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**Research Article**

# Thermal Comfort Examination of the Staircase as a Transitional Space**

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## Abstract

Transitional spaces, such as staircases, often present challenges for building designers in achieving optimal thermal comfort. The lack of established guidelines and predictive methods for these environments necessitates further research. This study aims to evaluate the impact of staircase design on thermal comfort and user experiences in transitional spaces. A field study was conducted in Arris, Algeria, involving 144 participants. Participants completed questionnaires assessing thermal sensation, comfort, preference, and acceptability. Additionally, physical measurements were taken at various points along the staircases to determine operative temperatures. Four case study buildings were selected for investigation during both winter and summer. In winter, reducing the opening percentage from 88% to 19% decreased step temperatures. However, further reductions to 11% led to increased step temperatures due to decreased sunlight. Reducing the opening to 5% reduced wind effects while treating the façade with glass allowed for increased sunlight penetration. Step temperatures generally remained acceptable in summer, with opening percentages between 88% and 11%. However, Building 4 with a 5% opening and a glass façade, experienced increased step temperatures due to enhanced sunlight exposure. This study demonstrates the significant impact of staircase design on thermal comfort and user experience in transitional spaces. The findings highlight the importance of considering factors such as opening percentages, façade treatments, and seasonal variations when designing these areas. By incorporating these insights, architects and engineers can create more thermally comfortable and user-friendly buildings, promoting the well-being of occupants.

**Keywords:** Transitional space, Thermal comfort, Staircase, Occupants

# Geçiş Mekanı Olarak Merdivenin Isıl Konfor İncelemesi

## Öz

Bina tasarımcıları ve mühendisleri, geçiş bölgelerinde uygun düzeyde ısıl konfor sağlama konusunda sorunlarla karşı karşıyadır. Ayrıca, geçiş ortamları için önerilen bir konfor aralığı veya ısıl konforu tahmin etmek için özel bir yöntem yoktur. Bu makalenin amacı, ısıl çevre performansını ve insanların merdivenlerle temsil edilen geçiş alanlarına ilişkin algılarını ve bunların tasarımının ısıl konforu nasıl etkilediğini incelemektir. Öncelikle anket ile yerinde saha çalışması yapılmıştır ve 144 kişiden anket yanıtı

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** This article is extracted from my doctorate dissertation entitled "Study of Comfort Factors in Intermediate Space as an Extension of the Habitat.", supervised by Samira LOUAFI Ph.D. Dissertation, Batna1 University, Batna (Algeria), in progress beford dissertation.

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toplanmıştır. İkinci olarak TSV (ısıl duyum oyu), TCV (ısıl konfor oyu), TPV (ısıl tercih oyu) ve TAV (ısıl kabul edilebilirlik oyu) değerlendirilerek bina dışından binaya giden yol boyunca farklı merdiven konumlarında fiziksel ölçümler alınmıştır. Evlerin içinde çeşitli seviyelerde ölçümler yapıldıktan sonra çalışma sıcaklıkları hesaplanmıştır. Cezayir'in Arris kentinde seçilen dört örnek olay çalışması binası için kış ve yaz aylarında saha çalışmaları gerçekleştirilmiştir. Sonuçlar, kış mevsiminde açıklık yüzdesinin %88'den %19'a düşürülmesinin basamak sıcaklığında düşüşe yol açtığını göstermektedir. Bununla birlikte, açıklık yüzdesinin %11'e düşmesi güneş ışığı miktarının ve etkisinin azalmasına ve basamak sıcaklığının artmasına yol açmıştır. Buna karşılık, açıklık yüzdesinin %5'e düşürülmesi rüzgarın etkisini azaltmış, ancak cephenin %17 oranında camla kaplanması güneş ışığının girmesine izin vermiştir. Yaz aylarında, açıklık yüzdesi %88 ile %11 arasında değişen üç binada, basamak sıcaklıkları kabul edilebilir düzeydedir ancak açıklık yüzdesi %5 olan Bina 4'te, %17 oranında şeffaf camla işlenmiş cephe güneş ışığının etkisini artırmış ve basamak sıcaklığını yükseltmiştir.
Bu çalışma, geçiş mekanı tasarımının içeriden dışarıya veya tam tersi yönde hareket ederken adaptasyonu nasıl etkilediğini göstermektedir. Çalışmanın sonuçları, yapılı çevre tasarımcılarının dikkatini bu mekanın önemine çekecek ve bu mekanların kullanıcılarına ısıl şoka maruz kalmadan veya sağlıklarını etkilemeden rahat bir geçiş sağlayacak geçiş mekanları tasarlamalarına yardımcı olacaktır.

**Anahtar Kelimeler:** Geçiş alanı, Termal konfor, Merdiven, Bina sakinleri

## 1. Introduction

Transitional spaces, such as entrance canopies, foyers, lift lobbies, corridors, and staircases, separate interior and exterior environments while facilitating physical movement between them (Chun et al., 2004, pp.1187-1192). There is a limited amount of research on these spaces, making transitional comfort a worthy area of focus for the present paper.

Transitional spaces are characterized by transient, dynamic, variable, unstable, or fluctuating conditions (Hui et al., 2014k, pp.13).

When comparing transitional areas to interior spaces, the latter often require fine temperature management and have comfort limits. Building designers, nonetheless, face difficulty in ensuring appropriate thermal comfort for such spaces (Pitts et al, 2007, pp. 815-822). Limited fieldwork studies have validated the comfort conditions of dynamic states within transitional spaces such as hallways and atria (Palma, 2017, pp. 17).

This could cause the continued opacity of existing comfort standards regarding transitional zones (Van Hoof, 2008, pp. 82–201). The physical environments of transitional spaces differ depending on the space type and architectural features. As these spaces can make up a significant portion of the building's volume and have a substantial influence on how inhabitants use the space and its energy consumption, many people move through transitional areas. A promising strategy for environmental control is to utilize free resources from nature. This approach can help mitigate heat shock for people entering and exiting spaces, thereby altering their comfort expectations. By introducing step variations in temperature as individuals transition from the outside to the interior, it is possible to prevent significant thermal discomfort.

Door placement and glazing choices impact the thermal separation between transitional and internal rooms, affecting their susceptibility to rapid temperature changes and strengthening the thermal connection between these areas and the outside environment.

The majority of research, including studies by Palma (2017, p.17), Jitkhajornwanich and Pitts (2002, p. 1196-1200), Pitts et al. (2008, p. 10), Kotopouleas and Nikolopoulou (2016, p. 189-192), Hou (2016, p. 125-199), Li et al. (2018, 30-32), Du et al. (2020, p. 16), and Lu and Li (2020, p. 12), has concluded that occupants of transitional spaces exhibit greater comfort tolerance than predicted by Fanger's model. This is likely attributed to the dynamic conditions of these spaces, which contrast with the steady-state environment assumed in the model development.

Studies by Kotopouleas and Nikolopoulou (2016, p. 189-192) and Hou (2016, p. 125-199) suggest that occupants of transitional spaces demonstrate greater thermal adaptability, potentially linked to the duration of their exposure and their previous thermal experiences.

To create a comprehensive understanding of thermal comfort in transitional spaces, these studies recommend additional research conducted across different seasons (Avantaggiato and Belleri, 2021, pp.1-11; Wu et al., 2022, pp. 186–202).

By providing a temperature gradient, transitional spaces can mitigate the risk of thermal discomfort caused by abrupt changes in environmental conditions for people moving from outside to inside (Nakano et al., 1999, pp. 172-177). The body is affected by a sharp and rapid change in temperature between the inside and the outside. As the body struggles to adapt from a heated environment to an air-conditioned one, it experiences stress. This rapid temperature change can lead to dryness in the skin, mucous membranes, and eyes.

Conditions within transitional spaces are often characterized by fluctuations and instability (URL-1; Zvold, 2000, pp. 587–92 Hayashi et al., 1996, pp. 293–9). The dynamic nature of transitional spaces is influenced by numerous factors, including temperature changes, sunlight, and wind, creating a potentially unpredictable environment for occupants. This unpredictability can cause dramatic discomfort due to sudden changes. (URL-1).

Within human physiology, internal organ temperature plays the most critical role in maintaining overall health, as subtle changes can significantly impact various bodily functions (Zvold, 2000, pp. 587–92). The body does not tolerate sudden temperature changes (Chun et al., 2004, pp.1187-1192). The maximum step temperature should not exceed 5-7°C. Beyond that, the person is exposed to a thermal shock or cold snap that can cause loss of consciousness or even cardiac arrest. (URL-1; URL-2). Health insurance often specifies that cold and dry air can cause a thermal shock in the bronchi and trigger an asthma attack (URL-2). Not to mention the other common minor annoyances such as torticollis, colds, sore throats, runny nose, headaches, dry eyes, and muscle cramps (Zvold, 2000, pp. 587–92).
According to Tiwari (2019), Dr. Suranjit Chatterjee, an internal medicine specialist at Apollo Hospital, states that the human body needs time to adjust to drastic temperature changes, such as those from extremely hot to extremely cold. (URL-1). Dr. Chatterjee explains that rapid temperature fluctuations between extremes can impact blood vessels, which in turn can affect the heart. In winter, our blood vessels retain heat, while in summer, they dilate to cool the body (Hensen, 1990, pp. 309–16). The human body struggles to adapt to sudden temperature changes. Exceeding a maximum difference of 5-7°C can lead to thermal shock (URL-3).

Sudden temperature shifts, or "step-changes," can significantly impact the body's physiological responses. Hot step changes were found to elevate heart rate, blood oxygen saturation, and skin temperature, while cold step changes had the opposite effect. Larger temperature changes were determined to be more stressful for the body, potentially increasing health risks (Hu et al., 2021, p. 11).

Transitional spaces can facilitate adaptation between different environments. This flexibility might allow for more relaxed comfort requirements compared to areas where people spend extended periods.

This research aims to conduct field studies using on-site questionnaires and physical assessments to investigate the influence of staircase design on user thermal comfort and adaptability within this transitional environment.

## 2. Methodology

### 2.1. *Case Study Description*

This research employs a two-pronged approach, combining field measurements with a thermal comfort survey conducted through a questionnaire.

The case study focuses on Arris, a district within the Batna Province in eastern Algeria, approximately sixty kilometers southeast of the provincial capital (Figure 1). Arris is located at 35° 15′ 30″ north, 6° 20′ 40″ east.

Arris experiences a semi-arid climate characterized by short, scorching summers and long, frigid winters with snowfall. The region generally enjoys clear skies year-round. Average annual temperatures typically range from -2°C to 31°C, with rare instances of temperatures falling below -5°C or exceeding 35°C.

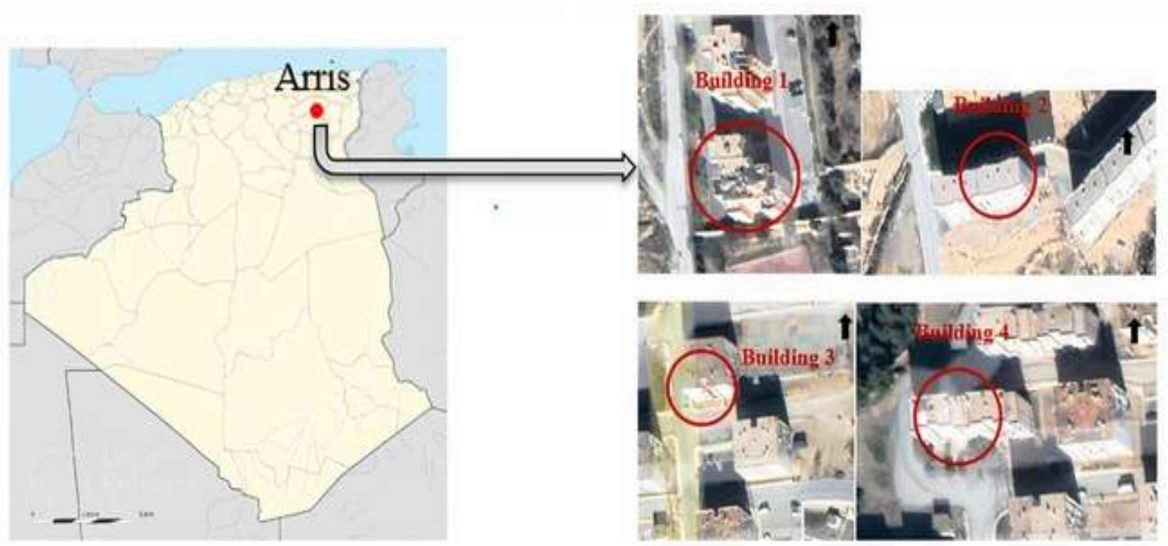
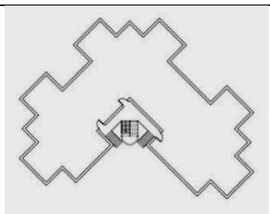
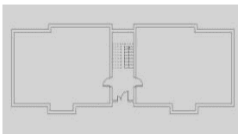
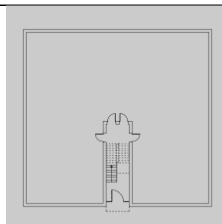
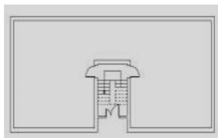



Figure 1. Geographical Location of Arris City (left) Ground Plan of the Different Buildings (right)

The study was conducted on four collective housing buildings located in three districts (Table 1): Building 1 in the 32-unit district, Building 2 in the Zarouali Ahmed Belahcen district, and Buildings 3 and 4 in the 1st November district. These buildings are depicted in Figure 2.


Figure 2. Surveyed Buildings. Source: Author

Table 1. Summaries of the Key Characteristics of the Surveyed Buildings

| Information | Building 1 | Building 2 | Building 3 | Building 4 |
|---|---|---|---|---|
| plan |  |  |  |  |
| Staircase dimensions | **5.60m*5.60m** | **2.60m*6.75m** | **2.35m*8.0m** | **2.70m*4.0m** |
| Facade opening percentage | **88%** | **19%** | **11%** | **5%** |
| Staircase treatment | **Opened** | **Vertical bays (10*60cm/120 cm)** | **Transom of clear glass (4*40cm/ 140cm)** | **Vertical bays of clear glass (8*40cm/220cm) (17% of facade)** |
| Floors number | **4** | **6** | **5** | **5** |
| Orientation | Northeast | | North | |
| Entrance door dimensions | **300*250cm** | | **90*210 cm** | |
| Distance between each two points of measurements | | | **250 cm** | |
| Measurements day | | **20, 21, 22 January (Winter period) and 19, 20, 21 August (Summer period)** | | |
| Measurements time | | | **8 am, 12 am, 2 pm, 4 pm** | |

## 2.2. *Field Measurements*

Field measurements were conducted in Arris during the winter of 2021 (January 20th, 21st, and 22nd), the coldest period, and the summer of 2021 (August 19th, 20th, and 21st), the hottest period. The measurements were taken at four collective housing buildings in Arris City at 8 AM, 12 PM, 2 PM, and 4 PM, which coincide with the times when residents commute to and from school and work. A total of 172 measurements were taken from the exterior of the buildings to the interior of the houses, traversing each landing in the staircase. A distance of 2.5 meters was maintained between each measuring point (Figure 3, left).

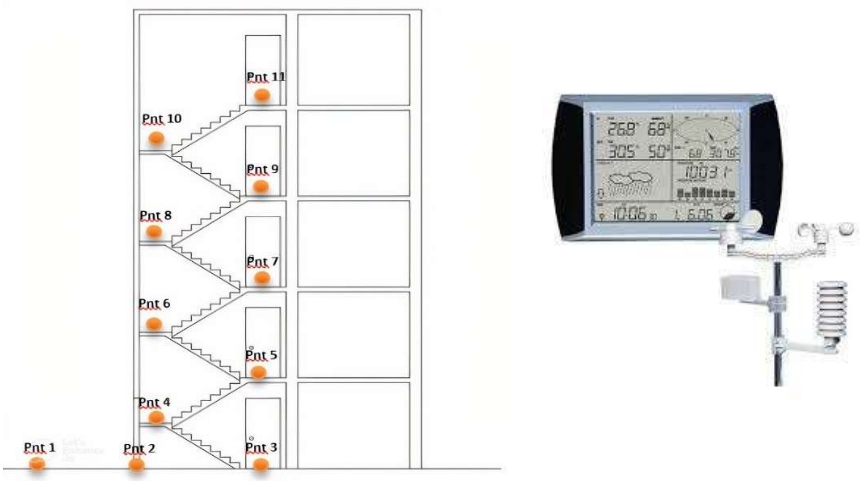



Figure 3. Measurements Points (left), Weather Station (right). Source: Author

Table 2. Field Instrument Specifications

| Parameter | Instrumentation model | Range | Accuracy |
|---|---|---|---|
| WBGT | Heat Stress Meter PCE-WB 20SD  | Inside: 0 ... +59 °C<br>Outside: 0 ... +56 °C | Outside ± 1.5 °C (+15 ... +56 °C)<br>± 2 °C (other temperature ranges)<br>Inside ± 1 °C (+15 ...+59 °C)<br>± 1.5 °C (other temperature ranges) |
| Air Temperature | | 0 ... +50 °C | ± 0.6 °C |
| Black-Globe Temperature | | 0 ... +80 °C | ± 0.8 °C |
| Humidity | | 5 ... 95 % R.H | > 70 % RH: ± (3 % read value + 1 %RH)<br>< 70 % RH: ± 3 % RH |
| Dew Point Temperature | | -25.3 ... +48.9 °C | |
| Wet Bulb Temperature | | -21.6 ... +50 °C | |
| Air speed | TA Hot wire anemometer – Dostmann  | 0,1..15 m/s | +- 5% FS |

Before commencing the measurements, the study employed measuring devices selected for their compliance with DIN EN 7726 standards and calibrated on-site to ensure accuracy (DIN EN ISO 7726, 2001, P.62, online 2022).

Measurements were taken at 30-second intervals at a standardized height of 1.2 meters above the floor. A PCE-FWS 20 weather station (Figure 3 (right) and Table 2), installed on a building rooftop, provided continuous outdoor environmental data at 5-minute intervals. Additionally, a comparison was conducted with the weather station data. Line graphs were visually inspected to identify potential outliers in the temperature data, which were then used for calibration and validation purposes. Four temperature data points, identified as outliers through visual inspection, were removed and replaced with linearly interpolated values. This interpolation affected less than 0.1% of the total dataset used in the study.

## 2.3. *Questionnaire Survey*

A questionnaire was developed to assess occupant comfort for evaluation purposes. TAV, TSV, TPV, and TCV were utilized to assess occupants' thermal comfort due to the inadequacy of the Fanger steady-state model in estimating their thermal sensation. Additionally, the adaptive thermal comfort model is not directly applicable to transitional spaces (Avantaggiato et al., 2021, p. 5 ). The questionnaire consisted of two sections: physiological symptoms and thermal comfort (Table 3).

- Thermal Acceptability (TAV): A 2-point scale ("acceptable" or "not acceptable") assessed whether occupants considered the thermal environment satisfactory.
- Thermal Sensation (TSV): A 7-point scale ranging from -3 ("cold") to +3 ("hot") measured occupants' perceived temperature, with intermediate options such as "cool," "neutral," and "warm."
- Thermal Preference (TPV): A 3-point scale offered options for desired temperature adjustments: "cooler," "no change," or "warmer."

Thermal Comfort (TCV): A 6-point scale ("very comfortable" to "very uncomfortable") evaluated occupants' overall comfort level.The study involved a total of 144 participants recruited using a convenience sampling method. Respondents were selected from four collective housing buildings in Arris, Algeria. The sample population comprised families residing in the four surveyed buildings, including children who attend school and parents who are employed. The demographic characteristics of the sample are: Age: 15 – 80 years, Height: 1.3 – 1.8 m, Male: 46%, Female: 54%.

To ensure adequate statistical power, a sample size of 144 was determined based on a desired confidence level of 95% and a margin of error of 5%. While this sample size is reasonable, it is important to acknowledge that the generalizability of the findings may be limited due to the specific characteristics of the study population.

After receiving verbal instructions, occupants completed the questionnaires under the supervision of one of the authors. The completed questionnaires were subsequently collected for analysis. The data collected from the field studies was analyzed using Microsoft Excel.

Table 3. Questionnaire Survey Used

**Part 1: physiological Symptoms**

Please pick an answer according to how you feel

**When leaving the building:**

| | | | | | |
|---|---|---|---|---|---|
| 1- | I have a headache | yes | ☐ | No | ☐ |
| 2- | I feel chills | yes | ☐ | No | ☐ |
| 3- | I feel pain in the joints | yes | ☐ | No | ☐ |
| 4- | I feel muscle cramps | yes | ☐ | No | ☐ |
| 5- | I have a runny nose | yes | ☐ | No | ☐ |

**Part 2: thermal comfort**

1 *How do you find the temperature in the staircase:*

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cold | ☐ | Cool | ☐ | Slightly cool | ☐ | neutral | ☐ | Slightly warm | ☐ | War m | ☐ | Hot | ☐ |

2 *How do you find thermal conditions:*

| | | | |
|---|---|---|---|
| Acceptable | ☐ | unacceptable | ☐ |

3 *How do you prefer the environment in the staircase to be:*

| | | | | | |
|---|---|---|---|---|---|
| Cooler | ☐ | No change | ☐ | Warmer | ☐ |

*4* *How do you find the environment in the staircase:*

| | | | | | |
|---|---|---|---|---|---|
| Very Comfortable | ☐ | Comfortable | ☐ | Just comfortable | ☐ |
| Just uncomfortable | ☐ | Uncomforta ble | ☐ | Very comfortable | ☐ |

## *2.4. A combined approach*

Given the lack of specific standards for transitional spaces and the inapplicability of interior space standards, our study employs a methodology that differs from the previous studies in several key areas:

Focus on Staircases: While the other studies explored general transitional spaces, this study specifically focused on staircases, providing an analysis of their impact on thermal comfort.

Seasonal Analysis: this study included measurements and analysis for both winter and summer, offering a comprehensive understanding of seasonal variations in thermal performance and occupant behavior.

Combined Approach: This study employed a combined approach of field measurements and questionnaires, providing a more holistic perspective on thermal comfort in staircases.

Detailed Analysis: This study delved into the impact of staircase design elements, such as opening percentage and façade treatment, on thermal comfort.
Cultural Context: this study was conducted in Algeria, providing insights into thermal comfort preferences in a specific cultural and climatic context.

# 3. Results

## 3.1. *Field Measurements Results*

Table 4 presents data for the four case studies, including average resident clothing levels (clo), as well as indoor and outdoor environmental conditions measured during the study. The operative temperature was calculated using equations (1) and (2).

Operative temperature = (tr + (ta x √10v)) / (1+√10v) ………… *(Eq1).*

Where:
ta = air temperature
tr = means radiant temperature / MRT = globe temperature + 2.42 x air velocity (globe temperature – air temperature)
v = air speed (m/s)
Where the airspeed is less than 0.1m/s, the equation can be simplified to:

Operative temperature = (ta + tr)/2 …………………………….. *(Eq2).*

The equation calculates the time (T) a person spends walking through the transitional space.
*T= D/V ………………………………………...(Eq3)*

Where: *T* is the time (sec)
*D* is the distance between two consecutive station points (m),
*V* is the average walking speed (m/sec)

An average walking speed of 0.77 m/s was assumed for all age groups traversing the stairs.
Consequently, the travel time from point to point was calculated to be 3.2 seconds (3.2 seconds = 2.5 m / 0.77 m/s).
Therefore, the average time required to traverse the transitional space in the studied cases was approximately 32 seconds.

Table 4. Outside Conditions

| | **Winter outdoor conditions** | | | **Summer outdoor conditions** | | |
|---|---|---|---|---|---|---|
| | Ta (°C) | RH (%) | Clo | Ta (°C) | RH (%) | Clo |
| 8:00 Am | 5.8 | 51 | 1.57 | 28.5 | 12 | 0.52 |
| 12:00 | 12.8 | 29 | 1.57 | 37.8 | 10 | 0.52 |
| 2:00 Pm | 12.2 | 35 | 1.57 | 39.9 | 11 | 0.52 |
| 4:00 Pm | 12.3 | 40 | 1.57 | 40.4 | 10 | 0.52 |

### 3.1.1. *Field measurements results at 8 AM*

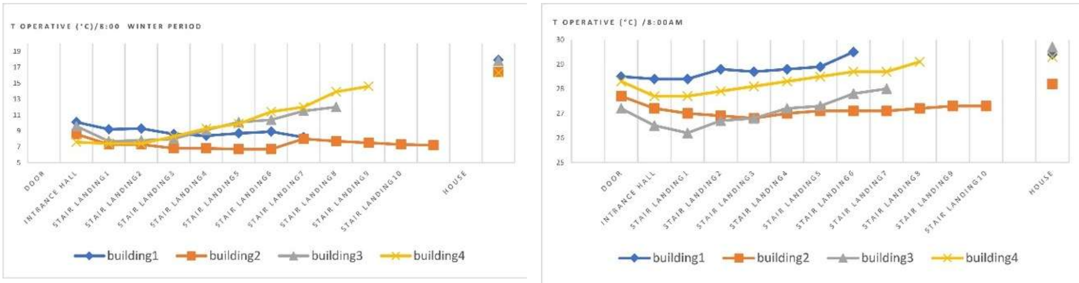
In the winter period, at 8 AM, operative temperatures in the staircases ranged from 6.7°C to 14.6°C (Table 5a). Building 2 recorded the lowest temperature while Building 4 had the highest. Air speeds ranged from 1.30 m/s to 0.01 m/s, with Buildings 3 and 4 having the lowest values and Building 1 having the highest (Table 5b). Relative humidity varied between 41.2% in Building 1 and 54.1% in Building 4. The outdoor air temperature was 5.8°C with a humidity of 51%. Occupants frequently wore clothing with an insulation value (clo) below the recommended 1.57 for winter comfort.

In the summer period, at 8 AM, operative temperatures in the staircases ranged from 26.2°C to 29.5°C. Building 3 recorded the lowest temperature while Building 1 had the highest.

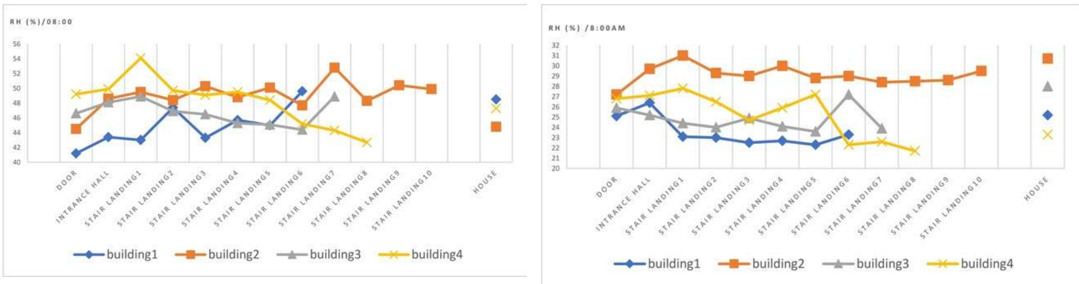
Air speeds in the staircases ranged from 0 m/s to 0.56 m/s (Table 5c). Buildings 3 and 4 had the lowest values while Building 1 had the highest. Relative humidity varied between 21.7% in Building 4 and 31% in Building 2. The outdoor air temperature was 28.5°C with a humidity of 12%. Occupants frequently wore clothing with an insulation value (clo) below the recommended 0.52 for summer comfort.

Table 5. Inside and Outside Conditions at 8 am

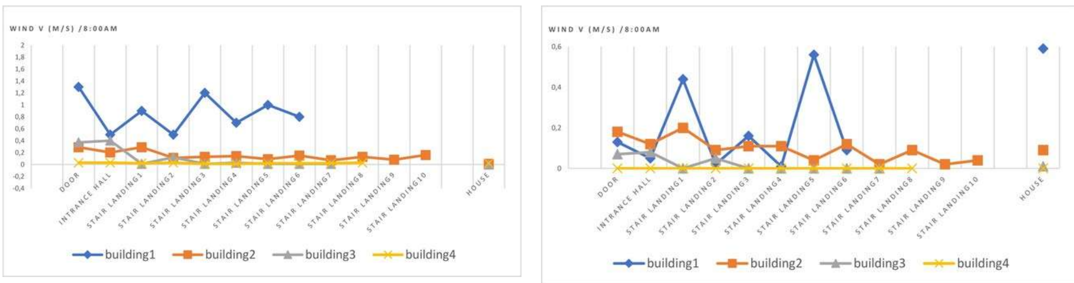
| Winter period | Summer period |
|---|---|




a - variation of operative T in different staircase buildings at 8:00 AM




b - variation of RH in different staircase buildings at 8:00 AM




c - variation of wind speed in different staircase buildings at 8:00 AM

### 3.1.2. *Field measurements results at 12AM*

In the winter season, at 12 PM, operative temperatures in the staircases ranged from 10°C to 16.9°C. Building 2 recorded the lowest temperature, while Building 4 had the highest (Table 6a).

Air speeds ranged from 1.30 m/s to 0.01 m/s. Buildings 3 and 4 had the lowest values, while Building 1 had the highest (Table 6c).

Relative humidity ranged from 32.0% in Building 4 to 50.2% in Building 3 (Table 6b), while the outdoor temperature was 12.8°C with a humidity of 29%.

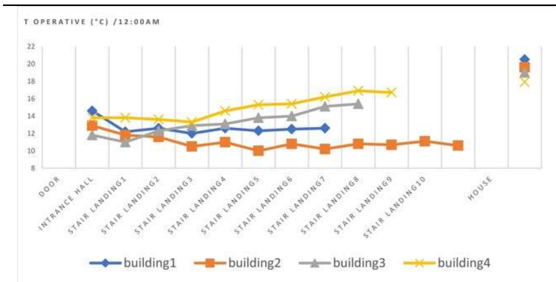
In the summer period, at 12 PM, operative temperatures in the staircases ranged from 30.7°C to 38°C. Building 3 recorded the lowest temperature while Building 4 had the highest.

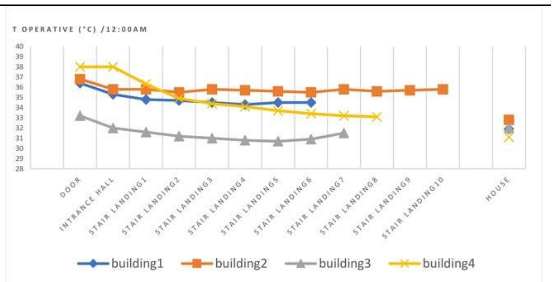
Air speeds ranged from 0 m/s to 1.8 m/s. Building 3 had the lowest value, while Building 2 had the highest.

Relative humidity ranged from 14.2% in Building 4 to 23.4% in Building 3, while the outdoor air temperature was 37.8°C with a humidity of 10%.

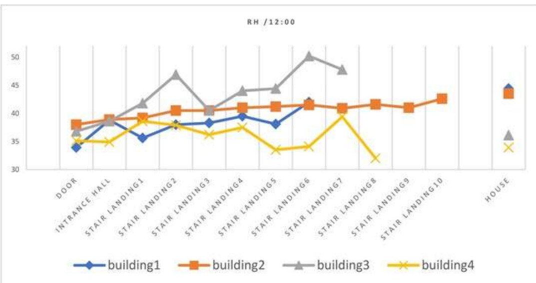
Table 6. Inside and Outside Conditions at 12 am (midday)

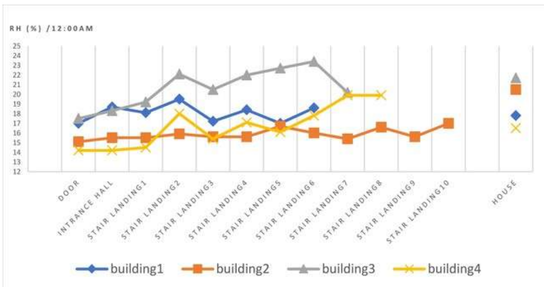
| Winter period | Summer period |
|---|---|



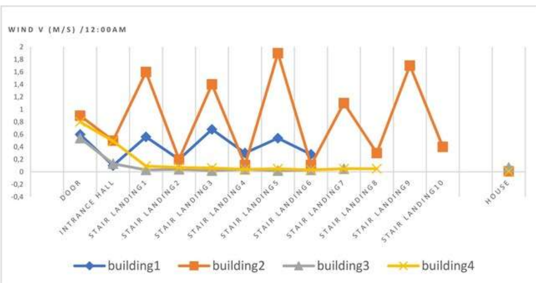



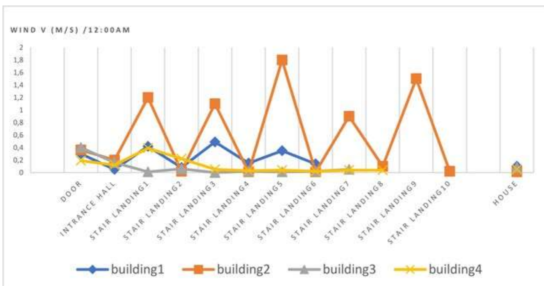

a - variation of operative T in different staircase buildings at 12:00 AM




b - variation of RH in different staircase buildings at 12:00 AM




c - variation of wind speed in different staircase buildings at 12:00 AM

### 3.1.3. *Field measurements results at 2 PM*

In the winter season, at 2 PM, operative temperatures in the staircases ranged from 11.4°C to 16.6°C. Building 2 recorded the lowest temperature, while Building 3 had the highest (Table 7a).

Air speeds ranged from 1.90 m/s to 0.01 m/s. Building 3 had the lowest value, while Building 2 had the highest (Table 7c).

Relative humidity ranged from 32.1% in Building 4 to 47.8% in Building 2 (Table 7b). The outdoor air temperature was 12.2°C with a humidity of 35%.

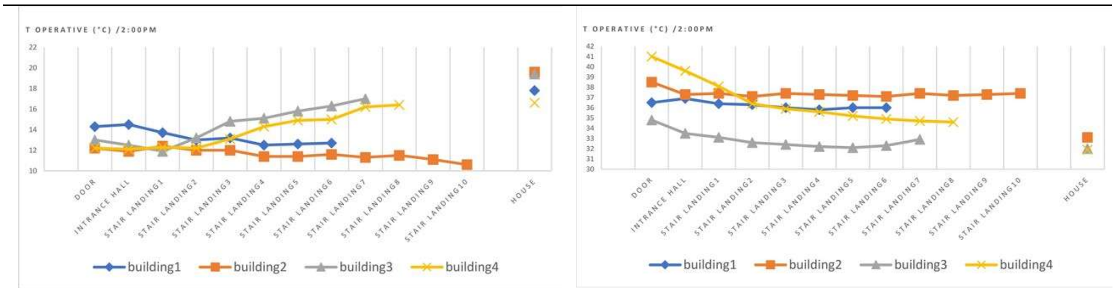
In the summer season, at 2 PM, operative temperatures in the staircases ranged from 32.1°C to 41°C. Building 3 recorded the lowest temperature, while Building 4 had the highest (Table 7a).

Air speeds ranged from 1.90 m/s to 0.01 m/s. Building 3 had the lowest value, while Building 2 had the highest (Table 7c).

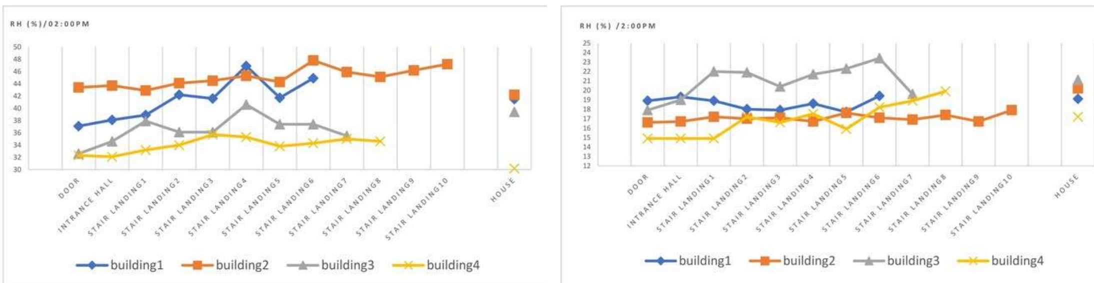
Relative humidity ranged from 14.9% in Building 4 to 23.4% in Building 3. The outdoor air temperature was 39.9°C with a humidity of 11% (Table 7b).

Table 7. Inside and Outside Conditions at 2 pm

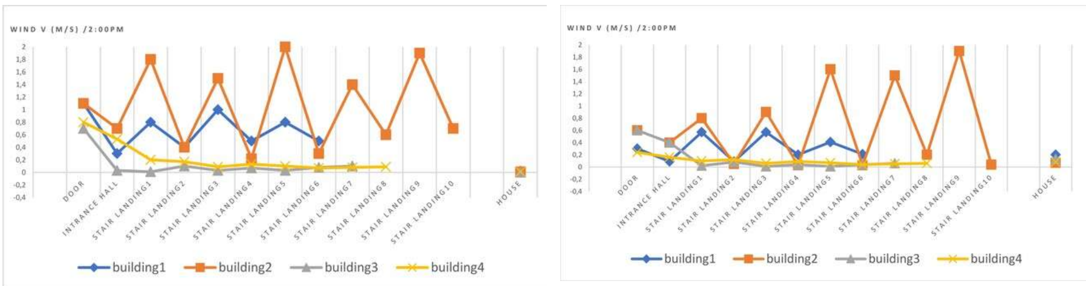
| Winter period | Summer period |
|---|---|




a - variation of Operative T in different building at 2:00 PM




b - variation of RH in different building at 2:00 PM




c - variation of wind speed in different building at 2:00 PM

### 3.1.4. *Field measurements results at 4 PM*

In the winter season, at 4 PM, operative temperatures in the staircases ranged from 11.1°C to 17°C. Building 2 recorded the lowest temperature while Building 3 had the highest (Table 8a).

Air speeds ranged from 1.80 m/s to 0.03 m/s. Buildings 3 and 4 had the lowest values, while Building 2 had the highest (Table 8c).

Relative humidity ranged from 29.5% in Building 4 to 49.6% in Building 1. The outdoor air temperature was 12.3°C with a humidity of 40% (Table 8b).

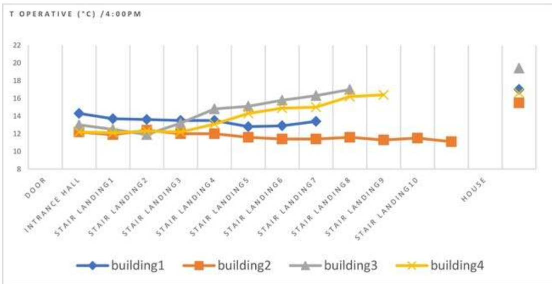
In the summer season, at 4 PM, operative temperatures in the staircases ranged from 31.5°C to 36.9°C. Building 3 recorded the lowest temperature, while Building 4 had the highest (Table 8a).

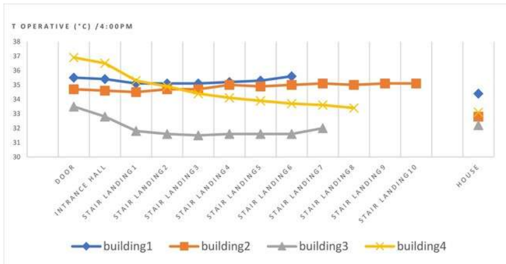
In the summer period, air speeds in the staircases ranged from 0 m/s to 1.9 m/s. Buildings 3 and 4 had the lowest values, while Building 2 had the highest.

Relative humidity varied between 15.5% in Building 4 and 26.2% in Building 3. The outdoor air temperature was 40.4°C with a humidity of 10%.

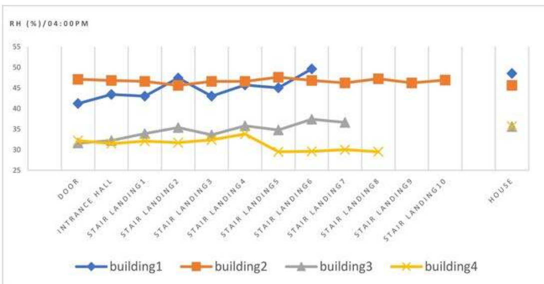
Table 8. Inside and Outside Conditions at 4 pm in winter and summer Periods

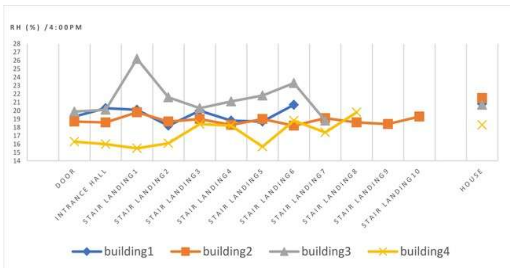
| Winter period | Summer period |
|---|---|



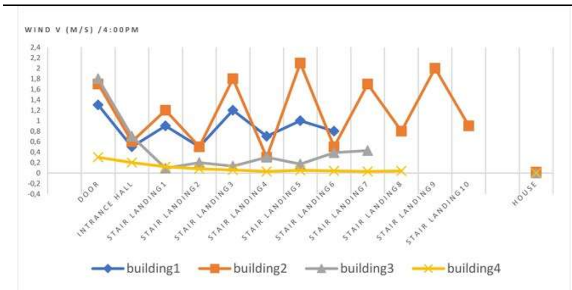
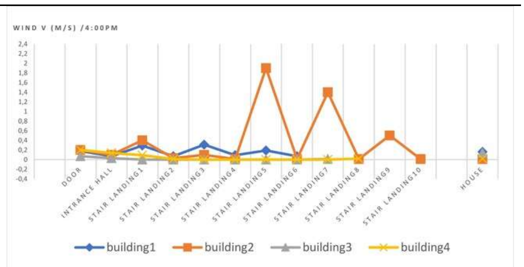

a - variation of Operative T in different stairescase building at 4:00 PM




b - variation of RH in different stairscase building at 4:00 PM

Table 8. Inside and Outside Conditions at 4 pm in winter and summer Periods (continued)

| Winter period | Summer period |
|---|---|
|  |  |



c - variation of wind speed in different stairscase building at 4:00 PM

The highest operative temperatures were recorded in Building 3 (11% of the opening) and Building 4 (5% of the opening) during the winter, but in summer, they were primarily recorded in Building 4.

The lowest operative temperatures were recorded in Building 2 (19% of the opening) during the winter and in Building 3 (11% of the opening) during the summer.

The highest values of airspeed were recorded in Buildings 1 and 2 (88% and 19% of the opening), while the lowest values were recorded in Buildings 3 and 4 (11% and 5% of the opening) during both seasons (Table 8c).

The extreme values of relative humidity were measured in different buildings during the day in winter, but in summer, they were primarily recorded in Building 3 (11% of the opening). The lowest values were primarily recorded in Building 4 (5% of the opening) during both seasons.

## 3.2. *Questionnaire Results*

A total of 144 questionnaires were collected across the four buildings, with 46% of respondents identifying as male and 54% identifying as female. The data from each section of the questionnaires was processed in Microsoft Excel and visualized using graphs and charts to facilitate further analysis and comparison.

### 3.2.1. Physiological symptoms

As depicted in Figure 4, residents from the four buildings experience physiological symptoms of thermal discomfort when exiting the building, indicating that the staircases do not serve as effective transitional spaces that provide the necessary conditions for adaptation.

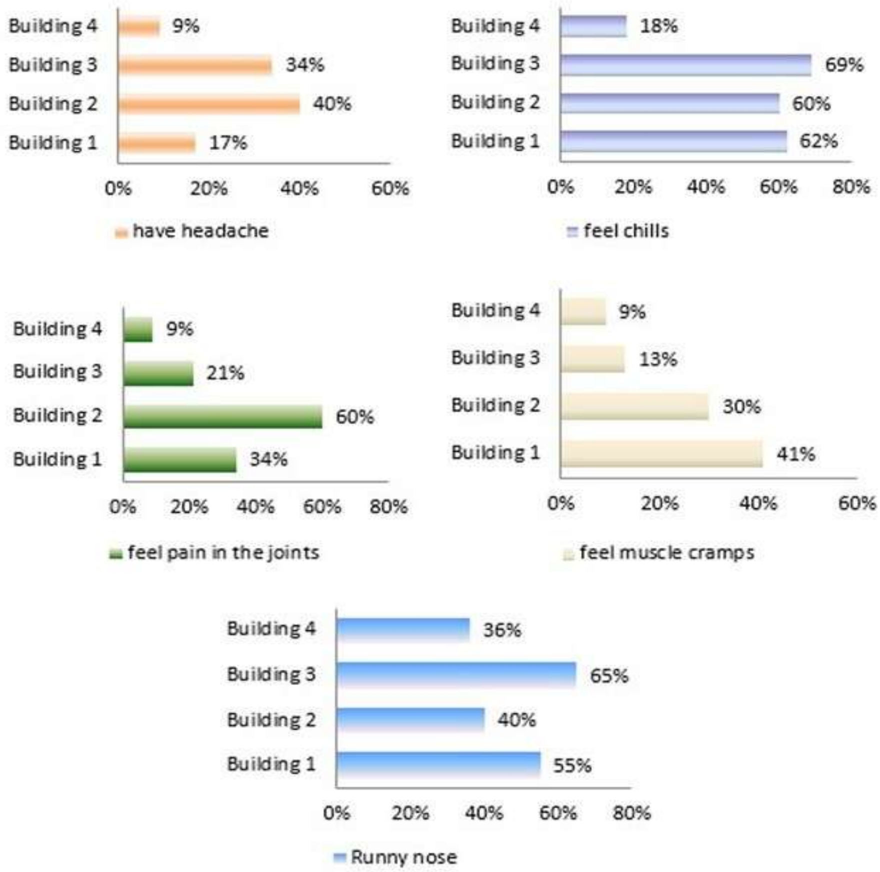



Figure 4. Answers to Physiological Symptoms in the Winter Period Part of the Questionnaire.2021. Source: Author

As shown in Figure 5, residents from the four buildings experience physiological symptoms of thermal discomfort when transitioning from outside to inside, indicating that the staircases do not serve as effective transitional spaces that provide the necessary conditions for adaptation.

The percentages are lower than in winter, with the lowest values primarily observed in Buildings 2 and 3.

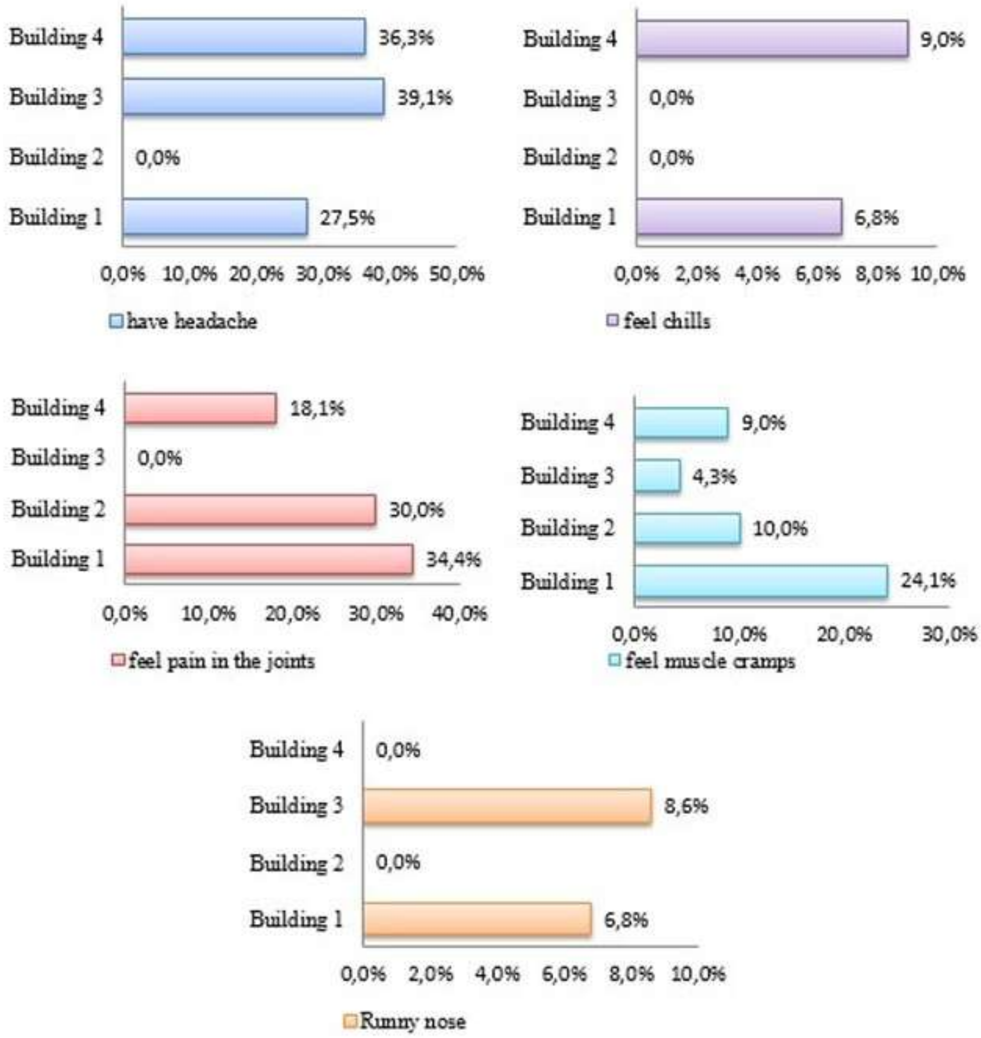



Figure 5. Answers to physiological symptoms part of the questionnaire (summer season 2021).
Source: Author

### 3.2.2. Thermal sensation, acceptability, comfort, and preference

This section presents and discusses occupants' responses regarding thermal sensation (TSV), acceptability (TAV), comfort (TCV), and preference (TPV).

The highest percentage of occupants reported a TSV of -1 (cold) in Building 1, Building 2, and Building 3, respectively 37%, 90%, and 53%. In Building 4, the highest percentage of occupants reported a TSV of 0 (neutral), which was 28% (Figure 6).

A few occupants reported TSV values between 1 (slightly warm) and 2 (warm) in Building 1, Building 3, and Building 4, but none reported these values in Building 2.

The highest percentage of occupants in Building 1 (20.6%) reported a TSV ranging from -2 (cool) to 0 (neutral). In Building 2, 50% of occupants reported a TSV of -1 (slightly cool). In Building 3, 34.7% of occupants reported a TSV of -2 (cool), and in Building 4, 36.3% reported a TSV of -1 (slightly cool) and 3 (hot).

The highest percentage of occupants who found the staircase slightly cool was recorded in Building 2 (19% of the opening, treated with vertical bays). The highest percentage of occupants who found the staircase hot was recorded in Building 4 (5% of the opening, treated with vertical bays of clear glass).

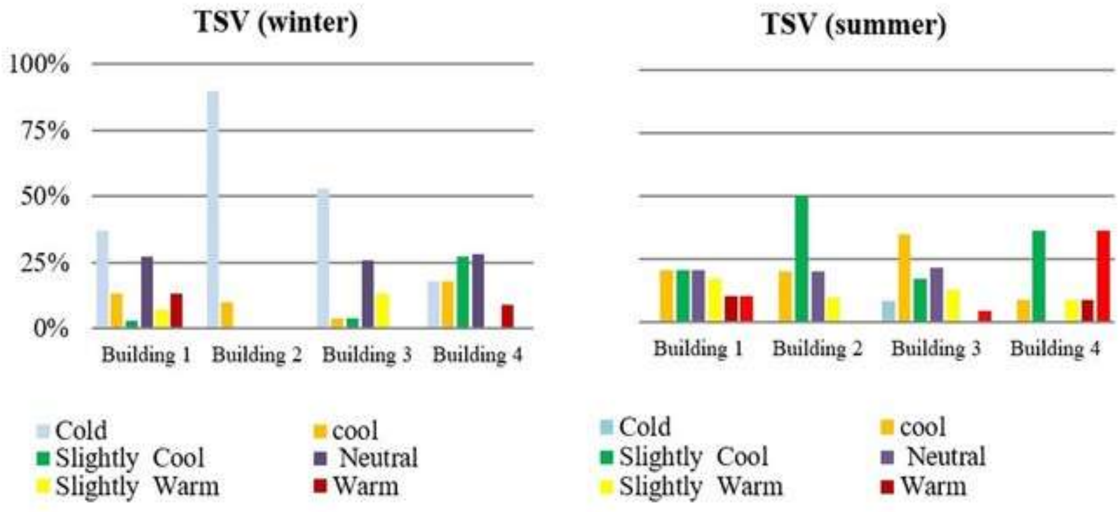



Figure 6. TSV Results. 2021. Source: Author

As shown in Figure 7, most occupants in Buildings 1 and 4 considered the environment thermally acceptable and comfortable (80% and 91%, respectively). In contrast, most occupants in Buildings 2 and 3 considered the environment thermally unacceptable (60% and 57%, respectively) and only slightly uncomfortable (40% and 52%, respectively).

When asked for their thermal preference, most occupants in Buildings 1 and 4 indicated that they would prefer no change in the environment (80% and 91%, respectively). A significant portion of occupants in Buildings 2 and 3 expressed a preference for warmer conditions.

This study found a strong correlation between occupants' views on acceptability, comfort, and preference, suggesting reliability in their responses.

In Buildings 1, 2, 3, and 4, residents expressed varying levels of thermal acceptability and comfort with the environment (86.2%, 100%, 82.6%, and 54.5%, respectively). The highest percentage was recorded in Building 2 (19% of the opening, treated with vertical bays), while the lowest was recorded in Building 4 (5% of the opening, treated with vertical bays of clear glass).

When asked about their temperature preference, most residents in Buildings 1, 2, 3, and 4 indicated that they would prefer no alteration in the surrounding environment (86.2%, 100%, 82.6%, and 54.5%, respectively).

The highest percentage was recorded in Building 2 (19% of the opening, treated with vertical bays), while the lowest was recorded in Building 4 (5% of the opening, treated with vertical bays of clear glass).

The highest percentage of occupants who preferred a cooler environment was recorded in Building 4 (45.5%).

This study found a strong correlation between occupants' views on acceptability, comfort, and preference, suggesting reliability in their responses.

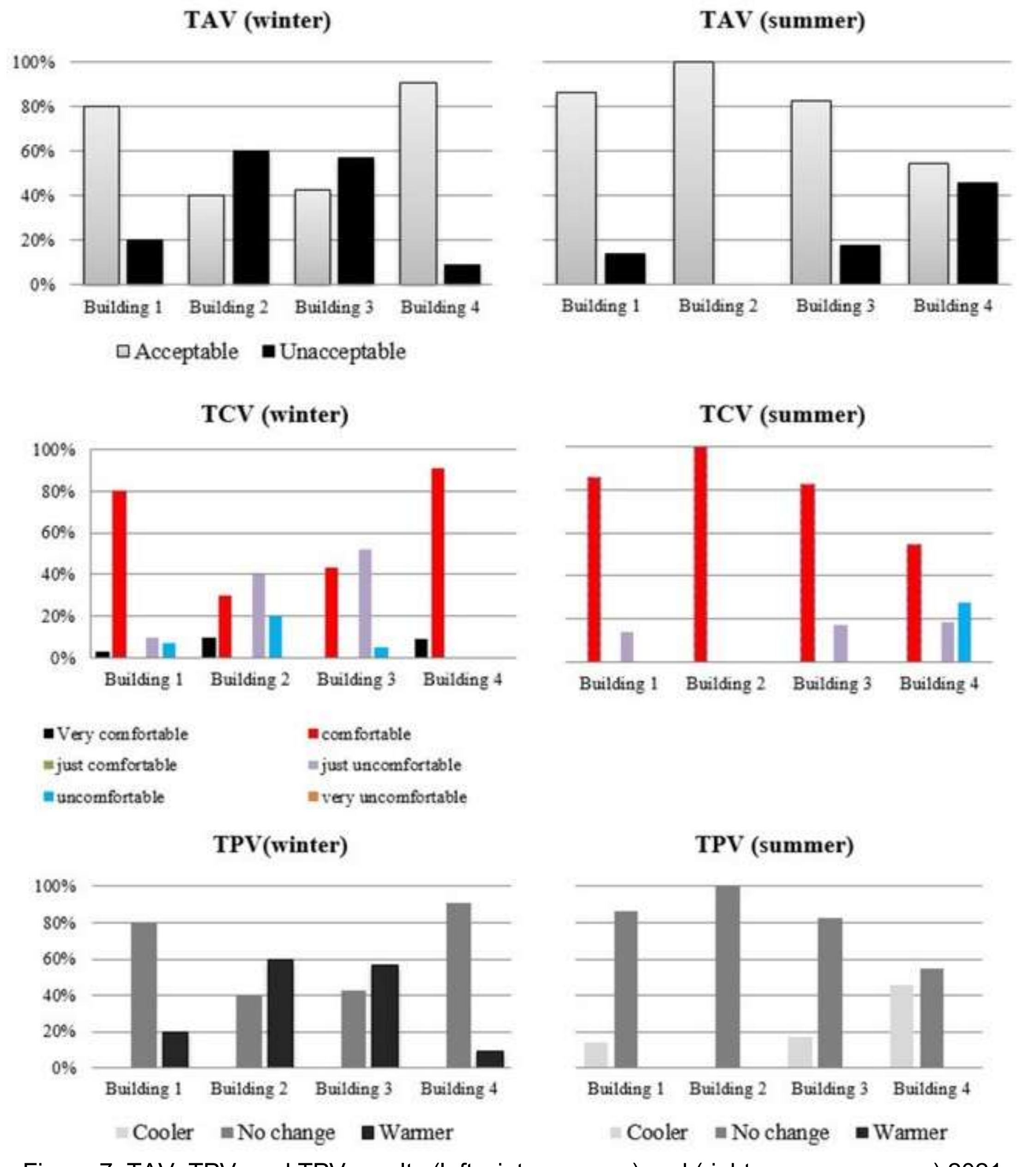


Figure 7. TAV, TPV, and TPV results (left winter season) and (right summer season) 2021

## 4. Discussion

The study results demonstrate that the percentage of staircase openings has a notable influence on thermal perception during spatial transitions in the winter.

To investigate tolerance levels for different staircase opening percentages, thermal sensation votes were categorized into three groups:

- TSV (-3, -2): Users who were cold and dissatisfied.
- TSV (-1, 0, 1): Users who were satisfied with the thermal environment.
- TSV (+2, +3): Users who were warm and dissatisfied.

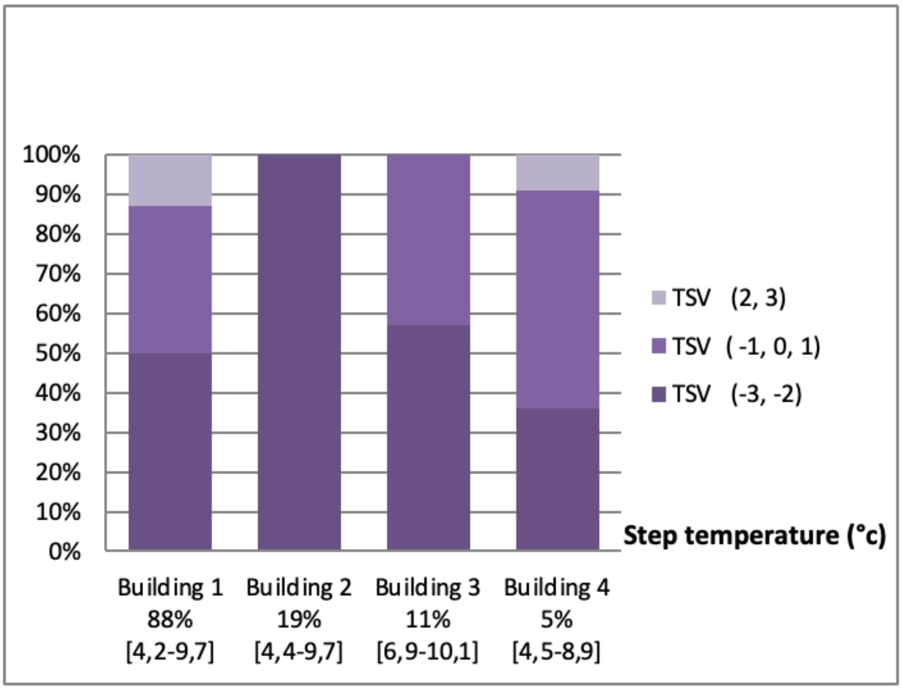



Figure 8. Relationship between percentage of the opening of the staircase, step temperature, and TSV in winter season

When the opening percentage in staircases of Buildings 2, 3, and 4 decreases (from 19% to 5%), the percentage of cold dissatisfaction also decreases (from 100% to 36%) (Figure 8).

Reducing the opening percentage in the staircase leads to a decrease in airspeed, which in turn reduces the operative temperature and step temperature, ultimately resulting in less cold dissatisfaction among users.

In Building 1 (Figure 8), despite a higher opening percentage (88%) compared to Buildings 2, 3, and 4, the percentage of dissatisfaction is lower. This can be attributed to the greater amount of sunlight that enters the staircase through the larger opening, influencing the operative temperature and reducing user dissatisfaction.

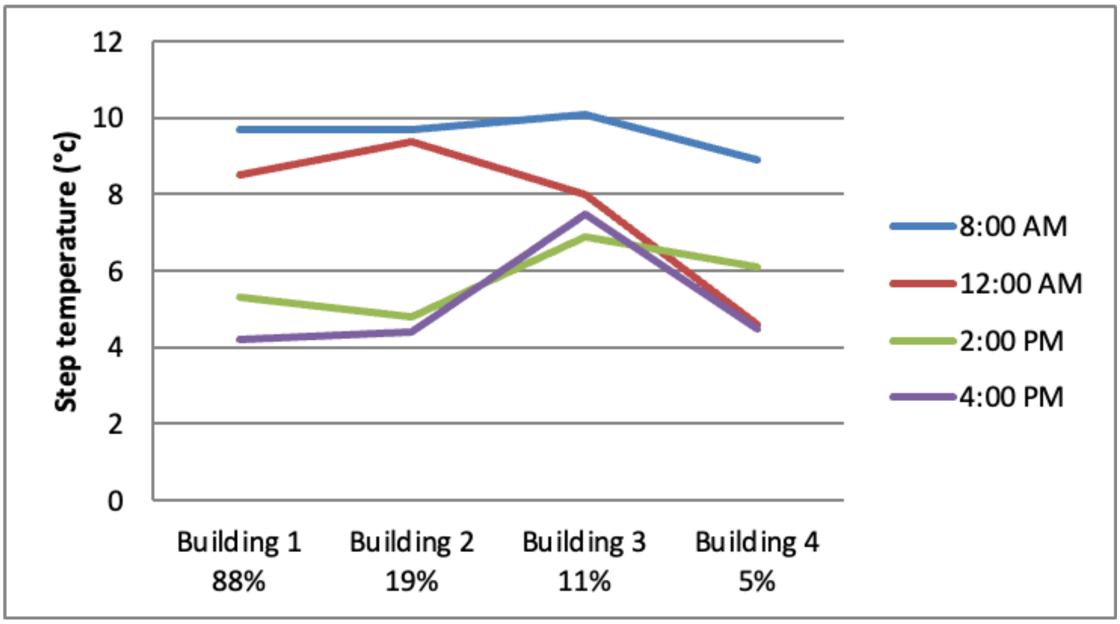



Figure 9. Relationship between percentage of opening and step temperature in winter season

As the temperature differential between houses and staircases increases, occupants will likely experience a greater sense of coldness, leading to decreased acceptability.

According to Lu and Li (2020) and Jason and Phillip (2019), a temperature difference of 4°C is generally considered sufficient to maintain an acceptable level of thermal comfort within building transitional spaces.

Bresson (2019) emphasizes that the human body struggles to adapt to sudden temperature fluctuations. The maximum tolerable difference should not exceed 5-7°C (URL-4). Exceeding this threshold can result in thermal shock.

During the winter, at 8 AM, the temperature difference was significant in all four stairwells as sunlight had not yet penetrated the buildings (9.7°C, 9.4°C, 10.1°C, and 8.9°C, respectively) (Figure 9).

In the stairwell of Building 4, the temperature difference became more comfortable starting at 12 PM, making it a more suitable option for winter (4.5°C, 6.1°C, and 4.5°C) (Figure 9). This is likely due to the lower dissatisfaction levels in this building.

In Buildings 1 and 2, the temperature difference became comfortable starting at 2 PM (5.3°C and 4.2°C in Building 1 and 4.8°C and 4.4°C in Building 2). The transparent glass treatment in the stairwell of Building 4 helped to reduce the temperature difference between the house and the stairwell more quickly.

In contrast, the stairwell of Building 3 experienced a significant temperature difference throughout the day (10.1°C, 8°C, 6.9°C, and 7.5°C) (Figure 9) due to the limited sunlight penetration resulting from the smaller opening percentage.

Therefore, in winter, stairwells with a transparent glass treatment and opening percentages of 5% and 17% appear to be more favorable options compared to other staircases.

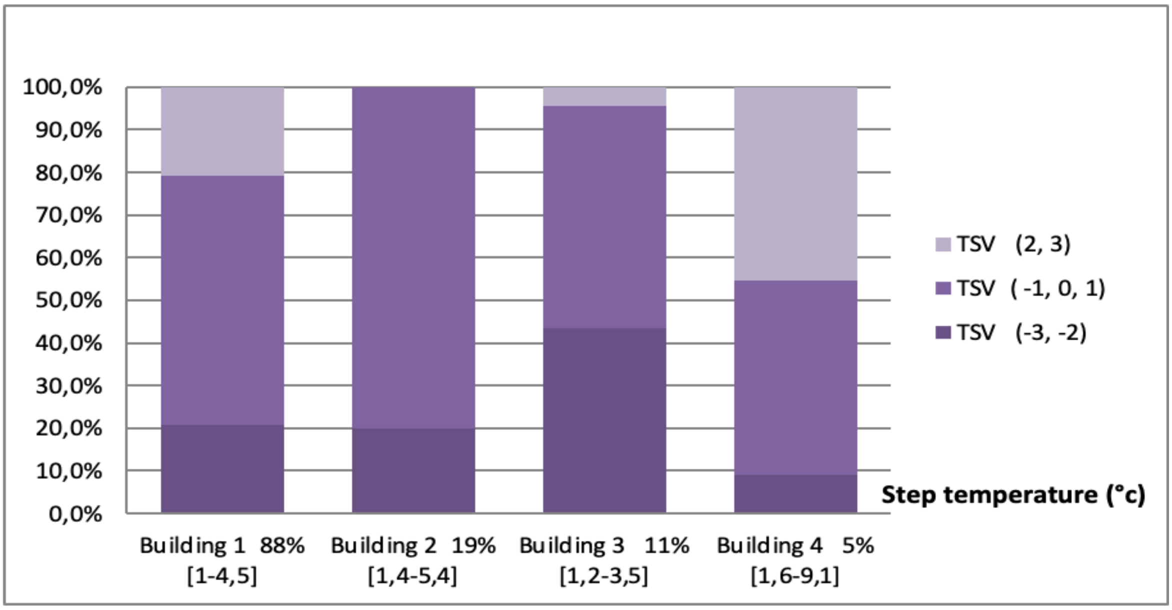


Figure 10. Relationship between percentage of the opening of the staircase, step temperature, and TSV in summer season

During the summer season, the step temperatures in the four buildings ranged between 1°C and 5.4°C (Figure 10). According to Lu and Li (2020, p. 12) and Tse and Jones (2019, p. 194-202), this temperature range is generally considered acceptable.

In Building 4 (5% of the opening, treated with clear glass bands and where the highest operative temperatures were recorded), the temperature step reached 6.9°C at 12 PM and 9.1°C at 2 PM (Figure 11). According to Bresson (2019), this level of temperature difference can potentially cause thermal shock (URL-4). This configuration, while beneficial in winter, may be problematic in summer.

The summer season measurements conducted during the COVID-19 period revealed low temperatures between houses and staircases. Residents attributed this to their avoidance of air conditioning use to prevent catching a cold or contracting COVID-19.

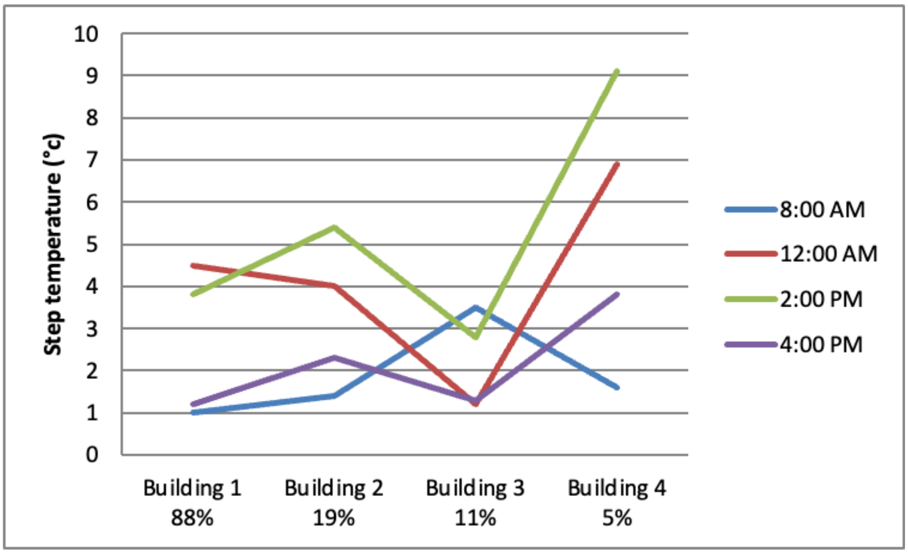


Figure 11. Relationship between percentage of opening and step temperature in summer season

## 4.1. Key Findings and Implications

This study investigated the influence of staircase design on thermal perception and comfort in residential buildings. Our findings highlight the critical role of staircase opening percentage and façade treatment in modulating thermal conditions and occupant satisfaction.

Staircase Openings:

- Winter: Smaller opening percentages (5% and 17%) generally led to more comfortable conditions, especially in buildings with transparent glass facades.
- Summer: Smaller openings (5% and 11%) were generally more comfortable, especially in buildings with solid facades.

Façade Treatment:

- Winter: Transparent glass facades allowed for greater sunlight penetration, reducing step temperatures and improving thermal comfort, it could provide additional warmth through solar heat gain.
- Summer: Transparent glass facades could increase solar heat gain, leading to higher temperatures and discomfort. Solid facades might be more suitable in regions with hot summers, it could help to mitigate the effects of excessive heat.

Seasonal Variation
Key Differences

- Solar Heat Gain: In winter, solar heat gain could be beneficial for improving thermal comfort. However, in summer, excessive solar heat gain could lead to discomfort.
- Heat Loss: Reducing heat loss through the staircase was a primary concern during winter. In summer, preventing heat gain was more important.
- Occupant Preferences: Seasonal variations in occupant preferences could also influence thermal comfort perceptions.

## 4.2. Practical Recommendations

- Building Design:

In winter, smaller openings and transparent glass facades can be beneficial. In summer, smaller openings and solid facades might be more suitable.

Here are some strategies to create a staircase design that can effectively adapt to different seasons:

- Adjustable Openings:

Incorporate adjustable openings, such as sliding panels or louvers, that can be closed during extreme weather conditions and opened for ventilation or sunlight during milder periods.

- Combination of Solid and Glass Facades:

Use a combination of solid and glass panels to create a versatile façade. Solid panels can be used on the northern or western sides to minimize heat gain in summer, while transparent glass panels can be used on the southern or eastern sides to maximize sunlight in winter.

- Solar Control Films:

Apply solar control films to glass panels to reduce heat gain and glare during summer while allowing natural light to enter during winter.

- Retrofitting:

For existing buildings, retrofitting staircases with adjustable openings or different façade materials can improve thermal performance.

Gaps in the Previous Studies:

The study of Jason and Tse (2019, p.191-202): While providing valuable insights into occupant adaptability, the study did not delve into specific design elements or their impact on thermal comfort.

The study of Lu and Li (2020, p.1-15): Although focusing on temperature steps, the study did not extensively explore the impact of staircase design or cultural factors.

The study of Avantaggiato et al. (2021, p. 1-11): While providing insights into the limitations of traditional comfort models, the study did not delve deeply into the specific design elements of transitional spaces and their influence on thermal comfort.

Contributions of this Study:

Staircase Focus: The study fills a gap by specifically focusing on staircases, providing analysis of their impact on thermal comfort.

Seasonal Analysis: By including both winter and summer data, the study addresses a gap in understanding seasonal variations in transitional spaces.

Design Element Analysis: the study provides insights into the impact of staircase design elements, such as opening percentage and façade treatment, on thermal comfort.

Advancing the Field

**The study advances the field by:**

- **Filling a Knowledge Gap: Addressing a previously understudied aspect of transitional spaces.**
- **Providing Practical Insights: Offering actionable recommendations for building designers.**
- **Enhancing Understanding: Contributing to a more comprehensive understanding of thermal comfort in transitional spaces across different seasons and cultural contexts.**

## 4.3. Limitations and Future Research

This study focused on a specific region and building typology. Further research is needed to assess the generalizability of these findings to different climates and building types.

## 5. Conclusion

This field study, conducted in the staircases of four residential buildings during winter and summer, evaluated thermal performance and occupant perception. Operative temperature was identified as a critical factor influencing thermal comfort, as evidenced by its strong correlation with occupant feedback. Key conclusions include:

In winter:
When the staircase opening percentage was 88%, the step temperature between houses and staircases reached 9.7°C, and the highest percentage of TSV was 37% for cold sensation.

When the staircase opening percentage was reduced to 19%, the step temperature remained at 9.7°C, but the highest percentage of TSV increased to 90% for cold sensation.

When the staircase opening percentage was 11%, the step temperature between houses and staircases reached 10.1°C, and the highest percentage of TSV was 53% for cold sensation.

When the staircase opening percentage was reduced to 5%, the step temperature between houses and staircases decreased to 8.9°C. The highest percentage of TSV shifted to 28% for neutral and 27% for slightly cool sensation.

Decreasing the opening percentage from 88% to 19% resulted in a lower step temperature due to reduced wind effects.

However, further reducing the opening percentage to 11% decreased the amount of sunlight entering the staircase, which in turn increased the step temperature.

In contrast, decreasing the opening percentage to 5% while treating the façade with 17% glass allowed sunlight to enter the staircase, reducing the step temperature. This design proved to be more effective in winter compared to previous configurations.

In summer:
In the three buildings, the opening percentage ranged from 88% to 11%, and the step temperatures ranged between 1°C and 5.4°C during the day, which is generally considered acceptable and does not cause thermal shock.

However, in Building 4, the opening percentage was 5%, and the façade treatment with clear glass (17%) increased the effect of sunlight, leading to a step temperature of 9.1°C, which could potentially cause thermal shock.

It is important to note that the summer season measurements were recorded during the COVID-19 pandemic when residents reported avoiding air conditioning use to prevent catching a cold or contracting COVID-19. This avoidance likely contributed to the lower step temperatures between houses and staircases.

## Author Contribution

The authors declare that they have contributed equally to the manuscript.

## Conflict of Interest Statement

The authors of the study declare that there is no financial or other substantive conflict of interest that could influence the results or interpretations of this work.

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