable, sustainable, and livable communities (Lo, 2009).The benefits of walking has been initially emphasized in public health and preventive medicine fields (E. Choi, 2012; Saelens et al., 2003). From public health and preventive medicine's perspective, the main reason for this interest is that walking is the most common and accessible from of physical activity for long-term health benefits. Moderate intensity physical activity, such as walking, significantly improves overall health (Saelens et al., 2003), reduces risks of high blood pressure, heart disease, obesity and diabetes (Kim et al., 2014). Moreover, daily walking have shown to improve mental and physical health including cardio-vascular fitness and reduces stress (Forsyth et al., 2008; Moura et al., 2017), in addition to mental alertness and creativity (Southworth, 2005). Studies also focused on walkability and pedestrian behavior as a basis for addressing obesity, cardiovascular disease and other prevalent conditions (Lo, 2009).

1.4.2.2 Climate

A consistent body of research is suggesting new approaches to the field of urban planning and transportation as climate change mitigation solutions. Urban planners are mainly concerned with increasing the proportion of walking trips in cities for the aim of enhancing the urban mobility while reducing energy consumption, lowering greenhouse gas emissions, and mitigating urban heat and air pollution. Car-dependency reduction has been one of the main goals in many countries over the past years due to the increasing negative effects of motorized traffic on outdoor climate and public health (Caprì et al., 2016; Ettema et al., 2011). Many transportation plans aim to reintegrate the physical activity as daily travel routine for many benefits, mainly to reduce the use of resources, reduce greenhouse gas emissions and improve the quality of urban climate and well-being (Forsyth et al., 2010). It is suggested that a one percent shift from automobile to walking can reduce up to four percent of fuel consumption (Litman, 2012). Promoting green walking networks, by ensuring shaded streets and enhancing urban greenery, have shown to have greater potential in reducing urban heat and gas emission (Caprì et al., 2016).

1.4.3 Walking experience

While walkability stands for the extend of which the built environment can promote the walking activity, walking experience refers to the affective experience of pedestrians within the built environment. It is assumed that pedestrians, characterized by individual factors, will dynamically perceive the built environment and therefore hold certain urban qualities that constantly trigger affective experiences, valence and arousal (Russell et al., 1984), (Johansson et al., 2016). These affective experiences shapes the walking experience and therefore influence future walking intention (Johansson et al., 2016).

walking experience and the influence of experience in triggering walking behavior have been receiving growing interest in the context of behavioral studies and quality of user experience (Ameli et al., 2015; Bornioli et al., 2019; Cambra et al., 2020; E. Choi, 2012; Dadpour et al., 2016; Hassan et al., 2021; M. Johansson et al., 2016).

Experiential qualities and satisfaction are factors believed to trigger and sustain behavior change, therefore influencing the walking experience (Isaacs, 2010; Kim et al., 2014) (Bornioli et al., 2019). It has been argued that of the amount of walking and duration of walking trip are insignificance as outcome variables, highlighting the importance of the quality of the walking experience in term of user experience and its influence on future walking decisions (Adkins et al., 2012). In the context of environmental affect, the physical environment impact psychological wellbeing and affective experience, thus influencing intentions to walk, (Bornioli et al., 2019). Perceived urban qualities are more significant for understanding walkability than the measured physical characteristics per se (Johansson et al., 2016). Moreover, pedestrian's satisfaction is highly impacted by experienced events, physical and non-physical environments, and their frequencies (Kim et al., 2014). Understanding the walking experience requires investigating the affective process mediating between the physical environment and pedestrian's dynamic perceptions and affective state (Johansson et al., 2016). Ettema et al (2011) indicated the significance of satisfactory walking experience and its influence of future walking decisions and travel choice, hence sustaining as regular practice (Ettema et al., 2011). Kim et al., (2014) investigated the relationship between pedestrian satisfaction and a variety of built environment and found that hilly streets decreases pedestrian satisfaction mainly because of the physical difficulty to walking uphill. In addition, personal characteristics tend to influence utilitarian walking more than recreational walking, as utilitarian walking is often non-voluntary (Kim et al., 2014).

1.4.4 Built environment factors

Walkability today stands for a multidisciplinary form of research as several element of the built environment intervene, hence the variability in approaching the walking activity. Walkability studies have different definitions on how to measure walkability due to the variation in the built environment components, complexity of the walking behavior, with respect to the scale of study areas. The complex nature of walkability led to a wide range of built environment factors that influence or characterize walkability. Sufficient factors have been presented and grouped under several frameworks according to different research field, scope of research, and type of investigation. A variety of built environment factors have been developed to describe, investigate or measure walkability. Each of these factors included a diversity of indicators describing the arrangement or the quality of the physical environment.

According to Forsyth & Southworth (2008), a walkable environment should feature short-distance destinations without major barriers, ensuring safety from crime and traffic (Forsyth et al., 2008). It should include comprehensive pedestrian infrastructure such as sidewalks or separated trails, marked crossings, street furniture, and street trees (Forsyth et al., 2008). Additionally, the environment should offer pleasant, tree-lined or architecturally interesting streets, well-maintained or scenic green spaces with clear paths, and multiple navigation options (Forsyth et al., 2008). Density, land use mix and connectivity have also been consistently indicated in the literature as most influencing factors on walkability rates at the neighborhoods scale (Moura et al., 2017).

A common approach has been followed to categorize the relevant factors to systematically measure walkability. These categories follow various frameworks (e.g., the 5C, 7C, 3D, 5D, SPCES, IMI, PEDS, etc.) (Su et al., 2019). At the scale of the neighborhood, Cervero and Kockelman (1997) proposed the 3D framework of Density, Diversity and Design (Cervero et al., 1997). The London Planning Advisory Committee developed the multidimensional 5C's layout, which consists of Connected, Convenient, Comfortable (e.g., pavement quality), Convivial and Conspicuous, of which Moura et al (2017) extended the factors to 7C by adding coexistence and commitment (Moura et al., 2017). A different study developed the Level of Service (LOS) based on safety, security, comfort, coherence and attractiveness

(Sarkar, 2002). Similarly, (Labdaoui et al., 2021) added thermal comfort and proposed the Street walkability and thermal comfort index (SWTCI). These frameworks offered systematical understanding of the contribution of multiple indicators on quantifying walkability, however the focus regarding the influence of each factor has been overlooked.

1.4.4.1 Walkability and the microclimate

Streets serve as key spaces for physical. The Walking experience would vary greatly along a single street segment. It has been suggested that more assessment methods should account for investigating street-level walkability (Su et al., 2019). More detailed urban qualities are needed as it may influence pedestrian’s behavior and decision to walk, of which the physical features, urban design qualities and individuals’ perceptions are significant determents of the overall walkability (Ewing et al., 2006). At the streel level, Ewing et al (2006) argued for the need for more perceptual qualities into the measuring of walkability. Despite the significant advancement in walkability measurement structures, one issue has been found to be common across theses frameworks that is related to the climate comfort on walking experience.

Facing the new challenges of climate change and temperature increase, the influence on the microclimate on walkability received recent interest. The street microclimate plays a crucial role in favoring or hindering the walking activity (Aghaabbasi et al., 2019; Labdaoui et al., 2021a; Mouada et al., 2019). The most efficient way to improve urban mobility is to promote convenient, comfortable walkable access to destination (Litman et al., 2003). While distance, density and land use are important factors influencing walkability, microclimate conditions are of a paramount importance. There are several walking barriers that need to be overcome in order to increase walking rates in cities, including several environmental factors related the microclimate and topography (Burk et al., 2006). Climate could be significant in shaping walking habits. For instance, residents of coastal regions and temperate climate may be more motivated to walk with elevated walking rates in comparison to cities of desert region and cold climates (Alfonzo, 2005).

In the context of walkability, comfort was defined as the extend of which walking is accommodated for all types of pedestrians with attributes and amenities ensuring the ease of the walking experience (Moura et al., 2017). Comfort received little attention in the walkability literature despite its evolving influence on outdoor activities. Few studies have included “comfort”, along with other indicators, to measure walkability. From a microclimatic perspective, walkability studies which included comfort, along with other factors, were often limited to sidewalks quality (Sarkar, 2002). These studies focus on comfort as a physical feature related to pavement qualities, benches, landscape and trees, width of sidewalk, cleanliness (Aghaabbasi et al., 2019) (Sarkar, 2002). Asadi-Shekari et al (2019) reviewed several pedestrian level of service (PLOS) methods and point to the variation is comfort indicators used to assess the quality of street conditions such as curb ramps, tactile pavements, accessible drinking fountains, lighting, bollards, seating areas, the landscape, trees, driveways, toilets and rubbish bins, slopes and natural barriers (Asadi-Shekari et al., 2019). Labdaoui et al (2021) proposed a modified PLOS by adding PET physical equivalent temperature an indicator of comfort and highlighted the correlation between thermal sensation and pedestrian choice of the shaded zone (Labdaoui et al., 2021). Accordingly, thermal comfort was found to be significant to increase or decrease walking rates, speed and frequency in cities (Mouada et al., 2019). The characteristic of the microclimate and its effect on pedestrian comfort is becoming significantly important since thermal comfort affect people's behavior and outdoor activities (Mouada et al., 2019; Nikolopoulou et al., 2001). Thermal stress could impact walking experience and indirectly reduce walkability (Lee et al., 2020). Within the social-psychological conceptual model of walkability, it was suggested that comfort and pleasurability are among the essential walking needs (Alfonzo, 2005). Comfort is also mentioned within the urban design qualities related to walkability suggested by (Ewing et al., 2009). Weather is found to significantly influence pedestrian perception, satisfaction and decision to walk (Alfonzo, 2005; Forsyth, 2015; Naderi et al., 2005).

Recognizing the importance of the interaction of microclimate with the urban design and its influence on walkability have been receiving growing interest. The emergence of heat mitigation strategies led to the appearance of new pedestrian-centered research focusing on pedestrians' experience and the variations of microclimate. Thermal walk, urban walks or climate walk methodology, were developed. (2.6. Thermal walk methodology)

1.5 Climate resilient approach Resilient walking

Urban mobility is one of the significant challenges for climate change mitigation. Walking, as the easiest and free of charge from of urban mobility, presents a variety of advantages on health, well-being and the urban microclimate. However, reducing cad-dependency requires comfortable and healthy walkable environments. Reconciling the double-sided challenge of promoting walkability to mitigate climate change while adapting the urban environments to support a comfortable walking experience emphasizes the importance of fostering resilient, climate-adaptive strategies that sustain walkability.

Resilience stands for the ability to absorb a major shock with the capacity of effective recovery and normal continuity (Leichenko, 2011). Resilience is understood to require flexibility, learning and change (Tyler et al., 2012). 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 resilient 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. Improving resilience has been widely cited as a primary goal to tackle challenges related to urban heat increase, encouraging both mitigation and adaptation strategies in cities

Recent studies developed climate-responsive strategies under the heat-resilient framework (He et al., 2021). While heat mitigation strategies focus on heating reduction and enhancing cooling sources through urban greenery, water bodies and shading structures, given the pace and magnitude of climate changes underway, the strategies developed to reduce heat exposure may no longer be sufficient to cope the alarming impacts of the climate change (Biagini et al., 2014). The need for more adapted solutions have become crucial to face current and upcoming temperature rises. Heat adaptation strategies involve taking advanced measures considering the interplay between individuals and their environmental adaptability.

the use of adaptive spatial configurations can enhance environmental flexibility, ensuring a diverse range of climate-responsive solutions that vary regularly, whether on a daily or seasonal basis. 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 (Chun et al., 2005; Dzyuban et al., 2022; Lau et al., 2019; Liu et al., 2021; Nikolopoulou et al., 2003; Peng et al., 2022; Potvin, 1996; Qi et al., 2021). 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.

The need to make cities more sustainable and resilient requires more extensive studies of urban dynamics (Steane & Steemers, 2004. P.8). As climate conditions are becoming more severe than ever, i.e. extreme temperature, it has become clear that the need for thermal diversity is essential to mitigate excessive thermal stress (Chatzipoulka et al., 2020) especially during prolonged heat exposure (Faustini et al., 2019, Tomassi et al., 2023). Environmental diversity in urban areas also plays an important role in providing adaptive possibilities to enable tolerance and recovery form thermal stress (Nikolopoulou et al., 2003). Moreover, environmental diversity helps us rethink the process of urban design as adaptive and dynamic, featuring interplays between individuals and their environments. 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. Such increase in adaptive capacity can offer opportunities to experience alliesthesia (de Dear, 2011; Cabanac, 1971) and psychological adaptation (Nikolopoulou et al., 2003) which enable the "training" of the capacity to recover (Schweiker, 2020).

1.6 Conclusion

Walkability is crucial in mitigating the influence of climate change. Encouraging individuals to engage more into walking requires a resilient walkability approach in the context of outdoor comfort. This chapter presented a brief overview of the actual climate change risks encountering climate and the people of Mediterranean cities. Increased temperature and prolonged heat exposures, along with topography, are main walking barriers. During the walking activity excessive solar exposure in absence of adequate shading systems decreases the body's tolerance thresholds leading to heat exhaustion and fatigue sensation. Continuous heat exhaustion and fatigue could lead to life threatening health risks, and could significantly hinder the walking activity.

Addressing the impacts of rising temperatures on walkability requires strategies that extend beyond the traditional mitigation strategies per se. It is further evident that walkability assessment methods based on attributed scores are insufficient to provide holistic understanding of the walking experience. Moreover, comfort and subjective walking experience are essential and require further understanding. The variability of the outdoor environment and adaptation possibilities are key elements of urban resilience. Developing a resilient approach to walkability requires a deeper understanding of environmental diversity and the ways pedestrians build resilience to discomfort and challenging conditions.

Chapter 2: Environmental diversity, In-between spaces and Pedestrian Dynamic Experience

2.1 Introduction

The urban environment is complex and dynamic over space and time. Architectural and urban developments in cities resulted is stratification of climatic scales in the context of urban climatology. The current research focuses mainly on the urban canopy layer with the aim of investigating transient microclimate conditions at street level and how it is experience by pedestrians. That is the area from the ground to the above-roof level of surrounding buildings or trees that is defined by the site’s characteristics (Oke et al., 2017c).

Following the previous chapter’s discussion of the importance of resilient walking and its relation with environmental diversity, current chapter is a detailed exploration of the hypothesis introduced earlier. This chapter examines the concept of environmental diversity and its relation to street geometry, in-between spaces and pedestrian walking experience. It explores the relation of environmental diversity with the variability of the street geometry main parameters such as degree of enclosure, orientation, density and coverage. Additionally, it repositions the in-between spaces as significant contributor to environmental diversity. The chapter also present an overview of the thermal aeraulic transients characteristics, highlighting the importance of the combination of thermal and aeraulic conditions in characterizing thermal diversity.

The second section offers a comprehensive overview of concepts related to diversity and the pedestrian dynamic thermal sensations. It highlights the shift in outdoor comfort standards in relation to non-steady outdoor conditions and delves into the physiological and psychological mechanisms influencing pedestrian comfort. Particular attention is given to the concept of Alliesthesia, which has recently gained prominence in outdoor comfort research and deserve a significant attention.

Finally, the chapter presents the innovative method of “thermal walks” for studying transient conditions and walking experiences. This method integrates three key elements: transient microclimatic conditions, walkability, and the dynamic thermal experience of pedestrians. These components form the foundation of the current research in exploring the interplay between urban design, environmental diversity, and pedestrian resilience in dynamic urban environments in presence of in-between spaces.

2.2 Environmental diversity

The evolution of comfort theories have long been related to individuals' interactions with the climate. The idea of diversity was first attributed from the nature of climate variability, such as seasonal changes, and how individuals unconsciously adapt to it (Potvin, 1996). On the other hand, traditional comfort standard have always tried to restrict 'comfortable' conditions around a small range of values, assuming that as long as these values are achieved, comfort is achieved. Such deterministic approach led to shrinking the individual's comfort zone and adaptation potential. This could be clearly noticed for indoor conditions. Moreover, such restriction of adaptation potential had led to even more discomfort in outdoor conditions with people having reduced tolerance to outdoor conditions. Thus, the concept 'Environmental diversity' was earlier introduced in the works of André Potvin (1996) and Koen Steemers and Mary Steans (2004) for the aim of exploring the importance of the adaptive component in comfort theories.

In the urban context, environmental diversity refers to the variability of microclimate conditions created by urban and architectural combinations and articulations between interior and exterior environments (Potvin, 1996; Steemers et al., 2004) and within outdoor urban spaces. It is a design characteristic related to our experience in outdoor spaces. That is to say the movement within dynamic patterns of environmental variations of heat, light or sound over time and space (Steemers et al., 2004, p.9). Temporal diversity refers to a specific environment transient conditions over time. Such as short-term variability in diurnal solar radiation, day and night air temperature and shading patterns throughout the day; and long-term seasonal variations (Steemers et al., 2004, p.15). Temporal diversity have indirect impact on spatial diversity since contrast intensities between spaces would change over time. Spatial diversity, the focus in this study, refers to the variations in environmental conditions that are structured as part of a sequence (Steemers et al., 2004, p.15). These variations could be achieved by variations in combinations of outdoor spaces or by the variability in urban morphology. Movements within such spaces, will influence our perceptions and opportunities to choose or anticipate contrasting conditions, hence, the intensity of transitions between these transient environments is a key feature which determines the perceived spatial diversity variations (Steemers et al., 2004, p.15).

Thermal diversity is defined as the continuous variations in microclimatic conditions in urban areas owing to the complex urban geometry (Krüger et al., 2011). These Variations, referred to as transient conditions, may be more or less intense, and/or sudden depending on the characteristics of the urban spaces, movement patterns and directions along with the microclimate conditions. As such, environmental diversity offers possibilities where individuals have the ability to choose to move into or away from sun, shade, breeze, etc., in order to avoid discomfort, offering greater 'freedom of choice' regarding the physical activity, i.e. waking paste, sitting or standing for recovery (Steemers et al., 2009). Considerable body of research since then have been developed for the aim of investigating diversity, psychological adaptation, adaptive comfort and alliesthesia in relation to walking experience in the literature (De Dear, 2011; Lau et al., 2019; Qi et al., 2021). These concepts introduced a significant shift in the thinking of outdoor comfort and pedestrian experience and how we communicate and evaluate comfort as dynamically experienced by pedestrians. Moreover, environmental diversity is more important than ever in the context of thermal resilience and heat adaptive strategies. Creating more diversified environment would offer highly climate-responsive urban spaces.

2.2.1 Transient conditions

The expression of 'Transient conditions' refers to dynamic, variable, unstable or variating conditions (Chun et al., 2005), characterizing environmental diversity. in contrast to steady-state environments, transient conditions are quite complex as they are compounded by combined effect of solar radiation, humidity, temperature difference and wind speed variations. They are often linked to the notion of movement and change, transitions (Nakano, 2003) or environmental step changes (Höppe, 2002; Potvin, 1996). According to Hansen (1990) Transient conditions could be:

Cyclical: triangular or sinusoidal variations defined by mean value, peak to peak amplitude and fluctuation period or frequency, such as those resulting from the dead band of the HVAC control system.

Ramps or drifts: monotonic steady changes which are actively or passively controlled. They are characterized by starting value, amplitude and rate of change

Steps: such as those encountered when passing from one thermal environment to another, and which are characterized by starting point, direction and amplitude. This type of transient conditions is the focus of the current study as it best describes the transition within outdoor spaces which are characterized by dynamic non-steady and non-control environments.

It has been consistently indicated that actual subjective judgements of the environment are always influence of the preceding environmental conditions (Lau et al., 2019; Nagara et al., 1996a; Peng et al., 2022; Potvin, 1996). Potvin (1996) proposed theoretical patterns of thermal transient conditions when moving within spaces of different environmental conditions (intensity). He stated that individuals are constantly conscious of positive transition in environmental condition, followed by a neutral phase where comfort is achieved, and then a negative change if the stimuli increased too much. Potvin (1996) suggested that when walking from a space with inadequate conditions to a space with greater intensity, a sensation of comfort is achieved and that the same stimuli becomes negatively perceived if it increases too much (Potvin, 1996) as indicated in figure 2.1. As result, two individuals will perceive the conditions differently if they experience the transition in opposite directions (Potvin, 1996)

That is when moving within a variety of environmental conditions, in a form of a sequence, the individual becomes aware of the dominance of a new environment and this transition may be developed to provide a sense of adaptation or discomfort. For instance, subliminal transients is when the environmental conditions slowly changes below the threshold of sensation of which the influence is minimal as individual's mechanism tend to adapt to accommodate the change, in both cases of increased or decreased stimulus (Potvin, 1996). Abrupt transients is when environmental conditions changes drastically, creating a sudden sense of comfort or discomfort. Here abrupt transition is preferable when moving from an uncomfortable environment to more comfortable one (Potvin, 1996).

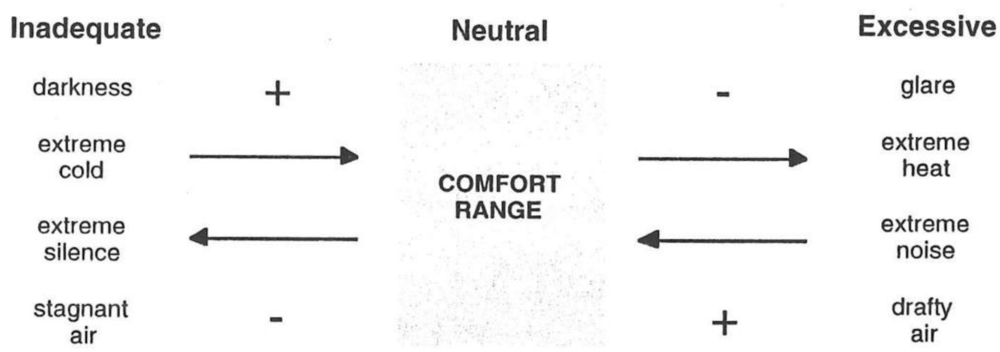


Figure 2.1: theoretical environmental transitions a proposed by (Potvin, 1996, p.9)

Knudsen and Fanger (1990) investigated how temperature step-changes influence thermal comfort in a climate chamber. Their findings states that the speed of adaptation to a new environment relies on the direction of the step change, away or towards neutral conditions.

Going away from neutral conditions results in decreased acceptability and requires at least 20 minutes to reach steady state level, while, going toward neutral conditions would imply fast return to neutrality within 5 minutes. Notably, they suggested that the immediacy of thermal response to thermal transients is supported by the rate of change of skin temperature rather ran the actual skin temperature (Knudsen and Fanger, 1990, as cited in Steemers et al., 2004, p. 123).

2.2.2 Walkability and diversity

From a pedestrian-centered approach, environmental diversity is the variation of environmental stimuli generated by the creation of one or several transient conditions within the outdoor environment. The experience of walking is related to diversity as it is a dynamic movement with transient or constant rhythm in urban areas such as streets, public squares and in-between spaces (Potvin, 1996). Among different outdoor activities, walking activity is the most sensitive to the microclimate conditions variability as pedestrians are consciously and unconsciously influenced. The level of thermal comfort experienced by pedestrians is directly influenced by these transient exposures and could offer more adaptive opportunities (Lau et al., 2019).

Individuals' thermal senses while walking are the combination of four environmental parameters, i.e. air temperature, relative humidity, solar radiation and wind speed. Additionally, the exposure durations, thermal history, and personal attributes, i.e. genetics, health, gender, metabolic rate, etc., play a significant influence in triggering these senses. Psychological state is also of a significant impact (Nikolopoulou et al., 2003). A consistent body of literature argues that outdoor comfort, pedestrians in specific, should be freed from the environmental determinism of uniformity, highlighting the importance of environmental diversity (Hwang et al., 2022; Nakano, 2003; Potvin, 1996). While this will not eliminate discomfort exposures, it could offer an effective solution for improving pedestrians' thermal experience by incorporating configurational transients that could support adaptability of urban areas, hence, a resilient walkability.

It is suggested that diversity, within a certain range of variation, is desirable to exercise the adaptive capacities (Potvin, 1996). Offering adaptive opportunities along a walking route could potentially improve the pedestrian experience. Research have indicated the potential of thermal diversity, in providing more enjoyable outdoor spaces and enhancing people's outdoor experience particularly in high-density cities (Steemers et al., 2009; Chatzipoulka et al., 2020). A diverse thermal environment is highly to be more responsive, inclusive and attractive to walk and interact (Chatzipoulka et al., 2020). Steemers & Ramos (2009) established in their research that a diverse environment correlated significantly with thermal comfort and even better than singular weather parameters such as air temperature or wind speed, highlighting the strong link between variations in built environment and pedestrians' actual comfort sensation (Steemers et al., 2009). Creating a variety of exposures would increase psychological adaptation by offering pedestrians 'freedom of choice' (Steemers et al., 2009) and therefore increasing satisfaction levels (Steemers et al., 2009; Thorsson et al., 2004). In a recent research in investigation pedestrian comfort of outdoor semi-transitional spaces, (Zhang et al., 2020) revealed that metabolic rate is not the only influencing parameter on thermal experience during walking and that the variations in air velocity around pedestrians is also important. Walking in transition space, results indicated a high linear correlation between wind velocity and mean thermal sensation indicating that the disturbance due to wind velocity had a significant influence on thermal sensation which results in a decrease heat storage (Zhang et al., 2020).

2.3 Outdoor Spatial transients

The urban environment is complex in nature. The arrangement and articulation between the urban elements is crucial in creating divers and dynamic environments. Microclimate conditions in an open space are different than a street canyon, shaded walkways or covered passages. The arrangement of these conditions can greatly influence the thermal and aeraulic conditions at street level. These variations within a walking route could be attributed to several street geometry characteristics that significantly influence the microclimate, mainly variations in: degree of enclosure (height-to-width ratio and Sky View Factor), solar orientation, density and coverage and land cover (vegetation, water bodies, albedo). Shading elements and in-between spaces such as Sabat and arcades are of a significant influence since their degree of enclosure significantly impact solar radiation and wind flow according to its position within the street and urban areas. Importantly, the distribution of these variables within the urban space is essential in characterizing the diversity in urban spaces.

2.3.1 Street geometry characteristics

Street geometry characteristics have direct effect on solar access (thermal conditions) and wind flow patterns (aeraulic conditions) within the street. The significant contribution of street geometry is that is can obstruct solar access and delay the surface cooling effect.

Thermal conditions such as solar radiations, surface temperature air temperature are significantly influenced by the degree of exposure, shading patterns (vegetation, shading devices), solar orientation and land cover properties. While wind flow is directly influenced by mechanical forces of wind direction, H/W ratio, building density and coverage along with the thermal effects of solar radiation and surface heating with respect to the wind direction.

2.3.1.1 Degree of enclosure

The degree of enclosure of a street has direct effect on solar radiations, surface and air temperatures, and sunlight-shade patterns (Oke, 1987). Degree of enclosure is often expressed in the literature as sky view factor (SVF) ; (Chatzipoulka et al., 2018; Steemers et al., 2004, p.89), Hight-to-width ratio (H/W) for street canyon (Ali-Toudert et al., 2007; Djenane et al., 2008), or degree of enclosure (DoE) in case of in-between spaces (Steemers et al., 2004). The larger the exposure of a street canyon, the larger solar radiations access, thus, the higher the level of heat stress (Oke, 1988).

2.3.1.1.1 Hight to width ratio

H/W is a geometric descriptor of a street canyon where H is the average height of the canyon buildings and W is the width of the canyon (Oke, 1988). The aspect ratio is dimensionless and quantifies the relationship between vertical and horizontal openings within the street. Higher H/W >1 ratio indicates narrow streets, while H/W = 1 or less indicates wider and more exposed streets (Fouad, 2007). H/W ratio can significantly impact wind flow with respect to wind direction. The width of the street and building heights could channel, decrease or disturb wind flow at street level near buildings (Fouad, 2007). Moreover, solar access, air temperature and heat trapping in dense urban areas is directly related to H/W ratios. The narrow the street canyon (larger aspect ratio), the greater the maximum heat island intensity (Oke, 1987, p. 293).

2.3.1.1.2 Sky View Factor

SVF has been commonly used as indicator of urban geometry. The sky view factor (ψs) (SVF) refers to the amount of radiation received by a planar surface from the sky to that received from the entire hemispheric radiating environment (Watson et al., 1987). That is the extent of which the sky is clearly visible at a certain location (Oke et al., 2017c). It could be calculated, obtained through fish-eye lens photographs, vector based estimated using GIS, or derived from digital elevation models (DEMs) or video image using fish-eye lenses (Watson et al., 1987). Fish-eye photographs requires manual processing such as using

Ryman model (Andrea), therefore provide more accurate knowledge of the street's degree of enclosure in contrast to the aspect ratio.

SVF values range between 1 and 0, with low values indicating high degree on enclosure while higher values indicate greater openness**.** Similar to the aspect ratio, variations in SVF has direct effect regulating long-wave radiative heat loss. It has been suggested that SVF positively correlated with day time temperature and negatively with night time temperature with respect to other street characteristics (Ha et al., 2016). It has been suggested that lower SVF reduces radiative cooling since the longwave radiation tend to be trapped in reduced sky visibility (Gál et al., 2009).

2.3.1.2 Orientation

As important as the degree of enclosure, solar orientation have been considered in several studies addressing shading levels and solar exposure (Ali-Toudert et al., 2007; Sinou et al., 2004). Solar orientation has direct effect in controlling sunlight-shade pattern distributions with respect to sun position, along with wind variations and prevailing wind direction. N-W street with elevated aspect ratio offers enhanced thermal conditions, while E-W streets offer the least comfortable conditions and have the longest discomfort periods Even for smaller Sky View factor (Ali-Toudert et al., 2007). Within this orientation, high H/W ratio offers protection only to the north facing side of the street in contrast to the continuous irradiation of the south-facing side (Ali-Toudert et al., 2007). Asymmetrical E-W cools faster in contrast to warmer regular E-W streets due to wider sky view factor (Ali-Toudert et al., 2007). Asymmetric canyons generate intermediate conditions between wider and narrower streets, offering shorter period of discomfort in the afternoon (Ali-Toudert et al., 2007).

2.3.1.3 Shading elements

Large tree canopies, overhanging façades, and in-between spaces, such as covered passages and arcades, are all significant in providing horizontal shading during critical solar exposures. Importantly, these shading elements could enhance air flow patterns within streets hen carefully implemented.

Vegetation is an important shading source especially during hot conditions. Carefully distributed trees within the street is effective in cooling the thermal environment (Shashua-Bar et al., 2000). Green surfaces are significant in reducing solar radiation and air temperature and enhancing the microclimate through evaporative cooling. Vegetation has significant heat mitigation effects on air temperature and urban surface heating (Chen et al., 2014; Taleghani, 2018). Vegetation reduces heat in three main ways including evapotranspiration, reflecting the sun due to the higher albedo and importantly by blocking the solar radiation (Taleghani, 2018).

Alternative shading devices could be implemented when planting vegetation is not feasible. Mobile shading elements offer flexible, adaptive and cost-effective solutions to mitigate excessive heat while preventing over-shading (Nouri et al., 2019). Different strategies to avoid over-sharing are semi-outdoor spaces such as lift-up buildings, covered passages and arcades, which can offer shaded-cooling effect during hot conditions while maintaining warm conditions during the winter season (Ali-Toudert et al., 2007; Sinou et al., 2004). The overhead plan contributes to reduce the amount of direct solar radiation exposure with respect to the surface material and orientation. The effectiveness of these devices depend on the structure, components and constructive materials properties (Lam et al., 2023) along with their geometry characteristics.

2.3.1.4 Density and coverage

Building density is a geometric descriptor, S=Ar/Al, where Ar is the plan or roof area of the average building and Al is the 'lot' area or unit ground area occupied by each building (Oke, 1988). Density indicates the total built volume and is measured as the ratio of built volume to the area of the studied site [m^3/m^2] (Chatzipoulka et al., 2020) as it measures the built volume relative to an area. Complimentary, coverage refers to the spatial distribution of the built density and represents the percentage of built-up area over the total site area [%], quantifying the two-dimensional characteristics at ground level (Chatzipoulka et al., 2020). At a larger scale (neighborhood scale), buildings density and their spatial distribution are significant to airflow and solar radiation exchange in the canopy layer (Oke et al., 2017c). The same building density could result in distinct built from and arrangement, thus, different microclimate outcomes according to the built coverage and distribution. High density may reduce access to solar energy but can slows the airflow at pedestrian level with respect to the direction of the wind and enhance the urban heat island (Oke et al., 2017b).

In investigating the relationship between urban geometry and thermal diversity in public urban spaces, Chatzipoulka et al., (2020) revealed a significant strong but non-linear relationship between density-coverage and thermal diversity (Chatzipoulka et al., 2020). Their findings indicate that a variation in building density and distribution favors the creations of urban spaces with transient wind and solar exposures, hence favoring thermal diversity. Additionally, authors stated that there are optimal density-coverage values, of which a further decrease or increase would reduce diversity since high building density significantly reduces solar availability and causes poor ventilation, hence reducing outdoor comfort and usability (Chatzipoulka et al., 2020).

2.3.2 In-between spaces

Shading is an important feature against heat stress. A balanced street geometry that mitigates solar exposure while allowing for heat dissipation is important when designing comfortable outdoor spaces. Street geometry could be more variated by containing other elements such as shading devices, overhanging façade elements, in-between spaces, all of which have direct effect in controlling sun exposure and enhancing wind flow at street level. While high shading levels enhance air temperature and reduce diurnal solar radiation, it can significantly reduce long-wave radiation dissipation during the night hence increasing thermal heat stress. In-between spaces such as lift-up building designs, sabats and galleries, all could contribute to a significant decrease in thermal discomfort duration, with respect to orientation and degree of enclosure.

In-between spaces, also called transitional, semi-outdoor, or semi-enclosed spaces, are those intermediate space in which the indoor and outdoor climates are modified without mechanical control system and in which individual may experience the dynamic effect of these changes (Chun et al., 2005). These spaces serve as both a buffer and a physical connection (Pitts, 2013; Zhang et al., 2020) and are characterized by their unique environmental behavior, being partially exposed to outdoor conditions with limited control on its performance (Potvin, 1996; Sinou et al., 2004). The conditions created within the in-between space are the result of outdoor conditions along with the spatial attributes of both the in-between and its surrounding environment, e.g. Street geometry.

Urban in-between spaces are outdoor semi-covered spaces open to one or more sides, and are integrated in the ground level of buildings providing outdoor shaded passages (Chun et al., 2005; Pereira et al., 2019; Steemers et al., 2004). The significant distinction of the in-between space from the outdoor space is that the former is sheltered from outdoor climate by an overhanging plane such as lobbies, porches, arcades and sabats, with the exception of courtyard and atrium. Moreover, in-between spaces serve as environmental devises that relates to climate control i.e., radiation shield, wind break, shading, evaporative cooling devices, etc. (Spagnolo et al., 2003). Different in-between types and geometries offers different environmental behavior (Sinou et al., 2004), depending mainly on its type of attachments to the buildings (Chun et al., 2005) and morphological conditions of outdoor spaces.

The in-between space serves one of two main purposes according to its location within indoor and outdoor environment. The first one is outdoor-indoor transition such as spaces in front or inside the buildings (fig.2. 2). These spaces are used to offer gradual transition when entering or living the indoor space; and serve as a buffer zone by filtering or blocking unwanted outdoor environmental conditions, therefore improving indoor comfort and energy saving solutions. The second purpose is outdoor-outdoor articulation: those intermediate spaces within streets and urban spaces (fig.2 2). This type serves as thermal buffer zone and temporary partial protection from outdoor unwanted weather conditions. It ensures connection and continuity of the urban space and provide gradual articulations within outdoor spaces (Doğan, 2016, p.64; Nooraddin, 1998). While the expression ‘transitional’ refers to that directional adjustment between two contrasting environments (indoor-outdoor relations), the expression ‘in-between’ refers to that space articulating two different or similar environments (outdoor-outdoor relations) ensuring movements between outdoor spaces. These spaces have overlapping nature of being both inside and outside, covered and opened at the same time as there is a certain level of exposure and connection with the outdoor environment. Therefore, the expression ‘in-between’ is chosen rather than ‘transitional’ in the current study since it is mainly related to pedestrians walking experience within urban outdoor space

The importance of in-between spaces in creating environmental diversity was earlier discussed in the literature (Chun et al., 2005; Doğan, 2016; Nooraddin, 1998; Potvin, 1996; Sinou et al., 2004; Spagnolo et al., 2003). According to its spatial attributes these spaces may

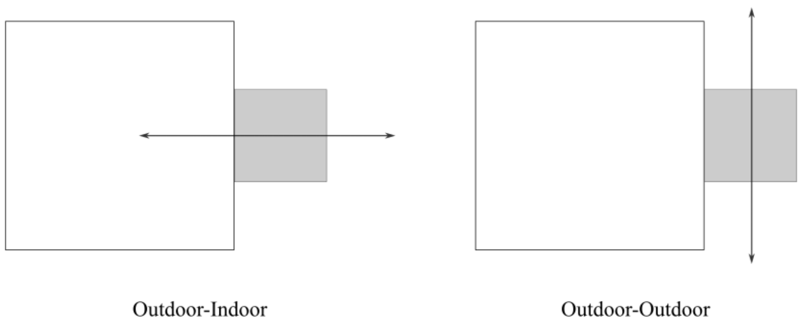


Figure 2.2: in-between space transition types. The grey square refers to an in-between space and the black arrow represent the type of the transition Outdoor-Indoor and Outdoor-Outdoor.

create transient thermal aeraulic conditions and generates environmental diversity. These transient conditions may have positive influence on pedestrian thermal sensation and walking experience.

2.3.2.1 In-between types

Outdoor in-between spaces have been categorized in the literature into different types in relation to their attachment to the building (Chun et al., 2005), degree of Enclosure (Steemers et al., 2004) and environmental performance (Gamero-Salinas et al., 2022; Pereira et al., 2019; Sinou et al., 2004). As such, four main types of in-between space can be identified: the porch, the arcade, the portico and the undercroft or outdoor room (Fig. 2. 4) (Chun et al., 2005; Pereira et al., 2019; Sinou et al., 2004; Steemers et al., 2004). These types are all sheltered by an overhead plan from direct sun exposure and rainfall in opposition to the outdoor environment.

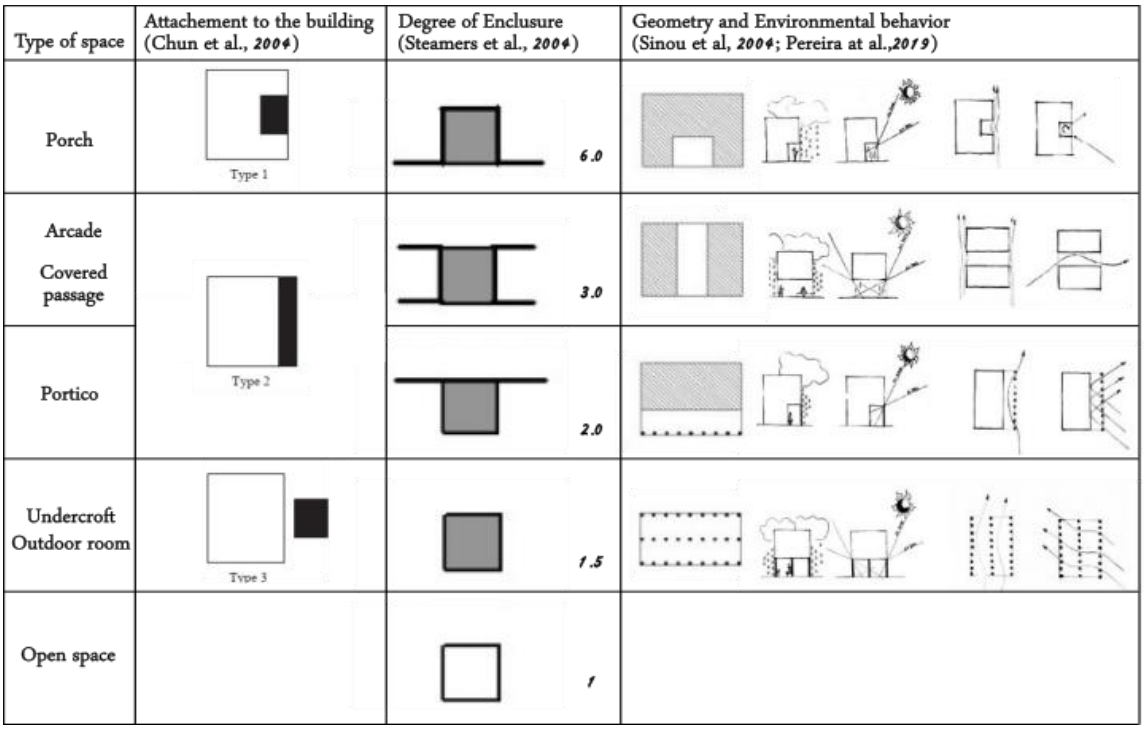


Figure 2.3: types of in-between spaces in relation to attachment to building, degree of enclosure and geometry and environmental behavior.

In current study, the in-between space is categorized into 4 types, in relation to the number of openings, by dividing the type 2 (Chun et al., 2005) into to subtypes: the porch, the portico (gallery or arcade), the covered passage and the undercroft following (Steemers et al., 2004)'s degree of enclosure (fig.2. 3).

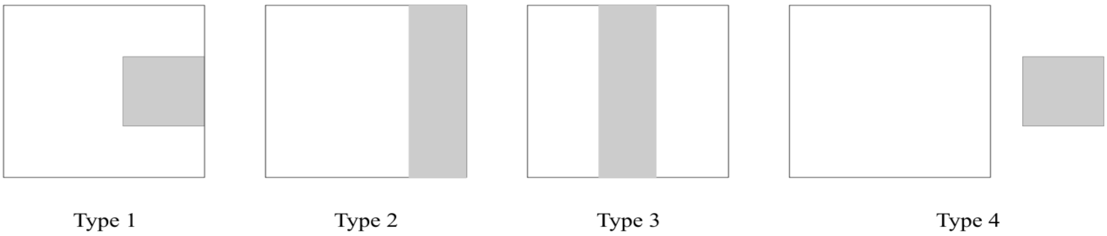


Figure 2.4: In-between spaces types in relation to the attachment to the building.

Type 1: The porch

The porch is contained within a building and is more related to indoor-outdoor transition, such as a hotel lobby or entry atrium where conditions are constantly mixed as people move in and out of the building (Chun et al., 2005). It is only open from on frontal side with a 6.0 DoF (Steemers et al., 2004). In the summer, solar radiations are blocked by the overhanging plan, which remains cooler that the outside conditions. The air movement is single sided and according to the wind direction it can create significant air movement and turbulence if I the wind direction is at an angle to the opening (Sinou et al., 2004).

Type 2: Arcade, Portico or gallery

The arcade refers to an attached, semi-covered space connected to the building, or implemented between buildings**.** We can identify two types of arcades according to their degree of enclosure: gallery or portico; and the covered passage (Sabat space). The first type

Figure 2.5: The portico or gallery type in Padova, Italy. (source: The author)

refers to covered alleys attached to buildings, also known as gallery or portico, which are characterized by two opposite openings following the direction of the street in addition to a frontal opening ensuring connection with the street. This type of arcade is characterized by 2.0 DoF according to (Steemers et al., 2004) (Fig.2. 3). Similarly, to the porch, the arcade is protected from rainfall and summer sun and allows the winter sun to enter. Furthermore, the wind flow can result in various patterns according to the predominant air flow direction and the geometry of the space (Sinou et al., 2004).

Type 3: Covered passage or "Sabat" types

This type of in-between space is perceived as covered passage such as glazed-covered European arcades, Sabats space in the Mediterranean medieval cities, and lift-up building design in subtropical cities. This type of arcade is contained within the street with only two opposite openings following the direction if the street and are characterized by 3.0 DoF according to (Steemers et al., 2004) (Fig. 2.3). As opposed to the porch, the sun may enter within the space twice a day from the two openings depending on orientation and if unobstructed conditions are assumed (Sinou et al., 2004). the wind inside the space depends on the predominant wind direction it can either create significant air movement if it is blowing normal or at an angle to the openings, or not affect the space significantly if the direction is parallel to the openings (Sinou et al., 2004). This type of space represents one of

Figure 2.6: The arcade type in Milan, Italy, on the left; the Sabat type in Bari Vecchia, Italy, on the right. (photos taken by the author)

the Mediterranean urban and building elements and therefore will have the main interest in the current research, specifically the Sabat type.

Type 4: The hypostyle or the undercroft

This type is not attached to a building and is essentially an outdoor room with 1.5 DoF (Steemers et al., 2004). entirely influenced by how the design of the structure modifies the outdoor climate, such as pergolas, bus stations, or pavilions (Chun et al., 2005). This type is well used in subtropical cities, known as lift-up building design, which consist of void creation at floor level, creating a covered alley (Du et al., 2017). The lift-up design could hold similarities with the Sabat and arcade in case of only two opposite horizontal opening. The creation of voids at ground level, often called lift-up building design, are commonly used in public flats in subtropical humid cities and is often used for social activities and events (Chew et al., 2019).

Similarly, to the portico, the exposure of its for sides depends of its architectural characteristics. Furthermore, the wind flows unobstructed in the space regardless of its predominant direction, possibly creating significant air movement (Sinou et al., 2004).

Figure 2.7: The lift-up building design type. Undercroft space in Glasgow, UK (source: www.archdaily.com), on the left; lift-up building in China on the right (Du et al., 2017)

2.3.2.2 Design attributes

According to design attributes and distribution, these spaces may create transient thermal aeraulic conditions and generate environmental diversity. Within the street, the in-between spaces may offer the possibility of enhancing environmental diversity by creating alternative, protected, and rhythmic environments, thus, positively influencing pedestrian's thermal sensation and walking experience. Characterizing the thermal aeraulic conditions of in-between spaces is complex and design attributes differ according to the type of the in-between space, mainly type of attachment within the street, The degree of Enclosure, orientation and coverage area. Within the scope of the current study, the focus will be held on the Sabat type.

The thermal aeraulic conditions within the Sabat are influenced by the street geometry as well as the geometry of the Sabat per se. Similar to the street, degree of enclosure and orientation are significant attributes. Area of coverage in term of the length is also important as it would highly influence positively or negatively the air flow and heat trapping inside the Sabat space.

2.3.2.2.1 Orientation

Orientation is important when considering the environmental behavior of the in between space. The orientation is defined as the direction of the axis from one end to the opening at the other end of a linear in between space, such as the case of covered passages (Steemers et al., 2004). It has been found that an E-W oriented covered passage space causes larger diurnal temperature fluctuations than a north-south oriented space by 3.5 °C (Steemers et al., 2004). This is attributed to the impact of solar radiation which is strongly related to orientation. A N-S oriented in-between space is more protected from direct solar radiation than an east-west oriented space, due to the different solar altitude angle (Sinou et al., 2004); (Steemers et al., 2004). It is suggested that the orientation of an arcade with two opposite open ends influences the temperature swing by 3.5°C, and that a west–east orientation creates the largest range of temperatures (Steemers et al., 2004). In the case of an open-sided, a west-facing portico or gallery would provide higher temperature variations (Steemers et al., 2004) (Fig. 2. 8)

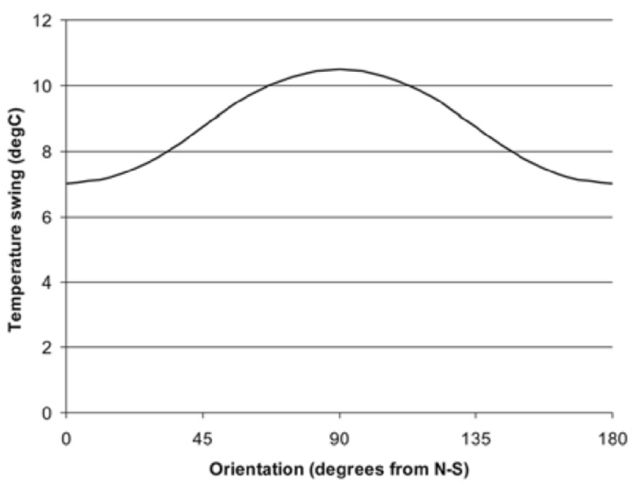


Figure 2.8: Predicted temperature variation in relation to changing orientation of an arcade type (Steemers et al., 2004. 92)

2.3.2.2.2 Degree of Enclosure

The height to width ratio is not an appropriate design characteristic to in-between space due to the overhead covered surface (Steemers et al., 2004). Steemers (2004) propose another indicator defined as the ratio of the sum of all surfaces, closed and open (A total), to the sum of the opening surfaces (A open), called the Degree of Enclosure (DoE) (Steemers et al., 2004). The DoE values are based on a number of generic in-between spaces assuming cubic proportions, as a DoF= 6.0 indicates a highly enclosed in-between space while a DoF=1.0 indicates a highly open in-between space (Steemers et al., 2004)

$DoE = \Sigma A_{total} / \Sigma A_{open}$

(Sinou et al., 2004) investigate different variants of arcade type with variant DoE in two urban areas in Cambridge and Kastro (Greece). The Field monitoring and a model predicting semi-enclosed spaces were compared to allow understanding between theoretical and actual monitored temperatures. Results highlighted the significance correlation between DoE and temperature swings in both the actual monitored and predicted temperatures. Lower DoE result in a wider range of temperature swings, whereas higher DoE tend to generate lower temperature swings (Sinou et al., 2004). Additionally, air speed was found to be the most influenced parameter with lower DoE having the greater effect on wind flow. However, it was indicated that the orientation have the most significant influence on temperature variations regardless of DoE (Sinou et al., 2004).

It is worth to mention that other design attributes such as floor to volume ratio, dimensions and proportions of the openings, building obstructions are all parameters related to temperature variations and wind flow of in-between spaces depending on the type of the in-between space.

2.3.2.3 The environmental potential

In-between space generate variations in thermal conditions that could create thermally diverse environment when articulated with open spaces (Sinou et al., 2004). The environmental potential of intermediate environment space has been recognized for comfort benefits, and climate control (Ali-Toudert et al., 2007; Nakano, 2003; Potvin, 1996; Spagnolo et al., 2003; Steemers et al., 2004). In the context of climate control and outdoor comfort, in-between spaces can favor adaptation opportunities especially for walking experience as they generate environmental diversity (Potvin, 1996; Zhang et al., 2020).

The covered passage with its half open design retained in the ground floor of buildings serves as comfortable passageway for pedestrians and offer better urban ventilation and shaded space (Juan et al., 2017). It has been revealed that the addition of an arcade design significantly increased ventilation efficiency in the urban canopy layer and increase the air change rate per hour by 60% at pedestrian level after adding an arcade design into a street canyon in humid-subtropical cities (Juan et al., 2017).

In a filed investigation of (Potvin, 2000) Experiments, Results of hot sunny day summer conditions showed that when moving from a sunlit street toward an arcade operative temperature decreased by 3°C with a gradual 54% decrease in air movement which counterbalance the positive cooling of temperature reduction. Moreover, when leaving the arcade toward a shaded street another 3°C reduction in operative temperature would be felt with a 46% increase in air movement, generating a gradual cooling effect. In the opposite direction, the heating effect would be experienced gradually and not strongly felt as if the pedestrian would move directly from a shaded street toward sun (Potvin, 2000). Here the advantage of the intermediate space, the arcade, is providing gradual process of adaptation as it relieves the pedestrian from any potential abrupt variation. The direction of the walk is important in the sensation of comfort (Potvin, 2000).

Lift up building design is an efficient strategy to channel wind in dense urban areas and it was found significant in enhancing wind speeds in dense areas (Chew et al., 2019). It has already been shown that the lift-p design can generate a local cooling spot for outdoor activities in hot and humid cities (Du et al., 2017). In a CFD simulation study to evaluate pedestrian-level wind speed, Chew et al., (2019)'s results showed that lift-up design, the void within the buildings allowed wind to flow through, enhancing wind speed in the urban street canyon and along the streets (Chew et al., 2019). Moreover, they revealed that the void height has a significant effect on wind amplification with taller voids being more effective to channel wind into the street (Chew et al., 2019). Notable, they stated that the building height has minor influence on the wind enhancement (Chew et al., 2019). 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. (Chew et al., 2019).

2.4 Thermal aeraulic transients

Thermal transients refer to the changes in thermal conditions indicated by variations in microclimate data between two or more assessment stops. In the current work, thermal aeraulic transients refer to the combined variation in thermal and aeraulic conditions resulting from the combination and articulation of the above-mentioned street geometry and in-between spaces. Microclimate variables are intercorrelated and are simultaneously influenced by urban geometry of which wind and solar radiation are the two main factors affecting outdoor activities and outdoor comfort. Wind and solar radiations are main features when investigating transient outdoor microclimate conditions (Chatzipoulka et al., 2020; Peng et al., 2020; Sinou et al., 2004) as they characterize the microclimate which influence our thermal experience (Peng et al., 2020). Thus, transient conditions are the results of complex combinations of these factors over time and space. (Potvin in (Potvin in Steemers et al., 2004, p.124). The conditions created by the combination of thermal and aeraulic conditions will be addressed as thermal aeraulic transients. Solar radiation influence both thermal and aeraulic behavior while aeraulic behavior could enhance or intensify the thermal resulting conditions therefore it is essential to understand the thermal aeraulic transient as a combined effect rather than isolated components.

Thermal variations are related to solar radiations, air and surface temperature, and humidity. Aeraulic variations are related to wind flow, wind speed, wind direction within buildings' arrangement along with the thermal influence of solar radiation's surface heating.

2.4.1 Thermal conditions

Thermal conditions at street level are expressed by the interaction of solar radiation and moister with the street geometry, resulting in variate microclimates. This variation could be intensified or reduced by the aeraulic conditions within streets. For example. In a grid-like street pattern, two perpendicular streets generate different microclimates as a result of different solar angle and prevailing wind direction (Oke, 1987, p.285). Solar radiation, with respect to albedo characteristics, H/W ratio and orientation, has direct impact on air temperature, radiation trapping and buoyancy flow.

2.4.1.1 Heat trapping

Solar radiation trapping is significantly pronounced in high density urban spaces wherein the incident solar radiation continues to bounce off of the urban surfaces within the street canyon (Choi et al., 2018). Heated air within large SVF is less trapped and easily dissipated to the atmosphere during the night. Moreover, streets with higher SVF have more desirable thermal conditions (Choi et al., 2018). Long and deep streets in dense areas contribute to trap heat (Djenane et al., 2008), here solar protection is not recommended since the depth of the street enables the heat dissipation during the night (Djenane et al., 2008). In contrast, more open streets enhances diurnal and nocturnal ventilation (Djenane et al., 2008).

Choi et al., 2018 examined the impact of urban physical environment on the duration of high air temperature during summer season and investigated possible interactions between solar radiation, SVF and albedo values in Seoul (Choi et al., 2018). Their results showed that high wind speeds leads to shorter durations of high air temperature, and more induced solar radiation generates longer durations of high air temperature (Choi et al., 2018). They also stated that increasing SVF can help mitigate the duration of high air temperature for both low and high albedo values. However, urban surfaces with high albedo values diminish the positive influence of SVFs on the duration of high air temperature due to solar radiation trapping effect (Choi et al., 2018). As such, appropriate choice of urban surface materials should be carefully addressed as cooling pavements can hinder the effective release of reflected radiation into the atmosphere (Fig.2.9) (Choi et al., 2018).

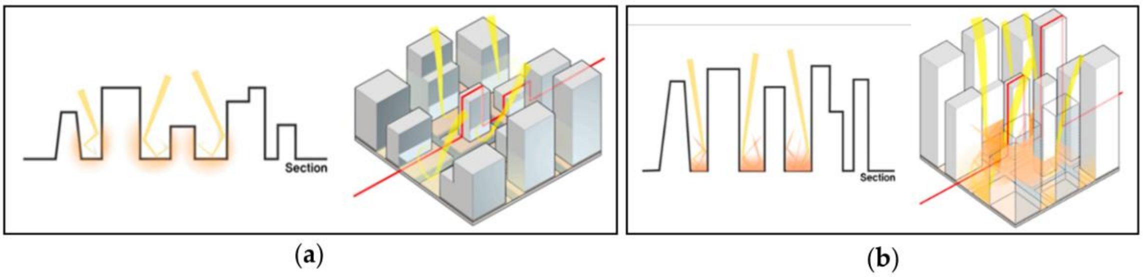


Figure 2.9: (a) weak trapping effect within low albedo values and high SVF; (b) high trapping effect within an urban canyon with high albedo and weak SVF (Choi et al., 2018).

In another study, (Guo et al., 2019) simulated 6 streets with a rage of 120 meters wide, 612 meters long and 18 meters high with a 45 degrees wind direction and revealed a positive correlation of temperature and SVF at noon, while the correlation was negative during the night (Guo et al., 2019). Streets with smaller SVF contribute to increase shadow coverage, hence cooler air temperatures during the day. Larger SVF indicates higher solar access within the street, hence higher air temperature during the day. However, while high-density urban areas have weak SVF and reduced air temperature during the day, the influence is reversed during the night, as high-density impede the thermal emittance from escaping into the environment (Guo et al., 2019).

2.4.2 Aeraulic conditions

Building arrangement within streets has a direct effect in altering the wind flow. When above-roof wind flow is perpendicular to the street, wind flow may differ according to the aspect ratio of the street. When the buildings are largely distanced (H/W < 0.35) the flow regenerate to the upwind profile before reaching the downwind building, described as ‘isolated roughness’ (Hunter et al., 1992; Oke et al., 2017a). At higher densities (0.35 <H/W < 0.65), closer buildings, the downwind building impacts the flow regeneration, causing a 'wake interference’ (Hunter et al., 1992; Oke et al., 2017a). In case of narrow/deep streets (H/W > 0.65), the above-roof flow have less tendency to enter the street canyon (Oke et al., 2017a) forming a ‘skimming’ flow characterized by a vortex circulation within the street (Hunter et al., 1992). When the street canyon is very deep, the main vortex slows and develops into one or more secondary cells towards the floor, resulting in stacked vortices (Oke et al., 2017a).

Wind amplification

When wind passes along a gap between buildings, it could significantly increase due to the ‘channeling effect’, of which the extent of the acceleration depends on the building size, distance and wind direction (Stathopoulos et al., 1992).When the above-roof flow is parallel to the street, non-paralleled buildings (staggered buildings) can accelerate wind through the reduced area between the buildings, while aligning open spaces with the prevailing wind direction contribute to channel wind flow (Chew et al., 2019). The street vortex may diminish for angles less than 30°, which contribute to channel the wind along the street canyon, depending on the length of the canyon and the aspect ratio (Fig. 2.10) (Oke et al., 2017a)

Wind channeling effect have always been related to passages between buildings. for wind blowing at an angle of 30 ° from the passage center line, it was indicated that a distance of 6 meters in case of 20 meters high buildings may generate wind velocity amplifications of about 40% , while, the wider the passage, the lower the velocity acceleration and the higher the turbulence intensities within the passage (Stathopoulos et al., 1992). However, a wind direction of 30° may create significant wind conditions in contrast to direction of 0° (Stathopoulos et al., 1992). When the above-roof wind is at an intermediate angle to the street (45°), it follows a helical path spiraling down the street, forming a helical vortex (Oke et al., 2017a).

The venturi effect refers to the increase in wind flow rate as due to the reduced flow section (Blocken et al., 2008 b). Different passages between buildings types could be identified including passages between parallel buildings, passages between parallel shifted buildings, and passages between perpendicular buildings section (Blocken et al., 2008 b). In passages between perpendicular buildings, depending on the wind direction, the passage could be a ‘converging passage’, or a ‘diverging passage’ section (Blocken et al., 2008 b). Blocken et al., 2008 analyzed wind speed conditions in converging and diverging passages between perpendicular buildings to investigate the venturi effect. That is the wind flow acceleration due to the reduced wind speed upstream of the buildings, allowing parts of the air mass to flow over the passage instead of being forced to flow through the passage opening (Li et al., 2015). Blocken et al. (2008) suggested the wind blocking effect, instead of the venturi effect, in increasing wind speed in converging passage (Blocken et al., 2008) (Fig. 2.11). they found that for converging passages, wind speed increased only near ground level due to the wind blocking effect, i.e., a large amount of oncoming are flows over and around buildings instead of being forced to pass between buildings. They also found that pedestrian-level wind speed and air flow rates increased more in the diverging passages, of which the wind-blocking effect is significant section (Blocken et al., 2008 b). Moreover, higher wind speeds in diverging and converging buildings are related to parallel winds to the passage centerline and reduced passages width-to-height ratio (Blocken et al., 2008).

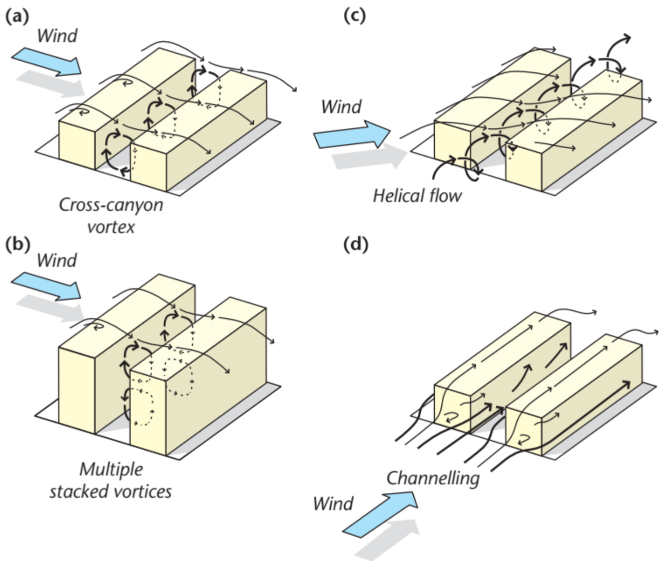


Figure 02.10: Wind flow patterns in urban canyons: (a) cross-canyon vortex; (b) helical flow; (c) multiple stacked vortices; (d) wind channeling (Oke et al., 2017a).

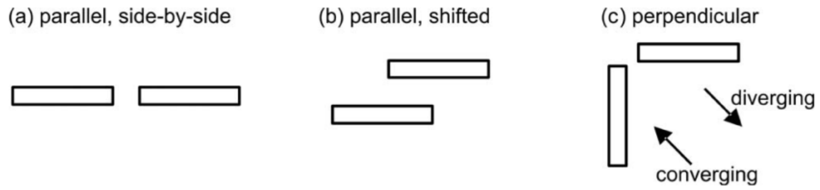


Figure 02.11:Wind block effect in the direction of converging and diverging winds (Blocken et al., 2008 b).

2.4.2.1 Thermal effect on wind flow

Solar radiation has significant role in affecting aeraulic conditions at street level, mainly by the effect of solar exposure and orientation, hence the influence on outdoor comfort, and pedestrians in specific. The vortices created inside canyons highly depend on the induced thermal effect of heated surfaces (walls and ground surface). A heated wall surface can either increases or decreases a mechanically wind flow, formed by a single vortex (H/W = 1), two counter-rotating vortices (H/W = 2) or even adjacent counter-rotating vortices near ground level in deeper canyons (H/W > 3) (Dimitrova et al., 2009; Xie et al., 2007)

Wind flow within the street canyon depends mainly on wind speed at roof-top level, wind direction (leeward and windward walls), heating wall(s) exposure and the street's H/W ratio (Dimitrova et al., 2009; Oke et al., 2017a). A heated wall exposed to solar irradiance heats up the adjacent air, streaming up a narrow sheet of buoyant air, with respect to street direction (Oke et al., 2017a). If the leeward wall is heated, the additional uplift increases the vortex circulation. In the case of the windward wall, the heated wall opposes the mechanical flow and slows down the vortex rotation or create a new one (Sini et al., 1996, as cited in Oke et al., 2017a). Thermally generated canyon exchange occurs at night as well, such as large aspect ratio canyons, wall floor and air temperatures do not cool down as quickly as on the roof due to the radiation and heat storage differences (Oke et al., 2017a).

Xie et al., 2017 investigated the influence of building façades and ground heating on the wind flow, covering basic flow regimes of skimming flow (H/ W = 1 or 2), wake interference flow (H/W = 0.5), and isolated roughness flow (H/W = 0.1). their results showed that the mechanically induced wind flow was impacted by the buoyancy under temperature stratification (Xie et al., 2007). Xie et al., (2007) showed that heating buildings' walls and ground surface generate strong buoyant force, which together with the mechanically induced force effects the wind flow structure. Their results indicate that in addition to the mechanical force impact of H/W ratio, the combined effect of surface heating is a significant factor influencing wind flow (Xie et al., 2007a)..

2.5 Pedestrian subjective experience

2.5.1 Overview of pedestrian subjective comfort

The thermal sensation of pedestrians differs from that of indoor thermal environment. The former is in a dynamic motion, whereas the latter could be static. One main difference is that when in motion the pedestrian experiences a sequence of different urban attributes for a short-term exposure, while in indoor spaces activities tend to be for long-term occupancy. The sequential nature of interconnected spaces enhances this dynamic perceptual mode when walking within the urban spaces (Potvin, 1996) (Potvin, 2000). Pedestrians are consistently conscious about environmental transients; however, they are only conscious of a comfortable environment upon experience it or when they abandon it (Steemers et al., 2004).

The perception of comfort for indoor and outdoor spaces differ greatly in term of rage of tolerance (Chokhachian et al., 2018). While indoor conditions are limited in terms of transient conditions, outdoor environments are relatively more dynamic and could enhance pedestrians' thermal experience (Chokhachian et al., 2018). The body in motion itself plays an important role for a comfortable thermal sensation, based on quality of movement, evaporative cooling and metabolic rate (Vasilikou et al., 2020). There is a comprehensive body of experimental support for the view that outdoor conditions are not static and that traditional standards are insufficient in assessing and predicting comfort in transient conditions (section 2.6). The measurement and appreciation of outdoor comfort are complex and not straightforward, and how we communicate and evaluate is even more complicated (Steemers et al., 2004). As such the necessity for a more dynamic approach is needed to understand to what extent transient conditions influence comfort (Steemers et al., 2004, p.7). Consequently, outdoor comfort started to shift from the deterministic approach of providing optimum and constant thermal environment to that of adaptive opportunities through creating thermal diversity (Steemers et al., 2004). In this context, thermal diversity stands for the ability to ensure wide range of microclimate conditions, within certain thresholds, allowing individuals to exercise their own preferences and adaptation (Chatzipoulka et al., 2020).

(Steemers et al., 2004, p.6) argue that while the absence of discomfort is recommended, it may also diminish the potential for pleasure that can be experienced by some degree of

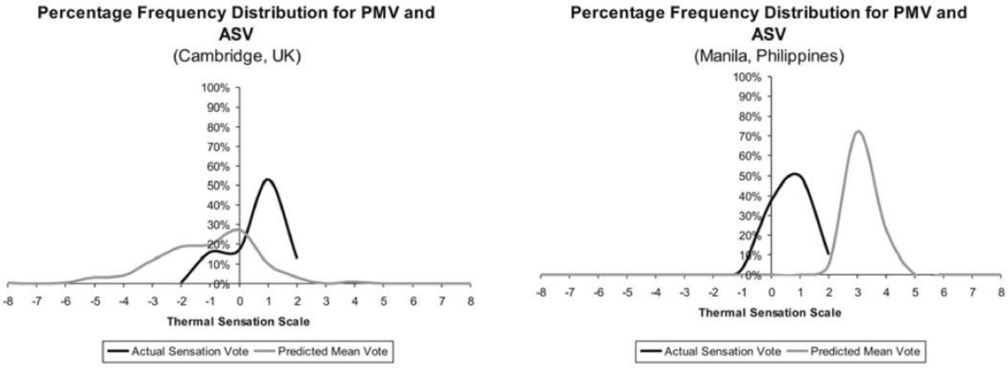


Figure 2.12: the divergence between Actual sensation vote and Predicted mean vote in two different cities Cambridge (Uk) and Manilla (Philippines) (Steemers et al., 2004)

variability. They compared people's perception of comfort with the theoretical prediction of physiological comfort in two urban spaces in Cambridge (UK) and one urban park in Manila (Philippines). Individuals' perception of comfort was compared with theoretical predictions of physiological comfort**.** Their Results significantly highlighted the divergence between the two indicators (fig.2. 12) raising speculations about the cause of difference between predicted physiological comfort levels and actual responses. Their findings suggested that offering diversity is a significant parameter to ensure optimum thermal conditions by providing increased freedom of choice as more choice results in a wider range of comfort (Steemers et al., 2004).

In Steemers & Ramos's study (2009), authors included over 14 urban sites across Europe to cover a range of urban morphologies and conditions to investigate the influence of environmental diversity on outdoor pedestrian comfort (Steemers et al., 2009). Results revealed a discrepancy between the surveyed ASV (actual sensation vote) and the calculated PMV (predicted mean vote, defined in ISO 7730), which was confirmed by weak correlation coefficient (R) of only 0.32 and 0.37**,** respectively (Steemers et al., 2009). These results confirmed similar results on actual reported outdoor comfort in outdoor spaces (Nikolopoulou et al., 2003). Authors also suggest the use of H/w ratios and SVF to assess peak temperature differences, sunshine hours and wind patterns to graphically calculate the diversity indicator (Steemers et al., 2009). The calculated diversity indicator was based on the standard deviation between the columns in de diversity profile (fig. 2. 13) (Steemers et al., 2009). A high diversity factor means that all combinations of environmental parameters are equally represented, while strongly skewed profiles indicate a low diversity. Their results revealed a moderate linear correlation between thermal diversity and comfort, however, authors revealed a better fitting polynomial line (R= 0.90), suggesting an optimum diversity of 0.6, of which any decrease or increase would lead to reduced discomfort (Steemers et al., 2009). This implies that any reduced diversity below 0.6 would reduce the chances of freedom of choice, leading to discomfort.

Temperature, wind speed and sunshine are the most significant microclimate parameters to influence pedestrians' outdoor comfort. however, thermal comfort, from a perceptual

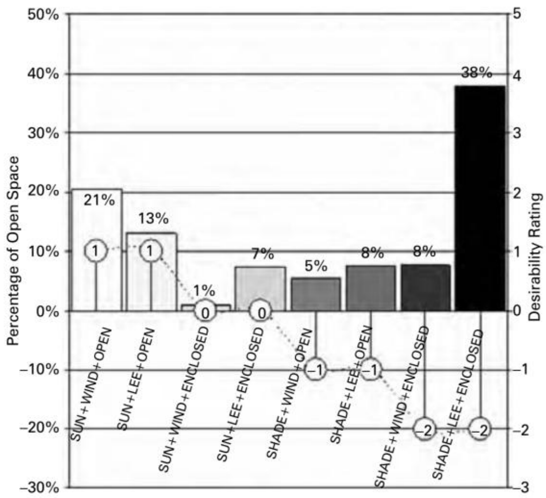


Figure 2.13: Diversity indicator based on the standard deviation between the columns (Steemers et al., 2009)

perspective, is highly influenced by past experiences (Taylor, 2014). Pedestrians' thermal preferences change as they are dynamically influenced by outdoor spaces, depending on their physical and metabolic rates, and on microclimatic conditions and exposure patterns. On the other hand, walking is energy consuming and along with outdoor conditions, thermoregulatory adjustments, an appropriate transient condition, i.e. combinations of sun-wind-temperature, would provide individuals with variety of chances to adapt and restore their thermal capacities. Creating diverse thermal stimuli, within a certain rage, may positively influence pedestrian experience as it offers transitions in extreme conditions or prolonged exposures, which has the potential to increase thermal adaptation (Peng et al., 2020). Moreover, understanding the human parameter and the subjective response of pedestrians is important in understanding the variability on the outdoor environment (Nikolopoulou et al., 2003). Outdoor physical parameters accounts of only 50% of the variations in thermal experience (Nikolopoulou et al., 2003).

2.5.2 Thermal sensation and thermal comfort

Psychological factors, adaptation, history of exposure along with other cognitive factors have been indicated as main factors influencing individual's judgment of the outdoor environment (Vasilikou et al., 2020). In understanding individuals subjective experience, research identified two main categories of sensory estimates: descriptive and affective/emotional estimates (Gagge et al., 1967). Understanding the influence of transient environment necessitate the tracking of the variations pattern of these estimates within time and space. Thermal sensation vote and comfort sensation vote have been widely used in the literature as indicators of the subjective evaluation of environmental stimulus and comfort in both indoor and outdoor environments. However, these two indicators refer to two different dimensions of subjective comfort. Moreover, the correlation between the two indicator is further complex in outdoor conditions.

Sensation is descriptive (Cabanac, 1971). (Hensen, 1990) pointed to the difference between thermal sensation and thermal comfort when understanding the pedestrians' subjective responses to environmental stimuli. He stated that thermal sensation is a rational experience which can describe an environmental stimulus in term of 'cold' and 'warm', which can be described as the objective evaluation of a conscious feeling (cold and hot) (Nagashima et al., 2018).

On the other hand. thermal comfort, indicating the state of mind that expresses satisfaction with the surrounding environment (Fanger, 1973), is an emotional experience and a hedonic sensation that can characterize individuals' emotional state, relative to experience and expectation, in terms of 'pleasant' and 'unpleasant' (Hensen, 1990). Thermal comfort is alternatively expressed as thermal pleasantness, thermal pleasure, or hedonic satiation" (Nagashima et al., 2018) and describes the overall state of the thermoregulatory mechanism (Hansen, 1990). As such, in a more objective definition of comfort than the ISO definition, the state of thermal comfort is defined as the conditions in which there are no compelling need to correct the environment by behavior (Benzinger, 1979, as cited in Hensen, 1990).

sensation describes the magnitude of a thermal experience (warm versus cool) and is considered as detection of an environmental stimuli, while comfort is qualitatively express the hedonic tone and pleasantness of the experience and is regarded as the way in which the individual interprets that stimuli, its load error and the thermal defense in action (de Dear, 2011).

2.5.3 Affective Thermal sensation

At the center of user experience, the walking experience is defined as an emotional process that is affected by different levels of appraisal of internal and external factors, resulting in affective experiences, which could be described along two dimensions (Russell, 2003; Russell et al., 1984). Valence varying between unpleasantness and pleasantness; and activation or arousal varying between deactivation and activation (a degree of intensity). Although thermal arousal is a new term for thermal comfort research, the related concept of thermal intensity is well established in pain research and refers to stimulus strength (Russell, 2003).

Sensation can also have an affective aspect, described as pleasure or displeasure (Cabanac, 1971). Existing research has generally focused on the descriptive component of thermal sensation, but very little attention has been given to the affective dimension (Parkinson et al., 2015). Thermal affect scale links descriptive and affective dimensions of pedestrian's thermal sensation by capturing the temperature sensation along with sensation of humidity, wind and solar radiation which fits with the study of thermal aeraulic combination (Liu et al., 2020). Liu et al., (2020) developed a multi-dimensional semantic approach called the outdoor thermal affect. Authors supporting thermal affect argue that the conventional outdoor thermal sensation (OTS) is purely descriptive and contains no affective information, hence not much is known about the variation in wind or humidity as main component of the thermal experience (De Dear, 2011; Liu et al., 2020; Parkinson et al., 2015). The proposed thermal affect reflects both descriptive information and affective status of the ambient outdoor environment unpleasant (Liu et al., 2020b). Their findings indicated that thermal affect on both pleasure and intensity dimensions does not show a simple linear relationship with any single environmental parameter consistently, but rather is impacted by diverse environmental factors under different climatic scenarios, suggesting that the descriptive state (sensation) doesn't predict affective status in and around thermal neutrality and that the neutral thermal sensation doesn't necessarily correspond to optimum thermal comfort (Liu et al., 2020), which is consistent with a review of field surveys across Europe (Liu et al., 2020; Nikolopoulou et al., 2007; Parkinson et al., 2015).

2.5.4 Thermal pleasure

Thermal pleasure is an affective expression in relation to individual experience of the outdoor environment, expressed between pleased and unpleased. Thermal pleasure is highly related to the transition state of the thermal stimuli (de Dear, 2011). A thermal pleasure is only perceived in transient states where the stimulus helps the subject to return to normothermia and once the normothermia is achieved, the stimulus loses its effect (Cabanac, 1979). Expectation and preference can persist for long and short time periods while thermal pleasure is a transient condition requiring a specific climatic context and physiological conditions (Dzyuban et al., 2022) related to the dismissal of comfort strain (de Dear, 2011).

In contrast to comfort sensation, thermal pleasure indicated the extent of which the outdoor environment contributed to return of step away from steady state conditions during transient conditions. In demonstrating the relationship between pleasure and transient conditions, early studies of Cabanac (1979) indicated that pleasure is a sign of the potential of a stimulus to return to 'non-thermia state'. That is, the same thermal stimulus could be perceived pleasant and unpleasant depending on the thermic state of the individual (Cabanac, 1979).

2.5.5 Thermal alliesthesia

The expression 'alliesthesia', coming from "esthesia" (meaning sensation) and "allios" (meaning changed), was proposed by Cabanac (1971) to describe the phenomenon of which a given stimulus can induce a pleasant or unpleasant sensation depending on the subject's internal state (core temperature), referring to the difference between a given core temperature and a set value (37°C) (Cabanac, 1971). in other words, a warm stimulus would be unpleasant to subjects with body temperature of 37.5°C since his set temperature is 37°C (Cabanac, 1971). A stimulus is pleasant when it facilitates the return of internal temperature to its normal value or prevents any further internal change. A negative alliesthesia is related to the change from a pleasant sensation toward an indifferent (unpleasant) sensation, while a positive alliesthesia is the change from indifferent (or unpleasant) sensation toward a pleasant one (Cabanac, 1979).

The introduced thermal alliesthesia made clear differentiation between thermal pleasure, neutrality and acceptability (de Dear, 2011). That is to say that any thermal stimulus that offsets a thermoregulatory load-error (the displacement of the regulated variable, core temperature, from its setpoint) will be pleasant to perceive (de Dear, 2011). Such effect of removing body heat accumulation (from physical activity) and generating a pleasant sensation is referred to as positive alliesthesia (Parkinson et al., 2015). Therefore, a pleasant sensation is only triggered in presence of a corrective stimulus which help return to normal internal state (normothermia) (Cabanac, 1971).

A significant body of literature explored alliesthesia in the context of thermal perception and its relation to environmental diversity. Research on thermal alliesthesia clearly show that thermal pleasure (positive alliesthesia) could not be achieved in environments where the body is in a neutral, steady-state heat balance with the environment (Parkinson et al., 2015).

De Dear established the earliest studies on thermal perception during transient thermal conditions (De Dear et al., 1993). It was presumed that the main driver of Alliesthesia was triggered by the deviation in core temperature (Cabanac, 1971). These assumptions were retained following discussions of (de Dear, 2011) (Parkinson et al., 2015) (Parkinson et al., 2016). These studies suggested that induced thermal sensations from small variations in skin temperature could potentially trigger alliesthesia, and that skin temperature variations, rather than core temperature, has more significance in explaining the alliesthesial potential on thermal perception (de Dear, 2011) (Parkinson et al., 2016).

Parkinson et al (2016) used thermal pleasure to explored the hedonic tone related to thermal transients to capture alliesthesia potential (Parkinson et al., 2016). Authors conducted an experiment design of a series of temperature step changes and temperature ramps to explore alliesthesia and thermal pleasure, with most transients intended to generate positive alliesthesia responses (Fig.2. 14). It was demonstrated that changes in thermal perception relates to rage of change of skin temperature with respect to time and that the dynamic response of cutaneous thermoreceptors is the main driver for sudden changes in environment (thermal) stimuli (Parkinson et al., 2016). Their results revealed strong negative correlation between change in skin temperature and changes in pleasure for warm exposures and strong positive correlation for cool exposures, while core temperature changes were negligible or non-existent. Displeasure was significantly observed when moving away from a neutral thermal exposure regardless of the direction of the stimuli (warmer or cooler). Importantly, the corrective changes, generated by thermal transitions, in the physiological load error resulted in driving the individual's thermal state back towards neutrality, inducing a positive alliesthesia response (Fig.2. 14) (Parkinson et al., 2016). Moreover, in accordance with (de Dear, 2011), the intensity of thermal pleasure during transient conditions is dependent on the magnitude of induced load error from previous exposure and the corrective potential of peripheral heat transfer in the following exposure (Parkinson et al., 2016). Such finding suggested that the key variable indicating reportative potential of a thermal environmental transient is the rate of change in skin temperature similarly to (De Dear et al., 1993)'s findings (Parkinson et al., 2016). In addition to (Cabanac, 1971)'s core temperature deviation assumptions, Parkinson et al., (2016) experimental results framed the concept of alliesthesia in the context of thermal comfort research and revealed that alliesthesia could be induced across different physiological state.

The concept of Alliesthesia introduces a fundamental new understanding of thermal perception and its relevance to the built environment has been first explored by (de Dear, 2011). Microclimatic diversity is significant in understanding outdoor comfort as it offers a wider choice of thermal stimuli and potential alliesthesia (Peng et al., 2020). The instant pleasant sensation upon entering a warm room in a cold weather or a sudden wind breeze in humid-hot climate are examples of psychophysical dynamics of alliesthesia (de Dear, 2011). The significant acknowledgement of the potential of alliesthesia in different physiological setpoints in the literature led to a very recent updated definition of the phenomenon of alliesthesia as:

"*Alliesthesia refers to a modified outcome or rise in the hedonic dimension of any mental process, from sensation to mental performance, and decision making, leading to physiological comfort and happiness. Positive alliesthesia is the rise in pleasure, or joy, and a decrease in displeasure or pain. Negative alliesthesia is the opposite*" (Cabanac, 2020)

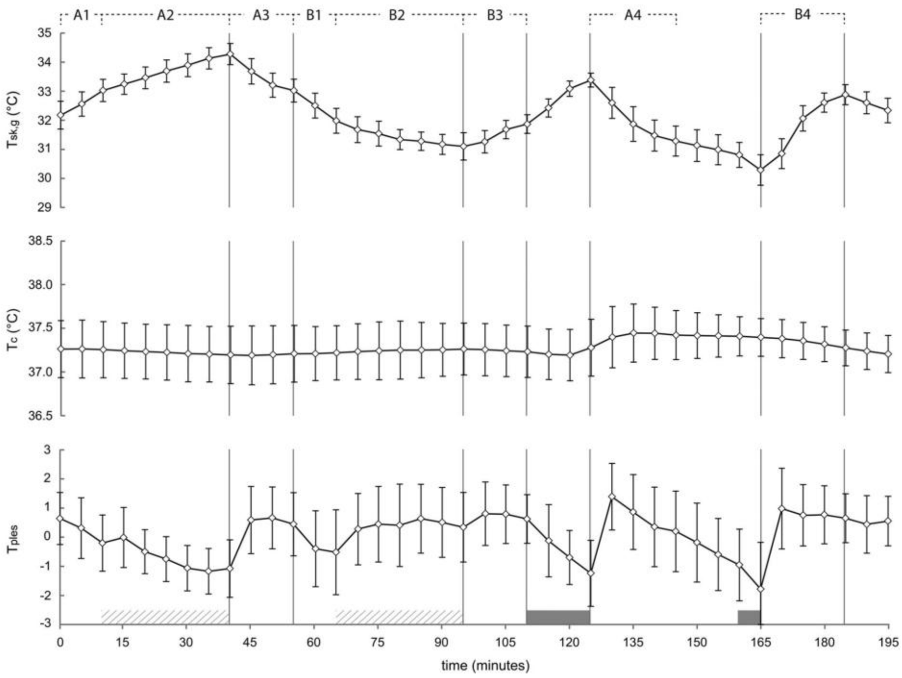


Figure 2.14: Experiment design of a series of temperature step changes and temperature ramps to explore alliesthesia (Parkinson et al., 2016)

That is to say rather than to keep body or skin temperature at constant temperatures, there is a need to shift toward creating transient exposures to stimulate dynamic thermal alliesthesia and 'manipulate' pleasure sensations (de Dear, 2011). A sequence of dynamic thermal environments could be generated through spatial diversity, shading patterns and wind exposures, which could highly promote alliesthesia (Lyu et al., 2022)

2.5.6 Adaptation and tolerance

Considering only the physiological parameters is insufficient to characterize outdoor thermal comfort (Nikolopoulou in Steemers et al., 2004, p.107). The growing interest in adaptive comfort, expectation, history of exposure, thermal alliesthesia and thermal pleasure reveal a more sensible understanding of why thermal experience in transient conditions differ from that of steady state environment. The aim to achieve comfort during walking needs to consider both temporal and spatial variations, as well as opportunities for adaptation (Vasilikou et al., 2020).

2.5.6.1 Physiological adaptation

Heat stress is imposed by physical changes that disturb the regulatory mechanism and can be quantified from the metabolic conditions (external activity) and environmental variables (climate and clothing) (Taylor, 2014). In fact, stress is highly necessary in the process of adaptation as without stress disturbance, adaptation do not occur, as quoted "*complete freedom of stress is death*" (Taylor, 2014). During physical activity, such as walking, up to 80% of the metabolic heat production results from the conversion of stored chemical energy into thermal energy, which significantly elevate tissue temperatures (Taylor, 2014). The human body is characterized by the ability to adapt with the necessary attribute to avoid, tolerate and adapt to a wide range of thermal stress (Taylor, 2014). Adaptation is the morphological, chemical, functional or genetic changes that decrease the physiological strain, consequently increasing thermal tolerance (Taylor, 2014). Heat adaptation is characterized by increased heat loss and reduced core and skin temperature (Kenny et al., 2017). Physiological adaptation is dependent on the type of thermal loads (environmental exposures and metabolic heat production), intensity, duration, frequency and number of heat exposures (Taylor, 2004, as cited in Kenny et al., 2017). Adaptation occurs through repeated exposure to a given stressor or by residing within a specific environment conditions., i.e., hot climatic region (Taylor, 2014). These adaptations occur only after the human body is repeatedly challenged, resulting the regulatory mechanism to restore the status of the 'milieu interieur' (Cabanac, 1979) and reducing the thermal strain (Taylor, 2014).

However, it is important to point out the difference between habituation that occurs after repeated application of the same thermal stress, from adaptation that results from progressive-overload thermal stress (Taylor, 2014). That is to say the repetitive exposure to a constant stimulus will results to tolerance while progressively elevated stimuli, non-monotonically, is essential in generating adaptation (Taylor, 2014). It is suggested that adaption is only triggered if the thermal disturbance exceeds a critical threshold, without inducing systemic failure as excessive disturbance impact adaptation and leads to thermal fatigue (Sawka et al., 2011; Taylor, 2014). This implies that there is an adaptation threshold with minimal disruption (overload) is necessary to activate corrective adjustments (Fig.2. 15) (Taylor, 2014).

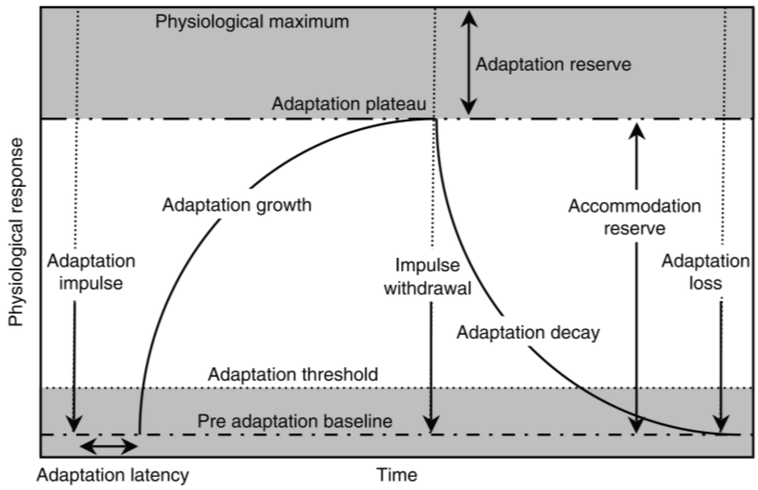


Figure 2.15: Characteristics of physiological adaptation (Taylor, 2014).

2.5.6.2 Psychological adaptation

People experience the environmental differently, and the human response to a stimulus is not straightforward and the adaptive opportunities could also be influenced by psychological parameters (Nikolopoulou et al., 2003). Psychological dimensions appear to play an important role in the perception of the thermal environment (Spagnolo et al., 2003). Psychological factors influence the thermal experience in different ways, including, naturalness, expectation, experience, time of exposure, and perceived control (Nikolopoulou et al., 2003) and perceptual alliesthesia (De Dear, 2011; Nikolopoulou et al., 2003; Spagnolo et al., 2003).

Outdoor conditions are characterized by certain degree of acceptability since individuals would expect a certain degree of uncomfortable conditions. Expectations significantly impact individuals' perceptions and are often reflected upon previous experiences (Nikolopoulou et al., 2003). Short-term experience is related to the memory of past experience and could influence changes in individuals' expectation from minutes to days (Liu et al., 2021; Nikolopoulou et al., 2003). Past exposure to discomfort would significantly influence pedestrians' perception in the proceeding environment (Nikolopoulou et al., 2003). If the environmental conditions remains uncomfortable, the individual discomfort perception would significantly increase. If the proceeding environment offer less uncomfortable conditions, individuals would highly judge the environment base on past experience, therefore, a certain amount of pleasure is expected to be experienced.

Duration of exposure in another significant factor influencing pedestrian's thermal experience. Short-duration exposure to discomfort would not be perceived negatively when people anticipate that is shortly experienced (Nikolopoulou et al., 2003). On the other hand, perceived control over the environment showed significant association with thermal tolerance. It was suggested that individuals with high degree of control over their environment expressed higher tolerance (Nikolopoulou et al., 2003). Hence, a sufficient diverse environment is highly required in order to perceive and/or experience control (Steemers et al., 2004, p.95). Research on perceived control suggest that the more control individuals' have, perceived or exercised, the greater the tolerance levels to shift away from constant comfort (Steemers et al., 2009).

Nikolopoulou summarized the influence of adaptation (physiological and psychological) on individual's actual sensation in figure 2.16 (Nikolopoulou in Steemers et al., 2004, p.112-113). Authors highlighted the discrepancy found between actual sensation vote and the calculated predicted mean vote, highlighting that the adaptation process is more pronounced in outdoor environments, translated by the significant difference between actual sensation vote and predicted mean vote in outdoor condition (Fig.2.16. a) and the marginal difference in the case of climate chamber conditions (Fig.2.16. d), while b and c refers to controlled HVAC buildings and free-running buildings, respectively (Nikolopoulou in Steemers et al., 2004, p.112-113).

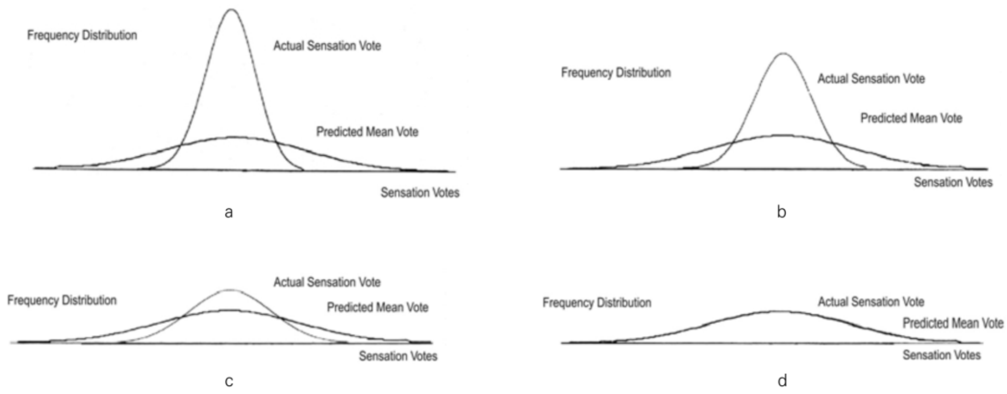


Figure 02.16: the influence of adaptation (physiological and psychological) on individual's actual sensation (Nikolopoulou in Steemers et al., 2004, p.112-113)

2.6 Thermal walks: Investigating transient conditions and dynamic walking experience

This study does not seek to quantify or evaluate the overall walkability of Algiers Casbah. Rather, it focuses on examining the impact of a specific built environment factors on the walking experience, adopting a more pedestrian-centered approach. Therefore, the focus is held on the influence of the microclimate, in the context of transient thermal aeraulic conditions, on the walking experience and the dynamic changes in pedestrians' subjective sensations. It is assumed that a pleasant walking experience would positively influence future walking decisions. If pedestrians have a pleasant walking experience, they will reconsider their future walking decisions. As such, this section reintroduces the thermal walk methodology that is focused on understanding the influence of the surrounding environment on the dynamic experience of pedestrians as they dynamically experience the variations of the outdoor spaces in motion. this section presents a literature review of recent thermal walks conducted across different Mediterranean cities as well as different climatic conditions. The aim of current section is to provide a holistic overview of the method, the environmental monitoring in relation to spatial diversity variables and micrometeorological parameters along with pedestrians' sensations.

2.6.1 Thermal walk methodology

The duration and quality of walking experience is more influenced by pedestrian's thermal experience than by the microclimate conditions per se. A considerable amount of research highlight the importance of pedestrian-centered approach to better understand the dynamic influence of the built environment on pedestrians walking experience (Ameli et al., 2015; Bornioli et al., 2019; Cambra et al., 2020; Dadpour et al., 2016; Johansson et al., 2016; Nagara et al., 1996) as it is crucial in understanding how to create suitable walkable environment. Following the pedestrian-centered approach, thermal walks allow for more holistic knowledge of the simultaneous interaction between the individuals and the transient conditions of their surrounding environment. The thermal walk methodology was proposed by Vasilikou and Nikolopoulou (2013) to analyze the spatio-thermal variability of the urban environment along with exploring the dynamic thermal experience of pedestrians. The methodology consist of conducting structured walks in the urban to capture the variability of the environmental condition while simultaneously assessing the pedestrians' dynamic thermal experience as they walk in the selected walking route(s) (Vasilikou et al., 2013). Such systematical approach was followed by several outdoor comfort studies in relation to the walking experience, and their results revealed in-depth knowledge of the variability of the outdoor environment and the potential of pedestrians to consciously perceive and discern the diversity of microclimate while walking (Chokhachian et al., 2018; Dzyuban et al., 2022; Lau et al., 2019; Liu et al., 2021; Peng et al., 2022; Vasilikou et al., 2020) (Li et l., (2022).

2.6.2 Mediterranean climate

2.6.2.1 Vasilikou & Nikolopoulou (2020)

(Vasilikou et al., 2020) conducted the first thermal walk methodology to identify thermal diversity within complex urban morphology. Their study focus on thermo-spatial diversity and thermal sensation as dynamically perceived by pedestrians as they walk through urban spaces. They investigated walkability in the context of outdoor comfort, specifically, how walking people in a series of transient conditions may experience thermal diversity within instantaneous variations with the possibility of reducing thermal discomfort. A series of thermal walks during summer and winter conditions were conducted in two different historical city centers in London (UK) and Rome (Italy) to represent respectively the cool and temperate (Csa Mediterranean) climate Zone, with a total of 314 filled questionnaires (Vasilikou et al., 2020). One walking route at each city was preselected based on variations on H/W ration, SVF in addition to pre-walk observations of pedestrians' frequentations. Mobile weather station was used to continuously measure variations in air temperature, globe temperature, relative humidity, wind speed and illuminance with 6 focus points after each transition, and where the questionnaire survey was filled simultaneously by subjects during 12 noon and 2pm (Fig.2.17). The questionnaire recorded point-to-point variations in actual thermal sensation vote (ASV), perceived thermal comfort (PTC), wind sensation sunlight sensation, thermal preference and satisfaction along with capturing people's position in relation to shaded and sunlight areas. Statistical analysis were used to describe variations and provide comparative analysis. Results indicated that it is not squares of streets that may present thermal discomfort, but rather the variations created by the transition between a street to an open space which may provide significant thermal variability in the urban continuum (Vasilikou et al., 2020). Significantly, authors stated that despite the low variations in microclimatic conditions from point to point, pedestrians' thermal perception was highly responsive to small microclimate transients (Vasilikou et al., 2020). Importantly, the variations of the aspect ratio within a spatial sequence was found to be the most influential in determining thermal comfort as wind speed and solar radiation variations had

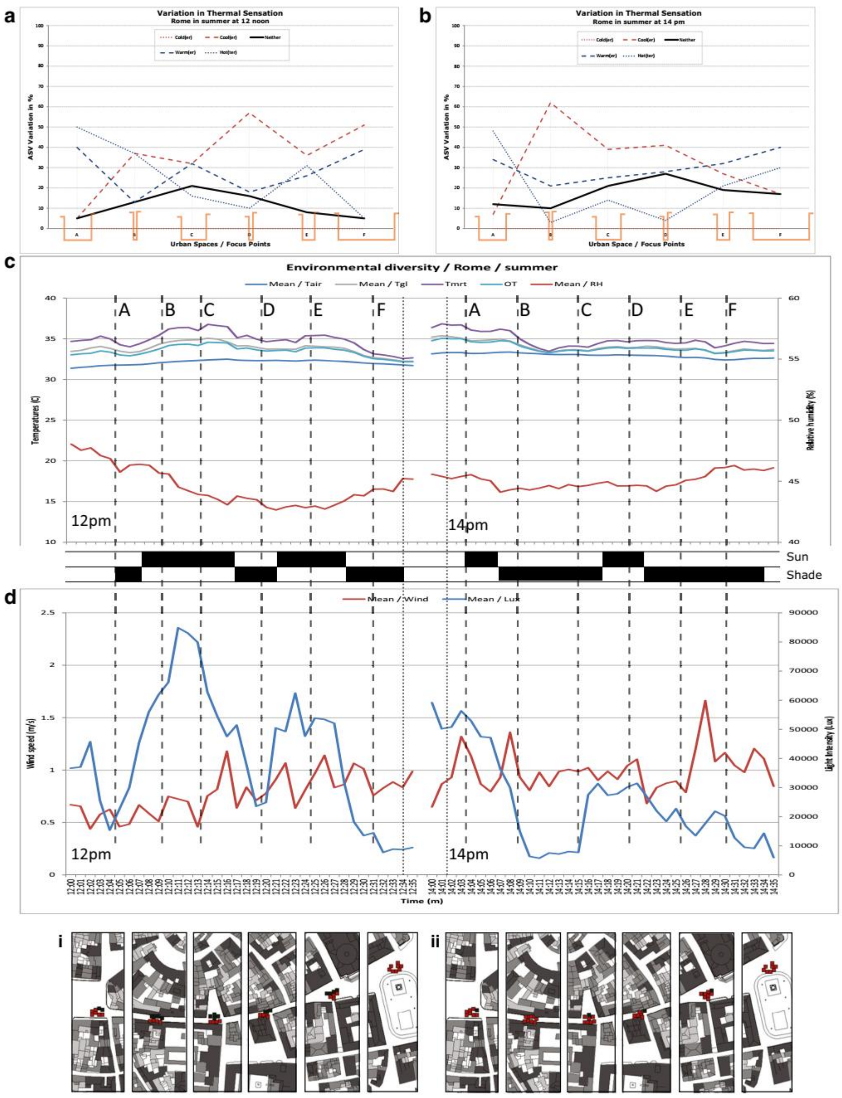


Figure 2.17: Environmental diversity in Rome during summer thermal walks at 12h noon and 14h (Vasilikou et al., 2020)

the highest influence on changes in ASV (Vasilikou et al., 2020). The importance of combining dynamic thermal experience and urban morphology provide a clear understanding of the influence of environmental diversity and transient conditions in enhancing outdoor experience (Vasilikou et al., 2020).

2.6.2.2 Chokhachian et al., (2018)

In sensing transient outdoor comfort, (Chokhachian et al., 2018) proposed thermal walk to monitor and map urban transient conditions in Genoa (Italy) during summer conditions (28th September 2017) for the aim of investigating the effect of thermal history on dynamic pedestrians' comfort. 11 subjects agreed to walk in a closed loop walking route (about 2.5 km) of which subjects shortly stopped every 10 minutes to record their dynamic sensations for a total of 8 stops, in addition to recording their skin temperature. The walking route was designed to cover spatial diversity related to land cover (vegetation, pavement and water), H/W ratios and SVFs, hence the transitions between courtyard with vegetation, paved square, paved street, waterfront street, paved street, paved square with fountain, paved street with green areas and back to the courtyard, respectively. Mobile meteorological station consisting of two sets of loggers (Testo480 and light sensor logger LI-COR LI-1500 with GPS and LI-200R Pyranometer) and were used for continuous measurements (5 seconds interval) of air temperature, relative humidity, wind speed and solar radiation. Microclimate collected data was used to calculate the universal temperature climate index (UTCI) and mean radiant temperature (MRT) in addition SVF using GIS 3D geometry of the 8 fixed points. Their findings revealed significant correlations between urban spatial diversity and outdoor pedestrian comfort, and to what extent people tolerate thermal stress during outdoor activities (Chokhachian et al., 2018). The statistical tests revealed low correlation between UTCI and Tskin and the transient conditions of outdoor conditions arguing that Tskin is only

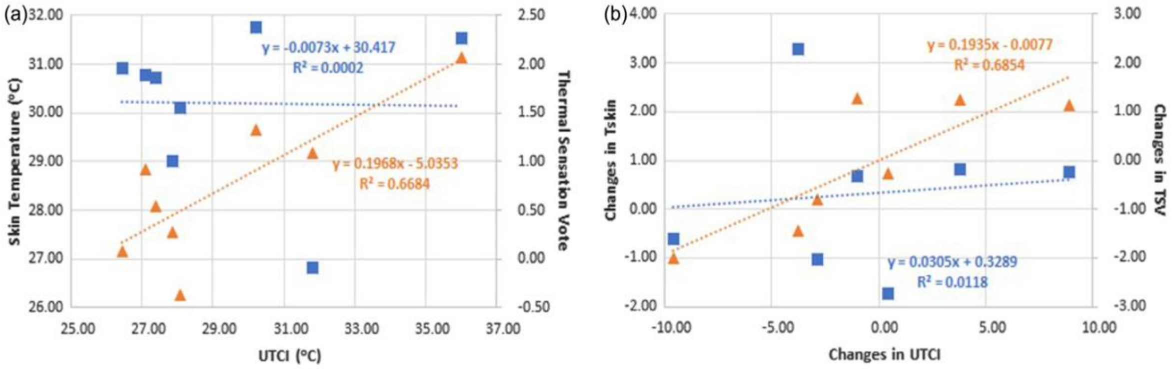


Figure 02.18: Scatterplots between (a) Tskin, TSV and UTC, and (b) changes in Tskin, TSV and UTCI (Chokhachian et al., 2018).

suitable for steady-state conditions, while thermal sensation vote correlated reasonably well with higher values of UTCI of more exposed assessment stops, especially for the changes in both values between survey points (Fig.2.18.(b)) (Chokhachian et al., 2018).

2.6.2.3 Peng et al., (2022)

In a different thermal walk study, (Peng et al., 2022) aimed at understanding the influence of thermal diversity on enhancing pedestrians walking experience in Rome during summer Mediterranean climate Csa. Their study explored the thermal transient sequences along two walking routes in two different walking routes in Rome, a dense and sparse urban suburban context, along with pedestrian dynamic physiological and thermal sensations changes during thermal transients (Peng et al., 2022). Authors combined physical and physiological data to analyzed alliesthesia and the extent of which subjective thermal perceptions correspond or follow actual microclimate conditions. Data were collected using spherical cameras to capture SVF, green view factor (GVF) and obstruction factor (OF); two HOBO portable weather stations to measure air temperature, globe temperature, wind speed and relative humidity, along with calculating the physiological equivalent temperature (PET) and UTCI, and mobile questionnaire survey to record thermal sensation vote, thermal pleasure vote, expected time of staying (ETS) and momentary thermal preference (MPT). Spatial diversity was related to land cover (waterfront and vegetation), density, and degree of enclosure (open and enclosed spaces). Each walking route consisted of 14 fixed points and 1800 m walking distance. 40 subjects (30 females and 10 males) simultaneously filled the questionnaire while the meteorological assessment followed the proposed stop-and-go assessment method of (Qi et al., 2021). Using two portable weather station, the method shortened the time of acclimatization to 4 min (Peng et al., 2022). The 40 subjects were asked to fill in the questionnaire upon arriving and after 5 minutes waiting in each fixed point (transition point) (Fig.2.19). R Studio was used to conducted statistical analysis which consisted of descriptive and correlation statistics (multiple pairs of thermal transitions at entering/leaving the survey Point) linear regression to analyze body thermal sensation and subjective thermal perception, and confounding factors analysis using z test and MANCOVA (Peng et al., 2022). Findings revealed the importance of enclosure, greenery and water bodies in enhancing the walking experience and highlighted that the lack of shading devices may reduce thermal diversity along with reducing walkability (Peng et al., 2022). Moreover, large-scale buildings reduce sun-wind combinations which negatively impacted alliesthesia and adaptation opportunities, aligning with previous findings on the importance of density and coverage in supporting sun-wind diversity (Chatzipoulka et al., 2018; Peng et al., 2022).

2.6.3 Subtropical and hot climates

2.6.3.1 (Lau et al., 2019)

In a different climate context, subtropical climate Cwa, (Lau et al., 2019) aimed at understanding the dynamic thermal comfort and the threshold for tolerance to thermal discomfort of walking pedestrians. Authors conducted thermal walks in two preselected walking routes in high-density commercial area of Hong Kong to compare the dynamic variations of pedestrians' thermal experience. The experiments were conducted during summer conditions on 8 and 22 August and 13 and 14 September 2016, from 2 p.m. to 4 p.m. to represent the critical summer conditions (Lau et al., 2019). The two walking routes were designed to cover the spatial diversity in relation to orientation, SVF, shade patterns and aspect ratio, for approximately a 60 minutes walking duration (Fig.2.20). Each walking route consisted of 15 survey points to capture variation in pedestrians' thermal sensation votes in a longitudinal survey of 14 participants (university students aged 19 and 21) (Lau et al., 2019). The mobile micrometeorological measurement were instantaneously conducted with the questionnaire survey using a mobile backpack-type weather station consisting of a

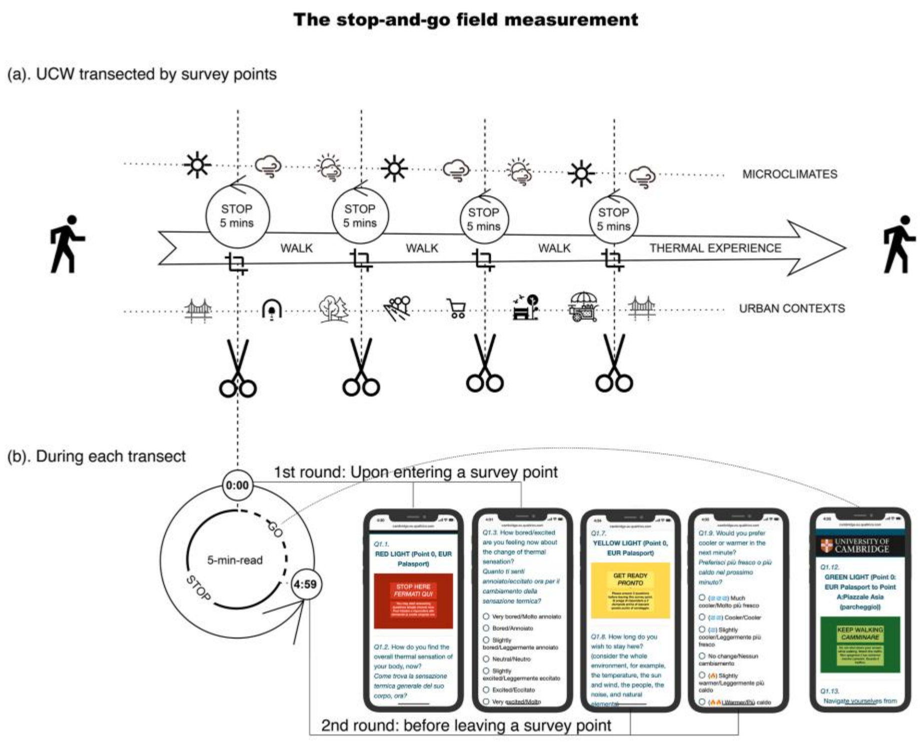


Figure 2.19: The stop-and-go- thermal walk framework (Peng et al., 2022)

TESTO480 digital microclimate sensor set to measure air temperature relative humidity, wind speed (v) and globe temperature (Lau et al., 2019). MRT and PET were calculated based on the measured microclimate data in addition to SVF values calculated from fisheye photos. Autocorrelation and partial autocorrelation were used to investigate the possible time-lag effect of thermal sensation, and cross-correlation analysis tests were used to determine the time lag (s) of the effect of the meteorological variables, PET, and the reported TSVs (Lau et al., 2019). Results indicated significant spatiotemporal variations in meteorological conditions with high fluctuation of Ta, wind speed (v) and MRT highlighting the significant effect of transient street morphology (Lau et al., 2019). High Ta and Tmrt were found in the N-S oriented street of route 2 with the exceptions of roadside trees that provided transient shading patterns, hence a significant decrease of Tmrt (Lau et al., 2019). Moreover, high wind speeds in the same road corresponds to lower air temperature, highlighting the significance of shading and ventilation in high density cities (Lau et al., 2019). Participants noted high TSV when moving form sunlit to shaded areas, and when there was significant difference in PET values (Lau et al., 2019). High TSV values were located in more exposed streets and large open space, however, trees marked noticeably lower PET of about 29°C and occasional lower TSVs between the higher TSVs, serving as ‘breaks’, which was explained by the influence of thermal history and thermal ‘alliesthesia’ using Autocorrelation and cross-autocorrelation statistical analysis (Lau et al., 2019). Authors suggested that the meteorological conditions may induced a possible effect of tolerance and a delayed response to pedestrians’ thermal sensation in motion and the short-

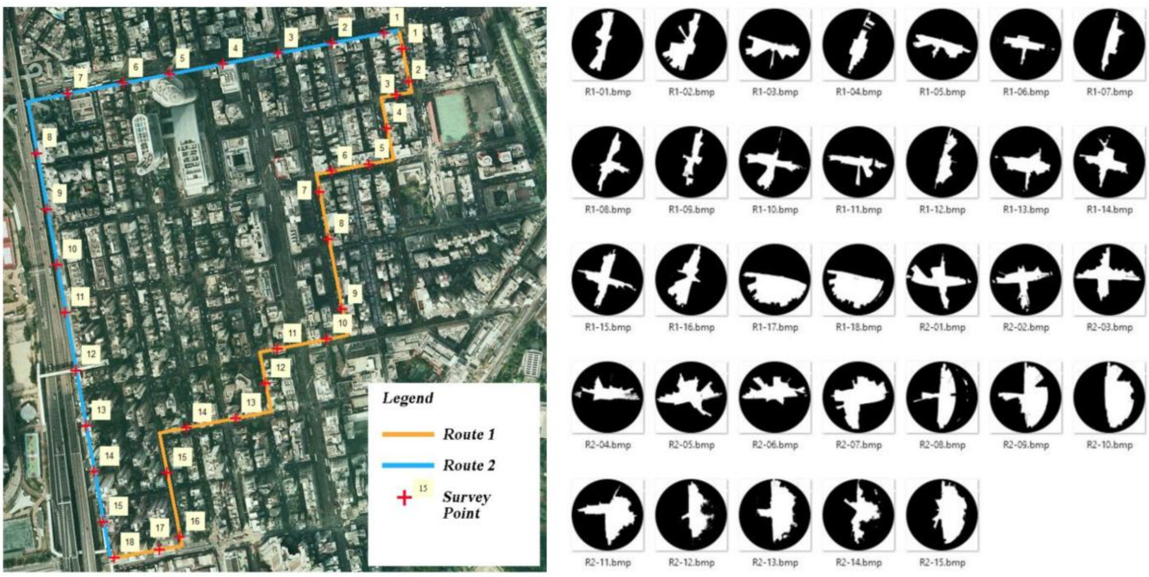


Figure 2.20: selected walking routes and fish-eye photos of each survey point (Lau et al., 2019)

term 'memory' of previous experience affected their satisfaction levels, which was confirmed with insignificant cross-correlation with lag-2 values (Lau et al., 2019). Authors concluded that in a continuous exposed environment, pedestrians' thermal experience is overwhelmed by prolonged exposures, while a dynamic environment with transient conditions may have higher potential to allow pedestrians to find pleasant conditions during their walk, accounting for the alliesthesia effect and levels of tolerance to thermal discomfort (Lau et al., 2019).

2.6.3.2 (Liu et al., 2021)

In a different thermal walk, (Liu et al., 2021) conducted thermal walks for the aim of validating a proposed six-dimensional semantic space in contrast to the one-dimensional scale of thermal sensation vote. Authors elaborated a six-dimensional semantic space for outdoor thermal comfort assessment that includes four descriptive dimensions – 'temperature', 'humidity', 'wind', 'solar radiation' - and two affective –'thermal pleasure' and 'thermal intensity' dimensions (Liu et al., 2021). Thermal walks consisted of exposing 22 selected participants to a variety of outdoor thermal microclimates and asking them to record their overall subjective thermal experience at each exposure in subtropical Sydney Cfa (Australia) during both summer winter conditions. Each walk was performed individually and consisted of 14 thermal transient scenarios for a total of 70 min. Thermal diversity consisted of exposing participants to direct sunshine for 5 min and then moving into shade for another 5 min. The sunshine-shade transition was repeated three times before applying local thermal stimulation to distal limbs for another 5 min; Later, participants were asked to step up and down a small stepladder for 15 min to elevate their heart rate; finally, they were asked to rest for 5 min before another cycle of local thermal stimuli (5 min of heating/cooling panel and 5 min of heating/cooling fan) (Fig.2.21). the subjects were given the questionnaire before and after thermal transition to capture the transient thermal alliesthesia with the intervals of 2–5 min. The questionnaire took less than 1 minute in which participant rated their overall subjective experience 'right-here right-now' by rating each of the six dimensions, later called 'thermal affect', with scores ranging from 0 to 100 (Liu et al., 2021). They recorded their thermal sensation (Tstr) along with its thermal pleasure rating (Pstr) on bipolar Likert scales (rescaled 0–100). Simultaneously microclimate data, air temperature, relative humidity, shortwave and longwave radiation and wind speed, were measured by a mobile weather station in addition to measuring metabolic rate for each participant and calculating MRT (Liu et al., 2021). Collected data was analyzed using different statistical analysis. Results of the microclimate exposure indicated that among the microclimate data, wind speed and MRT showed the most variability in the field experiments. Importantly, subjects were insensitive to changes in wind exposure due the small range of transitions (e.g. 0.5 m/s ~1.1 m/s) in addition to the fact that the walks were conducted in mild-to-warm conditions (Liu et al., 2021). Notably, participant were more sensitive to changes in solar radiation intensity when their thermal status was in the warm-hot range, suggesting evidence of negative and positive alliesthesia which was further demonstrated when moving back and forth between negative and positive alliesthesia with each transient from sun to shade or vice versa (Liu et al., 2021).

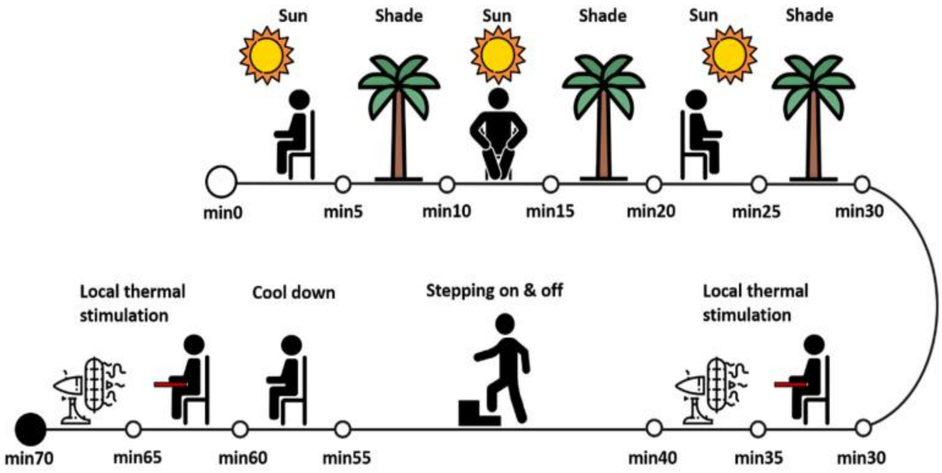


Figure 2.21: the timeline of the field experiment of moving between sunlit and shaded areas in the outdoor environment (Liu et al., 2021)

2.6.3.3 (Dzyuban et al., 2022)

In a hot and dry climate (Bwh), (Dzyuban et al., 2022) conducted thermal walks for the aim of understanding the variations in subjective thermal judgments of pedestrians within transient urban morphologies. Thermal walks were one of the efforts of redeveloping the study area, The Edison Eastlake neighborhood (Phoenix, USA), by ensuring street walkability and public safety. A 1 hour walk around the neighborhood was planned to capture transient urban conditions including narrow arterial streets, large vacant land, two parking lots and a school playground (Dzyuban et al., 2022). The spatial diversity was related to SVF, shade, vegetation and orientation, two main elements for controlling shading patterns. The walks were divided into seven stops, dividing the walking route into street segments. 14 residents agreed to participate in the thermal walks in September 29 (2018) between 4 pm and 5 pm. After resting for 30 minutes, subjects were asked to report their thermal sensation (TSV) and outdoor comfort (OTC) in relation to momentary sensation at each stop, while they were advised to report their perception of pleasure regarding the previously walked segment in addition to questions of proposed changes in urban design and estimated percent of shade (Dzyuban et al., 2022). Simultaneously, continuous micrometeorological measurements of air temperature, relative humidity, wind speed, short wave and longwave rations were taken using mobile weather station ‘MaaRTy’ to calculate MRT, physiologically equivalent temperature (PET) and modified physiologically equivalent temperature (mPET) for each study participant. Additionally, SVF of each stop and per segments were calculated using fisheye images captured during the thermal walks. Data analysis were based on statistical tests conducted using RStudio (Version 1.3.1056). Descriptive statistics and Spearman's rho correlations were used to analyze Demographic and Likert scale for the aim of revealing significant relationships between subjective thermal judgments and microclimate conditions; Subjective thermal sensations were separately analyzed for correlations with average meteorological values per stop, previously walked segment, and combined average per stop and previous segment; Z-scores were calculated and plotted for subjective sensations to compare changes between the stops (Fig.2.22); both PET and mPET exhibited non-normal trends, hence the use of non-parametric statistical significance tests (Wilcoxon-Pratt Signed-Rank. Kruskal-Wallis chi-squared and Linear regression (Dzyuban et al., 2022). Their findings revealed that the largest changes in thermal sensations and pleasure occurred at the point of PET changes and not at the lowest values. that is to say that changes in subjective thermal experience occurred at the point of transient microclimate conditions and not at the lowest/highest values per se (Dzyuban et al., 2022).

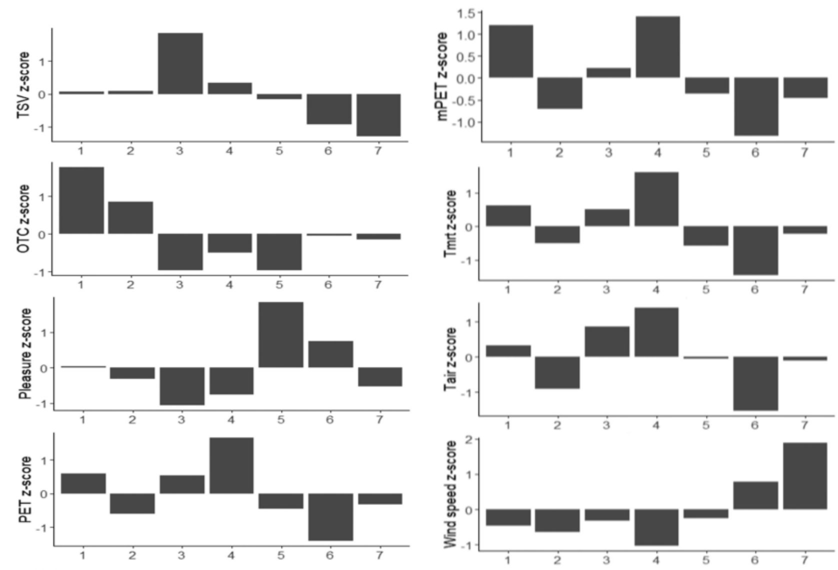


Figure 2.22: Calculated and plotted Z-scores for subjective sensations to compare changes between the stops (Dzyuban et al., 2022).

2.6.4 In-between spaces

2.6.4.1 Nagara et al., (1996)

Similar to thermal walks, the consideration of thermal perception and sensations in transient conditions in designing thermally pleasant outdoor spaces have long been stated by (Nagara et al., 1996). The authors conducted structured walks for the aim of understanding the influence of variant thermal environments of urban outdoor spaces. The walks conducted (Summer & autumn) June, August, October and November 1991 at around 3 pm, in the business district of Osaka (Japan) (Subtropical climate Cfa) (Nagara et al., 1996). Outdoor spaces consisted of a sidewalk on the ground, an air-conditioned underground shopping center and a concourse of a subway station which was a no air-conditioned in-between space. The sidewalk was characterized by the presence of vegetation (trees), an elevated road passing by a river and areas covered with pilotis. Air temperature, relative humidity and wind velocity were measured while walking in series of 6 fixed point along the walking route named A-B-C-D-E-F. Simultaneously, university students aged between 19 and 24 were recruited to fill in questionnaire of thermal sensation variations along the walking route. Participants were divided into two groups; the first group walked in the order of A-B-C-D-E-D-F (route 1) while the second group walked in the inverse order of F-D-E-D-C-B-A (route 2) (Fig.2.23). Subjects were asked to record their thermal sensation in the map of the survey area in addition to the reason when they felt a change independently from the fixed assessment points. Subjects were asked to record their thermal sensation, using the seven-point scale, while walking as well as when they stopped at an intersection. Results from the microclimate measurements revealed significant fluctuations in air temperature around the underground shopping center which was air-conditioned. Results also revealed significant differences in the thermal evaluation between the two groups (Nagara et al., 1996). In comparing between the physico-thermal environment and thermal sensation, results indicated that in route 1, many points indicating hot to very hot sensations were concentrated around point D, due to moving from air-conditioned underground street to an over-ground outdoor street, therefore experiencing a sudden rise in air temperature. Notably, in route 2, the concentration around point D has disappeared. More specifically, at the entrance of the underground street. Authors suggested that pedestrian thermal sensations were affected by history of exposure to the previous environment, which explains the difference of thermal sensation between two subjects walking in opposite directs (Nagara et al., 1996). It was concluded that the difference in the history of exposure is an important factor in reporting thermal sensation. Importantly, authors highlighted the importance of designing in-between spaces as buffer zone from the exit to the outdoor space and an intersection is important for outdoor pedestrian comfort (Nagara et al., 1996).

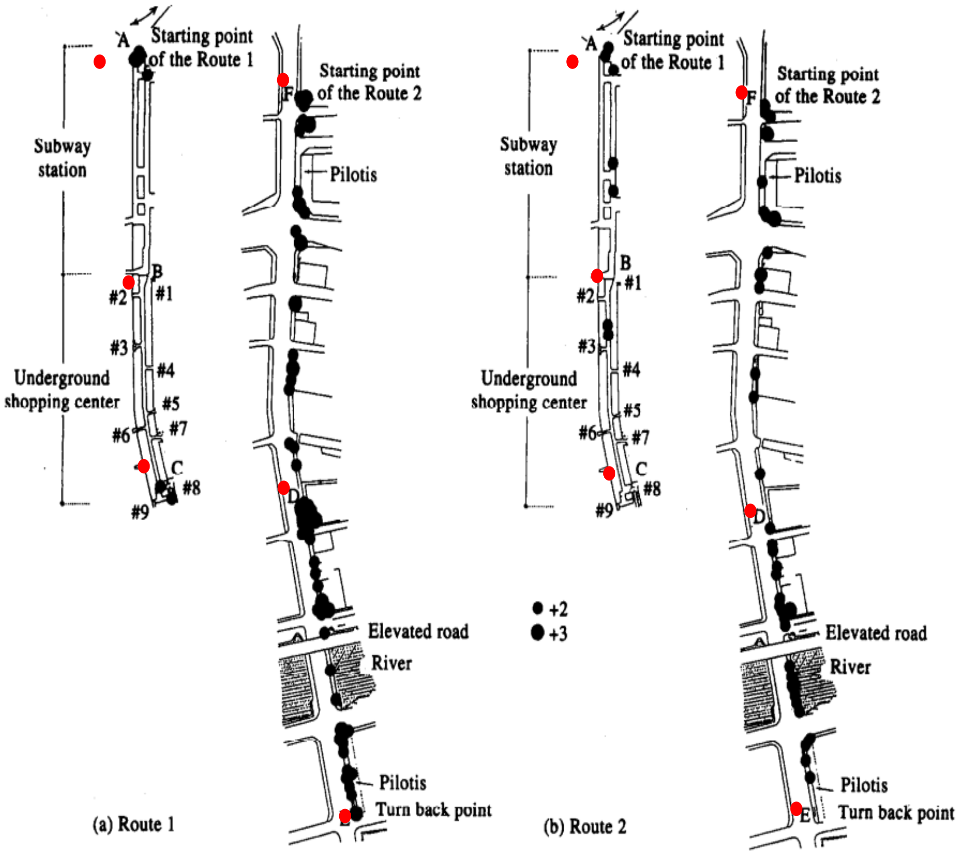


Figure 2.23: selected walking route in the order of A-B-C-D- E-D-F (route 1) and in the inverse order of F-D-E-D-C-B-A (route 2) (Nagara et al., 1996).

2.6.4.2 Nakano (2003)

Nakano (2003) revealed the influence of short occupancy time within in-between spaces on thermal comfort in the succeeding environment (Nakano, 2003). The author evaluated the influence of a buffer space's thermal conditions on individuals' thermal comfort changes in a succeeding environment. The subjective experiment was conducted in a climate chamber to simulate subjects leaving indoor space toward an outdoor space, passing by a buffer space (in-between), and then going back to the indoor space. Summer conditions were chosen for outdoor space since buffer space's effect was assumed to be greater in Waseda University, humid subtropical Tokyo (Cfa) (Japan), starting from 9:00, 13:00 and 17:00. Thermal transitions were controlled following the order of 60 minutes in indoor space (25 °C, 50-60 %RH), followed by a buffer space controlled at 3 conditions of 22, 25, 28 °C, with different transition periods set at 3, 5, and 10 minutes, outdoor space for 15 minutes (32 °C, 70 %RH), back to the buffer space for the same settings, and the indoor space for another 60 minutes (Nakano, 2003). 12 Participants were asked toto fill in the questionnaire every 10 minutes in the indoor conditions, upon entering and before leaving each buffer space and outdoor conditions and every minute for the first 10 minutes upon entering the indoor space and then every 5 min (Nakano, 2003). the questionnaire included “environmental temperature sensation vote (ESV)”, “whole body thermal sensation vote (TSV)”, “comfort sensation vote (CSV)”, “sweat sensation”, “clothing acceptability”, “wet body part”, and “thermal acceptability” (Nakano, 2003). Results indicated that subjects were more sensitive to lower temperature changes than higher temperature changes (Nakano, 2003) (Fig.2.24). Temperature conditions of the in-between space had the most significant effect on ESV, while the thermal transitions of buffer space was confirmed to have very small influence on thermal sensations after 40 minutes occupancy (Nakano, 2003). Variations in ESV was associated to that of CSV during step changes toward neutral conditions (25°C) (Fig.2.25), suggesting that larger deviation from comfort results to larger positive comfort (Nakano,

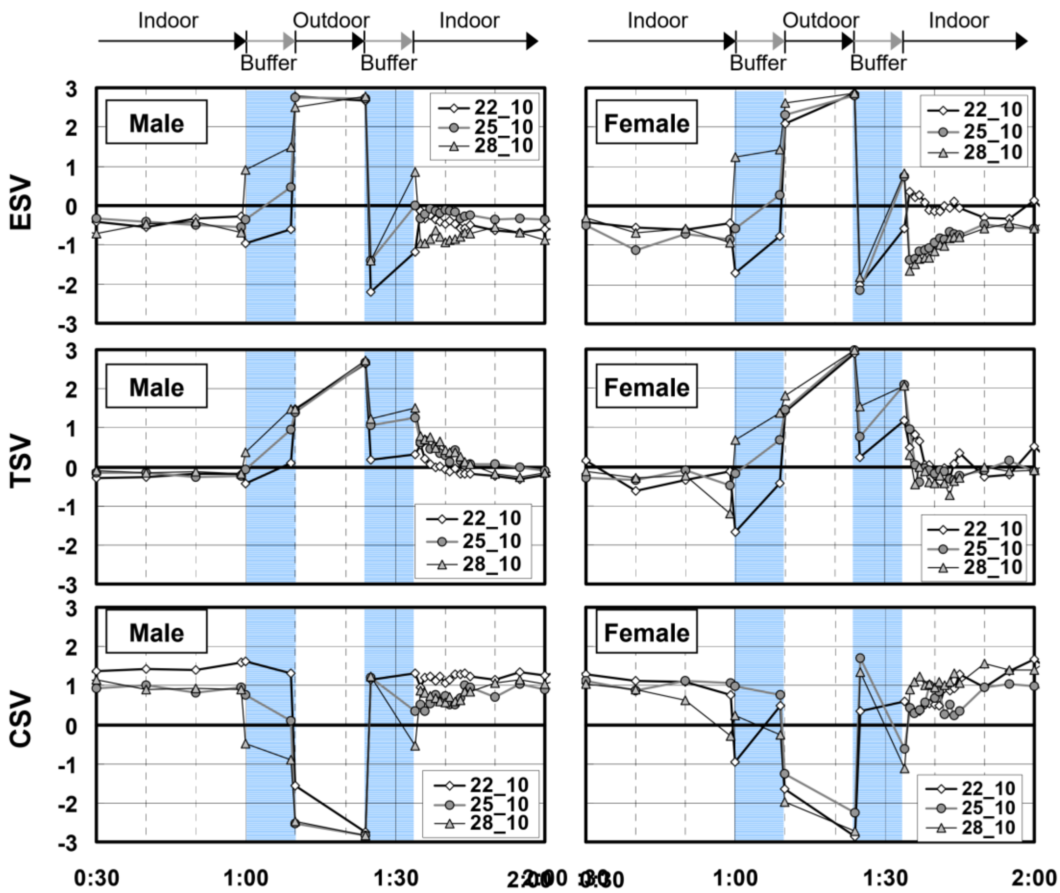


Figure 2.24: ESV, TSV, and CSV during 10-minute transition phase (Nakano, 2003)

2003). However, author argued that assigning the optimum CSV variation pattern for a given period of time requires further investigations (Nakano, 2003).

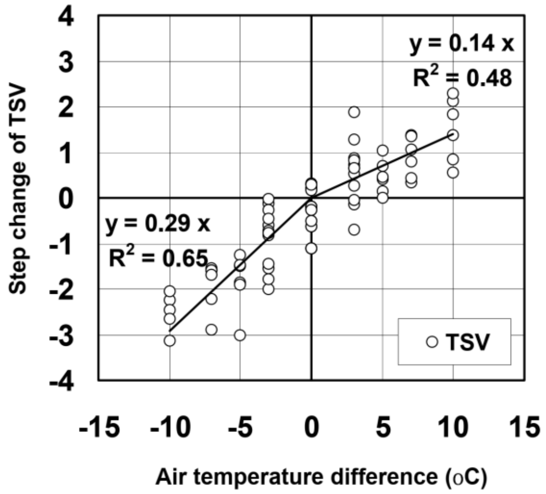


Figure 02.25: step changes of TSV in relation to air temperature differences (Nakano, 2003)

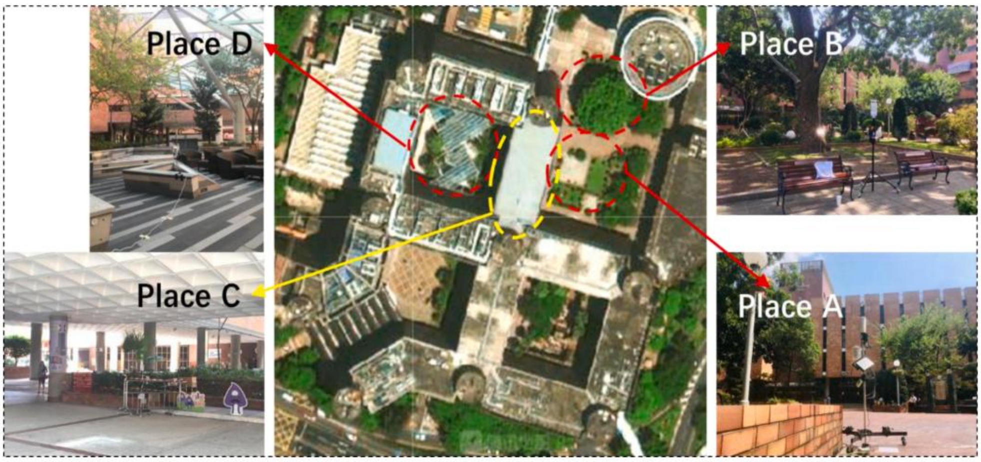
2.6.4.3 Lie et al., (2022)

Li et l., (2022) investigated the dynamic effect of frequent step changes in outdoor environment on pedestrian's thermal sensations during summer conditions in subtropical hot-humid climate Cwa Hong Kong (china). The aim was to understand how microclimate step changes of different frequencies affect thermal comfort for the aim of improving outdoor comfort. Authors highlight the importance of treating the frequency of these step changes as a potential factor. A second aim was to point out limitation of UTCI in estimating impacts of variations of sun and wind conditions on thermal comfort (Li et l., (2022).

Following thermal walks approach, the field surveys were conducted in adjacent 4 places A, B, C and D on campus of a university in May, July and September (2018), during the afternoon, when thermal condition difference between sunlight and shade exposure is expected to be larger in hot-humid subtropical climate. The spatial diversity consisted of variations between sunlight-shade exposure. The place A is an open area exposed directly to solar radiation, place B is a shaded area with a large tree, place C in an in-between space with lift-up design characterized with low solar exposure and strong wind velocity, and place D is a semi-open area beneath a glass canopy allowing solar exposure.

48 participants were asked to expose to sunlight and shade transients formed by the four places. That is walking from shade to sunlight (downward) and from sunlight to shade (upward). (Li et l., (2022). In addition, authors combined different frequencies related to time of exposure to shade which was set to be either longer or shorter that in sunlight, or to be equally the same, assuming that “a sequential downward step change appears within the time required to achieve steady state might assist in relieving the heat stress on hot days” (Li et l., (2022). Each experiment lasted about 45 min and had no more than 8 rounds (Fig.2.26).

The questionnaire consisted of ASHRAE 7-point Thermal Sensation Vote (TSV), Thermal Comfort Vote (TCV), Desire for changing Wind/Solar conditions. Subjects were asked to fill in the questionnaire in the first minute upon and last minute before each transition (if the exposure lasted more than 1 minute). Microclimate conditions of air temperature, relative humidity, wind velocity and globe temperature, in sunlight and shade were measured by two sets of mini-weather stations, with a 10 s interval. Data analysis were conducted using statistical analysis IBM SPSS 24.00, mainly Spearman rank correlation between subjective sensation and comfort indices; T-test and one-way/two-way between groups ANOVA analysis were used to examine the differentiation of a dependent variable. Findings revealed the significance of alternating between shaded and sunlit areas in amplifying the cooling effect, especially at lower transition frequencies. The authors also revealed the importance



	Sunlight	Shade	Sunlight	Shade	Sunlight	Shade	Sunlight	Shade	Sunlight	Shade	Sunlight	Shade	Sunlight	Shade	Sunlight
Sequence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Round	1	2	3	4	5	6	7	8							
Experiment type1	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min
Experiment type2	3 min	6 min	3 min	6 min	3 min	6 min	3 min	6 min	3 min						
Experiment type3	3 min	3 min	3 min	3 min	3 min	3 min	3 min	3 min	3 min	3 min	3 min	3 min	3 min	3 min	3 min
Experiment type4	6 min	3 min	6 min	3 min	6 min	3 min	6 min	3 min min	6 min						
Experiment type5	4 min	1 min	4 min	1 min	4 min	1 min	4 min	1 min	4 min	1 min	4 min	1 min	4 min	1 min	4 min

Figure 2.26: location of the measurement and questionnaire survey points and the timeline framework (Lie et al., 2021)

of frequency of microclimate changes in enhancing psychological factors related to thermal expectation and alliesthesia. On the other hand, authors suggested that UTCI in insufficient in case of non-steady state environment assessment (Lie et al., 2021).

2.6.5 Conclusion

Pedestrian's walking experience is constantly influenced by the surrounding environment. In addition to the outdoor environment, the walking activity, pedestrians in motion, is impacted by several factors including the duration of the walk, history of exposure and past experience along with threshold of adaptation and tolerance. The current chapter shed light of the importance of environmental diversity in enhancing outdoor comfort. it introduced how variations in the street geometry characteristics and in-between spaces design attribute could generate spatial and thermal aeraulic transients. Both the degree of enclosure and solar orientation have significant influence on heat access and wind flow patterns within the streets. While open streets increase solar exposure and heat stress, a reduced degree of enclosure can trap heat in the absence of adequate wind flow. Therefore, achieving balanced density and coverage is critical to ensuring adequate environmental diversity. Notably, the process of adaptation depends on the range of diversity variations. it was suggested that environmental diversity enhances outdoor comfort up to a certain threshold, beyond which additional diversity may no longer be (Chatzipoulka et al., 2020). The aim of environmental diversity in current study goes beyond designing choices between alternatives, but also by design gradually adaptive environments.

Accordingly, pedestrians' subjective experience is influence by several elements, rather than the outdoor conditions per se. Along with the importance of environmental diversity, thermal alliesthesia was also highlighted. The influence of history of exposure, past experience and their influence on physiological and psychological adaptation and threshold of tolerance is of a significant importance. On the one hand, the influence of outdoor environmental conditions, spatially and thermally, on the walking experience was recently addressed in the literature using the thermal walk methodology. The literature review highlighted the significance of thermal walks methodology in providing in-situ detailed environmental and subjective data. Moreover, it revealed the importance of the interaction between the outdoor conditions and the instant and dynamic variations in pedestrian's experience. The aim of the literature review was to provide holistic knowledge of current thermal walks methodological approach and results and to reveal the research gap in relation to the current study.

Building on this knowledge, the following chapter will present how the thermal walk methodology was adapted within the framework of the current study, with the novelty of addressing historical center with steep topography and its influence on the fatigue sensation, thermal alliesthesia and overall walking experience.

Chapter 3: The Sabat space in Mediterranean cities: Algiers Casbah case study

3.1 Introduction

Human settlements had a major role in diffusion and continuity of cultures, arts, architecture and urbanism. In the Mediterranean region, the different influences and fusion of overlapping empires, mainly, Byzantine, Islamic and Ottoman, contributed to the adoption of the Sabat design in several Mediterranean cities of different reigns and cultural influences such as the case of Islamic and non-Islamic cities. This chapter does not aim to chronologically trace the formation of Mediterranean cities or to define their characteristics. Instead, it focuses on examining the successive empires and dynasties that emerged and spread across the Mediterranean basin during the Middle Ages, highlighting their role in the diffusion of the Sabat space across both Muslim and non-Muslim cities. Emphasis is placed on how the Sabat space was manifested and adapted within various cultural contexts including Islamic, Arabic and European cultures.

In the second part of this chapter, the scope is held on the historical city of Algiers Casbah, a prominent example of a Mediterranean city. The Casbah exemplifies cultural fusion and stratification, shaped by its topography, natural environment, and historical events, all of which contribute to its unique Mediterranean identity. Focusing on the Sabat design, the second focuses on identifying and mapping the existing Sabats within the urban fabric of the Casbah, shedding light on their spatial distribution and current condition. By documenting and analyzing these structures, the chapter establishes a critical foundation for applying the methodological approach of this study, offering valuable insights into the Sabat's role within this iconic Mediterranean city.

3.2 Mediterranean region's historical overview

Between the 23rd BC and 16th century CE, the Mediterranean Basin, surrounded by lands of the North Africa, Western Asia, and Southern Europe, witnessed the rise and decline of various powerful empires (Valério, 2018). That is to say, in Common Era (CE): Algeria, Morocco, Tunisia, Libya, Egypt, Syria, Turkey, Greece, Italy, France and Spain. Human settlements in these lands played a major force in shaping the history of the Mediterranean region. The cultural spread and fusions within the Mediterranean cities emerged from commerce and trades on one hand, and through invasions and conquests on the other hand, which extended beyond the physical boundaries (Shmueli, 1981). The Egyptians, Sumerians, Babylonians, Persians, Hittites, Phoenicians, Mycenaeans, the Greeks, the Romans, Byzantines and later the Muslims, including Ottomans as they diffused and overlapped within the Mediterranean lands, have all influenced the formation if the cultures, architectures and cities (Shmueli, 1981).

Despite growing complexity in the Mediterranean in ancient history, it remained politically and economically fragmented. However, the potential for unity was observed in large populated states forming—first in the eastern Mediterranean and later in the west, led by the rise of the Roman Republic on the Italian peninsula (Hitchner, 2009, p.432). These traditional cities across the Mediterranean region developed while highlighting the significance of cultural transmission in the region that surpassed the tempo-physical boundaries.

3.2.1 Roman and Byzantine Empires

The Mediterranean Basin was unified under the Roman Empire from the 2nd century BC to the 4th century CE, which covered the majority of land surrounding the Mediterranean Sea, mainly what is now Italy, Greece, Turkey (where the Byzantine capital was Constantinople), North Africa and the Middle East, while the Near East region was mostly occupied by the Parthian Empire (Iran) (Benabed, 2011, p.24-28). The beginning of the middle age marked the taking of the Parthians (Iran) by the Sassanid Empire (pre-islamic iranian empire) between 3rd -7th century CE, the fall of Spain and Carthage to the Vandals in 436 and the fall of the Roman Empire which led to a fragile western Roman Empire (4th – 6th centuries) and a resilient Eastern Roman (4th – 13th centuries CE) (Benabed, 2011, p.24-28). The center of the Roman Empire shifted to the East in Constantinople, becoming the Byzantine Empire which regained Carthage in 533 and parts of Italy and Spain (Benabed, 2011, p.24-28).

3.2.2 Islamic conquests

On the other side, the Medieval history was marked by the significant appearing of the Islam and Islamic conquests starting the 7th century CE. Islamic conquests established a new unity across the Mediterranean, especially with the main focus of Islamic trades and communication confined to the southern and eastern shores (Benabed, 2011, p.24-28). During 674 to 717 (7th century), the Constantinople of Byzantines (Istanbul) faced Arab sieges, marking the major conflict of the Arab-Byzantine war and revealing a new era during which there established the Islamic world (7th – 9th centuries) which replaced the Sassanid Empire and parts of the Eastern Roman empire (Valério, 2018) (Fig 3.2). The Arab-Islamic conquests originated from the Arabian Peninsula (Saoudi Arabia), expanded along the North African coast and reached the coast of Sicily and Spain, hence the influence of Arabs on

Italian and European cultures (Moscati, 1985). The Arabs, having embraced the new religion of Islam, began a rapid conquest of Byzantine Syria-Palestine and Egypt and Cyrenaica (northeastern Libya) around 642 (Chaïbi, 2012) p46.

Beginning with the Umayyads (661–750) ruling out of Damascus (Syria) and later Cordoba (Spain) (756−1031), a series of dynastic empires assumed the leadership of Islam each contributing to the development of Islamic urbanism (Alsayyad et al., 2009). By the 8th century the Islamic empire extended to India and China in the east, and reached Spain, passing by several Berber tribes of north Africa through several Islamic Caliphates (Chaïbi, 2012, p.48). In the 8th Century, North African tribes (*Harawa*, *Kutama*, *Zanata*, *and Sanhadja*) gradually embraced Islam in 697-698 (Chaïbi, 2012, p.48). In the East, opposition movements against the Umayyad central authority began spreading among the populations of the Maghreb (Chaïbi, 2012, p.51). North Africa became a refuge for a continuous influx of people from the East, including soldiers, merchants, and those fleeing the Umayyad rule in Damascus, and found a degree of stability with the establishment of the Aghlabid dynasty in Kairouan (in Tunisia) who launched later conquests toward Sicily and the coasts of Provence (Chaïbi, 2012, p.51) (Fig. 3.3). The new Abbasid dynasty in Baghdad overthrown the Umayyads of Damascus from 750 to 1258 (Chaibi, 2012 p.51) (Fig. 3.4) while Fatimid of Egypt (909-1171) undertook efforts to regain control of the far Maghreb in 935, following Umayyad attempts from al-Andalus (Islamic Spain) to influence the region (Chaïbi, 2012, p.57) (Fig. 3.5). A new local Berber governor of the Maghreb, Yusuf Bologhine (Zirid), had to launch campaigns against several centers of rebellion in north Africa (Chaïbi, 2012, p.57) . By 960, the entire North Africa had been pacified and was under the Fatimids, who lunched expeditions targeting Sicily, southern Italy, and even Crete (Chaïbi, 2012). Later, The

Figure 3.1: Umayyad Dynasty of Damas extending toward North Africa and Spain *((Bisheh in Assari, 2011, p.38)*.

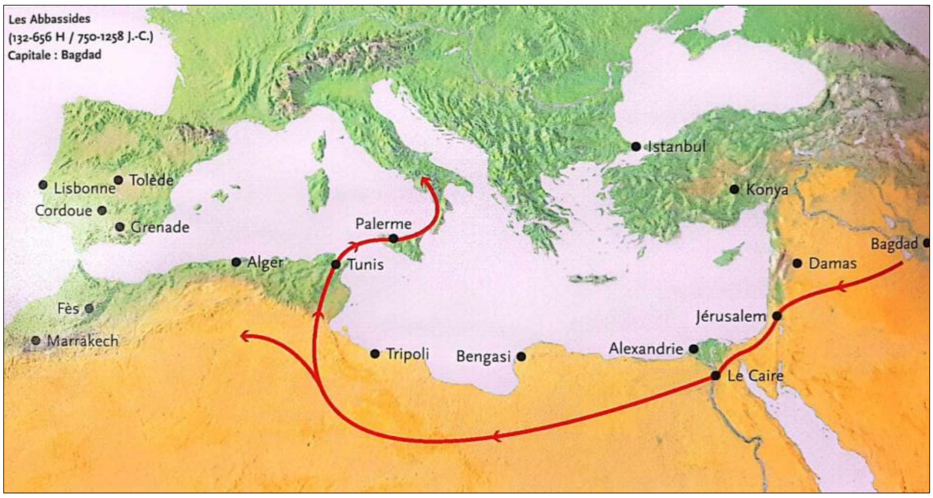


Figure 3.3: Abbasid Dynasty of Baghdad reaching Sicily and parts of the Southern Italy *((Al-Ghilani and Chapoutot Remadi in Assari, 2011, p.60).*

Figure 3.2: Fatimid Dynasty of Damas reaching Palermo in Sicily *((Al-Khamic in Assari, 2011, p.106).*

Almoravids, Saharan Berber group (Sanhadj), began their conquest of central Maghreb in 1079, occupying parts of north Algeria (Chaïbi, 2012, p.62). From 1150 to 1250, the Maghreb was unified by the Almohad during which the period was marked by the peak of Muslim art and culture (Assari, 2011, p.19-20).

3.2.3 Ottoman Empire and European conquests

The 16th century witnessed the emergence of the Ottoman Empire, while the western Mediterranean was much influenced by the Crusade and Christianism (Valério, 2018). The Ottoman seized Egypt from the Mamluks in 1517 and expanded their domination to Constantinople, the last Byzantine bastion, taken in 1453, therefore dominating eastern and Western Mediterranean (Chaïbi, 2012, p.77). The Empire expanded to North Africa, the

Middle East and the Balkan around the 15th and 18th centuries (Alsayyad et al., 2009). All the coasts surrounding Greece came under Ottoman domination, with numerous raids on southern Italy, Libya and the northern coast of Africa. (Chaïbi, 2012, p.77). Starting in 1587, the empire reorganized its territories in North Africa into three Pashaliks: Algiers, Tripoli, and Tunis (fig.3 4) (Chaïbi, 2012).

The year 1300 CE (13th century) was marked by the obliterated of Arabs from Italy, resulting in a great shift in History with the return of the European dimension who began to regain the initiative in the western Mediterranean (Chaïbi, 2012, p.75). Two events contributed to this, which were the fell of Arabs in Spain and the emergence of the Ottoman caliphate which extended to all north African states (Moscati, 1985). The struggle for the Mediterranean culminated in 1571 with a major confrontation at the Battle of Lepanto, marking a turning point in Ottoman naval (Chaïbi, 2012, p.80). Moreover, Portuguese and Spanish expansions toward the North African coasts were accompanied by mass expulsions of Muslims, thousands sought refuge in the northern African cities such as Algiers (Chaïbi, 2012, p.75).

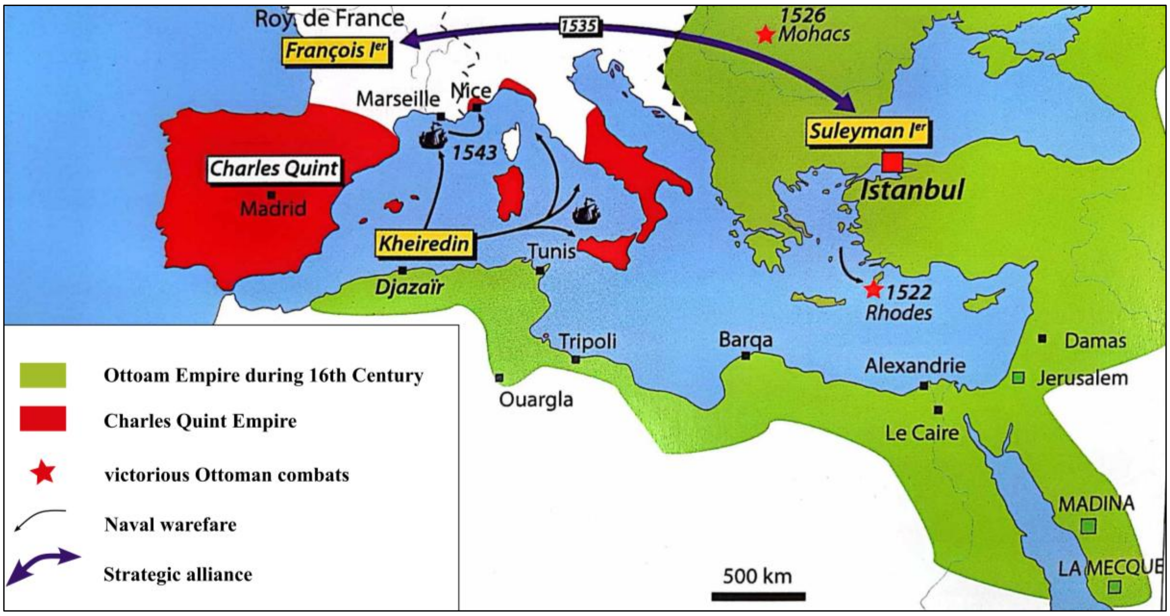


Figure 3.4: Ottoman Empire during the 16th century, adapted from (Chaïbi, 2012, p.80).

3.3 Mediterranean urban similarities

During these overlapping dominations, cities around the Mediterranean region encountered several similarities as well as significant differences. Climate, topography, political and socio-economic factors all contributed to shaping their architecture and urban practices. Exploring the origin creation of the Sabat spaces goes beyond the scope of the current study. Instead, this section present an overview of the Islamic urbanism as the Islamic period emerged in-between the Byzantine and Ottoman eras, historically, allowing to reveal urban similarities on how the Sabat space was manifested and adopted, within these empires, highlighting the interplay between the Sabat design, climate and cultural differences that ensured the continuous influence over time and space.

3.3.1 The Islamic influence

The middle East and North Africa were the center of Islamic cities where Islam originated and spread. Overlapping the previous influence of the Byzantine, along the southern and Eastern Mediterranean cities, Arab and Islamic influences have felt their traces on Sicily, Italy, and Arab (Moorish) influence was notably felt in Spain (Shmueli, 1981). Such influence is not only the result of the Islamic occupation in the Italian territories but also from contacts and trades with Islamic cities across the Mediterranean Sea (Moscati, 1985). The spread of Islam was simultaneous with the formation of cities as it framed the urban society (Acun, 2002, p.260). The Islamic urbanism reflects reasonably the Islamic culture, hence the special relationship between Islam practices and the process of urbanization (Alsayyad et al., 2009). The principles urban rules were derived from general tradition (‘urf) and jurisprudence (Fiqh, in Arabic for science of religious) (Alsayyad et al., 2009). These cities seemed to follow an irregular, labyrinthine urban form (Alsayyad et al., 2009). Streets were characterized by narrow open-ended or cul-de-sac type of streets, which were following the Islamic law considerations of privacy (Bessim, 2007). Of the main urban elements found in the majority of the Islamic world constituted of Mosque, the Suk (Permanent market), narrow and winding, maze-like streets, cul-de-sac, the *Fina*, the *Sabat* and the courtyard houses (Acun, 2002, p.260; Hakim, 2007). Houses were characterized by courtyard units as they group extended families (Alsayyad et al., 2009). Islamic rules and jurisprudence paid a significant attention to the neighborhood buildings and the relationship of the houses to the streets, the private and the public, mostly relying on Quran values and from sayings of the Prophet Mohamed (Hakim, 2007). It is worth mentioning that the courtyard buildings and cul-de-dac street pre-date Islam, however, Islamic cities developed, refined and spread this system (Hakim, 2007).

3.3.2 The Ottoman influence

Ottoman and Islamic cities were highly related (Veinstein, 2008, p.214). However, there were a significant distinction between eastern and western cities whose originated not as Ottoman but rather as Arabic cities in the Ottoman era as reported from André Raymond

(Veinstein, 2008, p.205). These distinctions were related to the proximity to the central part of the Ottoman empire (relative to the capital) (Veinstein, 2008, p.205).

The integration of the newly conquered Islamic cities into the Ottoman administration system was challenging. These cities were integrated through two distinctive ways Waqfs' (Acun, 2002, p.260): They were either directly incorporated into the Ottoman administrative system, or left in the responsibility of the local elite. The first system was applied in the Balkan and Anatolia where settlements were divided onto provinces. Cities were either included in the imperial domains as bass or allocated to state officials, or attached to the 'Waqfs' (Acun, 2002, p.260). The second system was applied in North Africa and part of the Middle Est (Acun, 2002, p.260). Pre-Ottoman local groups and individuals took part of the governing of small and medium size cities, leading in the long term, to the total independency if these cities such as Algiers as it became provincial centers (Acun, 2002, p.260).

That is to say that Ottoman domain also emerged while preserving the continuity of previous urban rules, mainly the use of the Fina and Sabat space, called in Turkish "Kabalti" (Doğan, 2016, p.79). The traditional use of the Sabat space was widely spread in many parts of Turkey such as Ufra, Kula and Mardin (Doğan, 2016, p.79) which were near the Ottoman capital and had previous interactions of the Islamic domain. Similarly, Islamic cities under the Ottoman domain such as Algiers also presented similarities in using the Sabat spaces.

3.3.3 The byzantine influence

Going back to the Byzantine period, Bessim Hakim (2007, 2008, 2014) presented a series of studies exploring Mediterranean urban codes and how Byzantine and Islamic urban rules emerged in creating similarities within the formation of traditional cities in the Mediterranean Basin. From these similarities, the use of covered passages can be clearly distinguished in several Mediterranean cities of different cultural-religious-political regimes. Bessim stipulates that Byzantine and Islamic codes have direct roots in practices and customary laws in the ancient civilizations of the Near East, but they evolved separately (Hakim, 2007). Their diffusion across Mediterranean basin demonstrates their look-alike impacts on the built environment due to overlapping similarities. Although there is no significant evidence clearly revealing the influence of the Byzantine system on Islamic urban rules, he suggested that Islamic rules evolved from existing practices during the 7^{th} century when Islamic emerged and spread (Hakim, 2007).

The byzantine-Islamic urban codes fusion within the Mediterranean basin was previously addressed by Bassim Hakim (Hakim, 2008). Where he analyzed several written urban rules and treaties released during the byzantine and Islamic periods (Hakim, 2008). In relation to the Byzantine codes, the treatise of Julian of Ascalon from Palestine 531–533 CE represents the oldest source of construction and design rules in the Byzantine Empire (Balkan countries, southern Italy, while the Islamic treaties were written by Imam Malik (712–795 CE) in Medina (Hakim, 2008). The earliest treatises on city, neighborhood, and building construction were written during this period in Cairo by Ibn Abd al-Hakam (767–829 CE) and Ibn Dinar in Cordoba (Spain), both directly influenced by Malik (Hakim, 2008). During the same period in Thessaloniki within the Byzantine empire, the Hexabiblos (i.e. six books) was explored by 'Armenopoulous', of which the Julian's treatise from 533 CE was included, and it is through this book that the Julian treaties were spread in the Balkan countries and Greece were its influence continued well into the late 19th century and early years of the 20th century (Hakim, 2008). Bessim Hakim used the treatises of Julian (written during the period 531–533 CE) to present the Byzantine rules and those of Ibn al-Imam (Isa bin Musa al-Tutaili) (940–996 CE) to represent the Islamic rules (Hakim, 2008). As such four main urban similarities have been universal in their influence in shaping the urban form of the traditional cities in the Mediterranean region: the party walls, *Fina*, visual corridors and *Sabat* (Hakim, 2008)

3.3.4 The Fina

Traditionality, streets were characterized by a virtual feature called *Fina* which refers to a virtual width of about one meter adjoining the edge of a building and extending vertically along surface of the façade, forming an in-between space to which the owner has certain rights for using it (Hakim, 2007) (Fig. 3.5). The term 'Fina' had multiple significations indicating threshold and transition, and had various functions: private, public or both (Nooraddin, 1998), and mainly severed as an in-between space in front of the building, serving to control the outdoor-indoor relationship. The Fina forms the bounding surface of the house mediating between public and private domains, providing gradual transition between the two domains (Doğan, 2016, p.114). One of the rights of using Fina is extending balconies starting the first floor of buildings, and extending a room bridging the street serving as an additional room and a covered passage on the outside, called *Sabat* (Hakim, 2007). These horizontal and vertical extension, Fina, differed in terms of architectural characteristics among Islamic, Ottoman and European cultures, such as balconies, porticoes and arcades, and Sabats. These differences could be justified by the cultural difference, the natural environment and constructive conditions, and the size of streets and cities.

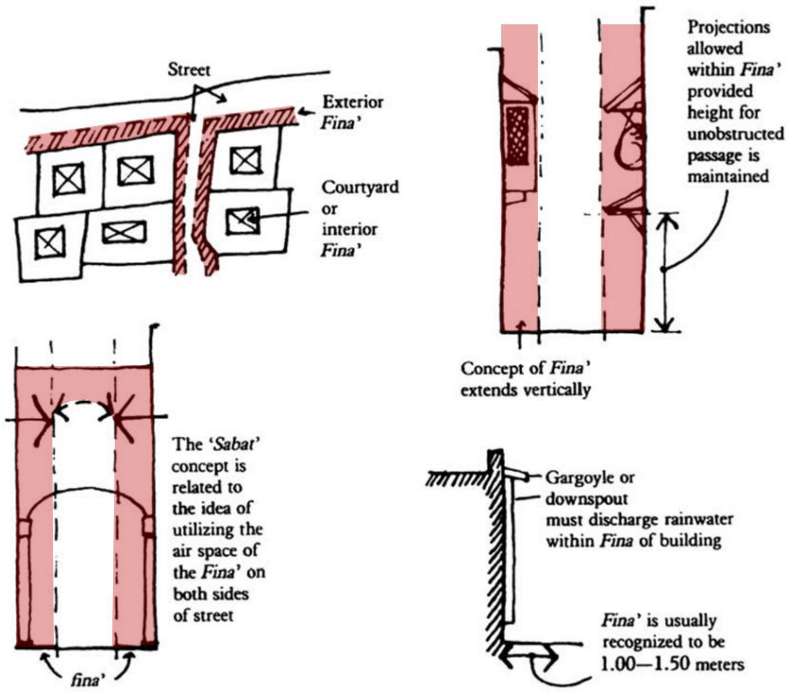


Figure 03.5: The Fina and Sabat. the Fina is an invisible space about 1.00–1.50 m wide alongside all exterior walls of buildings – primarily alongside streets and access paths (Hakim, 2008)

3.3.5 The Sabat

The "Sabat" space is a type of outdoor in-between spaces. The term "Sabat", of which the terminology originated from Arabic (ar: ساباط) (Hakim, 2008), refers 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 (Hakim, 2008) (Fig. 3.7). Due to its dual functions, the term 'Sabat' could refers to two distinct spaces. First, it refers to the space above the passage, serving as an indoor architectural element that represents its original purpose. Second, it denotes the covered passage at street level, created by the extended space above, which is the focus of our research. Architecturally, Sabat is a "lift-up" building design (Du et al., 2017; Xia et al., 2015) at ground level within the street, resulting in a short 'covered passage' (Arrar et al., 2022; Jafari Sharami et al., 2024; Missoum , 2003) or "roofed alley" (Akrami Abarghuie et al., 2022; Jafari Sharami et al., 2024), limited by the opposite buildings, offering protection from sun exposure and precipitation while maintaining natural air flow (Fig.3.6-7).

The possibility to extend room in the upper floors of the houses and bridging the right-of-way in streets originated from the concept of Fina (Hakim, 2007). Following the rules of using the Fina, the Sabat space were used to create additional space for its owner, along with offering covered passage at street level (Hakim, 2007). If an owner needs an additional space, when vertical extension is not possible, one option is to extend horizontally, by extending the Fina space to build an additional room in the upper levels of the buildings called Sabat. In order to support the structure on the opposite side, the owner must ask for permission from the owner of the opposite building. Alternatively, if the latter refuses, the owner can use external columns for support (Hakim, 2007) (Fig. 3.7).

Elements above the street, 'Sabats', were one of the significant urban elements found in most cities in the Islamic word (Hakim, 2007), including Ottoman traditional cities. However, such configuration were also widely spread in Persian architecture (Pre-Islam Iran) (Akrami Abarghuie et al., 2022; Jafari Sharami et al., 2024; Keshtkaran, 2011) and in non-Muslim

Figure 3.7: Examples of Fina space such as extended corbels in Algiers Casbah (a) of which two opposite extended Fina can form a Sabat space; extended staircase in Ostuni, Italy (b); extended balconies and plants decoration in Bari Vecchia, Italy (c). (credit: author 2022)

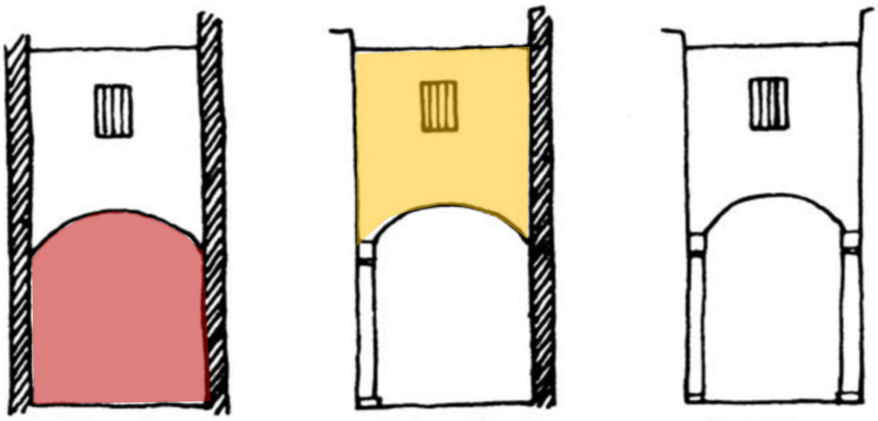


Figure 3.6: Different type of support system. The Sabat space serving two distinctive roles: a covered passage (in red) and a room bridging the street (in yellow). adapted from (Hakim, 2008)

countries such as Greece, Southern Italy, Spain and Portugal (Hakim, 2007), with similarities in using covered passage between historical cities in North Africa and those in the Puglia and Calabria regions of southern Italy (Hakim, 2008) (Fig. 3.8). Several medieval Mediterranean cities in Southern Spain, Greece, Puglia and Calabria (southern Italy) display interesting similarities in urban structure and form to those in North Africa, featuring elements such as the Sabat space. despite the socio-cultural differences and divergences in the ruling system and origin of their creation. Muslim presence in these Italian regions (excluding southern Spain and Sicily, where Muslim rule lasted over two centuries) was brief, limited to the 9th and 10th centuries CE. (Hakim, 2008), leaving the origins of such spaces open to speculation.

Such configuration was adapted in relation to culture, socio-economic and climate needs while also responding to the availability of construction materials and the natural environment's spatial constraints, especially in hilly cities, and. Design attributes of such space differ in relation to climate, cultural background and urban rules (Akrami Abarghuie et al., 2022; Hakim, 2008; Jafari Sharami et al., 2024). The terminology also was and still different in naming the this covered passage, Sabat**,** also called Stegasto or Katastegia [Greece]; *Sorbados* [Spain] (Hakim, 2014); *Sottoportini* or Archo [Italy]; *Kabalti* (vaulted room) [Turkey] (Doğan, 2016).

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 (Hakim, 2008) (Hakim, 2014). Rules written by Muslim clearly indicated the legal rights of constructing the Sabat (Hakim, 2008) (Doğan, 2016, p.84-86). When buildings of opposite sides are owned by the same owners, he can directly use the walls' support to create the Sabat. Alternatively, if it was not the same owner, he can create external columns for support (Hakim, 2008) (Fig. 3.7). As for the height of the covered passage, resulting from the Sabat, Muslim rules stipulated that the clearance should be high enough to allow the height of a rider of a beast or a fully loaded camel (Hakim, 2008). In the 'Armenopoulos's Hexabiblos' codes (mid-14th century Byzantine), and, the Spanish codes of post-Islamic Toledo in the early 15th

century, codes indicated the height of a knight with all his weapons, about 15 feet above the street level (Hakim, 2008).

Figure 3.8: Sabats around the Mediterranean region. (a-c) Algiers'Casbah, Algeria; (d) Rhodes, Greece; (e) Ostuni, Italy; (f) Bari Vecchia, Italy (Source: Author); (g-h) Toledo, Spain; (i) Urfa, Turkey.

As such, the height, width and constructing materials of these covered passages differ within cities and this could be explained by the type of the building it is attached to and the layout of the urban structure. For example, European traditional Mediterranean cities, Sabats are more elevated in height and are larger in width following larger street patterns which could allow the passage of a vehicle such as Bari Vecchia (Italy). In contrast, North African traditional cities, where streets were narrower, resulting in a reduced Sabat height and width. The size of the population and the reduced available space in cities also contributed to increased number of Sabats in cities limited with ramparts such as the example of Algiers Casbah (Algeria). Therefore, it could be suggested that use of the Sabat space can be attributed to the need for horizontal expansion of houses when vertical extension was not possible. This need arose from increasing population density and the lack of available free space within the city. Notably, some Islamic cities, such as Muharraq and Manama, did not adopt the Sabat space, which was explained by (Hakim, 2007) by to smaller population sizes, suggesting that residents in these cities did not require additional building spaces. Another explanation may relate to safety measures, particularly earthquake-resistant construction techniques (see section 3.4.2.4).

3.4 The Sabat space in Algiers Casbah

3.4.1 Historical background

Located in the center of the Capital Algiers (Algeria), the old city Casbah was built on a steep slope (118m.high), facing the harbor bay and the Mediterranean Sea in North Africa. Its history goes back to antiquity, Eukosiae, Icosium and later Dzaïr Beni Mezghena, Algiers's Casbah witnessed the overlapping of multiple civilizations and was under the domination of multiple dominations of the Phoenicians, Romans, Vandals, Byzantines, Arabo-Islamic, Ottomans and French occupation, all along with the presence and resistance of indigene local groups.

Roman byzantine

During 40 BC, Algiers was annexed by the Roman under the name *Icosium* (Assari Nadir, 2011, p.18). The Byzantines followed the Roman Model up until the local groups gained their autonomy and presented potential allies to the Byzantines during the 7th century CE, and later remained largely unknown until the 10th century (Chaïbi, 2012, p.43).

Islamic Zirid

During the Islamic period, the Arab-Berber renaissance dates back to the 10th century (Deluz, 1988. P9) p9). The old city of today was founded in the 10th century by the Berber Ziri Bouloughin Ben Menad and named al'Jaza'ir (the islands) in reference to the islands facing the waterfront (Çelik, 1997. P12) p12. In 950, Bologhine Ibn Ziri -a Berber from the Sanhadja tribe of Beni Mezghenna (Kaddache, 2003)- reestablished a city on the Roman ruins and the city seemed to have prospered, and it is likely that the structures of the Ottoman city (the current Casbah) were established at that time (Deluz, 1988, p.9) (Khelifa, 2007, p.45) (Ferrah, 2006. p.39). The city accounted of a collection of single-story houses surrounding more or less preserved ruins of Roman origin (Khelifa, 2007, p.42-45). The city had defensive ramparts was equipped with a citadel -*El Qassaba el-Qadima* which was located near Sidi Ramdane mosque, in opposition to the Ottoman Casbah at the summit of the city, which gave its name to the city (Fig.3.9) (Ferrah, 2006). The city witnessed divers Arab-Muslim dynasties from the 13th to the 15th that successively dominate the central Maghreb (Çelik, 1997, p14; Ferrah, 2006, p12; Khelifa, 2007, p180). From 1370 to 1500, the Abdelouadids made the city a center of Hispano-Moorish civilization after the fall of Granada in 1492 when Muslim Andalusian refugees, escaped throughout North Africa, spreading their knowledge, arts, and thought in Algiers (Assari Nadir, 2011, p19-20).

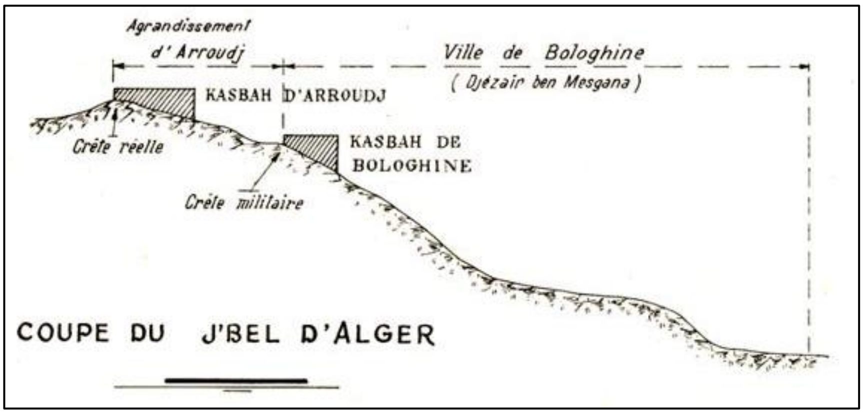


Figure 3.9: The difference between the old citadel built by local Zirid (Kasbah of Bologhine) and the citadel built later by the Ottoman (Kasbah d'Arroudj) (source: http://www.alger-roi.fr/Alger)

Ottoman

during 16th century the city reached its peak prosperity and was named capital of Algeria by the Ottomans (Çelik, 1997, p.12) (Khelifa, 2007, p.108). In 1516, the Ottoman Regency of El-Djazair began under the Barbarossa brothers (Chaïbi, 2012, p.77). From 1544 to 1586, Algiers was governed by Beylerbeys, then by Agha From 1659 to 1671, marking the beginning of Algeria's autonomy from Turkey (Assari, 2011). From 1671 to 1830, the position of the Dey, the administrator of the country, began to overshadow the role of the pasha, marking Algeria's independence from the Ottoman control (Assari, 2011) p.19-20. The 17th century marked the peak of Algiers' maritime power in the Mediterranean, as the Regency of Algiers (Chaïbi, 2012, p.85).

The French occupation

During the French domination 1830-1962, the Casbah survived severe damages, demolitions and modifications held by the French colonization. It was the lower Casbah that experienced the most demolitions, resulting in the complete erasure of all houses, public buildings, and religious structures (Khelifa, 2007, p.166). From 1830, the French chose to settle in the lower city with a purely military character, leading further displacement of the local population to the upper Casbah (Deluz,1988, p.11). These modifications led to distinct difference between the European city in the lower Casbah, and the Muslim-Ottoman city in the upper Casbah. the lower city was massively destroyed and was reshaped following the European architecture and street grid system, with streets lined with covered European-like arcades/ galleries; while the upper Casbah preserved its authentic identity (Deluz, 1988, p.11), despite the demolition of several Sabats and the integration of several European

Figure 3.10: Casbah of Algiers: map of the current state of the historical center after 1962 (Missoum, 2003),

buildings (Missoum S, 2003), in addition to the historical events during the revolution period that led to the independence of Algeria in 1962 (Fig.3.10).

3.4.2 The Casbah

3.4.2.1 The citadel

The Casbah (Kasbah or Casabah) takes its name from the Ottoman Citadel (in Arabic, القصبة, Casbah, which gave its name to the city) that overlooked the old Berber city, initially Sanhadjienne, and later Andalusian-Ottoman at the highest point on the fortifications was built in 1556 (Çelik, 1997, p.13). The neighborhoods near the Ottoman citadel were the oldest and occupied the site of a part of the original Berber town, which was destroyed by the French to isolate the fortress. (Assari, 2011, p.85).

3.4.2.2 The old city

with the arrival of the Ottoman (1516), Algiers' Casbah was already adorned with its ramparts, and had a population of about 400 households and featured numerous well-organized souks and streets lined with the houses (Ferrah, 2006, p.39). The old city assumed the form of a skewed trapezoid, with about 46 hectares comprising built space, the city constructed on the side of a hill facing the sea, gained its uniqueness from the topography (Khelifa, 2007, p.161-162). Not much is known about the structure of the city in antiquity, during the Roman, Vandal, or Byzantine periods and the Muslim period is equally unclear (Khelifa, 2007, p.161-162). However, the Casbah city differs from the Islamic Medina (Ferrah, 2006) P14. While the latter can open up and expand, a Casbah naturally forms a citadel nestled behind its fortified walls with no possibility of expanding (Ferrah, 2006, p.14). In 1518, the Ottoman adapted the ramparts of the old city and covered a larger area of El Djazair, of which it did not notably increase over the following decade despite the increase in population size due to defensive and military reasons(Cresti, 2008, p.408).

The Bab Azzoun-Bab el Oued streets represented the cardo (north-south axis), while the Marine Street was the decumanus (east-west axis) of the Roman period, dividing the city into two parts (Khelifa, 2007, p.205-206). These two areas differed in both the layout of the streets—narrower and more winding in the upper part, and often staired-streets—and in social-economical composition (Khelifa, 2007, p.205-206) (Çelik, 1997, p.13). The lower city (El Outa), running along the narrow strip at the foot of the hill by the sea, and the upper city (djebel, mountain), rising from the lower slopes to the citadel. The lower city was both the business district and urban center of various administrative buildings, commercial activities and large religious buildings (Khelifa, 2007) p.205–206. Within the upper city, there was no comprehensive plan nor administrative infrastructure (Kaddache, 2003) p. 510 (Khelifa, 2007) p.166. The upper city was primarily a residential area with a few baths, ovens, Quranic schools, and mosques and the citadel at the summit. Construction took place everywhere, with houses crowded closely together, barely leaving space between them (Kaddache, 2003) p.510. The city's layout was not dictated solely by the steep topography, instead, a maze of streets of varying sizes ran in every direction, intersecting or ending in cul-de-sac, however, the slope of the terrain required staired streets, making orientation easy despite the labyrinth of streets: you climb to reach the citadel and descend to reach the port (Kaddache, 2003, p.509-510).

3.4.2.3 Streets

Streets were characterized by the narrowness and winding nature, with a labyrinth an irregular street pattern. The city descends toward the sea through narrow, stair-stepped streets due to the steep slope of the terrain (Khelifa, 2007, p.205-206). These streets were characterized by projecting upper floors called *Qbou or* 'Corbels' (Missoum S, 2003) following the concept of Fina- supported by wood beams, called '*thuya'* , which sometimes meet overhead, or extend for an additional room in the upper levels forming covered passages (Sabat) which provided access to shaded and cool areas (Khelifa, 2007, p.161-162) . Authors often explain the narrowness of the streets by defensive reasons, heat mitigation solutions, in addition to the limited place caused by overpopulation during that period. This urban layout can be explained by two factors according to Mahfoud Kaddache: the first is spatial with the aim to occupy the entire site, and free spaces managed through architecture and the layout of the buildings which opened onto an inner courtyard; The second factor is climatic (Kaddache, 2003, p.511). The streets were adapted to protect against the sun's intensity, with a cooling airflow at the foot of the houses.

the street network demonstrated a clear and functional hierarchy, made up of three distinct types, revealing a carefully articulated logic, a "system of filtered access", the streets of the lower city catering to commercial, military and administration functions differed in their physical character and the concentration of their activities: they were lined with shops, cafés, and large structures, and crowded with people (Çelik, 1997, p.15). The transversal roads that climbed the upper city formed the second type; as straight as the topography allowed, they cut vertically the urban tissue and provided efficient communication between the two sections of the city such as Casbah and Bab Djdid streets. The neighborhood streets made up the third type which were largely distributed within the upper city (Çelik, 1997). Narrow, irregular, often with dead ends, they accommodate the introverted lifestyle that centered around the privacy of the home and family(Çelik, 1997, p.15).

3.4.2.4 Houses

Houses were packed tightly together and constructed with bricks and their facades were generally blank not allowing much views toward the outside following cultural purposes (Khelifa, 2007, p.205-206). By the 17th century, the number of houses had reached 15,000 of courtyard houses (Khelifa, 2007, p.161-162). The population of city increased drastically mainly due to the Muslim immigrants forced to escape the Iberian Peninsula during the Christian conquests form Spain after 1609 (Cresti, 2008) p 09-410-413. This phenomenon had important impact in the formation of the city since it was hypothesized that buildings in pre-ottoman city were limited with more free open spaces, in contrast to dense housing areas and absence of open spaces during and after the Ottoman period (Cresti, 2008, p.409-413). The increased population resulted in progressive congestion of the built environment within the city walls during the 17th century (Cresti, 2008, p.409-413).

3.4.2.5 Earthquakes and Natural Disasters.

Algiers' urban structure and its population were severely affected by a series of earthquakes in the second half of the 18th century (Cresti, 2008, p.421-423) (Khelifa, 2007, p.141). Between 1365 and 1716, devastating series of earthquakes impacted many houses and buildings, destroying two-thirds of the houses in Algiers, flooding a large part of the city, and damaging the rest to an extent that all the inhabitants abandoned the city (Khelifa, 2007) p.141. This led to an initial demographic decline toward the half the 17th century (Cresti, 2008, p.421-423). As a result, the authorities established seismic-resistant construction rules which could be seen in the walls of the old city and at the base of arches: the logs and Beams of *Thuya* wood, which provided elasticity to the structures and which could be seen in supporting the corbels as well as Sabat structure. As such, it is well observed that houses almost touch at the top, and since earthquakes were frequent, the houses, being close to each other, support one another and did not collapse so easily (Khelifa, 2007, p.141).

3.4.3 Sabats

It can be hypothesized that the seismic characteristics of the region, combined with the dense urban fabric—where houses supported on another—and the lack of open spaces within the old city walls due to a significant population increase, collectively influenced the horizontal expansion of houses, hence the Sabat spaces. This expansion led to the formation of Sabat spaces, particularly in the upper residential area of the Casbah. These Sabats not only added additional space to the upper levels but also provided shelter from rain, a cool environment during summer, and seismic-resistant structural support for the houses (Khelifa, 2007, p.205-206).

The overhead ceiling structure of the Sabats varied and could be made of horizontal wooden beams of thuya supporting reeds (Fig.3.11.a), a simple vault or several interlocking arches (Fig.3.11.b) (Khelifa, 2007, p.205). Sometimes, upper level projection with '*Qbou*' were supported by oblique T*huya* wood beams, being so close to one another that only a few centimeters remained between them, and in some cases, they even touched, forming a Sabat (Fig.3.10.c) (Khelifa, 2007, p.206).

Moreover, the Sabat's structure differed in relation to its position within the street and the type of the house it is attached to. In palaces or bigger houses with arcaded courtyard, the Sabat's structure often had a simple vault or interlocking arches; Sabats situated in cul-de-

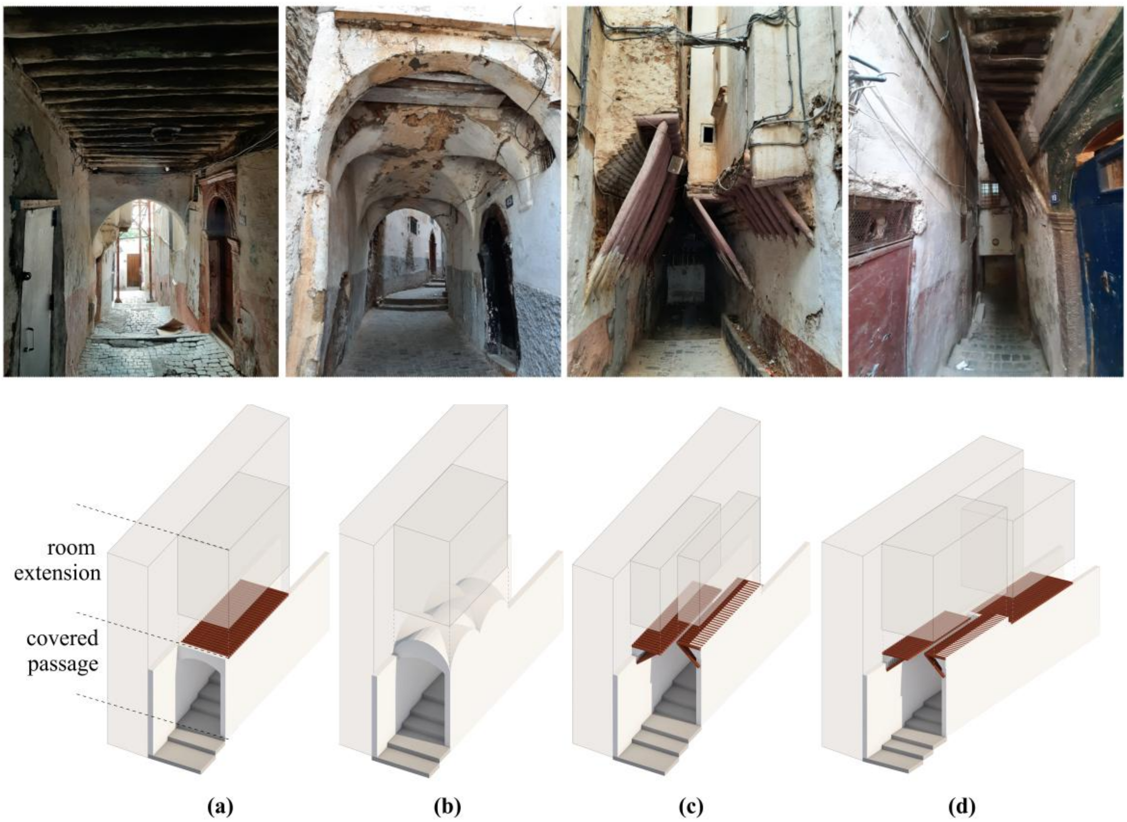


Figure 03.11: Algiers Casbah's Sabat types. The overhead structure of the covered passage varies and could be made of wooden beams (a) or groin vault (b). Sometimes, two extended corbels (room with *Q'bou)* end-up colliding as demonstrated in (c), or two or more adjacent Sabats (d)

sac and those attached to smaller houses called "Dwira", and houses with gridded atrium called "*Chebak*", or "*Alwi*" houses which had a flat ceiling structure made of wooden beams, or result of "*Qbou*" or room extension (Missoum S, 2003). 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 (Fig.3.12-14).

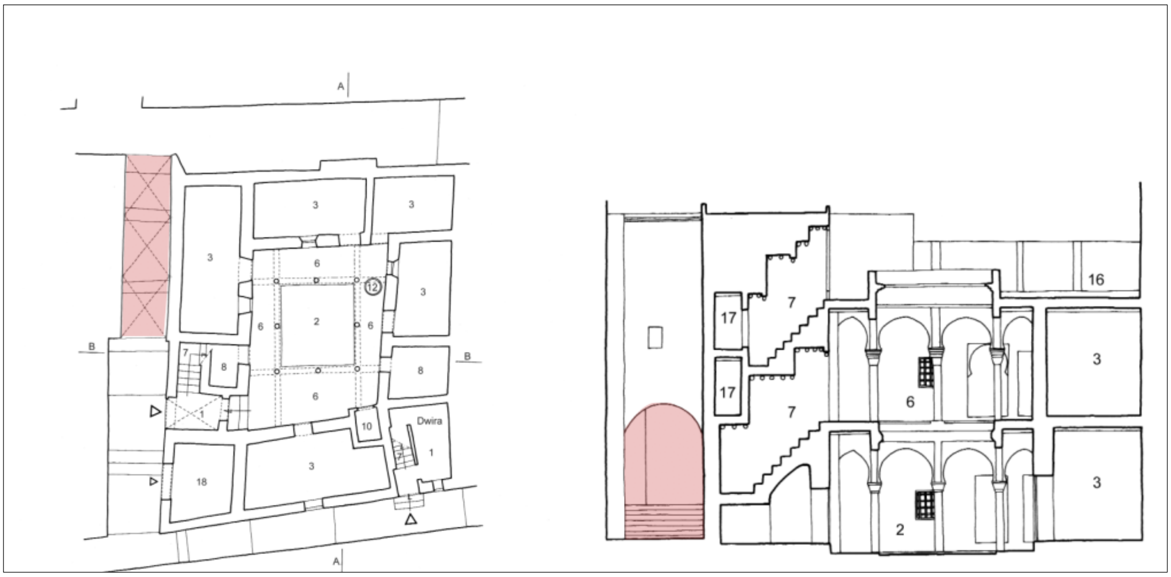


Figure 3.13: Example of arched-type Sabat (adapted from (Missoum, 2003.18). The covered passage is highlighted in red color.

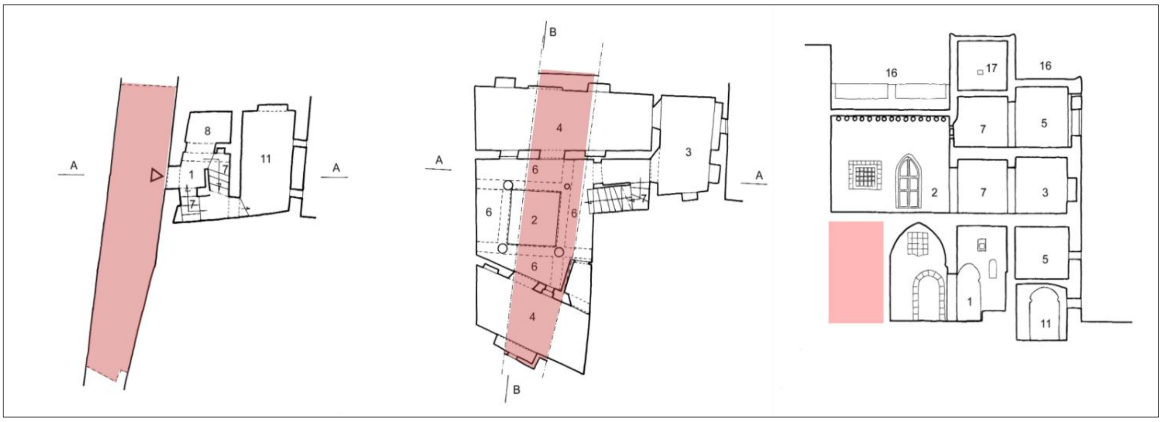


Figure 3.12: example of Sabat space (adapted from (Missoum, 2003, p.55). The upper level covers parts of Q'bou rooms and the central courtyard of the house.

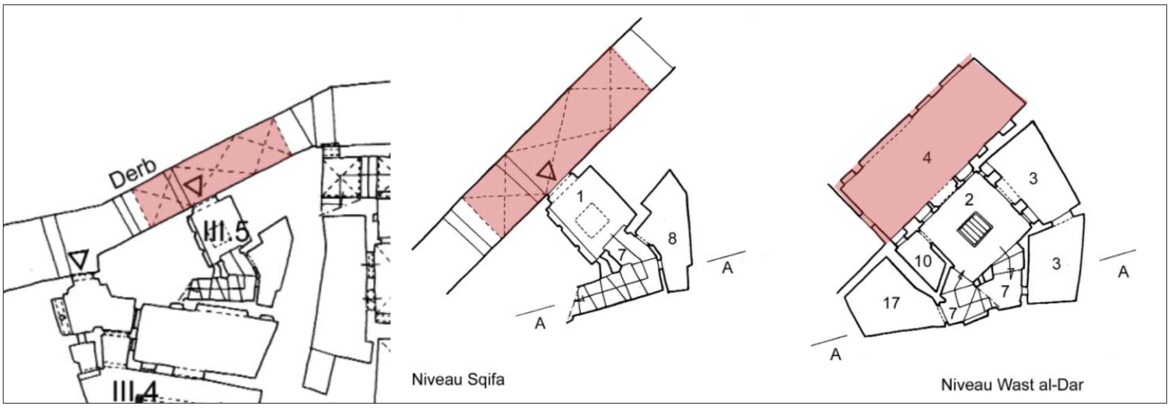


Figure 03.14: example of Sabat space in a house with *Chebak* (adapted from (Missoum, 2003, p.64).

3.4.3.1 Sabat localization

Algiers' Casbah is still characterized by dense urban fabric and noticeable presence of covered passage at street level (Sabat), which ate not evenly distributed within the urban fabric and are more concentrated in its upper residential part. Figure. 3.15 shows the actual localization of the Sabats in Algiers Casbah. The localization was based on the available literature, mainly (Kaddache, 2003), (Missoum, 2003), and PPSMVSS's operational master plan of the safeguarded sector of Casbah, followed by several on-site field investigations.

Figure 3.15: Casbah Sabat localization shaded in black color. credit: the author, adapted from PPSMVSS's operational master plan of the safeguarded sector of Casbah

3.5 Conclusion

The scope of our research is held on in-between spaces design in the Mediterranean region, focusing on Algiers Casbah. Although studies have investigated the use of in-between spaces for both indoor and outdoor environment (Juan et al., 2017; Sinou et al., 2004; Wen et al., 2017), 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.

This chapter presented a holistic overview of the formation of the Mediterranean cities along with the overlapping influences of significant civilizations and empires through history, and middle age in specific. Hence the formation of cities within the Mediterranean basin engaged within a continuous process while adapting to changes related to topography, availability of materials, cultural differences, economy and defensive reasons. Therefore, the outdoor-indoor relationships were carefully addressed. While there was significant similarities in urban codes within these cities, each city translated these codes differently according to socio-cultural factors and societies needs and ambitions during that period. Of these Similarities related to outdoor-indoor relationships and in-between spaces, the Sabat space has been widely spread. Moreover, this chapter presented an overview definition and terminology of the Sabat space within several Mediterranean cities with the aim of exploring how its design manifested within various cultural and climate differences. The second half of the chapter focus mainly in introducing the case study of Algiers Casbah and the localization of Sabat in current the city. The aim is to provide the necessary corpus study and form the base of the current research. Aligning with the current research objectives, a detailed typo-morphological analysis of Sabats within the Casbah represents a valuable avenue for future research, offering the potential to deepen understanding of their architectural and urban significance.

Part two: Methodological Framework and Result Analysis

Chapter 4: Methodology

4.1 Introduction

The walking experience is a complex phenomenon in which many interconnected factors can intervene: the physical environment, psychological factors and the affective state. In the present study, the walking experience is referred to as the quality of walking in relation to the user experience. The aim of investigating the walking experience is to obtain assets and recommendation of a positive walking experience according to the user' affective state in a given environment. In particular, how does a certain environment conditions make individuals feel about their walking experience. The thermal walks conducted for the aim of exploring the hypothesis of the current study are based on a mixed method methodology by combining mobile meteorological measurements of the microclimate variables along with the simultaneous questionnaire survey recording the dynamic changes in pedestrians' subjective walking experience.

This chapter demonstrates how the thermal walks methodology is adapted with the research's question and objectives. The significance of Algiers' Casbah in relation to walking barriers (topography) and potential adaptive solutions (Sabats) is highlighted along with the novel approach in investigating the fatigue sensation and fatigue recovery regarding the heat exposure, stairs count and Sabats presence on the one hand, and its relation to transient thermal aeraulic conditions on the other hand. It also provide detail description of the measurements protocol and the instruments used for the environmental monitoring. The questionnaire survey is described in relation to the choice of subjective and affective experience indicators. This chapter also outlines the scheme of the selected statistical analysis while providing an overview, assumptions and aim of each statistical test.

4.2 Casbah thermal walks

Thermal walks in Algiers Casbah included mobile monitoring of thermal aeraulic conditions and simultaneous walking experience questionnaire within two preselected walking routes in the upper Algiers' Casbah. The two selected walking routes consisted of 16 assessment points of covered passages (Sabat) and non-covered streets. Since Casbah is known for its steep street character, walking uphill was the selected route for the current study to investigate the least favorable conditions for walking activities that requires special attention, specifically in relation to walkability and pedestrian comfort. The framework of thermal walks in the context of Algiers Casbah is presented in figure 4.1.

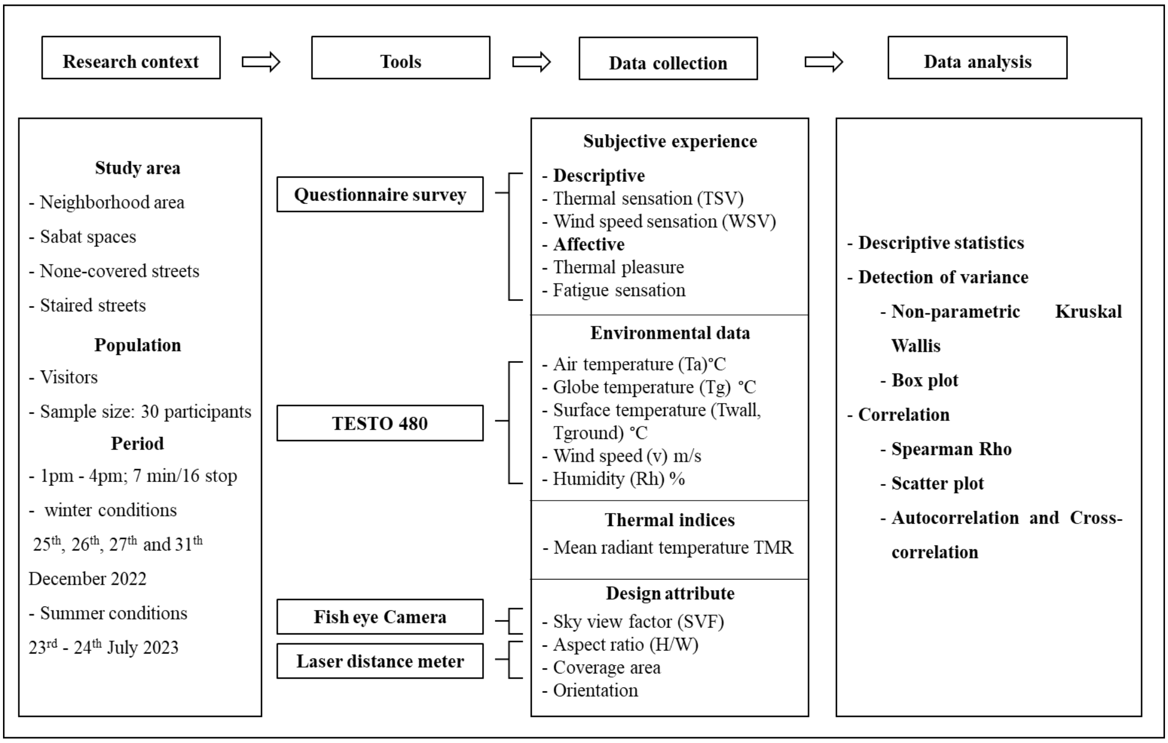


Figure 4.1: Thermal walks framework applied in the context of Algiers Casbah. (source: the author 2022)

4.2.1 Study area

The thermal walks has been conducted in Algiers's 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 107m, in proximity to the Mediterranean Sea (Fig.4. 2). The historical city has been shaped by a variety of influences (Chapter 3, section 3.4). Despite serious threats of physical decay due to lack of maintenance, today's Casbah still preserves its Sanhadjian-Islamic-Ottoman architectural and urban significance. The old city today 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. The historical city still remains a vibrant residential area while offering a prominent tourist destination hosting daily to weekly visitor groups. Hence, ensuring a comfortable walking experience is as also important in historical and traditional cities for both the residents and the visitors.

Casbah is characterized by an upper city mainly residential, and a lower city that is more divers in land use (Fig.4. 2 A,B). These two parts are distinctively separated by a commercial mechanical street. The city is traversed by two main vertical non-pedestrian streets characterized with moderate land use. The more privacy increases, the less the street to be linear. In addition, pedestrians' patterns in Casbah are not evenly distributed in relation to residential areas and land use. Important parts of Casbah are under decay situation and are inaccessible or being under restoration and reconstruction programs.

Figure.2: Algiers Casbah map showing the upper part (A) and the lower part (B) of the historical center, and highlighting the selected route 1 (yellow) and route 2 (green) (source: google earth 2022).

In addition to the microclimate, the walking activity is also influenced by street topography (Alfonzo, 2005; Burke et al., 2006; Southworth, 2005). From the main issues related to walkability in Algiers' Casbah is the significant presence of staired streets as a result of the topography, especially when walking from the lower to the upper Casbah (fig.4. 3). Stairs are significant walking barrier since walking in hilly cities with steep slops or staired streets, such as the case in many Mediterranean cities, including Algeria, is challenging in term of thermal loads in comparison to flat terrains cities (Lee et al., 2006). In Algiers' Casbah, this challenge is more significant during the hot-humid summer conditions, when the combined effect of prolonged exposure to heat with continuous stairs climbing increases the physical exertion and fatigue due to the body's inability to dissipate heat effectively. Sabat spaces are not distributed evenly in Casbah, therefore, investigating the transient conditions of Sabats with different distribution could provide significant insights on its influence on fatigue recovery.

Figure 4.3: Staired-streets of Algiers' Casbah. (source: authors 2019-2022)

4.2.2 Walking routes selection

The selection of the walking routes were based on accessibility and presence and distribution of Sabat spaces. Accessibility is related to the ability to reach relevant destinations (Handy, 2005). In this study we restrict to place based accessibility in relation to: quality of infrastructure in terms of safety, streets quality, topography and stairs. Pre-walking observations were conducted to observe streets quality and safety, pedestrians' patterns, presence of stairs, location and quality and distribution of Sabats. After conducting early walking experiments, it was suggested to conduct the thermal walks starting the midway to the upper casbah. The assessment stops were selected to cover a variety of Sabat spaces, depending on streets' morphology characteristics (SVF, H/W) (Fig.4.4), orientation, distribution and Sabats' design attributes (Fig.4.7) within two different walking routes (Fig.4.5). Additionally, the selection of walking routes prioritized ensuring safety and security for both the surveyors and the participants. certain walking routes were excluded due to the impossibility to walk through safely, or due to excessive stairs counts which could negatively affect participants experience and bias the research's results.

The two walking routes have different Sabat distributions, while maintaining same walking direction (up-hill), stairs count and street morphology. These selection criteria allow for comparative analysis of the influence of Sabats distribution on the walking experience. Specifically, the two walking routes have the same starting point and end differently in the direction of uphill walking. They both differ in terms of Sabat distribution (number and position), and are characterized by similar aspect ratio and relatively equal topography and stairs number (Fig.4.5). The aim is to investigate the influence of different Sabat distributions, number and positions on reducing the influence of heat exposure and stairs count, hence supporting a positive walking experience.

Figure 04.4: non-covered streets as demonstrated in yellow traced profiles.

Route 1 begins at Amar Ali street from the secondary pathway Brahim Fateh and ends at the Boulevard de la Victoire, passing by Frere Bachara and Boualam Bouchlaghem pathways. The walking route has a total walking distance of 350 meters and 191 stair steps. It consists of 9 street segments and 7 Sabat spaces, of which two are located in the first part and five in the second half of the walking route (Fig. 4.5-6).

Route 2 begins at Amar Ali street from the secondary pathway Brahim Fateh and ends at the Boulevard de la Victoire, passing by Frere Bachara and Boualam Bouchlaghem pathways passing by Frere Bachagha and Rabah Riyah pathways which end differently from route 1. The route has a total walking distance of 300 meters and 186 stair steps. It consists of 6 street segments and 4 Sabat spaces, all located in the first half of the walking route (Fig. 4.5-6).

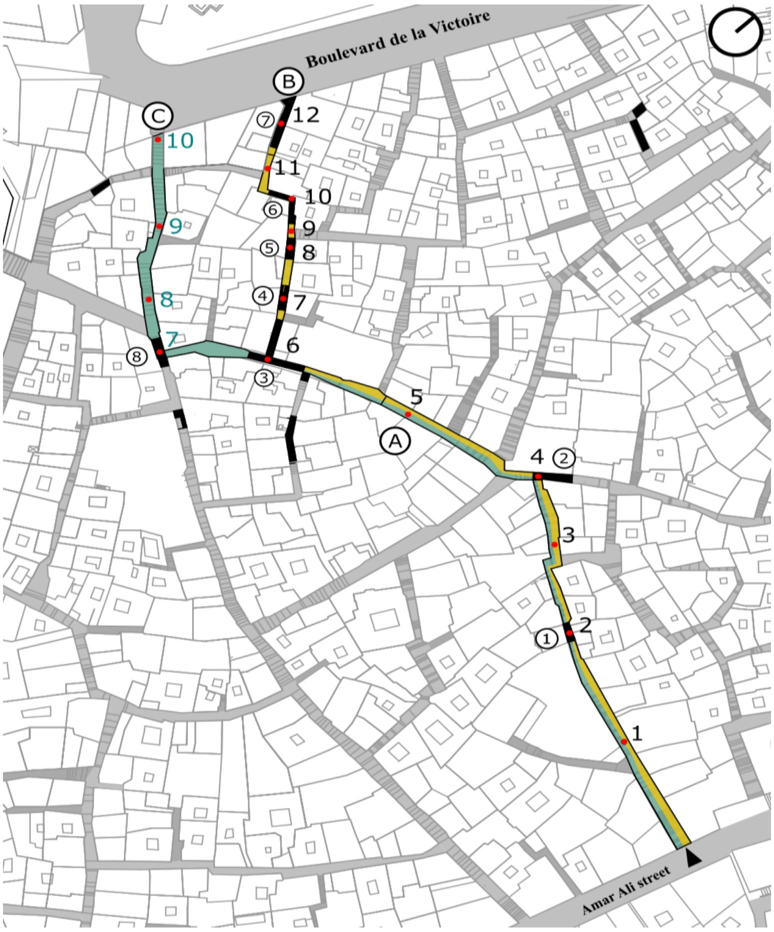


Figure 4.6: The selected two walking routes for Casbah thermal walks starting from Amar Ali street and ending at boulevard de la Victoire. (Credit: author, adapted from PMSSV Casbah master-plan)

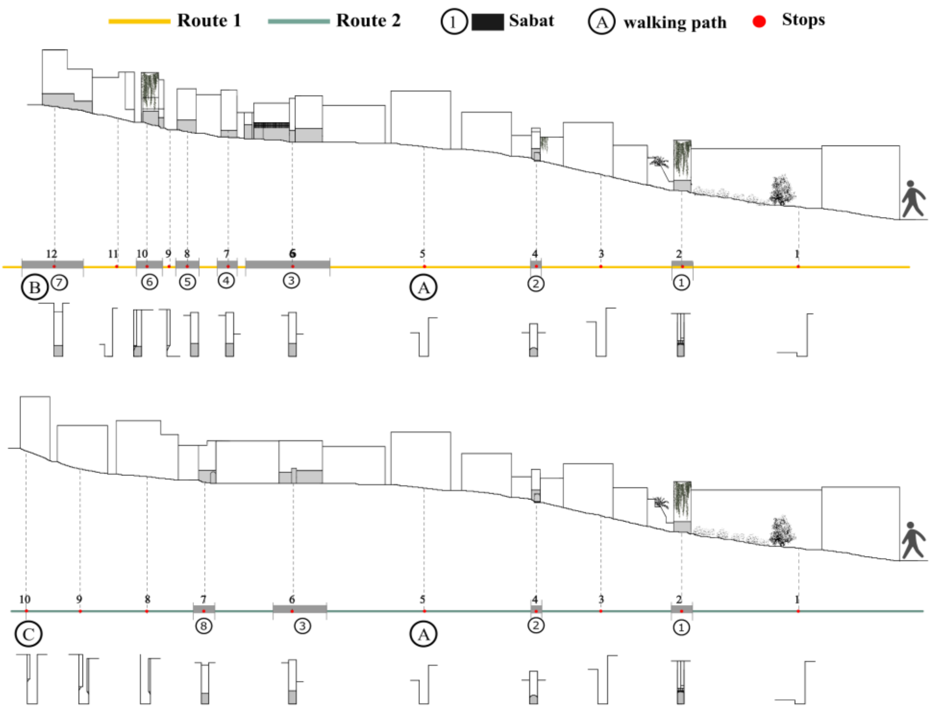


Figure 4.5: Thermal walks in two preselected walking route 1 and route 2. Stairs count is represented for both walking routes in addition to the position and distribution of the Sabat spaces.

4.2.3 Sabats

the walking route selection criteria ensured a variety of Sabats of different orientation and coverage area and distribution. Sabats in route 1 are denser in the second part of the route while Sabats of route 2 are more distanced and are relatively located in the first part of the

Figure 4.7: Sabat details related to coverage area; plan, elevation and section with measured proportions; inside and outside photos.

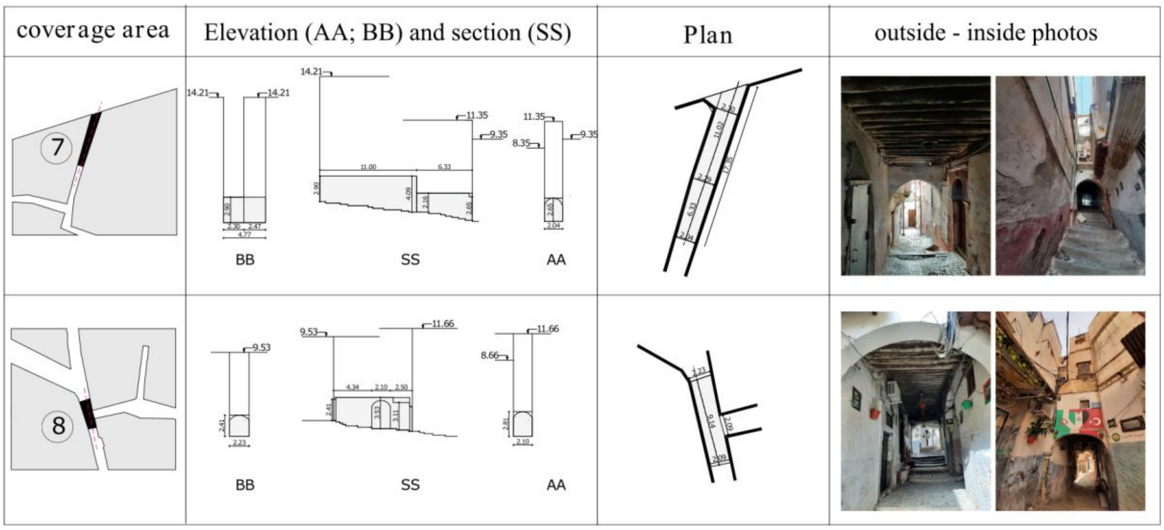


Figure 04.8: Idem.

route. Sabat 1, 2, 4, 5, and 8 have medium length, ranging between 6 to11 meters, with an average width of 2 meters. Sabats 3 and 7 are the deepest, reaching up to 16 meters in length. The Sabat 3 have cross-orientation located at two streets intersection, while Sabat 6 is cornered in an angled street. All Sabats have flat wood ceiling with the exception of the second part of Sabat 3 which consist of two extended rooms in the upper floor level (Fig.4.7).

4.3 Data collection

4.3.1 Meteorological conditions

Climate overview

Following Köppen–Geiger climate classification, Algiers has a Mediterranean warm temperate climate (Csa) with humid-hot summer and mild winters (Kottek et al., 2006). The prevailing winds come from the north-east in summer and from the north-west in winter. The city benefits from the sea breeze being at proximity to the Mediterranean Sea. However, the effect of sea breeze has been insignificant in Casbah of Algiers in a recent sea breeze and outdoor comfort investigation in Casbah (Arrar et al., 2022). During summer and winter measurements survey, (Arrar et al., 2022) recorded relatively low wind measurements combined with concentration of high rate of humidity reaching more than 70% in January and almost 80% in August due to the sea proximity.

Moreover, Algeria is witnessing a significant rise in temperature of 1.25°C and this trend causing a significant contraction of the warm temperate climate in Algiers (Zeroual et al., 2018). Consequently, Summer conditions are even more intensified and the warm conditions are further prolonged daily, with extended hours of heat, and seasonally, with the hot conditions period extending into the winter season, resulting in milder winters (Fig. 4. 8). Despite being comfortable for most of the outdoor activities, the globally increased air temperature is unsatisfactory for the walking activity. Therefore, both temperate and hot conditions are considered for investigation in the current study.

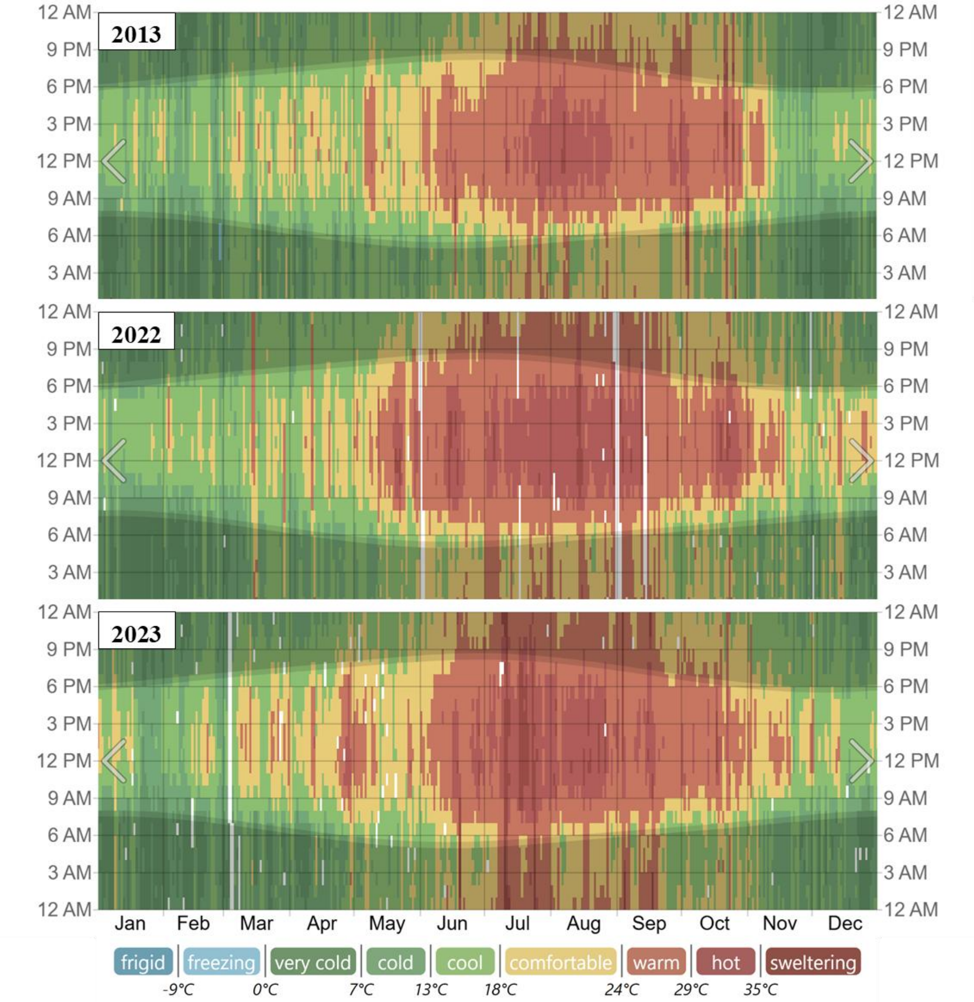


Figure 04.9: Hourly Temperature variations during 2013, 2022 and 2023. (source: https://weatherspark.com)

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.

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

4.3.2 Meteorological monitoring

The choice of 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.

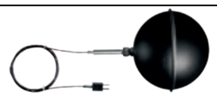
A portable weather station was tailored for the mobile measurements, consisting of the digital multifunction Testo 480 described in Table 2. The vane probe, the humidity and temperature probe were fixed on a camera tripod at a height of 1.40 m. while the wind speed probe was extended to reach 1.70 m 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 black globe probe was fixed on a secondary camera tripod away from obstructions (walls, moving pedestrians or surveyors). To overcome the vane probe sensitivity, the vane was fixed in the tripod away from obstructions that could disrupt airflow to ensure the most accurate measurement (Fig. 4. 10). We rotated the vane in the first 30 seconds to capture the highest value and was later fixed and values were recorded each minute during the 7-minute stop.

The weather data were recorded from 1 p.m. to 4 p.m. with an interval of 1h30 and 7-minute 'stopping time' (Peng et al., 2022; Qi et al., 2021). Data analysis was based on the mean value of the last 3-minute assessment. It included a total of 16 assessment points of covered (Sabat) and non-covered streets (Fig.4. 5-7).

In developing an optimized measurement strategy to characterized the outdoor environment (Qi et al., 2021) concluded that 5 min could meet the average setting time while 10 min represents the maximum setting time and further staying time. Moreover, excluding the data of the first 5 min improved Tg accuracy by 30 % (Qi et al., 2021). The aim of the current study is not to characterize the outdoor environment of the Sabats and non-covered streets but rather to reveal an understanding of the transient conditions. As such, the staying time was limited to 7-min at each stop taking into consideration the average of the last 3 min measurements. The staying time is function of the number of the assessment stops and to keep on simultaneous assessment of the questionnaire survey within an interval of 1h30.

Table 2

Tools used for the mobile measurement surveys: air temperature (Ta), relative humidity (Rh), wind speed (v), surface temperature (Ts), and Globe temperature (Tg)

		Data	Instrument	Accuracy
		Ws	vane probe (Ø 16 mm) with telescope (960mm)	± (0.2 m/s +1 % of m.v.) (0.6 to 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
		Tg	Globe probe Ø 150mm, TC Type K, for measuring radiant heat	0 to +120 °C

4.3.3 Walking experience questionnaire

4.3.3.1 Participants selection

A total of 30 adults and non-resident of Casbah individuals, aged between 18-45 years old (11 male/19 females) participated in the thermal walks during both winter (20 participants) and summer (10 participants) conditions with a total of 6 days of monitoring (4 winter days and 2 summer days). Previous studies suggested than a sample size range of 5-16 participants is appropriate when investigating mobile and point-to-point surveys (Liu et al., 2021). Additionally, the sample size was limited to the conditions of uphill walking and the

Figure 04.10: mobile measurement set within the street and inside Sabat demonstration.

simultaneous mobile measuring of the micrometeorological conditions. The reduced size during the summer walks was due to the heatwave conditions in addition to the difficulties encountered due to the topography and the uphill walking. The thermal walks relayed on visitors and non-residents of Casbah since residents of Casbah would be attached to their neighborhood and it is more likely that their experience would be more positive or negative in comparison to visitors (Johansson et al., 2016). Moreover, residents would be more adapted to the environmental conditions and staired streets and their thermal acceptability would be different from that of a visitor (de Dear, 2011) (Nakano, 2003). The questionnaire aims at capturing dynamic and sensitive-climate responses, hence the choice to recruit young and healthy adults was to reduce the influence of additional physical exhaustion and/or injury of individuals with health issue and elderly people such as dehydration, cardiac and respiratory issues, knee injuries, etc. Participants were recruited based on an online call for participants in addition to on-site volunteers at random after being introduced to the research's aim and content.

4.3.3.2 Pedestrians subjective experience

It is crucial to note that the transient thermal aeraulic conditions should be considered for the evaluation of transitional phases (Nakano, 2003). i.e. the questionnaire aims in assessing the dynamic changes in affective appraisals and thermal effect of pedestrians as they experience transient thermal aeraulic conditions when walking. In the field, affective experience must be assessed quickly with as little interference as possible to the on-going walk. Instant, rapid and repeated answers provides row experience information and aims to capture the instant change in experience (Johansson, 2016). In order to address these dynamic changes, the questionnaire relies on Instant, rapid and repeated answers.

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 questionnaire aims in assessing the dynamic changes in affective appraisals and thermal affect of pedestrians as they experience transient thermal aeraulic conditions when walking. The first part of the questionnaire included general participant information, i.e., age, gender, familiarity with study area and clothing. In the field, affective experience must be assessed quickly with as little interference as possible to the on-going walk Instant, rapid and repeated answers provides row experience information and aims to capture the instant change in experience (Johansson, 2016). In order to address these dynamic changes, the questionnaire relies on Instant, rapid and repeated answers. 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.

Thermal walks, urban walks or climate walks, consist of recording mobile point-to-point or continuous microclimatic variables along with capturing simultaneous and direct pedestrian’s experience as they walk within a preselected walking route(s). these walks rely on subjective experience of thermal condition (Al Sabbagh, 2017; Barbosa et al., 2020; Chokhachian et al., 2018a; Dzyuban et al., 2022; Lau et al., 2019; Lenzholzer et al., 2018; Liu et al., 2021; Peng et al., 2022; Vasilikou et al., 2013, 2020; Zhang et al., 2020b), with thermal sensation vote (TSV), thermal pleasure being the most used indicators, as well as the proposed thermal affect (Liu et al., 2020). Other thermal walks included wearable sensors to collect physiological data such as skin temperature, metabolic rate and body motion (Nakayoshi et al., 2014; Nazarian et al., 2021; Ohashi et al., 2018; Peng et al., 2022; Zhang et al., 2020). More recent thermal walks investigated the thermal history (Nikolopoulou et al., 2003) and the ability of environmental transients in generating thermal alliesthesia (R. de Dear, 2011). Studies used physiological data to detect the alliesthesial potential using the

Basal metabolic rate for each participant (Peng et al., 2022), while Other studies used the difference in subjective perceptions such as thermal pleasure to detect evidence of alliesthesia (Dzyuban et al., 2022; Lau et al., 2019; Liu et al., 2020; Peng et al., 2022). In addition to the variations in temperature sensation, the novelty of the current study is to investigates 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 will be analyzed for potential effect of alliesthesia. fatigue sensation was 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 et al., 1984) with two dimensions. Valence' represents positive to negative subjective feelings or attitudes towards an emotion-eliciting stimulus (pleasant – unpleasant); while Arousal (activation) describes the level of which subjects are influenced by the surrounding environment (Russell et al., 1984). 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 (Liu et al., 2020; Nakano, 2003; Parkinson et al., 2015). 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)'s affective model, and was rated according to the Swedish short measure scale of affective state (Västfjäll et al., 2007). Therefore, affective fatigue sensation was rated with two different nine-point scales from refreshed to tired and rested to fatigued.

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

4.4 Statistical analysis

Collected data were than treated in IBM SPSS statistical analysis. The significance of investigating transient thermal aeraulic conditions along with pedestrians' dynamic experience is to overlay, compare, detect variance and correlate and cross-analyze changes of the thermal aeraulic conditions with the changes with pedestrian's point-to-point sensations.

All statistical data were conducted in IBM SPSS version 29.0.0.0. All subjective data expressed a good alpha reliability test (α=0.694 to α=0.853). The selection of the statistical test was guided by Yaffee & McGee (Yaffee et al., 2001), Pallant (Pallant, 2010) and Sage Research Methods Datasets (Sage Publications, Ltd., 2017). The statistical tests were selected to describe and detect variance, to establish correlations and cross-correlations and to confirm the following hypothesis:

- Thermal aeraulic conditions differ between, Sabats and non-covered streets within Routes (1 and 2) (1), and total assessed points (2); in both summer and winter conditions creating transient thermal aeraulic conditions.
- Pedestrians' TSV, WSV, thermal pleasure and fatigue sensation differ between walking routes (3) and are influenced by the transient thermal aeraulic conditions along with stairs presence (4)
- TSV, WSV, thermal pleasure and fatigue sensation differ between paths (A, B and C) (5)
- Fatigue sensation is reduced with the presence of transient thermal aeraulic conditions (Alliesthesia) (6)

Figure 4.11 summarizes the statistical analysis structure of the current study. Descriptive statistics were used to describe the variation in thermal aeraulic conditions between routes and between Sabats and non-covered stops (1) and variations in pedestrian's walking experience (3). Since the data exhibited non-normal trends (normality distribution histograms), the non-parametric one-way ANOVA alternative Kruskal Wallis tests were conducted to analyze the difference in the thermal aeraulic conditions among Sabats and non-covered stops (1) and among total assessed points (2) on the one hand; and the difference in TSV, WSV, thermal Pleasure and Fatigue sensation on the other hand (5). TSV, WSV, thermal Pleasure and Fatigue sensation were analyzed for correlation with the thermal aeraulic conditions within routes using Spearman Rho correlation test (4) and scatter **plots**.

Autocorrelation and Cross-correlation tests were conducted to assess the time lag effect of transient thermal conditions on pedestrian thermal aeraulic and fatigue sensation (6).

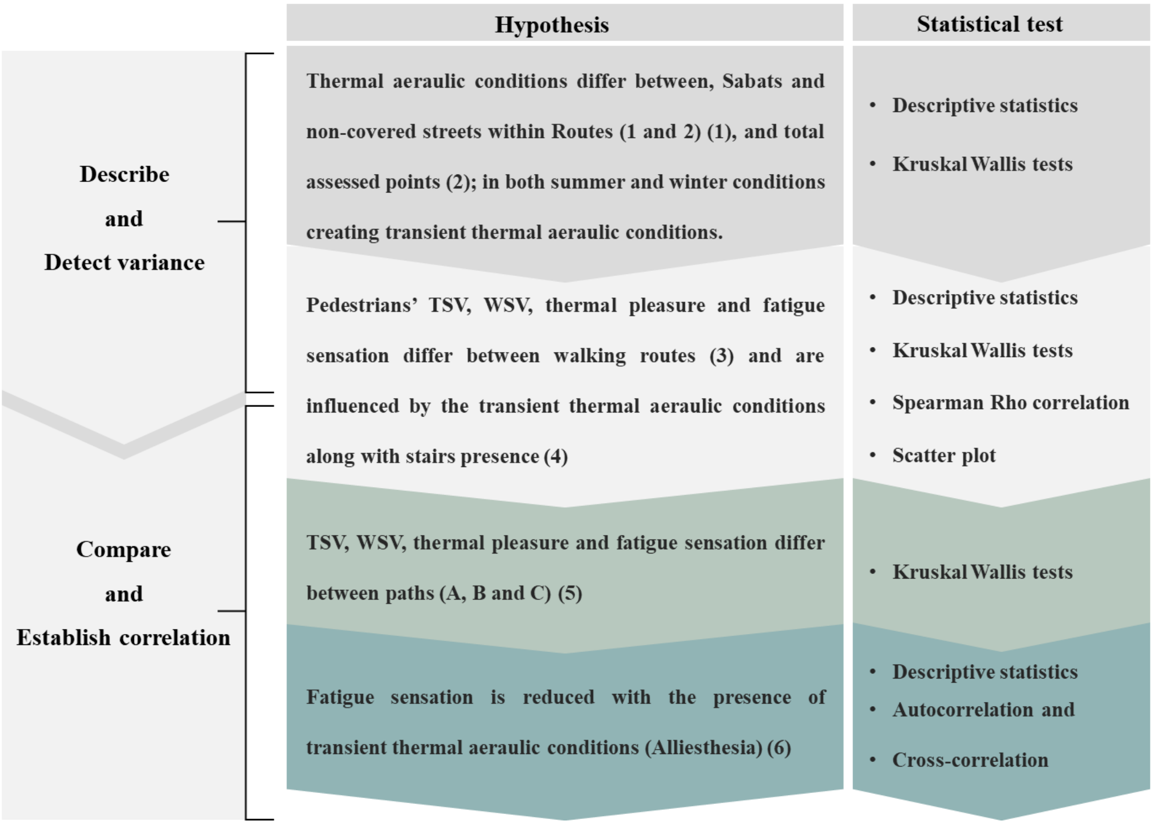


Figure 04.11: structure of the statistical analysis.

4.4.1 Descriptive analysis

In the descriptive analysis, meteorological variations were analyzed based on the mean values, while pedestrians' subjective responses were analyzed based on the median values. Variations of Mean and median values were than visualized using line graphs tool and were overlaid with streets and sabats morphology characteristics to allow for comprehensive comparison between the two walking routes and in different climate conditions (summer and winter).

4.4.2 Analysis of variance

The one- way-ANOVA test is a statistical analysis of variance and is used to compare means of k independent groups to determine whether there is a statistically significant difference between them. Specifically, it investigates the impact of a single independent variable (groups) on a dependent variables (measurable). Before conducting one-way-ANOVA, it is essential to ensure that its assumptions are not violated which are the independence of the observations, the dependent variable should be normally distributed within each group, and the variance of the dependent variable should be equal across all groups. The Kruskal-Wallis analysis of variance is the alternative of ANOVA when the test if normality is not satisfied (Pallant, 2010). That is when the dependent variable is not normally distributed within each group, such as the case in the current study. The interpretation if the Kruskal-Wallis test are based on the p-value and the null hypothesis that there is no difference between the groups. That is if the p-value < 0.05, the null hypothesis is rejected, indicating that a statistically significant difference between groups; and If p-value > 0.05: results fail to reject the null hypothesis, indicating that there is no significant difference between the groups. Additionally, Kruskal-Wallis results provide visual representations of the dependent variable distribution across different groups allowing for comparison using Box plots.

4.4.3 Correlation analysis

The Spearman's Rho and Pearson correlation tests are analysis of correlation to measure the strength and direction of the relationship between two variables. While Pearson measures the linear relationship between two continuous variables that are normally distributed, the Spearman's Rho measures the monotonic relationship between two ranked or continuous variables that do not have to be normally distributed (Pallant, 2010). Additionally, scatter plots are used to complement the Spearman's Rho numerical correlation summary by providing a visual overview of the correlation strength, direction and linearity or non-linearity.

4.4.4 Cross-correlation analysis

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 (Yaffee et al., 2001). 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.

4.5 Conclusion

This chapter presented a holistic overview of the thermal walks conducted in Algiers Casbah. The aim of the chapter was to demonstrate the different selected parameters related to investigating the transient thermal aeraulic conditions, and the subjective indicators related to pedestrians' subjective sensations used in the questionnaire survey. The instruments used for the environmental monitoring and the measurement protocol was explained highlighting the significance of multiple factors in the careful selection of the walking routes and the measurement stops, of which the influence on pedestrian sensation was highly influential. The selected walking routes followed the aim of covering a wide range of Sabat spaces of different distribution while accounting for the physical efforts on the participants. The significance of the topography was also addressed. Thermal walks were conducted during summer and winter conditions allowing for more profound understanding of the significance of transient conditions of the sabats on the one hand, and the influence of stairs on walking experience on the other hand. The selected statistical test, following a triangulation methodology, revealed a variety of related results that approached the suggested hypothesis from different angles which will be discussed in the following chapter.

Chapter 5: Transient Thermal Aeraulic Conditions and Pedestrian Walking Experience

5.1 Introduction

The current study investigated walkability in the context of outdoor comfort in Mediterranean cities, the case of Algiers Casbah, Thermal walks have been conducted in Algiers Casbah for the aim of investigating the transient thermal aeraulic conditions -air temperature, wind speed, relative humidity and surface temperature- of the Sabat space and its influence on pedestrians' walking experience, mainly temperature sensation, wind sensation, thermal pleasure and fatigue sensation. Field investigation consisted of conducting mobile meteorological and subjective monitoring, and data analysis were conducted to describe, detected variance, correlation and cross-correlation while allowing for comparative insights using IBM SPSS. This chapter presents the findings of the field investigations and statistical analysis during both summer and winter conditions. The influence of Sabat design in generating transient thermal aeraulic conditions is reported in the first section. The significant influence on pedestrians' walking experience is later presented along with the results from analyzing alliesthesia and fatigue recovery. The last section expands upon the findings and present fruitful discussion on the thermal aeraulic behavior of the assessed Sabats, the significant association between thermal alliesthesia, thermal diversity and fatigue recovery. the potential of Sabat design as a cooling-shaded spots and its contribution to resilient walkability.

5.2 Transient thermal aeraulic condition of the Sabat space

The variations in the meteorological measurements revealed the significance of Sabat design, distribution and orientation within the street in generating transient thermal aeraulic conditions. Figure.5.1. 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 design attributes: orientation, Sky view factor (SVF), profile (H/W), Sabats section and coverage area. Kruskal Wallis boxplots in Figure.5. 2-3. present the statistical variance in thermal aeraulic conditions between total assessed Sabats and non-covered streets during winter (Fig. 5.2.) and summer (Fig. 5.3)) conditions. As expected, the most significant variations are observed after walking from non-covered streets, with moderate to high SVF and lower aspect ratio, to Sabats with fully obstructed SVF and deep shaded section (Fig. 5.1).

Ta was lower inside Sabats during winter (H (1) = 6.353, $p < 0.05$) and summer (H (1) = 8.415, $p < 0.05$) (Fig.5. 2-3). The variation in Ta was further noticeable during the summer survey in Sabat 3, 4, 5 and 6 where Ta dropped below 32°C, featuring 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 SVF (stop 1 and 10 in route 2 and stop 11 in route 1). The greatest Ta fluctuation is observed at Sabat 1, where the variations in SVF and H/W were the largest. 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 were important. During winter, the North-West orientated Sabat 7 was the warmest among Sabats due to its location facing the wide main street from its northern opening. This could be attributed to the exposure to direct solar radiations between 1 pm to 4 pm when the sun is low during the

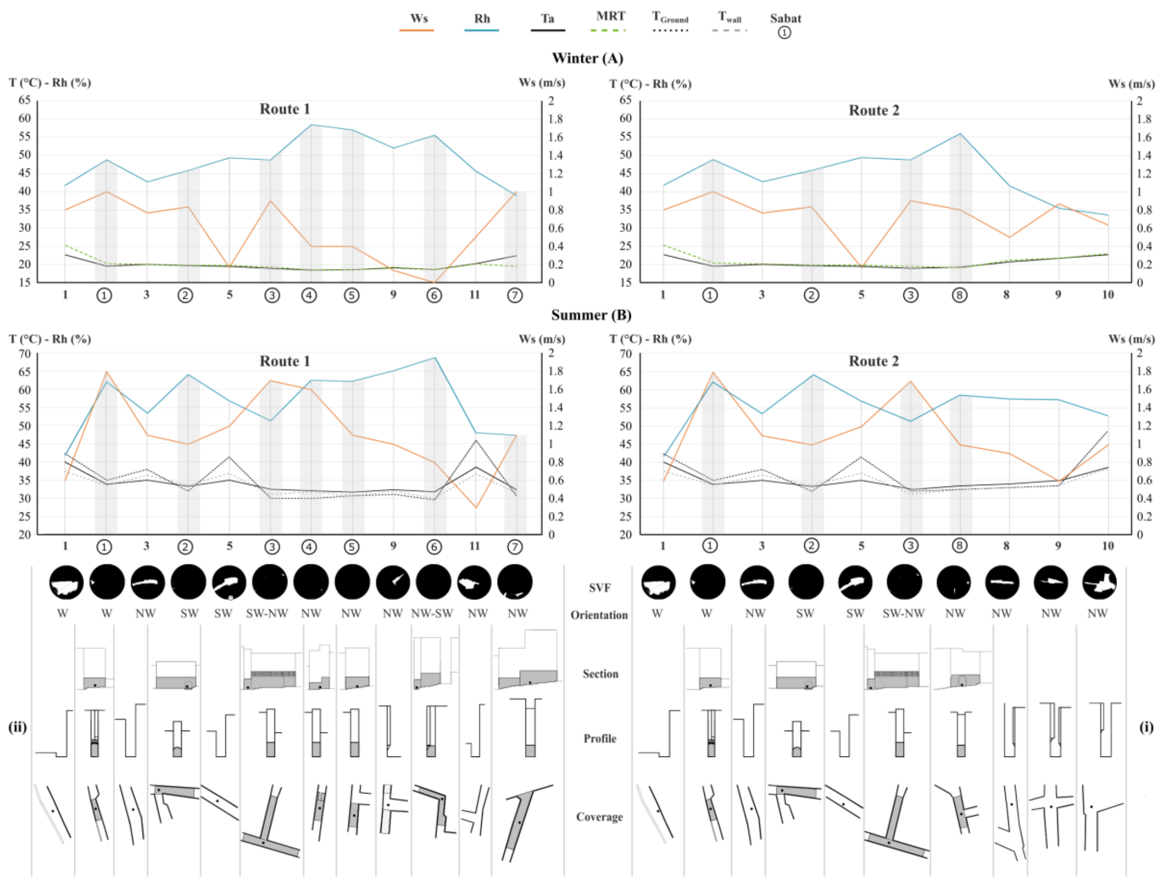


Figure 5.1: Mean variations of Ta, MRT, Tground, Twall and Rh (on the right Y axe) and Ws (on the left Z axe) recorded during winter (A) and Summer (B) mobile measurements. (i) and (ii) show the spatial variations of the Sabats and non-covered stops, mainly SVF, o

winter, hence, resulting in a significant heat storage. The vertical overhead structure of the Sabat can contribute to high degree of enclosure that resulted in enabling heat dissipation, therefore, warmer air temperature (Sinou et al., 2004), suggesting that Sabats exposed to direct solar exposure tends to trap heat, leading to warmer temperature during winter conditions**.**

Mean radiant temperatures (MRT) were calculated using the following equation (Johansson et al., 2014).

$$MRT = \left[(\mathrm{Tg} + 273.15)^4 + \frac{1.1 \times 10^8 \times \mathrm{v}^{0.6}\,(\mathrm{Tg} - \mathrm{Ta})}{\varepsilon \times \mathrm{D}^{0.4}} \right]^{1/4} - 273.15$$

where: Tg is the globe temperature (°C), Va is the wind speed (ms-1), Ta is the air temperature (°C), D is the globe diameter (m) and ε is the globe emissivity.

MRT was marginally, but non-significantly, lower in Sabats (H (1) = 6.353, p = .012) in (a) and (H (1) = 3.086, p = .079) in (b). MRT maw marginally closer to air temperature values is all measurement stops with the exception of the first non/covered stop and Sabat 7 in route 1. This suggest that the surface temperatures may have similar temperatures to that of the air, especially in shaded areas, and that the thermal environment would be predominantly influenced by air flow. However, it is worth to mention that the glob temperature was fixed for a maximum of 7 minutes, and moving between covered and non-covered streets would require more time for the globe temperature to adjust, which could introduce bias into the results.

Wind speeds (Ws) were relatively lower in non-covered streets during both winter and summer measurements. Wind speed 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. 5.1). Similar to air temperature, 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. 5.2). 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. 5.2.(a)). An increase in wind speed 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

(Fig.5.1). The short distance between these Sabats and the short-exposed areas in-between may contributed to lower exposure to solar radiation which resulted in reduced air temperature variations and decreasing the wind speed. Focusing on Sabat 1, 2, 3, 7, and 8, to demonstrate the impact of Sabat's position, wind speed significantly varied between Sabat and non-covered stops ($H(1) = 6.617$, $p < 0.05$) (Fig. 5.2.(b)), which suggest the influence of orientation and distribution of Sabats on wind variation.

During the summer conditions, Kruskal Wallis revealed a significant difference in Ws despite the presence of Sabat 3, 4, 5 and 6 in the input data (Fig. 5.3). 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 by the higher variation in ground temperature during the summer season. Fig. 5.1 of summer surveys shows that a reduction in ground temperature within Sabats was consistently accompanied by an increase 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 air temperature 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 amplification inside the sabats may be associated to the heated surface variations in relation to the significant difference in ground temperatures.

Surface temperatures were additionally monitored during the summer thermal walks. Ground temperature (Tgr) and wall temperature (Tw) were significantly lower in all measured Sabats ($H(1) = 8.064$, $p < .05$), ($H(1) = 6.904$, $p < .05$) (Fig. 5.3), respectively, in comparison to that of non-covered stops with open section streets with high SVF. Inside Sabats, Tg was marginally equal to air temperature with the exception of deep and closed Sabats, 3 to Sabat 6, where ground temperature was below air temperature and reached 26°C in the absence of access to direct solar exposure.

Relative humidity (Rh) was relatively higher during the summer season (Table1). Rh was significantly higher inside Sabats ($H(1) = 5.835$, $p < 0.05$) during the winter surveys while there is no significant variations during the hot summer conditions ($H(1) = 2.162$, $p > 0.05$) between Sabats and non-covered streets.

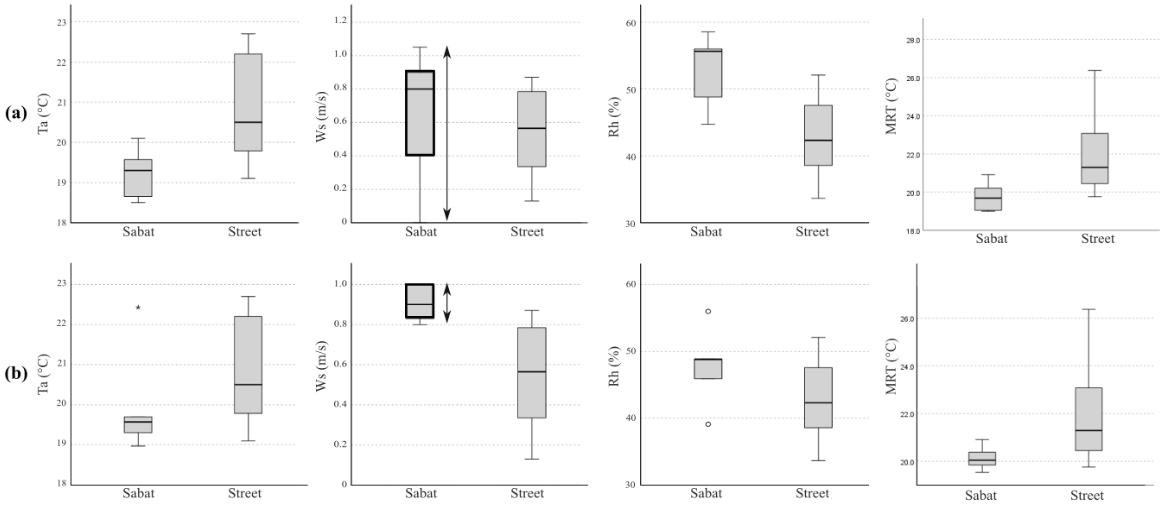


Figure 5.2: Kruskal Wallis Boxplots showing distributions in Ta, Ws, Rh and MRT at Sabats and non-covered stops during the winter (a). (b) shows Kruskal Wallis boxplots results, focusing only on Sabat 1, 2, 3, 7, and 8.

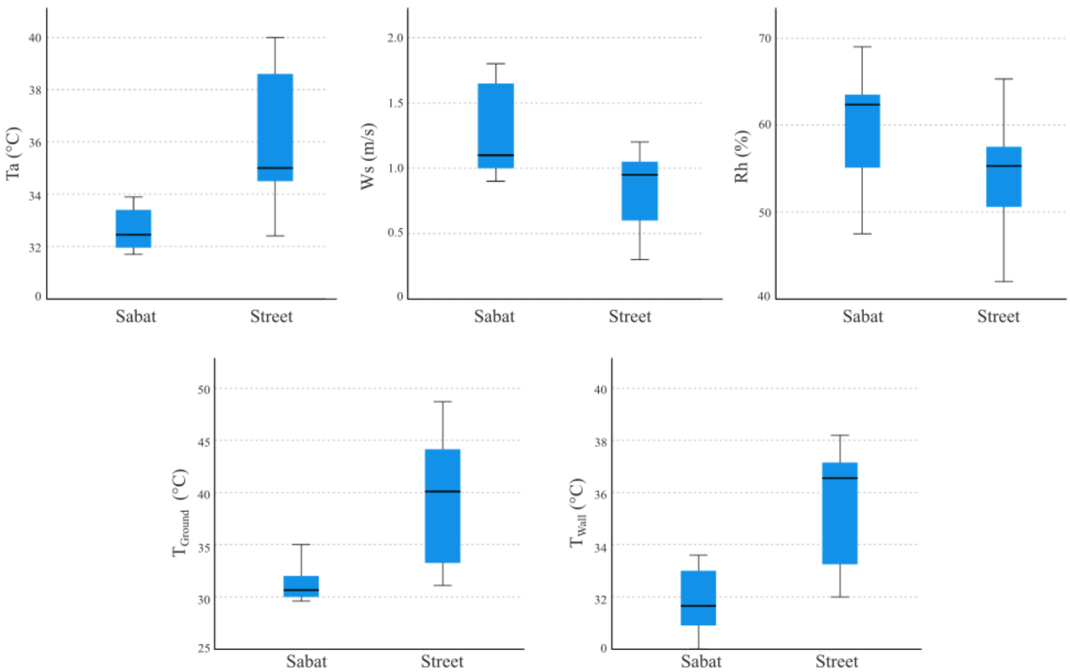


Figure 5.3: Kruskal Wallis Boxplots showing distributions in Ta, Ws, Rh and surface temperatures at Sabats and non-covered stops during summer conditions

5.3 Pedestrian walking experience and fatigue reduction

5.3.1 Sabat effect on pedestrians' walking experience

As indicated, the thermal aeraulic conditions inside the Sabats were significantly different from that of the non-covered streets, hence generating thermal-aeraulic variability with respect to the Sabats position and distribution. The analysis of the subjective response of participants revealed the significant impact of the transient thermal aeraulic conditions generated by Sabats, especially in the second part of route 1, on subjects' walking experience. Figure. 5.4. shows the clustered bar medians of fatigue sensation, pleasure, TSV and WSV recorded during winter and summer thermal walks. Figures. 5.5-6 shows the dynamic variations in fatigue sensation, pleasure, TSV, and WSV, during winter (Fig. 5.5) and summer (Fig. 5.6) thermal walks, as stairs count increases. Additionally, the figure is combined with Sabat distribution to highlight the potential influence of Sabat on pedestrians' sensations in relation to stairs count (Black line).

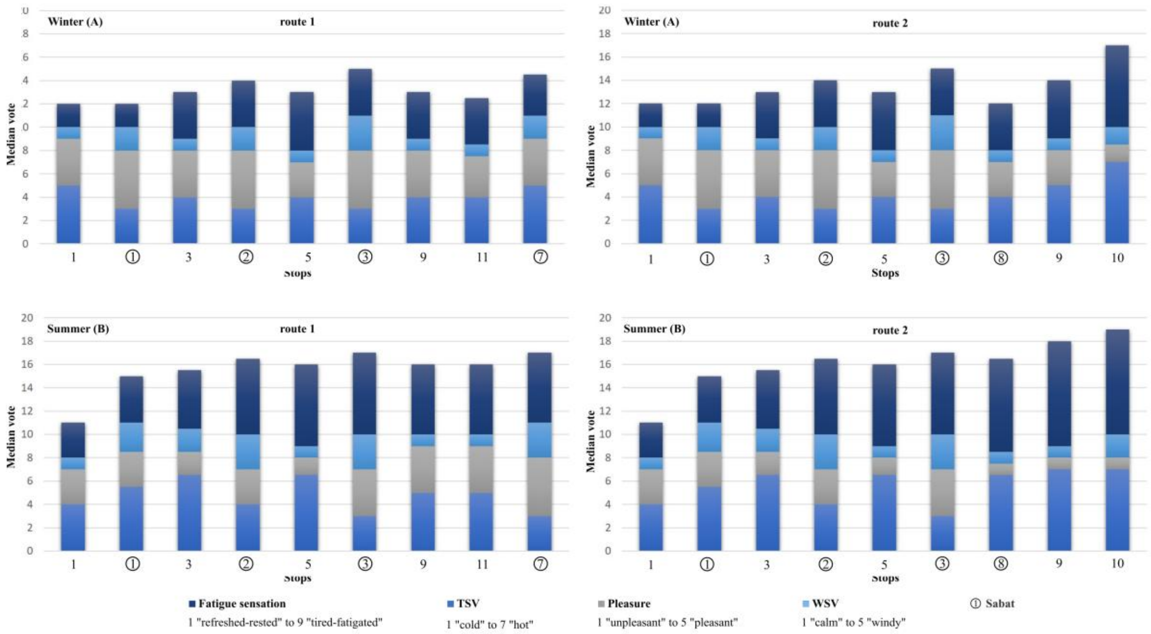


Figure 05.4: Clustered bar median of Fatigue sensation, Pleasure, TSV and WSV in route 1 and route 2 during winter (A) and summer (B) thermal walks. Circled stop numbers represent Sabats.

Winter conditions

In the first part of the walk (path A), high values of TSV were observed along non-covered stops with moderate air temperature followed by immediate TSV improvement when walking within shaded Sabat with cooler air temperature and refreshing effect of the wind enhancement, therefore higher thermal pleasure (Fig. 5.4-6). Moreover, each increase in WSV inside Sabat was followed by immediate increase in pleasure while fatigue was gradually increasing. Notably, the elevated fatigue sensation was slowed upon passing by Sabats (Fig. 5.5-6). The sequential movements from non-covered streets 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 Wind speed and marginal change in air temperature (Fig. 5.1), along with the accumulated thermal load of stairs climbing. Thermal 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. TSV significantly increased in route 2 (path C) and ranged between “slightly hot” and “hot” when walking non-covered street due to increased air temperature 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. 5.4-6).

Additionally, there was a 0.3°C difference in air temperature between Sabat 7 in route 1 and Stop 9 in route 2 (Fig. 5.1), 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. Here, results revealed the significant influence of other parameters on pedestrian subjective experience rather than the environmental conditions per se. Moreover, the findings suggest that transient conditions shape pedestrians' thermal history, which, in turn, affects their actual perceptions of the surrounding environment.

Summer conditions

The influence of staired streets and elevated air temperature is further evident on pedestrians’ fatigue sensation in the absence of Sabats in route 2 (Fig. 5.4-6). In the first part of the walk (path A), higher TSV was recorded in the beginning of the walk and even 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 wind speed before rapidly recovering after reaching Sabat 3 (Fig. 5.5.(B)), simultaneously with increased WSV as a result of deep shaded and windy Sabat (Fig. 5-6).

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). Here, the transient conditions offered a gradual rather than instant fatigue recovery. 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)). Continuous exposure to excessive heat in addition to the continuous uphill walking in absence of shaded elements and wind speed resulted in continuous heat accumulation and fatigue exhaustion translated in increase TSV and significant displeasure.

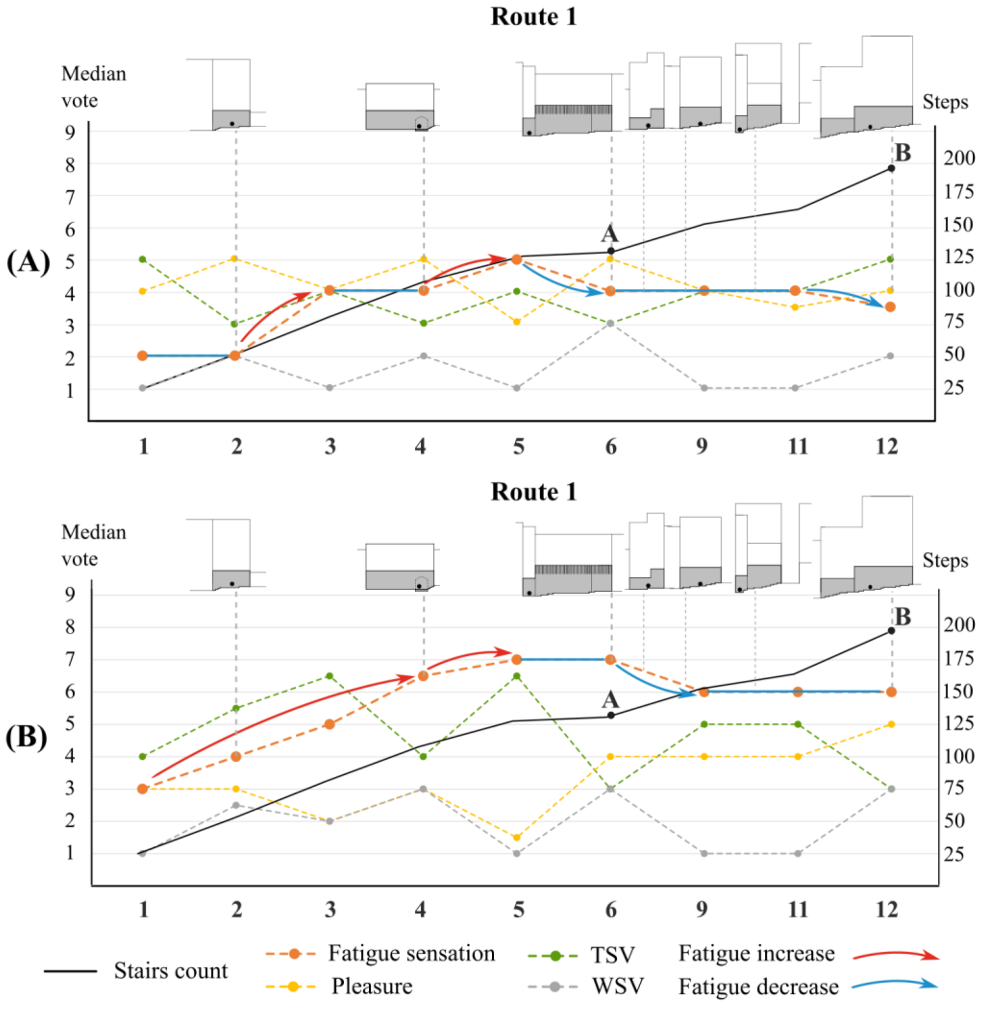


Figure 5.5: Changes in fatigue sensation, pleasure, TSV and WSV in relation to Sabat distribution and stairs count in route 1 during winter (A) and summer (B) thermal walks. A, B, and C represent the walking paths.

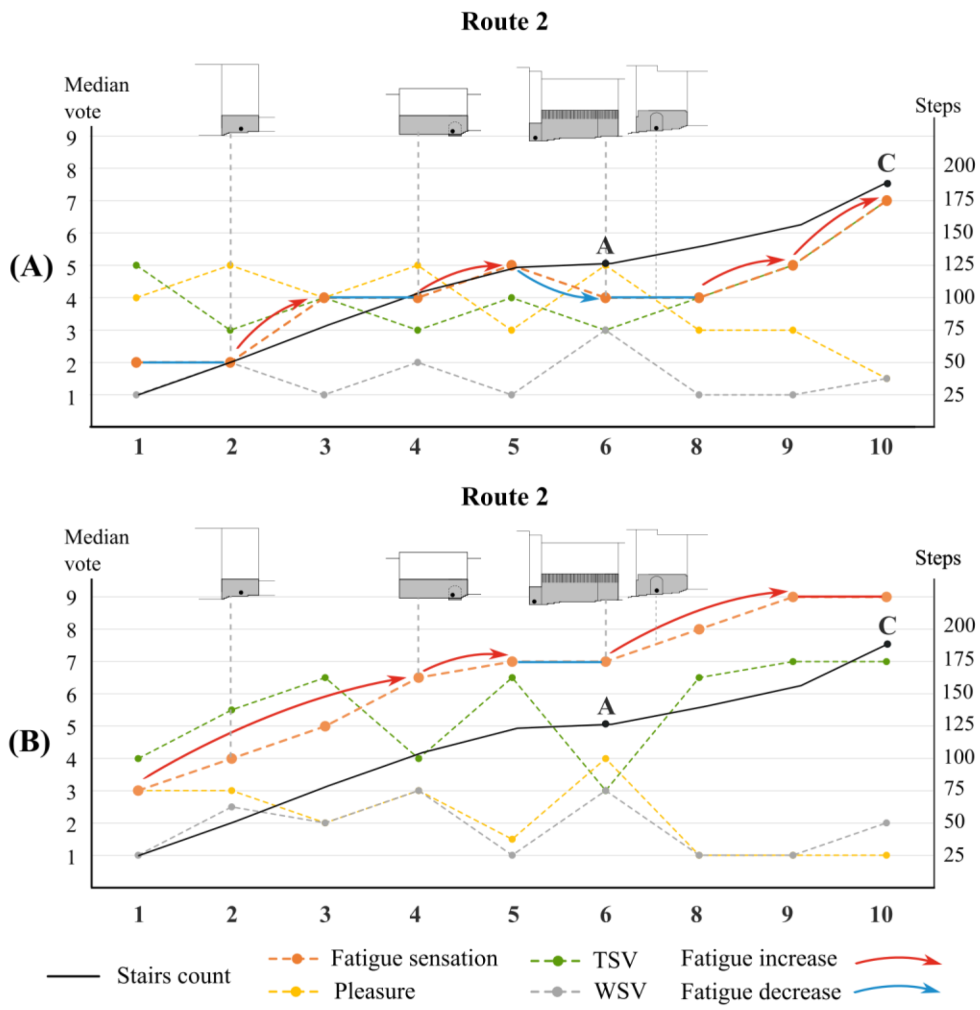


Figure 5.6: Changes in fatigue sensation, pleasure, TSV and WSV in relation to Sabat distribution and stairs count in route 2 during winter (A) and summer (B) thermal walks. A, B, and C represent the walking paths.

5.3.2 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 Figure. 5.7. During the winter thermal walks (Fig.5.7.(i)), there was no significant difference in fatigue sensation between path 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 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 significant higher level of TSV in comparison to A and B.

During the summer thermal walks (Fig. 5.7. (ii)), 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 ($Z= .550$, $p > 0.05$, 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. 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 Figures. 5.4-6. 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 (Fig.5.7). 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.

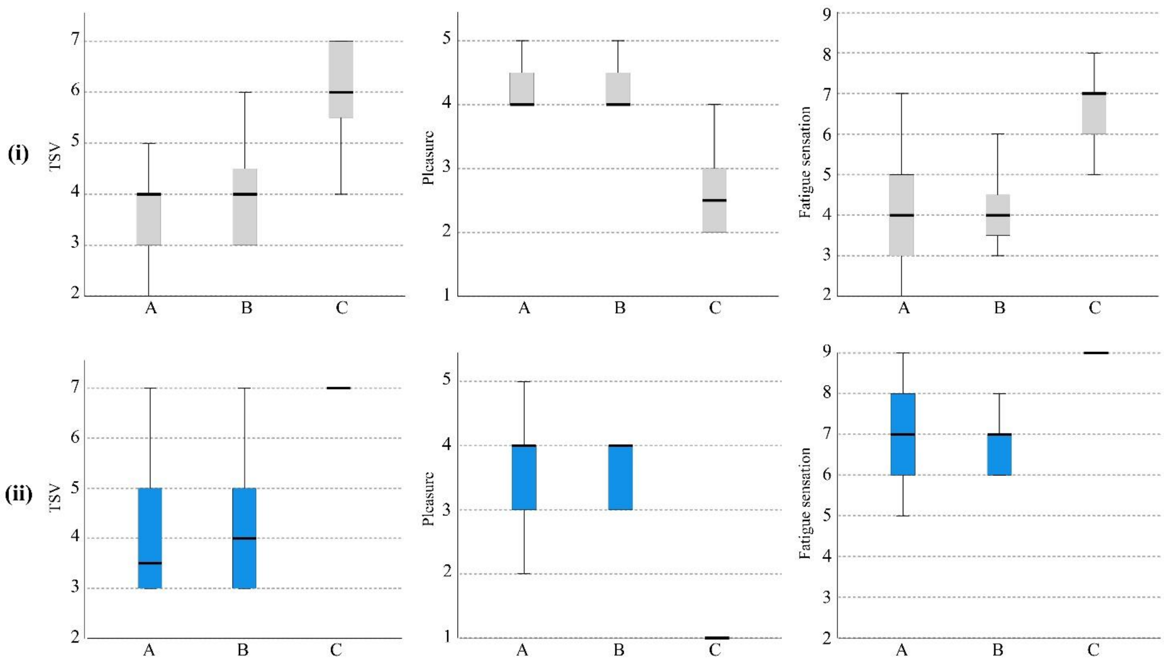


Figure 5.7: Kruskal-Wallis boxplots of Fatigue sensation, pleasure and TSV along path A, B, and C during winter (i) and summer (ii) thermal walks.

5.3.3 Correlation analysis

Correlation analysis followed Spearman's Rho correlation coefficients significance along with scatter plot to provides a visual assessment of the relationship type (linear, non-linear, or none). The focus of this section is held on analyzing significant correlation related to fatigue sensation. Correlations followed a triangulation approach by analyzing: overall walking experience recorded during winter and summer walks in both walking routes; walking experience during winter conditions and during summer conditions to reveal the relevance of the climate conditions; walking experience in route 1 and in route 2 during both seasonal conditions; and walking experience during each walking route during winter and summer conditions. Here, analyzing correlations in different sampling number (N) played an important role in enhancing the reliability and significance of the findings. The current section indicates the most significant correlations, while al correlation matrices are demonstrated in Appendix B. Overall fatigue sensation in route 1 and in route 2 to reveal the relevance of stairs count and possible influence of the Sabats.

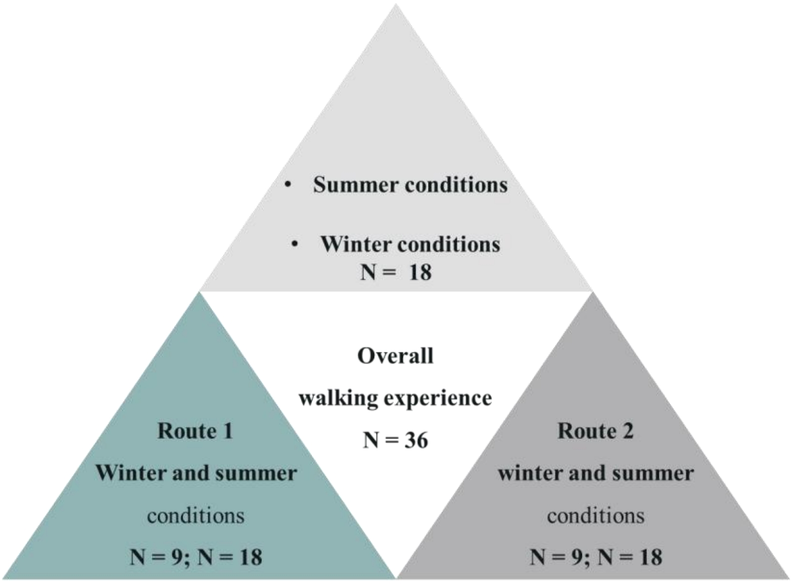


Figure 5.8: Correlation analysis triangulation approach (N: sample size).

5.3.3.1 Overall pedestrian's sensations

The scatter plot illustrate a moderate positive linear relationship between stairs count and overall increased fatigue (R^2= 0.453; Spearman Rho $\rho = 0.660$, $p < 0.001$, $N = 36$) (Appendix B. Table.1). 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 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-walking and the sensation of fatigue and highlight the possible implication of Sabats presence in this relationship.

Spearman Rho correlation showed a significant positive relationship of air temperature with fatigue ($\rho = 0.4530$, $p < 0.05$, $N = 36$) (See Appendix B). That is as air temperature increases, the sensation of physical exhaustion is likely to increase as a result of heat accumulation. However, scatter plot displays a non-linear relationship (Fig. 10(d)) suggesting the significance of exposure duration and tolerance threshold on fatigue sensation.

Thermal pleasure strongly correlates with TSV **(**$\rho = -0.821$, $p < 0.001$, $N = 36$ (Appendix B.1). Fatigue sensation correlated better with pleasure than with TSV **(**$\rho = -0.568$, $p < 0.001$, $N = 36$; $\rho = 0.428$, $p < 0.05$, $N = 36$) respectively (Appendix C.1). Pleasure's scatter plot confirms a negative linear relationship (R2 = 0.411), while TSV's reveals a weak positive relationship (Fig. 5.10; Fig. 5.11). This suggest that changes in fatigue sensations are more associated in changes in TSV, reflected in thermal pleasure, rather than TSV itself, indicating potential for thermal alliesthesia.

5.3.3.2 Fatigue during winter and during summer

Fatigue sensation is found to vary among winter and summer thermal walks. During temperate winter conditions, fatigue strongly correlates with stairs ($\rho = 0.840$, $p < 0.000$, $N = 18$), with moderate negative correlation with pleasure ($\rho = -0.610$, $p < 0.05$, $N = 18$) (Appendix B) (Fig.5.9.a). However, during the summer, fatigue only correlates with stairs ($\rho = 0.734$, $p < 0.001$, $N = 18$) with 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 indicate that walking experience, in terms of fatigue sensation, is associated to both the metabolic heat production to accommodate the physical activity, uphill walking, and the external microclimate conditions contributing to increasing the thermal loads in the thermoregulatory mechanism.

5.3.3.3 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. 5.9.b). In the presence of Sabat spaces, the increasing number of stair count within the progress of the walk does not appear to have a significant impact on fatigue sensation. Conversely in route 2, scatter plot and Spearman Rho reveal a moderate positive relationship between stairs and fatigue (R^2 = 0.608; ρ = 0.767, p < 0.001, N = 18) ((Fig. 5.9 .c). Moreover, the influence of air temperature is only significant in route 2 (ρ = 0.483, p < 0.05, N = 18) (Appendix B. Table.5). Similarly, TSV and pleasure tend to only have significant correlations with fatigue in route 2 (ρ = 0.619, p < 0.05, N = 18; ρ = -0.644, p < 0.05, N = 18) respectively (Appendix B. Table.5) (Fig. 5.11-12).

Overall, the walking experience is negatively impacted in non-covered streets with increasing stairs count within the walking route. 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, elevating thermal sensation, and lowering the overall pleasure of the experience, such is the case of route 2. Here, the thermal defenses operate to offset heat production induced by both internal and external heat gains, ultimately contributing to an increased sensation of fatigue. In the presence of transient conditions generated by Sabats within the walking route 1, the walking experience is not impacted by the increasing stairs count. Short-term exposure to shaded passage with increased wind speed tends to offer recovery conditions, which relieves the thermal

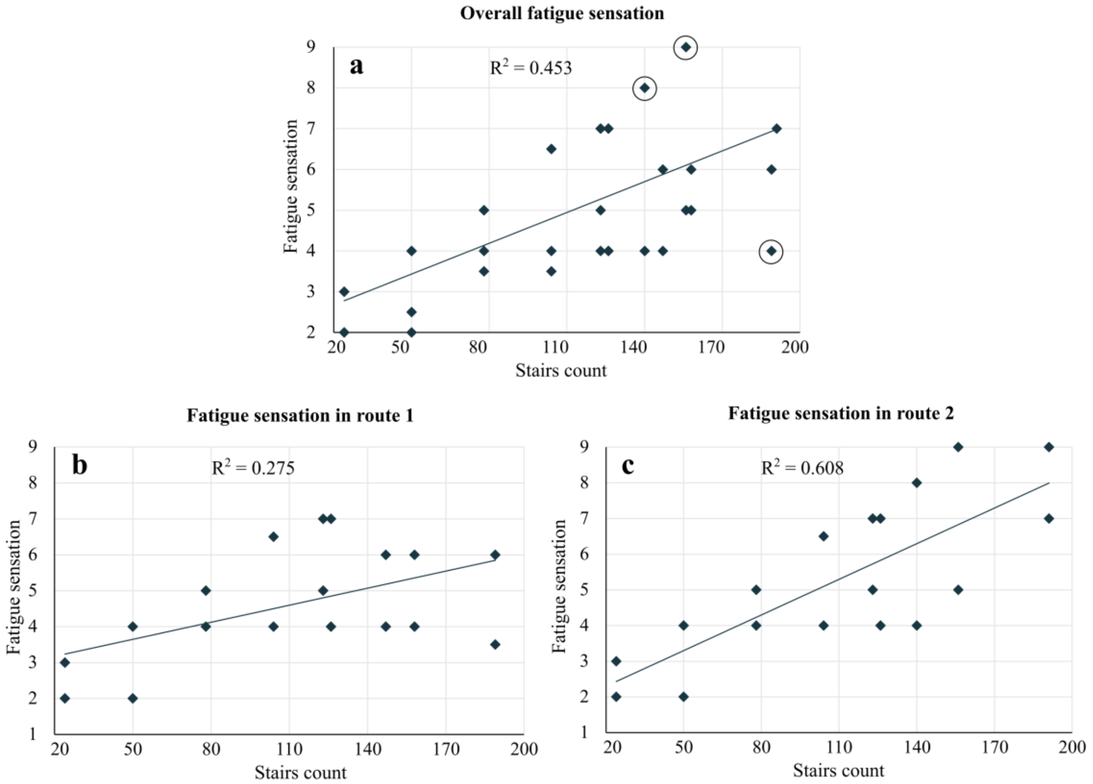


Figure 05.9: Scatter plot correlation of overall fatigue sensation, fatigue sensation in route 1 and fatigue sensation in route 2 with stairs count.

regulatory system, allowing to lower the accumulated thermal loads. This, in turn, would enhance thermal tolerance for both the physical activity, including stairs-climbing and external heat gains. Such findings suggest the possible contribution of the sabat spaces, with their transient thermal aeraulic conditions, in reducing thermal fatigue sensation in route 1, despite internal and external heat gains produced by both uphill walking and heat exposure, highlighting the potential of thermal alliesthesia.

Transient conditions' effect on Thermal pleasure

Thermal pleasure correlated better with TSV and Ta during the summer conditions. While it correlated more with WSV and Ws during winter conditions. 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.

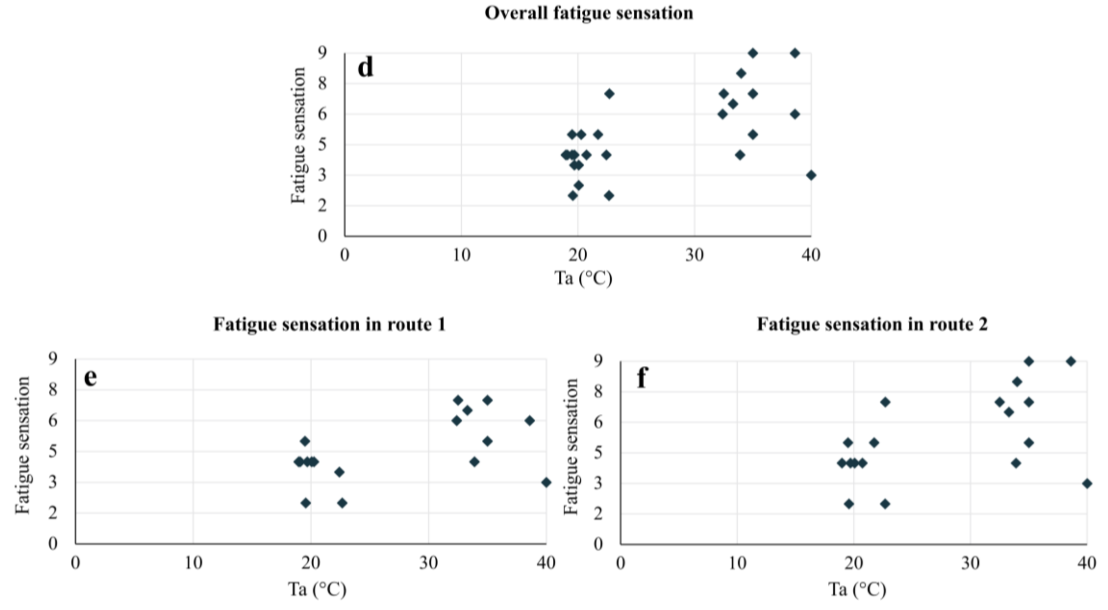


Figure 05.10: Scatter plot correlation of overall fatigue sensation, fatigue sensation in route 1 and fatigue sensation in route 2 with Ta

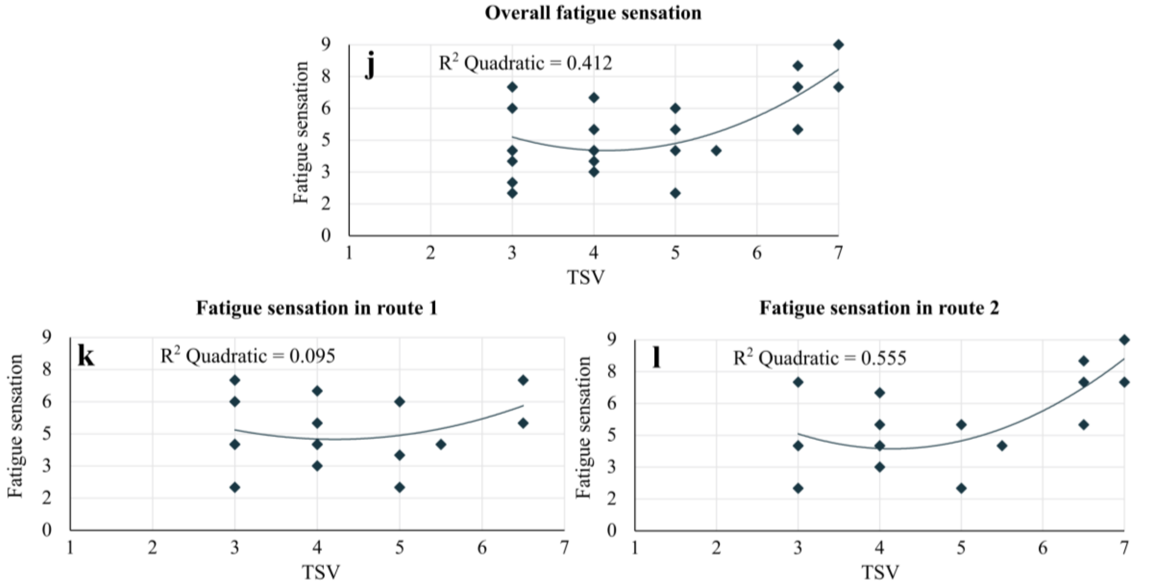


Figure 5.11: Scatter plot correlation of overall fatigue sensation, fatigue sensation in route 1 and fatigue sensation in route 2 and TSV.

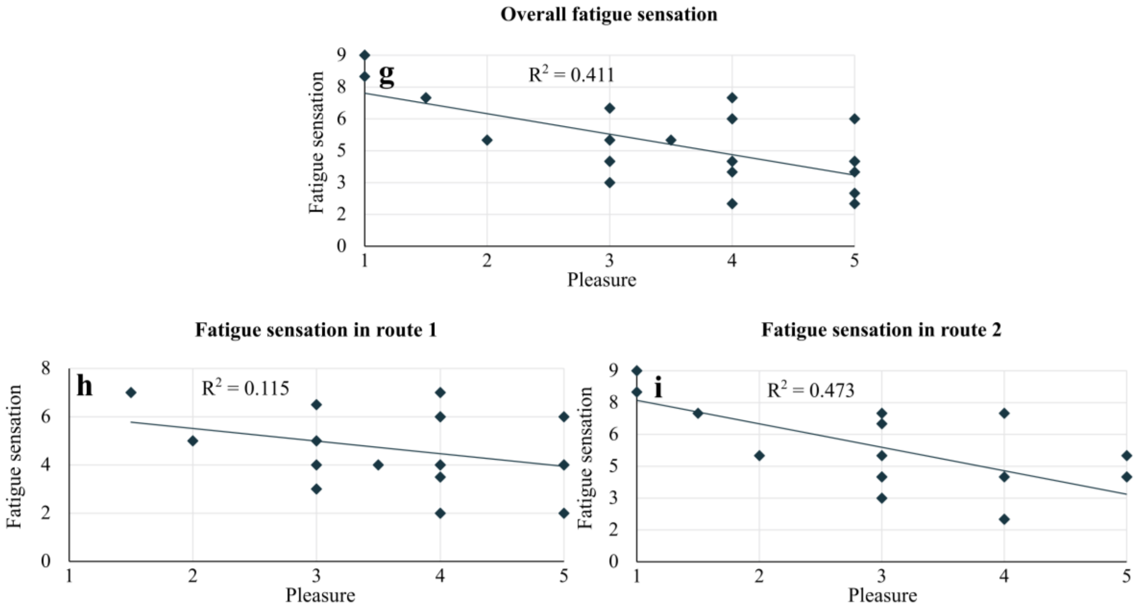


Figure 5.12: Scatter plot correlation of overall fatigue sensation, fatigue sensation in route 1 and fatigue sensation in route 2 with thermal pleasure.

5.3.4 Analyzing alliesthesia

5.3.4.1 Autocorrelation of fatigue sensation in two different walking routes

Figure 5.13 revealed significant autocorrelations 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. 5.13), results imply the significant influence of previous experience, walking by Sabats within the street, in 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 a significant PACF autocorrelation. This time, fatigue sensation gradually increased in route 2 (Fig.5.13), suggesting an accumulative effect of previous fatigue sensation on actual fatigue sensation.

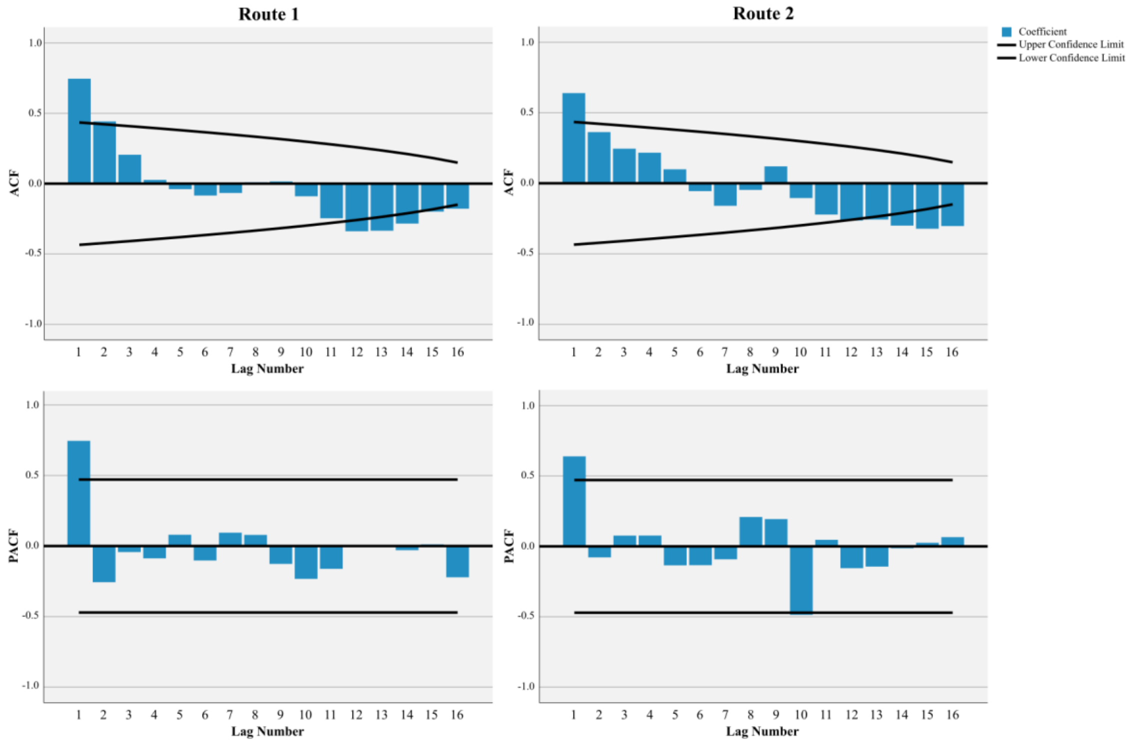


Figure 5.13: Autocorrelation (ACF) and partial autocorrelation (PACF) of fatigue sensation at each walking route. The solid lines indicate the 95% confidence interval, used to determine whether the null hypothesis is rejected. The bars indicate the autocorrelation.

5.3.4.2 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 (Yaffee et al., 2001). Cross-correlation analysis was conducted to examine the delayed effect of stairs on fatigue sensation while walking route 1 and route 2 (Fig. 5.14). 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 Sabat spaces. 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 exposure to the same environmental conditions may induce additional thermal loads since subjects were continuously climbing staired street with continuous heat exposure.

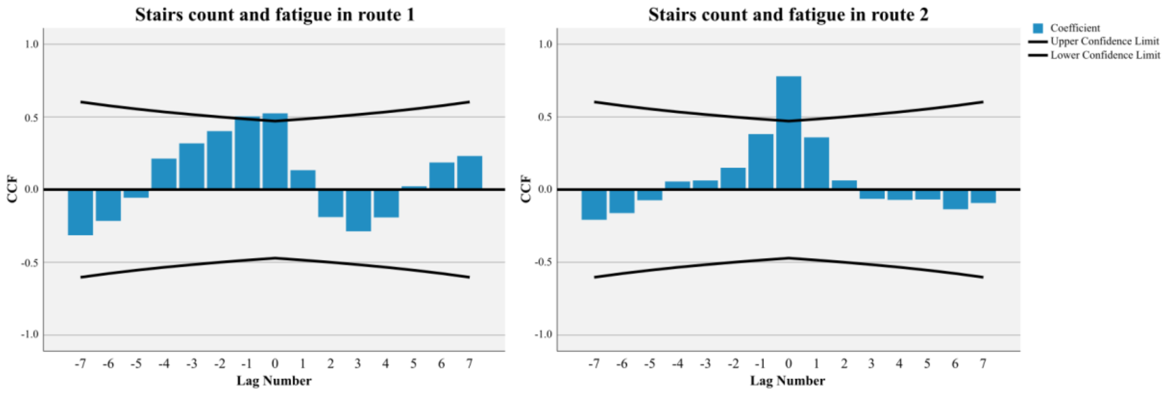


Figure 5.14: Cross-correlation (CCF) between stairs count and fatigue sensation in route 1 and route 2. The solid lines indicate the 95% confidence interval, used to determine whether the null hypothesis is rejected. The bars indicate the autocorrelation coefficient.

5.4 The Sabat as a cooling-shaded spot for walking activity

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, and its significance in supporting resilient walkability.

Thermal heating plays an important role in controlling wind flow within urban areas (Kim et al., 2001; Xie et al., 2007). 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 (Stathopoulos et al., 1992). The wind acceleration inside Sabat could be attributed by the channeling effect (or wind blocking effect). The void created at ground level of the Sabat design along with the height above the Sabat may contributed to block the upstream wind flow and accelerate wind flow near ground du to variation in enclosure between non-covered street and the opening of the Sabat.

In case of lift-up configuration, such as 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 meter). Such results align with Chew and Norford (Chew et al., 2019). 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 (Du et al., 2017) 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 (Chew et al., 2019; Du et al., 2017; Weng et al., 2022; Xia et al., 2015). These studies have demonstrated its benefits in providing wind amplification and shading breaks which provides optimal microclimates for the walking activity. 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 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 Mediterranean cities at the pedestrian level by providing cool-shaded and ventilated spots along the walking route, especially during the hot season.

5.5 The role of Sabat in supporting resilient comfort and resilient walkability

An environment that is enriched with diverse conditions promises 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 and would encourage for 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. 5.5;14) 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 (Nikolopoulou et al., 2001; Vasilikou et al., 2020). Moreover, people response to a physical stimulus also depends on psychological factors such as history of exposure and perceived control (Nikolopoulou et al., 2001; Spagnolo et al., 2003). Physical adaptation implies the changes in the physiological responses resulting from short frequent exposures to Sabats' pleasant conditions, leading to 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" (Lyu et al., 2022). Such increase in adaptive capacities can offer opportunities to experience alliesthesia (Cabanac, 1979b) which enhances of the capacity to recover (Schweiker, 2020), 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 (Monroe et al., 2016).

The use of Sabats, as cool-shaded and ventilated breaks, would reduce the impact of long walks and prolonged discomfort exposure, therefore resilience encouraging walkability.

5.6 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 (Al Sabbagh, 2017; Ji et al., 2017; Lau et al., 2019) and that thermal pleasure is strongly associated to restorative opportunities (Lyu et al., 2022). 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 (Cabanac, 1979b; de Dear, 2011). 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.

5.7 Conclusion

Casbah, the traditional center of Algiers, represents an authentic Mediterranean architecture and urbanism, specifically the presence of the Sabat space. The city is Characterized by its vided urban life along with its significant urban attraction for tourists,

Amid current climate change challenges, walkability became a common concern in both traditional and contemporary urban design. There are significant walking barriers in the context of pedestrian comfort that needs to be addressed, specifically climate and topography. In absence of adequate shading strategies, prolonged heat exposure along with steep slops and staired streets significantly elevate heat accumulation, physical exertion and fatigue therefore hindering the walking activity, especially for uphill walking. These walking barriers are not specific to the traditional cities, and are common concerns in many hilly cities across the Mediterranean region. Addressing these walking barriers, the current study introduced for the first time the application of thermal walks in the historical center of Algiers, Casbah, to investigate walkability.

The aim of the current research was to investigate the influence of the Sabat space on generating transient thermal aeraulic conditions and its influence on reducing pedestrian fatigue sensation, hence supporting a positive walking experience. Thermal walks were conducted during temperate and hot conditions in two preselected walking routes in Algiers' Casbah. these walks were conducted during critical hours of day from 1pm to 4 pm, following the uphill walking direction to highlight to the most critical conditions. The two walking routes had similar stairs count, street aspect ratio and differed in terms of Sabat presence and distribution to provide comparative results. The mobile meteorological measurements and questionnaire survey were conducted simultaneously. Meteorological data and subjective data were than analyzed by overlaying and cross-analyzing the mean and median values point to point and between paths and walking routes.

The thermal walks provided valuables insights about the influence of environmental diversity, presence of sabats, on the walking experience. Findings reported in this chapter significantly contribute to confirm the current study' hypothesis about the influence of the Sabats within the street in generating transient thermal aeraulic conditions, and their influence on reducing fatigue sensation and improving thermal pleasure, hence supporting a positive walking experience.

The lift-up design of the Sabat spaces allowed for creating shaded-cool spot and generating wind amplification inside the Sabat, with respect to orientation, heating surface variations, and street morphology. Shaded sabats with narrow openings generated different air pressures and generated wind blocking effect in the ends of the Sabats, therefore creating air amplification inside the covered passages. This created transient conditions in comparison to low wind speeds in non-covered streets, was instantaneously perceived by pedestrians with the progress of the walk.

These cool-shaded passages provided instant thermal sensation and thermal pleasure improvement and gradual fatigue sensation mitigation with the progress of the walk. The comparison of two walking routes with different sabats distributions, number and location revealed key findings. While the sabat space generate cool-shaded spots, its location and distribution within the walking route is important in reducing the fatigue sensation as Sabats located in the second half of the walking routes were more significant in improving pedestrians' thermal pleasure and fatigue sensation.

Moreover, the cross-correlation analysis of the environmental and subjective monitoring revealed significant results. Findings revealed the alliesthesial potential of the Sabats in providing restorative experience and reducing fatigue sensation. The alliesthesia effect was validated by the delayed effect of stairs count on the sensation of fatigue in route 1. In presence of Sabats, the progressive stairs count had no influence in increasing fatigue sensation and the shaded-cool conditions contributed to gradually decrease the sensation of fatigue and enhance thermal pleasure.

General Conclusion

6.1 General conclusion

The presented work addressed walkability as both a critical feature influenced by climate change and a key element that could reshape its magnitude. The broader aim is to investigate potential solutions that are climate-resilient and able to enhance pedestrian's walking experience facing the actual and future consequences of climate change and temperature increase. As such, the current study investigated the influence of environmental diversity in improving walkability. The aim was to provide knowledge of the potential of in-between spaces in supporting more resilient walking experience.

To achieve the research's aim, the current manuscript was divided into two complementary parts; the first part cornered the issues related to climate change, temperature increase and heat-related risks threatening pedestrians health and well-being in the context of the Mediterranean region. Within the climate resilience framework, this part presented a holistic approach and definitions related to environmental diversity and pedestrian subjective sensations. It provided the link between walkability, climate and outdoor comfort in terms to heat exhaustion and fatigue as a significant walking barrier. Specifically, the focus was held on the outdoor heat exposure duration and the importance of supporting environmental diversity within the framework of urban resilience strategies. In the context of the Mediterranean region, the Sabat space was reintroduced as potential solution to enhance walkability and mitigate heat exposure, supporting both environmental diversity and walkability.

The second part of the thesis provided detailed demonstration of the research methodology, thermal walks, and provided in details the main results and conclusions answering the proposed hypothesis. The thermal walks consisted of monitoring mobile thermal aeraulic conditions within two preselected walking routes along with simultaneous assessment of pedestrians' dynamic walking experience during both winter and summer conditions. The in-between space, the Sabat type, was found to significantly provide thermal aeraulic conditions that are different from that of outdoor exposed streets, therefore providing short-term restorative qualities and enhancing pedestrians' walking experience. Specifically, results revealed novel and primary understanding on the role of creating rhythmic cool-shaded and ventilated Sabat design on reducing fatigue sensation and the and the importance of dynamic alliesthesia in urban restorative design strategies.

The potential of the Sabat design, a traditional in-between 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 was investigated in the context of uphill walking in Mediterranean cities, the case of Algiers Casbah. Following a pedestrian-centered approach, thermal walks have been conducted in Algiers Casbah to report on the thermal aeraulic conditions generated by the in-between spaces, the Sabat type, along with the simultaneous pedestrian dynamic experience, during summer and winter conditions.

In addition to climate implications, hilly cities present serious walking barriers to walking activity and walkability. However, addressing such barrier is overlooked in the literature of walkability and pedestrian outdoor comfort. The significance of Casbah thermal walks was the inclusion of uphill-walking for the first time and its impact on pedestrian walking experience. Additionally, the current study proposed for the first time including the fatigue sensation vote as an affective dimension influencing pedestrian comfort and its relevance to thermal alliesthesia. The influence of Sabat spaces on walking experience was investigated later by overlaying and cross-analyzing the environmental data along with pedestrian's subjective experience while allowing for comparison between two walking routes with different Sabat distribution. The statistical analysis followed a triangulation approach, of which the influence of Sabats was gradually confirmed at each statistical from describing the significance, detecting variance, providing correlational relationships, and finally cross-correlation test delayed effect.

The findings of the current study support our theoretical framework. The main conclusions positively answers the research question and the hypothesis by highlighting the multifaceted role of in-between spaces, the Sabat type, in influencing thermal aeraulic conditions and pedestrian's walking experience. The Sabat design and distribution were found to significantly generate transient thermal aeraulic conditions within street. Conditions inside Sabats were characterized by lower air and ground temperatures and higher wind speeds compared to non-covered street. Notably, wind amplification inside Sabats is largely attributed to the void created at ground level of the Sabat. This could be attributed to the difference in ground temperatures and by the blocking effect of upstream air flow near the openings of the sabat. The intensity of wind acceleration depends on the orientation of the prevailing winds and the solar orientation, distribution and design attributes of the Sabat (height, length and width), and the geometry of the street.

The dynamic thermal experience of walking by frequents Sabats within the street positively influenced pedestrians' affective state, particularly in terms of pleasure and fatigue sensations**.** The distribution of such short interval conditions along the street provided rhythmic, restorative breaks, considerably reducing the thermal loads of heat exposure and uphill walking. Hence the significance of the combined effect of shade and wind in elevating thermal strains. The distribution of Sabats within streets could be interesting in training the thermal regulatory system to tolerate thermal discomfort, therefore fostering resilient comfort.

Moreover, different distributions and placement of the sabats along the two walking routes had varying effects on pedestrians' walking experience. Sabats located in the latter part of the walking route were more effective in mitigating the sensation of 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. Sabats located only at the beginning of the walking route would be less effective since pedestrians did not reach their threshold tolerance levels.

Finally, results were concluded by the cross-correlation analysis to understand the delayed effect between changes in thermal aeraulic conditions and changes in the fatigue sensation, accounting for the gradual increase of the stairs count as the independent variable and the fatigue sensation as the dependent variable. the significant 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 ($r = 0.640$) in presence of sabats within the street. Such findings reveals the implication of positive thermal alliesthesia in providing short restorative conditions-when brief exposure to cool, shaded and ventilated condition within sabat provides a sense of relief-gradually reducing fatigue sensation in short rhythmic intervals of cool-shaded and ventilated passages (Sabats).

6.2 Limitations and future work

While current findings presented valuable insights related to walkability and, urban resilience, there are also limitations related to the methodology that could be highlighted in terms of the sample size and population, as well as the instruments employed for the environmental monitoring.

The vulnerability of the elderly to fatigue is not discussed and was limited the small sample size and narrow age group of participants. fatigue has been found to be an important feature for activity restriction for older people (Egerton et al., 2016). Additionally, summer thermal walks were administrated for only two days due to heat wave conditions especially during the survey hours from 1pm to 4pm, in addition to the difficulties encounters due to the inadequacy of the topography and the uphill walking per se. To overcome this limitation, summer thermal walks supplemented initial results from winter thermal walks to account for the influence of transient conditions during extreme temperatures. Moreover, to overcome the limitation of small sample size during summer conditions, correlation analysis were conducted based on overall experience during both summer and winter conditions, and overall experience in each walking route therefore increasing the sample size and enhancing the reliability and robustness of the statistical significance in the analysis. The findings from this constrained sample offer a valuable starting point for hypothesizing broader trends. Future research can expand upon these findings by incorporating larger and more diverse age groups in different urban configurations, climate and terrain conditions., i.e., down-hill walking and flat terrain walking.

To overcome the vane probe sensitivity, the vane was fixed in the tripod away from obstructions (moving pedestrians or surveyors) that could disrupt airflow 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.

The mobile meteorological measurements were conducted simultaneously with the thermal walk questionnaire survey. The stopping time at each assessment stop was limited to the number the assessment stops in the two selected walking route and the simultaneous assessment of participants subjective experience within an interval of 1h30 and 7-minute stopping time. However, the 7-minute may not be sufficient to accurately measure the globe temperature since the globe requires longer duration, up to 15 minutes, to calibrate to new temperatures especially when moving to sunlit to shaded environments. Therefore, the MRT was assessed during the winter condition in order to obtain general knowledge of the transient conditions rather than to characterizing the environmental behavior. Moreover, results of the correlation and cross-correlation were independent of the MRT values. More focused assessment for longer stopping durations in necessary to comprehend globe temperature and MRT variations in transient conditions, especially for transitions from sunlit to shaded stops and vice versa.

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.

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 (outsides, beginning, middle and end) are required in future work to quantify the thermal aeraulic behavior and performance of such configuration. Scholars are invited to investigate different covered passage designs and in different climates.

6.3 Broader impacts

From a broader perspective, the current findings highlight 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.

Findings expand on previous literature about alliesthesia and shed lights 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. As such, the Sabat design can inspire creating climate-resilient outdoor environments by providing adequate environmental diversity. Careful implementation of Sabat design is important in creating adaptive and restorative opportunities for resilient walking facing the current climate change conditions. 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.

Findings provides valuable insights for enhancing the walking experience in traditional cities with similar context to Algiers Casbah. Sabat design, when carefully implemented, has proven to provide restorative qualities in the traditional city of Casbah, and could present a promising step toward resilient urban design. However, it should be noted that these findings are limited to uphill walking within a historical Mediterranean city and do not represent optimal implementation of Sabats. Such interventions hold the potential to ensure that all urban areas, including historical cities, benefit from restorative design strategies, which can promote social equity and inclusiveness in city planning as well as creating urban environments that are not only walkable but also culturally resonant. By examining the role of Sabat spaces in urban design, this study lays a foundation for hypothesizing broader trends that could inform the integration of Sabat-inspired elements into contemporary city planning.

In the context of Algiers' Casbah, the current study sheds light on how traditional urban in-between spaces, the Sabat, can play a crucial role in addressing contemporary climate change challenges. Current findings could encourage city planners to prioritize the urgent restoration and conservation of damages Sabats. Such efforts would not only ensure comfortable walking in traditional cities with the same context but also preserve the architectural and cultural identity of the city, fostering sustainable urban environments. Moreover, their revitalization could play key attraction role for the tourism sector, taking Bari Vecchia in Italy as an example. Such intervention could generate economic opportunities as well as community engagements.

In the context of new urbanism, findings of the current study inspire the implementation of the sabat through a dual approach: as a climate-responsive device and as a climate-resilient design strategy. Incorporating such design in to the planning of future extensions could significantly contribute to creating dense, diverse and walkable environment within the 15-minute city framework. Ensuring the accessibility to various amenities within a 15-minute walkable distance requires enhancing heat resilience capacities (Wang et al., 2022). Integrating the sabat design would not only favor heat resilience through its restorative potential but also expand beyond its environmental benefits, adopting social and economic features. In addition to ensuring cool-shaded breaks, the covered passage could serve various services and social interaction i.e. coffee shops, book store, resting spots, etc., thereby enhancing land use diversity and proximity to amenities. Ultimately, this will promote livable, resilient and walkable communities. On the other hand, learning from the Sabat distribution as climate-resilient strategy would inspire urban designers on how to dynamically integrate shaded and restorative elements within the outdoor spaces while preserving balanced openness and usability.

As for implementing the Sabat design, as a tradition device in new urban structures requires thoughtful adaptations. Interpreting the design as transient lift-up, shaded walkaways within streets or between buildings would highly extend the streets' walkable distance. Further investigations are imperative to gain deeper understanding of the thermal aeraulic behavior of these covered passage of different design attributes and in different climate conditions. Utilizing CFD (Computational Fluid Dynamics) modeling could provide more valuable insights into airflow patterns and thermal distribution, allowing for more effective evaluations of various design possibilities. Additionally, investigating the influence on pedestrian's affective state in relation to different factors related to enclosure and sense of security is important. Such holistic approach is necessary as it would determine the feasibility and optimal integration of the Sabat design in modern urbanism while considering cultural differences in the context of the Mediterranean region.

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Appendices

Appendix A: Questionnaire survey

[ENG] the thermal experience **التجربة الحرارية**

[1]

1 Indicate how you feel the environment at the moment : كيف تصف شعورك بالعوامل الجوية في الوقت الحالي

Temperature :	Cold	Slightly cold	Cool	Neutral	Warm	Slightly hot	Hot	**: الحرارة**
	بارد	متوسط البرودة	منعش قليلا	مريح	دافئ قليلا	دافئ	حار	

Wind speed :	☐ Calm	☐ breezy	☐ Gentle breeze	☐ Slightly windy	☐ Windy	**: سرعة الرياح**
	هادئة	نسيم	نسيم لطيف	مضطربة	قوية	

2 Do you feel the actual weather to be pleasant or unpleasant ? هل تعتقد أن العوامل الجوية الحالية لطيفة أم غير لطيفة؟

Unpleasant	Slightly Unpleasant	Indifferent	Slightly pleasant	Pleasant
غيرلطيفة	غيرلطيفة بعض الشيء	محايد	لطيفة بعض الشيء	لطيفة

3 How would you rate your current physical condition ? كيف تقيم حالتك البدنية الحالية؟

منتعش مرتاح	Refreshed Rested	1	2	3	4	5	6	7	8	9	Tired Fatigated	مرهق متعب

[FR] l'expérience thermique

[1]

1 Veuillez indiquer comment vous ressentez l'environnement en ce moment :

Température	Froid	légèrement froid	Frais	Neutre	tiède	légèrement tiède	Chaud

Vitesse de l'air	☐ Calme	☐ Brise	☐ Brise légère	☐ Modérée	☐ Forte

2 Que pensez-vous des conditions météorologiques actuelles ?

Désagréable	Légèrement Désagréable	Indifférent	Légèrement agréable	Agréable

3 Comment évaluez-vous votre état physique actuel ?

Rafraîchi reposé	1	2	3	4	5	6	7	8	9	Epuisé Fatigué

Figure 6.1: example of one questionnaire sheet translated to Arabic and French, fillet at each assessment stop.

[ENG] the walking experience **تجربة المشي :**

[A]

1 In relation to the path you took, how do you evaluate the environment ?
فيما يتعلق بالمسار الذي سلكته ، كيف تصف شعورك الحراري ؟

Cold	Slightly cold	Cool	Neutral	Warm	Slightly hot	Hot
بارد	متوسط البرودة	منعش قليلا	مريح	دافئ قليلا	دافئ	حار

2 Did you find the weather conditions to be pleasant or unpleasant ? هل كانت العوامل الجوية لطيفة أم غير لطيفة؟

Unpleasant	Slightly Unpleasant	Indifferent	Slightly pleasant	Pleasant
غيرلطيفة	غيرلطيفة بعض الشيء	محايد	لطيفة بعض الشيء	لطيفة

3 In relation to the path you took, how would you rate your physical condition ?
فيما يتعلق بالمسار الذي سلكته ، كيف تقيم حالتك البدنية ؟

منتعش مرتاح Refreshed Rested 1 2 3 4 5 6 7 8 9 Tired Fatigated مرهق متعب

[FR] l'expérience de marcher

[A]

1 Par rapport au chemin parcouru, comment vous ressentez l'environnement ?

Froid — légèrement froid — Frais — Neutre — tiède — légèrement tiède — Chaud

2 Par rapport au chemin parcouru, que pensez-vous des conditions météorologiques ?

Désagréable — Légèrement Désagréable — Indifférent — Légèrement agréable — Agréable

3 Par rapport au chemin parcouru, comment évaluez-vous votre état physique ?

Rafraîchi reposé 1 2 3 4 5 6 7 8 9 Epuisé Fatigué

Figure 6.2: example of one questionnaire sheet translated to Arabic and French, fillet at the end of each walking path A, B, and C.

Appendix B: Spearman's Rho correlation matrices

Table 6-1: Spearman's rho correlations between overall sensations and stairs count, Ta, Rh and Ws.

Spearman's rho Correlations

Overall sensations		Fatigue sensation	Thermal pleasure	TSV	WSV	Stairs count	Ta	Rh	Ws
Fatigue sensation	Correlation Coefficient	1.000	-.568**	.428**	.123	.660**	.437**	.500**	.278
	Sig. (2-tailed)	.	.000	.009	.474	.000	.008	.002	.101
	N	36	36	36	36	36	36	36	36
Thermal pleasure	Correlation Coefficient	-.568**	1.000	-.821**	.316	-.130	-.643**	-.333*	-.037
	Sig. (2-tailed)	.000	.	.000	.060	.451	.000	.047	.832
	N	36	36	36	36	36	36	36	36
TSV	Correlation Coefficient	.428**	-.821**	1.000	-.387*	.160	.600**	.235	.086
	Sig. (2-tailed)	.009	.000	.	.020	.352	.000	.168	.619
	N	36	36	36	36	36	36	36	36
WSV	Correlation Coefficient	.123	.316	-.387*	1.000	.006	-.058	.288	.647**
	Sig. (2-tailed)	.474	.060	.020	.	.972	.737	.088	.000
	N	36	36	36	36	36	36	36	36
Stairs count	Correlation Coefficient	.660**	-.130	.160	.006	1.000	-.055	-.028	-.128
	Sig. (2-tailed)	.000	.451	.352	.972	.	.752	.872	.458
	N	36	36	36	36	36	36	36	36
Ta	Correlation Coefficient	.437**	-.643**	.600**	-.058	-.055	1.000	.330*	.334*
	Sig. (2-tailed)	.008	.000	.000	.737	.752	.	.050	.047
	N	36	36	36	36	36	36	36	36
Rh	Correlation Coefficient	.500**	-.333*	.235	.288	-.028	.330*	1.000	.506**
	Sig. (2-tailed)	.002	.047	.168	.088	.872	.050	.	.002
	N	36	36	36	36	36	36	36	36
Ws	Correlation Coefficient	.278	-.037	.086	.647**	-.128	.334*	.506**	1.000
	Sig. (2-tailed)	.101	.832	.619	.000	.458	.047	.002	.
	N	36	36	36	36	36	36	36	36

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 6-2: Spearman's rho correlations between overall sensations during winter walks and stairs count, Ta, Rh and Ws

Overall sensations during winter walks (route 1 and route 2)		Fatigue sensation	Thermal pleasure	TSV	WSV	Stairs count	Ta	Rh	Ws
Fatigue sensation	Correlation Coefficient	1.000	-.610**	.270	-.137	.840**	-.058	-.155	-.405
	Sig. (2-tailed)	.	.007	.278	.588	.000	.818	.539	.096
	N	18	18	18	18	18	18	18	18
Thermal pleasure	Correlation Coefficient	-.610**	1.000	-.763**	.722**	-.478*	-.415	.380	.681**
	Sig. (2-tailed)	.007	.	.000	.001	.045	.086	.119	.002
	N	18	18	18	18	18	18	18	18
TSV	Correlation Coefficient	.270	-.763**	1.000	-.607**	.283	.716**	-.669**	-.342
	Sig. (2-tailed)	.278	.000	.	.008	.255	.001	.002	.165
	N	18	18	18	18	18	18	18	18
WSV	Correlation Coefficient	-.137	.722**	-.607**	1.000	.052	-.296	.166	.752**
	Sig. (2-tailed)	.588	.001	.008	.	.838	.234	.511	.000
	N	18	18	18	18	18	18	18	18
Stairs count	Correlation Coefficient	.840**	-.478*	.283	.052	1.000	.043	-.246	-.217
	Sig. (2-tailed)	.000	.045	.255	.838	.	.867	.325	.386
	N	18	18	18	18	18	18	18	18
Ta	Correlation Coefficient	-.058	-.415	.716**	-.296	.043	1.000	-.805**	.057
	Sig. (2-tailed)	.818	.086	.001	.234	.867	.	.000	.823
	N	18	18	18	18	18	18	18	18
Rh	Correlation Coefficient	-.155	.380	-.669**	.166	-.246	-.805**	1.000	-.143
	Sig. (2-tailed)	.539	.119	.002	.511	.325	.000	.	.573
	N	18	18	18	18	18	18	18	18
Ws	Correlation Coefficient	-.405	.681**	-.342	.752**	-.217	.057	-.143	1.000
	Sig. (2-tailed)	.096	.002	.165	.000	.386	.823	.573	.
	N	18	18	18	18	18	18	18	18

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 06-3: Spearman's rho correlations between overall sensations during summer walks and stairs count, Ta, Rh and Ws.

Spearman's rho Correlations										
Overall sensation during summer walks (route 1 and route 2)		Fatigue sensation	Thermal pleasure	TSV	WSV	Stairs count	Ta	Rh	Ws
Fatigue sensation	Correlation Coefficient	1.000	-.414	.331	.004	.734**	-.170	.197	-.025
	Sig. (2-tailed)	.	.087	.180	.988	.001	.501	.434	.922
	N	18	18	18	18	18	18	18	18
Thermal pleasure	Correlation Coefficient	-.414	1.000	-.877**	.451	.031	-.533*	-.229	.148
	Sig. (2-tailed)	.087	.	.000	.060	.903	.023	.361	.557
	N	18	18	18	18	18	18	18	18
TSV	Correlation Coefficient	.331	-.877**	1.000	-.539*	.132	.484*	.294	-.097
	Sig. (2-tailed)	.180	.000	.	.021	.602	.042	.236	.702
	N	18	18	18	18	18	18	18	18
WSV	Correlation Coefficient	.004	.451	-.539*	1.000	-.015	-.652**	.109	.538*
	Sig. (2-tailed)	.988	.060	.021	.	.952	.003	.667	.021
	N	18	18	18	18	18	18	18	18
Stairs count	Correlation Coefficient	.734**	.031	.132	-.015	1.000	-.264	-.020	-.196
	Sig. (2-tailed)	.001	.903	.602	.952	.	.289	.938	.436
	N	18	18	18	18	18	18	18	18
Ta	Correlation Coefficient	-.170	-.533*	.484*	-.652**	-.264	1.000	-.452	-.502*
	Sig. (2-tailed)	.501	.023	.042	.003	.289	.	.059	.034
	N	18	18	18	18	18	18	18	18
Rh	Correlation Coefficient	.197	-.229	.294	.109	-.020	-.452	1.000	.222
	Sig. (2-tailed)	.434	.361	.236	.667	.938	.059	.	.376
	N	18	18	18	18	18	18	18	18
Ws	Correlation Coefficient	-.025	.148	-.097	.538*	-.196	-.502*	.222	1.000
	Sig. (2-tailed)	.922	.557	.702	.021	.436	.034	.376	.
	N	18	18	18	18	18	18	18	18

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 0-4: Spearman's rho correlations between overall sensations in route 1 (summer and winter walks) and stairs count, Ta, Rh and Ws.

Spearman's rho Correlations									
Overall sensations in route 1 (summer and winter walks)		Fatigue sensation	Thermal pleasure	TSV	WSV	Stairs count	Ta	Rh	Ws
Fatigue sensation	Correlation Coefficient	1.000	-.289	.109	.205	.416	.375	.629**	.353
	Sig. (2-tailed)	.	.246	.668	.415	.086	.125	.005	.150
	N	18	18	18	18	18	18	18	18
Thermal pleasure	Correlation Coefficient	-.289	1.000	-.699**	.297	.274	-.571*	-.363	-.110
	Sig. (2-tailed)	.246	.	.001	.231	.271	.013	.138	.665
	N	18	18	18	18	18	18	18	18
TSV	Correlation Coefficient	.109	-.699**	1.000	-.425	-.114	.550*	.242	.158
	Sig. (2-tailed)	.668	.001	.	.079	.653	.018	.334	.531
	N	18	18	18	18	18	18	18	18
WSV	Correlation Coefficient	.205	.297	-.425	1.000	.078	-.028	.209	.642**
	Sig. (2-tailed)	.415	.231	.079	.	.757	.912	.406	.004
	N	18	18	18	18	18	18	18	18
Stairs count	Correlation Coefficient	.416	.274	-.114	.078	1.000	-.162	-.012	-.088
	Sig. (2-tailed)	.086	.271	.653	.757	.	.521	.961	.730
	N	18	18	18	18	18	18	18	18
Ta	Correlation Coefficient	.375	-.571*	.550*	-.028	-.162	1.000	.185	.394
	Sig. (2-tailed)	.125	.013	.018	.912	.521	.	.463	.105
	N	18	18	18	18	18	18	18	18
Rh	Correlation Coefficient	.629**	-.363	.242	.209	-.012	.185	1.000	.419
	Sig. (2-tailed)	.005	.138	.334	.406	.961	.463	.	.083
	N	18	18	18	18	18	18	18	18
Ws	Correlation Coefficient	.353	-.110	.158	.642**	-.088	.394	.419	1.000
	Sig. (2-tailed)	.150	.665	.531	.004	.730	.105	.083	.
	N	18	18	18	18	18	18	18	18

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 6-5: Spearman's rho correlations between overall sensations in route 2 (summer and winter walks) and stairs count, Ta, Rh and Ws

Spearman's rho Correlations

Overall sensations in route 2 (summer and winter walks)		**Fatigue sensation**	**Thermal pleasure**	**TSV**	**WSV**	**Stairs count**	**Ta**	**RH**	**Ws**
Fatigue sensation	Correlation Coefficient	1.000	**-.644****	**.619****	.016	**.767****	**.483***	.450	.164
	Sig. (2-tailed)	.	**.004**	**.006**	.950	**.000**	**.042**	.061	.517
	N	18	18	18	18	18	**18**	18	18
Thermal pleasure	Correlation Coefficient	**-.644****	1.000	**-.707****	-.048	-.369	**-.740****	**-.515***	-.361
	Sig. (2-tailed)	**.004**	.	**.001**	.850	.132	**.000**	**.029**	.141
	N	18	18	18	18	18	**18**	18	18
TSV	Correlation Coefficient	**.619****	**-.707****	1.000	-.342	.425	**.665****	.215	.012
	Sig. (2-tailed)	**.006**	**.001**	.	.165	.078	**.003**	.392	.962
	N	18	18	18	18	18	18	18	18
WSV	Correlation Coefficient	.016	-.048	-.342	1.000	-.058	-.107	.349	**.645****
	Sig. (2-tailed)	.950	.850	.165	.	.819	.673	.156	**.004**
	N	18	18	18	18	18	18	18	18
Stairs count	Correlation Coefficient	**.767****	-.369	.425	-.058	1.000	.062	-.071	-.150
	Sig. (2-tailed)	**.000**	.132	.078	.819	.	.806	.781	.553
	N	18	18	18	18	18	18	18	18
Ta	Correlation Coefficient	**.483***	**-.740****	**.665****	-.107	.062	1.000	.425	.274
	Sig. (2-tailed)	**.042**	**.000**	**.003**	.673	.806	.	.079	.271
	N	18	18	18	18	18	18	18	18
Rh	Correlation Coefficient	.450	-.515*	.215	.349	-.071	.425	1.000	**.570***
	Sig. (2-tailed)	.061	.029	.392	.156	.781	.079	.	**.013**
	N	18	18	18	18	18	18	18	18
Ws	Correlation Coefficient	.164	-.361	.012	**.645****	-.150	.274	**.570***	1.000
	Sig. (2-tailed)	.517	.141	.962	**.004**	.553	.271	**.013**	.
	N	18	18	18	18	18	18	18	18

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 6-6: Spearman's rho correlations between sensations in route 2 during winter walks and stairs count, Ta, Rh and Ws.

Spearman's rho **Correlations**

Sensation in route 2 during winter walks		**Fatigue sensation**	**Thermal pleasure**	**TSV**	**WSV**	**Stairs count**	**Ta**	**RH**	**Ws**
Fatigue sensation	Correlation Coefficient	1.000	**-.740***	.493	-.174	**.843****	.211	-.369	-.474
	Sig. (2-tailed)	.	**.023**	.177	.654	**.004**	.586	.329	.197
	N	9	9	9	9	9	9	9	9
Thermal pleasure	Correlation Coefficient	**-.740***	1.000	**-.842****	.630	-.659	-.615	.615	**.719***
	Sig. (2-tailed)	**.023**	.	**.004**	.069	.054	.078	.078	**.029**
	N	9	9	9	9	9	9	9	9
TSV	Correlation Coefficient	.493	**-.842****	1.000	-.630	.390	**.858****	**-.762***	-.468
	Sig. (2-tailed)	.177	**.004**	.	.069	.300	**.003**	**.017**	.204
	N	9	9	9	9	9	9	9	9
WSV	Correlation Coefficient	-.174	.630	-.630	1.000	.000	-.468	.330	.633
	Sig. (2-tailed)	.654	.069	.069	.	1.000	.204	.385	.067
	N	9	9	9	9	9	9	9	9
Stairs count	Correlation Coefficient	**.843****	-.659	.390	.000	1.000	.250	-.550	-.267
	Sig. (2-tailed)	**.004**	.054	.300	1.000	.	.516	.125	.488
	N	9	9	9	9	9	9	9	9
Ta	Correlation Coefficient	.211	-.615	**.858****	-.468	.250	1.000	**-.900****	-.267
	Sig. (2-tailed)	.586	.078	**.003**	.204	.516	.	**.001**	.488
	N	9	9	9	9	9	9	9	9
Rh	Correlation Coefficient	-.369	.615	**-.762***	.330	-.550	**-.900****	1.000	.183
	Sig. (2-tailed)	.329	.078	**.017**	.385	.125	**.001**	.	.637
	N	9	9	9	9	9	9	9	9
Ws	Correlation Coefficient	-.474	.719*	-.468	.633	-.267	-.267	.183	1.000
	Sig. (2-tailed)	.197	.029	.204	.067	.488	.488	.637	.
	N	9	9	9	9	9	9	9	9

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6-7: Spearman's rho correlations between sensations in route 1 during winter walks and stairs count, Ta, Rh and Ws.

Spearman's rho Correlations									
Sensations in route 1 during winter walks		Fatigue sensation	Thermal pleasure	TSV	WSV	Stairs count	Ta	RH	Ws
Fatigue sensation	Correlation Coefficient	1.000	-.425	-.221	-.246	.358	-.523	.468	-.650
	Sig. (2-tailed)	.	.255	.568	.523	.344	.149	.204	.058
	N	9	9	9	9	9	9	9	9
Thermal pleasure	Correlation Coefficient	-.425	1.000	-.654	.793*	-.319	-.275	.044	.681*
	Sig. (2-tailed)	.255	.	.056	.011	.402	.474	.910	.043
	N	9	9	9	9	9	9	9	9
TSV	Correlation Coefficient	-.221	-.654	1.000	-.558	.187	.686*	-.561	-.219
	Sig. (2-tailed)	.568	.056	.	.119	.630	.041	.116	.571
	N	9	9	9	9	9	9	9	9
WSV	Correlation Coefficient	-.246	.793*	-.558	1.000	.112	-.298	-.037	.823**
	Sig. (2-tailed)	.523	.011	.119	.	.775	.436	.924	.006
	N	9	9	9	9	9	9	9	9
Stairs count	Correlation Coefficient	.358	-.319	.187	.112	1.000	-.117	.000	-.126
	Sig. (2-tailed)	.344	.402	.630	.775	.	.765	1.000	.748
	N	9	9	9	9	9	9	9	9
Ta	Correlation Coefficient	-.523	-.275	.686*	-.298	-.117	1.000	-.867**	.201
	Sig. (2-tailed)	.149	.474	.041	.436	.765	.	.002	.604
	N	9	9	9	9	9	9	9	9
Rh	Correlation Coefficient	.468	.044	-.561	-.037	.000	-.867**	1.000	-.435
	Sig. (2-tailed)	.204	.910	.116	.924	1.000	.002	.	.242
	N	9	9	9	9	9	9	9	9
Ws	Correlation Coefficient	-.650	.681*	-.219	.823**	-.126	.201	-.435	1.000
	Sig. (2-tailed)	.058	.043	.571	.006	.748	.604	.242	.
	N	9	9	9	9	9	9	9	9

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6-8: Spearman's rho correlations between sensations in route 1 during summer walks and stairs count, Ta, Rh and Ws.

Spearman's rho Correlations									
Sensation in route 1 during summer walks		Fatigue sensation	Thermal pleasure	TSV	WSV	Stairs count	Ta	RH	Ws
Fatigue sensation	Correlation Coefficient	1.000	.070	-.173	.267	.519	-.326	.272	.232
	Sig. (2-tailed)	.	.857	.656	.487	.152	.392	.478	.548
	N	9	9	9	9	9	9	9	9
Thermal pleasure	Correlation Coefficient	.070	1.000	-.746*	.303	.725*	-.855**	-.259	-.209
	Sig. (2-tailed)	.857	.	.021	.428	.027	.003	.501	.590
	N	9	9	9	9	9	9	9	9
TSV	Correlation Coefficient	-.173	-.746*	1.000	-.559	-.348	.424	.407	.145
	Sig. (2-tailed)	.656	.021	.	.118	.359	.255	.277	.709
	N	9	9	9	9	9	9	9	9
WSV	Correlation Coefficient	.267	.303	-.559	1.000	.115	-.222	.027	.469
	Sig. (2-tailed)	.487	.428	.118	.	.768	.566	.946	.202
	N	9	9	9	9	9	9	9	9
Stairs count	Correlation Coefficient	.519	.725*	-.348	.115	1.000	-.885**	-.067	-.160
	Sig. (2-tailed)	.152	.027	.359	.768	.	.002	.865	.682
	N	9	9	9	9	9	9	9	9
Ta	Correlation Coefficient	-.326	-.855**	.424	-.222	-.885**	1.000	-.128	.176
	Sig. (2-tailed)	.392	.003	.255	.566	.002	.	.743	.651
	N	9	9	9	9	9	9	9	9
Rh	Correlation Coefficient	.272	-.259	.407	.027	-.067	-.128	1.000	.252
	Sig. (2-tailed)	.478	.501	.277	.946	.865	.743	.	.513
	N	9	9	9	9	9	9	9	9
Ws	Correlation Coefficient	.232	-.209	.145	.469	-.160	.176	.252	1.000
	Sig. (2-tailed)	.548	.590	.709	.202	.682	.651	.513	.
	N	9	9	9	9	9	9	9	9

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6-9: Spearman's rho correlations between sensations in route 2 during summer walks and stairs count, Ta, Rh and Ws.

Spearman's rho Correlations										
Sensations in route 2 during summer walks		**Fatigue sensation**	**Thermal pleasure**	**TSV**	**WSV**	**Stairs count**	**Ta**	**RH**	**Ws**
Fatigue sensation	Correlation Coefficient	1.000	**-.722***	.664	-.213	**.992****	.026	.067	-.254
	Sig. (2-tailed)	.	**.028**	.051	.583	**.000**	.948	.864	.509
	N	9	9	9	9	9	9	9	9
Thermal pleasure	Correlation Coefficient	**-.722***	1.000	**-.938****	.655	**-.673***	-.491	-.155	.487
	Sig. (2-tailed)	**.028**	.	**.000**	.056	**.047**	.179	.690	.184
	N	9	9	9	9	9	9	9	9
TSV	Correlation Coefficient	**.664**	**-.938****	1.000	-.541	.616	.530	.111	-.328
	Sig. (2-tailed)	**.051**	**.000**	.	.133	.078	.142	.776	.389
	N	9	9	9	9	9	9	9	9
WSV	Correlation Coefficient	-.213	.655	-.541	1.000	-.132	**-.697***	.184	.611
	Sig. (2-tailed)	.583	.056	.133	.	.735	**.037**	.635	.080
	N	9	9	9	9	9	9	9	9
Stairs count	Correlation Coefficient	**.992****	**-.673***	.616	-.132	1.000	.000	.017	-.218
	Sig. (2-tailed)	**.000**	**.047**	.078	.735	.	1.000	.966	.572
	N	9	9	9	9	9	9	9	9
Ta	Correlation Coefficient	.026	-.491	.530	**-.697***	.000	1.000	-.509	-.556
	Sig. (2-tailed)	.948	.179	.142	**.037**	1.000	.	.162	.120
	N	9	9	9	9	9	9	9	9
Rh	Correlation Coefficient	.067	-.155	.111	.184	.017	-.509	1.000	.126
	Sig. (2-tailed)	.864	.690	.776	.635	.966	.162	.	.747
	N	9	9	9	9	9	9	9	9
Ws	Correlation Coefficient	-.254	.487	-.328	.611	-.218	-.556	.126	1.000
	Sig. (2-tailed)	.509	.184	.389	.080	.572	.120	.747	.
	N	9	9	9	9	9	9	9	9

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).