Summer thermal comfort conditions in shopping arcades and their adjoining streets in hot and dry climates. The case of the Nicosia’s historic centre.

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Abstract. Twentieth century urban planning policies systematically neglected the bioclimatic parameter in the conception and realisation of open and semi-open spaces. The negative effects of such practices relate, but are not limited, to the increasing duration and intensity of thermal discomfort in the public and semi-public realm. Considering the significance of improved microclimate, this research focuses on the summer thermal comfort conditions of three shopping arcades. The study is undertaken in the context of a research on semi-open spaces as a means of excessive discomfort moderation. The adjoining streets, were examined to compare the thermal performance of arcades with other urban typologies. The research is carried out in the historic centre of Nicosia which experiences an intense Mediterranean climate. On-site environmental monitoring has allowed a detailed thermal comfort analysis, using the PET thermal index scale which is applicable to warm climates. Compared to open streets, shopping arcades were found able to mitigate extreme thermal comfort conditions, although they remained above acceptable thermal comfort limits for most of the monitoring time. Arcades are associated with less intense heat stress levels which give evidence to their thermal advantages over completely exposed open streets and highlight their bioclimatic potential in the Mediterranean climate. Arcades may thus be re-considered and re-introduced as beneficial microclimate control elements in sustainable urban planning agendas.

1. Introduction
In hot regions, exposure to direct solar radiation and peak summer temperatures could increase thermal discomfort and heat stress while affecting negatively human health and decreasing the duration, use and activity in open spaces. The trend of urban design, over the last decades, towards less green places, limited semi-open areas, wide open spaces and the use of hard materials, has intensified these consequential effects. To this end, many scientists and professionals have focused on the re-consideration and re-evaluation of ‘common practice’ passive cooling techniques, such as atria, courtyards, patios, porticos, arcades, galleries etc., as a means of minimizing the duration and level of uncomfortable conditions.

The present study examines the thermal comfort conditions of shopping arcades, i.e. a covered semi-open passage aligned with shops on either side, in comparison with the corresponding conditions of open streets during the cooling period, in the historic urban centre of Nicosia. Although comfort studies and research on the passive cooling potential of indoor spaces do exist, there is a lack of scientific
literature related to the thermal performance of semi-open spaces and to the comparative thermal assessment of open and semi-open spaces. In view of the scarcity of thermal studies in semi-open spaces [1], this research aims (a) to determine whether thermal comfort conditions in semi-open spaces remain within the thermal comfort zone under the harsh summer climatic conditions of the Mediterranean, (b) to quantify the differences between semi-open and open spaces thermal comfort conditions and (c) to assess the possible suitability of the semi-open prototype over completely open spaces in terms of thermal comfort and heat stress, in a hot climate.

A number of studies have illustrated that the planning of semi-open spaces may offer thermal advantages over completely exposed open spaces, due to their ability to regulate solar exposure. Givoni [2] mentions that, protection from solar radiation has a larger physiological effect in reducing heat stress, compared to other measures such as lowering air temperatures, underlining the primacy of shading in sustainable urban design. A recent study [3] that examined the summer thermal comfort conditions of a private ground floor veranda and a public square in a Mediterranean climate by means of on-site microclimatic measurements and calculation of PET thermal index concluded that the veranda was mainly associated with moderate and strong heat stress, whereas the square was associated with extreme heat stress levels increasing thermal discomfort conditions. Another study [4] undertaken in an urban canyon with galleries on either side, using a numerical modelling method, has given evidence that the summer thermal comfort conditions in the area of galleries was improved due to effective shading. More specifically, galleries had PET values which ranged mainly between 34°C and 42°C, while a significant surface area of open streets presented PET values of over 42°C, the benchmark for extreme heat stress.

The on-site monitoring study of Andre Potvin [5] on several shopping arcades and their adjoining streets in the UK climate showed that both streets and arcades remained above the thermal comfort zone during the summer. Although arcades were slightly warmer than streets, they did not overheat. Other studies in vernacular settlements of the Mediterranean islands in Greece [6, 7] and Algeria [8] illustrated a significant decrease of temperatures within the covered part of traditional streets, which enhance the passive cooling effect during summer.

This brief overview points that the appropriate design of semi-open spaces has, indeed, the capacity to achieve thermal control in urban spaces. It is noted however, that the researches that have been undertaken so far, are oftentimes limited to a thermal performance analysis, and less often to a quantitative human thermal comfort assessment using thermal indices, which would allow drawing more comprehensive results. The present research intends to fill this research gap and to deepen the understanding on the thermal comfort conditions of the spaces between the indoor and outdoor environment.

2. Methodology

2.1. Selection of case studies

Based on a survey of more than 50 shopping arcades in the historic centre of Nicosia, a sample of three arcades, i.e. *Stoa Papadopoulou*, *Stoa Tarsi* and *Stoa Ledra*, located along a major commercial thoroughfare, was selected for an environmental field survey. The human thermal comfort analysis in these particular areas was decided due to their liveliness and social activity. For comparison of the thermal comfort conditions, the field survey also included the monitoring of the adjoining open streets of *Stoa Papadopoulou* and *Stoa Tarsi*. Note also that *Stoa Ledra* was recorded in two different spots, i.e. at the centre and at the edge. The other two arcades selected were measured only at their centre. Case study arcades, i.e. *Stoa Papadopoulou* and *Stoa Tarsi*, built in the first half of the 20th century were selected as indicative of the ‘traditional’ arcade prototype, while *Stoa Ledra* constructed at the beginning of the 21st century, is representative of contemporary arcade models. ‘Traditional’ arcade prototypes mainly differ from contemporary examples in terms of their scale and building materials used. The design characteristics of the selected sites are presented in Table 1. It is important to note that the glass part of the roof of *Stoa Papadopoulou* was covered with light-coloured fabrics during the cooling monitoring period to reduce solar load.
| Table 1. Architectural plans and design characteristics of survey areas |
|-----------------------------------------------|
| **Plans**                                      |
| ![Stoa Papadopoulou](image1)                  |
| ![Stoa Tarsi](image2)                         |
| ![Stoa Ledra](image3)                        |
| **View of the arcade**                        |
| ![Stoa Papadopoulou](image4)                  |
| ![Stoa Tarsi](image5)                         |
| ![Stoa Ledra](image6)                        |
| **View of the adjoining survey areas**         |
| ![Stoa Papadopoulou](image7)                  |
| ![Stoa Tarsi](image8)                         |
| ![Stoa Ledra](image9)                        |
| **Year built**                                |
| Stoa Papadopoulou: 1932                       |
| Stoa Tarsi: Prior 1920                        |
| Stoa Ledra: 2004                              |
| **Orientation°**                              |
| Stoa Papadopoulou: 99                         |
| Stoa Tarsi: 98                                |
| Stoa Ledra: 101                               |
| **Typology**                                  |
| Stoa Papadopoulou: I-shaped                  |
| Stoa Tarsi: I-shaped                          |
| Stoa Ledra: I-shaped                          |
| **Dimensions (m)**                            |
| Stoa Papadopoulou: 27.7*8.4*13.9              |
| Stoa Tarsi: 18.4*4.8*5.0                      |
| Stoa Ledra: 57.8*4.0*8.2                      |
| **Height**                                    |
| Stoa Papadopoulou: Triple height with recessed balconies |
| Stoa Tarsi: Single height                     |
| Stoa Ledra: Double height                     |
| **Materials**                                 |
| Stoa Papadopoulou: Local loadbearing stone walls and concrete slabs |
| Stoa Tarsi: Local loadbearing stone structure |
| Stoa Ledra: Concrete structure filled with bricks |
| **Roof**                                      |
| Stoa Papadopoulou: Glass-covered              |
| Stoa Tarsi: Wooden roof under an upper storey |
| Stoa Ledra: Glass-covered at the edges and metal roof at the centre of the space |

*°Degrees from North, **Length*Width*Height, ● Data-logger location
2.2. Instrumentation and thermal monitoring
Continuous measurements of air temperature, globe temperature, wind speed and relative humidity were carried out using the ELR610M, LSI LASTEM mobile meteorological station. The mobile weather station was equipped with a dry-bulb thermometer protected with radiant screen, a Pt-100 globe thermometer, a relative humidity sensor and a hot wire anemometer. A globe of matt grey colour was used instead of a black coloured globe, as suggested in [9]. The measurement height was 1.1m above ground level, corresponding to the average height of the centre of gravity for adults [10]. Outdoor conditions were recorded separately with a Vantage Pro weather station installed near the examined sites, at a height above the surrounding built environment. Field surveys were conducted between July and August 2017, covering the summer season. For the intense Mediterranean climate of Cyprus, summer thermal conditions are considered to be the most critical in terms of thermal comfort and stress. Thermal monitoring was conducted from 9:00 to 19:00 for five consecutive days per season. Simultaneous thermal monitoring of the three survey areas has not been possible due to restriction in the number of available monitoring equipment. For the summer season, Stoa Papadopoulou was monitored between the 14th and 18th of July, Stoa Ledra between the 21st and 25th of July and Stoa Tarsi between the 4th and 8th of August. Note that due to a malfunction of hot wire anemometer, wind data for the 14th of July and 5th of August are unavailable. Due to incomplete data, it has not been possible to calculate PET thermal index for these two particular days.

2.3. Thermal index, Rayman model and thermal comfort analysis
For the thermal comfort and thermal stress analysis, the Physiological Equivalent Temperature (PET) thermal index was applied. PET index is appropriate to assess thermal comfort conditions in outdoor spaces and takes into account air temperature, relative humidity, mean radiant temperature and wind speed. PET was calculated through Rayman model, where meteorological data are entered by loading microclimate data files and outputs are provided as text files. PET thermal index was originally developed by Matzarakis and Mayer [11]. In the framework of this study, instead of the ‘standard’ PET classification of Matzarakis and Mayer, which may be considered more suitable for central European countries, a PET classification scale valid for the Mediterranean region was used to define the thermal comfort range for the local people of Cyprus. This classification was adopted from the study of Tsiros and Hoffman [3] who suggested an amended PET thermal index scale based on microclimatic and thermal sensation data for Athens, Greece. The values of thermal sensations for the Mediterranean region, which were used to quantitatively evaluate the thermal environment of the selected sites, are given in Table 2. As shown in the Table, compared to the standard PET classification, the upper thermal comfort limit for the Mediterranean region is higher, implying that local people can tolerate and adapt to warmer conditions than their counterparts in colder climates.

| PET Range (°C) | PET Range (°C) for Mediterranean region | Stress Category          |
|---------------|----------------------------------------|--------------------------|
| <4.0          | <1.0                                  | Extreme cold stress      |
| 4.1–8.0       | 1.1–7.0                                | Strong cold stress       |
| 8.1–13.0      | 7.1–13.0                               | Moderate cold stress     |
| 13.1–18.0     | 13.1–19.0                              | Slight cold stress       |
| 18.1–23.0     | 19.1–25.0                              | No thermal stress        |
| 23.1–29.0     | 25.1–31.0                              | Slight heat stress       |
| 29.1–35.0     | 31.1–37                                | Moderate heat stress     |
| 35.1–41       | 37.1–43                                | Strong heat stress       |
| >41           | >43                                    | Extreme heat stress      |

Table 2. PET thermal index scale based on standard values and amended values to apply in the Mediterranean climate
3. Results

3.1. Thermal environment

PET values within the central space of arcades and their adjoining streets, or edge, are plotted against outdoor air temperatures in Figure 1. Plots present the results for two representative days of the monitoring period for each case study arcade. Figure 2 shows the PET thermal index daily patterns for three representative days. As shown in the figures, streets adjoining Stoa Papadopoulou and Tarsi, as well as the edge of Stoa Ledra are clearly warmer, than the corresponding central arcade spaces. It is however noted that, compared to Stoa Papadopoulou and Stoa Tarsi and their adjoining streets, the thermal differences between the central space of Stoa Ledra and its edge are significantly smaller due to the protection provided by the roof. More exposed, less shaded streets and edges are then, associated with higher PET values compared to the more ‘sheltered’ arcades that are better protected from direct solar radiation, and achieve moderation of thermal stress level. Maximum differences in PET values between Stoa Papadopoulou and its adjoining street equal to 28.6K. Maximum PET differentials between Stoa Tarsi and its adjoining street equals to 24.1K. Maximum differences in PET values between the central space of Stoa Ledra and its edge, correspond to 8.1K.

As shown in Figure 1 and Figure 2, the larger thermal differences are observed between Stoa Papadopoulou and its adjoining street. These results could be attributed to the direct solar exposure of the street next to Stoa Papadopoulou throughout the monitoring period. Interestingly, a negative ‘instant’ sharp increase of the PET values in the street area of Stoa Tarsi during morning and afternoon hours and in the edge area of Stoa Ledra during afternoon hours, coincides with the time of direct solar exposure of these sites. Solar exposure then, proves to be a significant parameter affecting negatively summer thermal comfort conditions.

It is also noted that the PET amplitudes are larger in the case of adjoining streets and edge compared to the central space of arcades (Figure 2). Arcades thus, confirm greater thermal stability, while streets are associated with more abrupt thermal changes due to the effect of direct solar radiation. In the case of Stoa Papadopoulou, the amplitude of the PET ranges between 5.0–9.1°C. For its adjoining street, the amplitude of PET is significantly larger, between 25.3°C and 29.1°C. For Stoa Tarsi, the amplitude of PET ranges between 5.2°C to 17.1°C. For its adjoining street, PET fluctuation exceeds 25.0°C, i.e. 25.5–27.4°C. A PET amplitude between 6.1–7.4°C and 7.7–12.3°C is recorded in the central space and the edge of Stoa Ledra respectively.

![Figure 1. PET characteristics of survey areas for two representative days of the monitoring: (a) Stoa Papadopoulou, (b) Stoa Tarsi and (c) Stoa Ledra](image-url)
3.2. Assessment of thermal comfort during the cooling period

Thermal comfort conditions are summarized in Table 3 and Table 4 based on the classification of PET thermal index for warm climates as described in the methodology section. The results are given as a percentage of time with heat stress conditions. In the following sections the thermal comfort conditions and heat stress levels during the cooling period are further analysed for the three case study arcades and their adjoining streets.

3.2.1. Stoa Papadopoulou. As can be seen in Table 3, on a daily basis, only a limited percentage of the arcades’ microclimatic conditions lay within the thermal comfort zone, while the microclimatic conditions at the adjoining street remain entirely above the acceptable PET range (less than 31°C). More specifically, the arcade remains within the thermal comfort zone only by 3% of the total monitoring time during the 14th, 15th and 16th of July. Despite these unacceptable thermal conditions of both arcade and street, the most shaded site, i.e. the arcade, was found able to mitigate outdoor climatic extremes to a greater extent indicating its thermal advantages. More specifically, the shady arcade, is associated only with moderate (less than 37°C) and strong (less than 43°C) heat stress, whereas the less shaded street is mainly associated with extreme heat stress conditions (more than 43°C). Extreme heat stress in the street accounts for more than 63% of the time, on a daily basis. It is noted that the multiple height of the arcade eliminates significantly the negative thermal impact of the glass roof.

Note that under hot spell days, there is an increase in the percentage of time with strong heat stress levels in the arcade and extreme heat stress levels in the adjoining streets (Table 4). Under normal summer conditions, nevertheless, the arcade achieves nearly a complete mitigation of strong heat stress levels (Table 4). For example, on a hot day of the monitoring period ($T_{\text{max out}} = 38.7°C$) 3%, 53% and 44% of the time corresponds to slight, moderate and strong heat stress within the arcade. Respectively, for the adjoining street 12%, 27% and 61% of the time accounts for moderate, strong and extreme heat stress. During a normal summer day ($T_{\text{max out}} = 36.3°C$) 97% and 3% of the time within the arcade is in the order of moderate and strong heat stress. For the street, 18% of the time corresponds to moderate heat stress, 17% to strong heat stress and 65% to extreme heat stress.

3.2.2. Stoa Tarsi. As shown in Table 3, although the arcade exceeds the acceptable comfort levels for the majority of the monitoring time, it lessens the dynamic discomfort created by the uncontrolled direct solar exposure of the open street. For the arcade, a limited percentage of 12%, 31%, 11% and 4% of the time lay within the PET thermal comfort zone, on a daily basis. For the adjoining street, these percentages are reduced to 5%, 16%, 3% and 2% respectively. For the shadier arcade, there is a small duration of strong and extreme heat stress (0–22%) on a daily basis, whereas for the sunnier street there is a further increase in the percentage of time associated with strong and extreme heat stress (40–90%). More specifically, there is an increase in the duration of strong and extreme heat stress in the streets, by 20–54% and 16–44% respectively. The appearance of unfavourable extreme heat stress in the case of the arcade (<6%), is attributed to its unobstructed West elevation, which allows unwanted solar penetration during afternoon hours, increasing by this way thermal load and discomfort.

It is observed that during hot spell days, there is a transition to the less thermally favorable PET scales for both street and arcade, whereas under normal days, the arcade moderates completely strong and extreme heat stress levels and the street eliminates extreme heat stress level (Table 4). To explain this in more detail, during the hottest day of the monitoring ($T_{\text{max out}} = 38.4°C$) 4%, 74%, 16% and 6% of the time corresponds to slight, moderate, strong and extreme heat stress respectively in the case of the arcade. In the case of the street, 2%, 8%, 40% and 50% of the time accounts for slight, moderate, strong and extreme heat stress respectively. Under a normal summer day ($T_{\text{max out}} = 33.1°C$) the duration of slight and moderate heat stress in the case of the arcade corresponds to 31% and 69% respectively. The street is associated with slight, moderate, strong and extreme heat stress at a percentage of 16%, 44%, 24% and 16% respectively.
Figure 2. PET thermal index daily patterns of survey areas for three representative days of the monitoring: (a) Stoa Papadopoulou, (b) Stoa Tarsi and (c) Stoa Ledra
3.2.3. *Stoa Ledra*. The results of PET thermal index analysis for *Stoa Ledra* are presented in Table 3. For both the central space and edge of *Stoa Ledra*, the microclimatic conditions mainly remain above the acceptable thermal limits. However, the level of thermal discomfort in the central area of the arcade is reduced compared to the edge due to the enhanced solar protection by the opaque roof and the limited exposure to the outdoors. In particular, a small 10% during the 21st of July and 7% during the 22nd and 23rd of July remains within the acceptable thermal limits in the central area of arcade, whereas during the other two days of the monitoring period the microclimatic conditions remain entirely above the thermal comfort zone. With respect to the edge area, the percentage of acceptable thermal comfort conditions is reduced to 7% and 2% during the 21st and 22nd of July, whereas during the 23rd, 24th and 25th of July microclimatic conditions exceed the acceptable PET thermal comfort range. Interestingly, both the central area and edge are not associated with extreme heat stress conditions, despite their lightweight roofs and the fact that the last two days of the microclimatic monitoring were particularly hot. This is maybe attributed to the high ceilinged space, which reduces the negative thermal impact of the roof. It is observed that in the edge of arcade, there is a further increase in the percentage of time associated with strong heat stress compared to the central area, despite the covering of its glass-roof.

**Table 3.** Classification of microclimatic recordings of survey areas, based on PET thermal index scale. The results are given as a percentage of time.

| Date   | Tmax_out (°C) | Survey Area | PET thermal classification (°C) |        |
|--------|--------------|-------------|---------------------------------|--------|
|        |              |             | 25.1–31 (%)                     | 31.1–37 (%) |
|        |              |             | Slight Heat Stress              | Moderate Heat Stress |
|        |              |             | 37.1–43 (%)                     | > 43 (%)  |
|        |              |             |                                 |        |
| **Stoa Papadopoulou** | | | | |
| 14/7   | 39.2         | Arcade       | 3                               | 39      |
|        |              |              | 58                              | 0       |
|        |              | Street       | Unavailable Data                |         |
| 15/7   | 38.7         | Arcade       | 3                               | 53      |
|        |              |              | 44                              | 0       |
|        |              | Street       | 0                               | 13      |
|        |              |              | 17                              | 70      |
| 16/7   | 38.5         | Arcade       | 3                               | 69      |
|        |              |              | 28                              | 0       |
|        |              | Street       | 0                               | 16      |
|        |              |              | 21                              | 63      |
| 17/7   | 36.3         | Arcade       | 0                               | 97      |
|        |              |              | 3                               | 0       |
|        |              | Street       | 0                               | 18      |
|        |              |              | 17                              | 65      |
| 18/7   | 37.2         | Arcade       | 0                               | 100     |
|        |              |              | 0                               | 0       |
|        |              | Street       | 0                               | 18      |
|        |              |              | 17                              | 65      |
| **Stoa Tarsi** | | | | |
| 4/8    | 34.8         | Arcade       | 12                              | 82      |
|        |              |              | 6                               | 0       |
|        |              | Street       | 5                               | 33      |
|        |              |              | 26                              | 36      |
| 6/8    | 33.1         | Arcade       | 31                              | 69      |
|        |              |              | 0                               | 0       |
|        |              | Street       | 16                              | 44      |
|        |              |              | 24                              | 16      |
| 7/8    | 33.8         | Arcade       | 11                              | 80      |
|        |              |              | 6                               | 3       |
|        |              | Street       | 3                               | 10      |
|        |              |              | 60                              | 27      |
| 8/8    | 38.4         | Arcade       | 4                               | 74      |
|        |              |              | 16                              | 6       |
|        |              | Street       | 2                               | 8       |
|        |              |              | 40                              | 50      |
| **Stoa Ledra** | | | | |
| 21/7   | 35.8         | Central Area | 10                              | 90      |
|        |              |              | 0                               | 0       |
|        |              | Edge Area    | 7                               | 88      |
|        |              |              | 5                               | 0       |
| 22/7   | 36.2         | Central Area | 7                               | 93      |
|        |              |              | 0                               | 0       |
|        |              | Edge Area    | 2                               | 84      |
|        |              |              | 14                              | 0       |
| 23/7   | 37.8         | Central Area | 7                               | 74      |
|        |              |              | 19                              | 0       |
|        |              | Edge Area    | 0                               | 63      |
|        |              |              | 37                              | 0       |
| 24/7   | 40.1         | Central Area | 0                               | 56      |
|        |              |              | 44                              | 0       |
|        |              | Edge Area    | 0                               | 35      |
|        |              |              | 65                              | 0       |
| 25/7   | 39.8         | Central Area | 0                               | 55      |
|        |              |              | 45                              | 0       |
|        |              | Edge Area    | 0                               | 37      |
|        |              |              | 63                              | 0       |
Table 4. Heat stress levels on a daily basis at the survey areas for a hot spell and normal day: (a) Stoa Papadopoulou, (b) Stoa Tarsi and (c) Stoa Ledra

|                  | Hot spell Day | Normal Day |
|------------------|---------------|------------|
|                  | (a) Stoa Papadopoulou | (b) Stoa Tarsi | (c) Stoa Ledra |
|                  | Arcade        | Open street | Arcade        | Open street | Arcade        | Street |
| Percentage (%)   |              |             |              |             |              |        |
| Extreme (> 43°C) | 2%            | 53%         | 2%           | 6%          | 4%           | 2%     |
| Strong (37.1–43°C) | 44%         | 17%         | 6%           | 50%         | 8%           | 4%     |
| Moderate (31.1–37°C) | 7%         | 13%         | 6%           | 31%         | 8%           | 8%     |
| Slight (25.1–31°C) | 53%         | 17%         | 6%           | 40%         | 8%           | 8%     |

|                  | Arcade        | Street      | Central area | Edge area |
|------------------|---------------|-------------|--------------|-----------|
| Percentage (%)   |              |             |              |           |
| Extreme (> 43°C) | 0%            | 0%          | 0%           | 10%       |
| Strong (37.1–43°C) | 0%         | 0%          | 0%           | 7%        |
| Moderate (31.1–37°C) | 90%         | 90%         | 90%          | 90%       |
| Slight (25.1–31°C) | 0%           | 0%          | 0%           | 7%        |
with light-coloured fabrics that reduce the radiant load. In particular, strong heat stress ranges between 0% and 45% in the central area, whereas in the edge ranges between 5% and 64%. This means that the duration of strong heat stress in the edge increases by 5% to 20% compared to the central area.

It is worth mentioning that during hot spell days, there is a further increase of the level of heat stress, for both the central area and the edge of the arcade, whereas during normal summer days the arcade, and especially its central area, achieves complete mitigation of strong heat stress levels (Table 4). More analytically, during the hottest day of the monitoring period ($T_{\text{max.out}} = 40.1^\circ\text{C}$), 56% and 44% of the time corresponds to moderate and strong heat stress respectively in the area of the central space. In the area of the edge, 35% and 65% of the time corresponds to moderate and strong heat stress. Under a normal summer day ($T_{\text{max.out}} =35.8^\circ\text{C}$) the central space of the arcade is associated with slight and moderate heat stress at a percentage of 10% and 90% respectively. The area of the edge is associated with slight, moderate and strong heat stress at a percentage of 7%, 88% and 5% respectively.

4. Conclusions
The microclimatic analysis carried out in this study, reveals that ‘sheltered’ arcades perform better compared to the less shaded streets. It is illustrated that in contrast to open streets, the areas of arcades achieve significant mitigation of strong and extreme heat stress, contributing to the minimization of the duration and level of uncomfortable conditions, i.e. excessive discomfort. The central spaces of arcades thus, provide thermal advantages over the open streets and edges of arcades during the cooling period. This positive thermal effect of semi-open spaces over the completely exposed open spaces is also documented by other researchers [3, 4]. Note however that, the majority of thermal conditions in arcades and open streets under case study remains above PET thermal comfort zone. In line with these results, other studies [3, 4, 5] also found that semi-open spaces are unable to achieve thermally comfortable conditions during the cooling period.

During normal summer days, the central spaces of arcades under case study were mostly associated with slight and moderate heat stress, whereas open streets were found to be associated with strong and, in some cases, even extreme heat stress levels. Arcades can thus, achieve a good thermal response under milder summer conditions. These results indicate the bioclimatic contribution of semi-open spaces with regard to the amelioration of outdoor climatic extremes and their suitability in hot climates where solar protection is a design priority. Future research could focus on testing thermal design improvement scenarios for thermal comfort amelioration of semi-open spaces in the urban realm and on recommending specific design criteria towards enhancing their thermal performance.

References
[1] J. Spagnolo and R. de Dear, "A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia," Building and Environment, vol. 38, no. 5, pp. 721-738, 2003.
[2] B. Givoni, Passive and low energy cooling of buildings, New York: John Wiley & Sons, 1994.
[3] I. Tsiros and M. Hoffman, "Thermal and comfort conditions in a semi-closed rear wooded garden and its adjacent semi-open spaces in a Mediterranean climate (Athens) during summer," Architectural Science Review, vol. 57, no. 1, pp. 63-82, 2014.
[4] F. Ali-Toudert and H. Mayer, "Effects of asymmetry, galleries, overhanging facades and vegetation on thermal comfort in urban street canyons," Solar Energy, vol. 81, no. 6, pp. 742-754, 2007.
[5] A. Potvin, "The arcade environment," Architectural Research Quarterly, vol. 2, pp. 64-79, 1997.
[6] E. Andreou and K. Axarli, "Investigation of urban canyon microclimate in traditional and contemporary environment. Experimental investigation and parametric analysis," Renewable Energy, vol. 43, pp. 354-363, 2012.
[7] M. Sinou and K. Steemers, "Urban space - thermal analysis of case studies," in *WIT Transactions on Ecology and the Environment*, 2003.

[8] K. Lamia, B. Rafik and S. Djaffar, "Thermal and airflow characteristics of transitional spaces in a traditional urban fabric. Case study of a covered walkway in Timimoun (Southwest of Algeria)," *VFAS Transactions on Mathematics*, vol. 7, no. 2, pp. 1-9, 2015.

[9] M. Nikolopoulou and S. Lykoudis, "Thermal comfort in outdoor urban spaces: Analysis across different European countries," *Building and Environment*, vol. 41, no. 11, pp. 1455-1470, 2006.

[10] S. Thorsson, F. Lindberg, I. Eliasson and B. Holmer, "Different methods for estimating the mean radiant temperature in an outdoor urban setting," *International Journal of Climatology*, vol. 27, no. 14, pp. 1983-1993, 2007.

[11] A. Matzarakis and H. Mayer, "Another kind of environmental stress: thermal stress," *WHO News*, vol. 18, no. 1, pp. 7-10, 1996.