Optimization of the shading efficiency in the urban spaces in hot arid climate regions

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Abstract

Purpose – The contemporary urban fabrics in hot climate regions have overextended urban spaces that face problems of high heat stress due to intense solar radiation and air temperature and that cause the pedestrians to abandon the urban spaces due to thermal discomfort. This work introduced the shading effects as one of the prime factors that contribute to restore thermal comfort and attract pedestrian activities. The purpose of this paper is to identify the proportional limits of the urban space to maintain feasible shades for pedestrian activities.

Design/methodology/approach – The urban space abstracted into a floor surrounded by four walls was then classified into four typologies. The assessment tool was developed to calculate the shading efficiency at the floor level of urban space. The width and the length of the floor equally was expanded in the range (0.5/0.5 to 4.0/4.0). The average shading efficiency of the expanded typologies was calculated along three intervals (Morning, midday and afternoon). The results were then analyzed, and critical guidelines were established that could be utilized in the design of the futuristic urban space and provide amendments to the existing urban space.

Findings – The paper concluded that the performance of urban spaces was not due to the accumulative performances of all walls but rather due to the combination specific effective walls in response to the interactive variations shading patterns concerning daily pedestrian activities. Any large shallow urban space could be segmented into multiples of the recommended typologies by a vertical landscape.

Originality/value – It is the first study that identified the expansion limit of the urban space that maintains feasible shades for the pedestrian. A further value of this study is establishing guidelines to the urban designers for the effective configurations of the urban space in terms of shading. These guidelines could be utilized in the design of the futuristic urban space and provide amendments to the existing urban space.

Keywords Hot arid climate, Pedestrian comfort, Shading efficiency

Paper type Research paper

1. Introduction

The urban space environment gets particularly overheated in hot climate regions due to the combination of intense solar radiation and high air temperature that creates much discomfort. It is necessary to improve the comfort level of outdoor environment of the urban space by the introduction of shade, air currents, and landscape features. Some researchers
have recognized the importance of providing shade to improve pedestrian thermal comfort in different climates over the world and deal with urban space layout from various aspects. Numerous studies have concentrated on the impact of aspect ratio, which is the proportion of the height to the width of urban space (Ahmed, 2003; Shashua-Bar et al., 2004; Georgakis and Santamouris, 2006; Lin et al., 2010; Abreu-Harbich et al., 2014; Perini and Magliocco, 2014). Researchers emphasized the significant impact of aspect ratio on pedestrian thermal comfort. Giannopoulou et al. (2010) in their study in a Mediterranean climate (Athens, Greece) discovered that there is an inverse relationship between the aspect ratio and the cooling rates. The research demonstrated that reducing the aspect ratio from 3 to 1.7 increased space air temperature between 1.5 and 2.8°C. The study of Emmanuel et al. (2007) used physiologically equivalent temperature index (PET) based on air, radiant temperature, wind, and humidity. They concluded that the increase of the H/W ratio from 1 to 3 leads to the decrease in PET by about 10°C. They further found that spaces between buildings should be shorter than the shadow lengths, although this could have a negative effect on airflow in the space.

Bourbia and Boucheriba (2010) attempted to assess the impact of the geometry on the space climate, in the downtown of Constantine, Algeria (semi-arid climate). They concluded that for spaces that are oriented to north-south direction, the floor canyon shading fraction increases with the increase in the space H/W ratio, with little seasonal variation. A further conclusion of this research is that the deep canyons have lower values of air temperatures (3–6°C) and surface temperatures (12°C) than shallow canyons. Andreou (2014) analyzed the effect of urban layout, street geometry and orientation on solar access and shading conditions and stated that they strongly affect urban canyon microclimate. The study demonstrated that the aspect ratio and orientation were the most effective parameters that influenced pedestrian thermal comfort. These findings agreed with the study of the hot-dry climate of El-Oued, Algeria, by Bourbia and Awbi (2004). The study showed that the space orientation and aspect ratio were the predominant factors that affect solar shading and urban space microclimate.

In Singapore (hot-humid tropical climate), Yang et al. (2015) investigated five alternative design scenarios with different aspect ratios (H/W = 1, 2, 3, 4, 5). The authors simulated these scenarios with the software ENVI-met, and their simulation results were compared with the base case. The finding of this study showed that maximum air temperature difference between the different scenarios is up to 0.8°C. However, the temperature stops decreasing when H/W reaches 4.

The same methodology was followed by Jihad and Tahiri (2016) when conducting a numerical simulation to investigate the impact of urban space geometry on the thermal conditions of external ambient air. The data were collected from three different climate zones in Algeria (Fez, Agadir and Errachidia). The natural climate of these zones is hot summer and cold winter. The study reveals that there are three thresholds of the aspect ratio to keep these zones in the appropriate range of thermal comfort. The obtained results identified the aspect ratio for Fez and Agadir within 1.2–1.9 and 2.5–3.4, respectively, whereas in Errachidia, the aspect ratio was lower than 1.2. Moreover, some researchers have studied other elements of the configuration of urban space. For example, Taleb and Abu-Hijleh (2013) endeavored to learn and apply lessons from the past to the historic urban fabric. They conducted a comparison study between the grid and organic configurations in the desert climate of Dubai, UAE. They concluded that organic urban configuration showed the higher level of shading in summer and promoted social interaction in the public spaces. These findings coincided with Ali et al. (2018) when they selected the urban fabric of Sana’a city in Yemen. They investigated the urban form of Sana’a city by comparing the urban morphologies of the traditional and old Sana’a with the modern. The comparison was conducted by applying three main basic principles of sustainability (Form and density, Walkability and connectivity and Building energy. The simulation results of the urban solar
analysis using ECOTECT showed a remarkable variation in shading rates between these two urban forms. The shading produced by the traditional morphology achieved sufficient values of solar access, exposure, and shadows over different periods of the year.

Nevertheless, the modern urban form showed normal values. The study highlighted the variation in shading rates due to the impact of the aspect ratio in attaining the permanent shade in traditional urban space. The average building height is between 15 and 30 m, whereas the street width is around 3–10 m, and the length of the social square is about 30 m maximum.

Other studies concentrated on the courtyard as a specific typology of the urban fabric. Steemers et al. (1998) conducted a review of the thermal performance of the courtyard archetype in London in 1997. They found out that courtyard is the most thermally comfortable urban configuration. On the other hand, some studies illustrated different types of modifications of urban layouts and their effects on the thermal comfort. Olgyay concluded that square urban layouts are more thermal efficiency than North-South extended longitudinal courtyard in both winter and summer seasons (Olgyay and Olgyay, 1963), whereas Johansson et al. (2013) compared the mean radiant temperature (MRT) in six different urban sites. They found significant variations in MRT through these sites. The authors emphasized the importance of shading as a factor in reducing MRT values. They concluded that high-rise urban fabric without vegetation registered lower MRT than the low-rise area without vegetation due to the provision of shading by tall buildings. It can be reached from the above literature that shade is one of the most important factors required to improve pedestrian comfort in hot climate regions.

Ben-hamouche analyzed some old cities located in the hot climate region of Arab Gulf countries. The author indicated that the compact city is the effective urban approach that could develop the environmental performance of the urban space (Ben-hamouche, 2008). This approach is utilized in the traditional Omani architecture. Buildings in traditional Omani architecture are huddled together to get maximum mutual shade and minimum surface exposure to intense solar radiation. Omani urban fabric, however, comprises detached dispersed building blocks with a vast grid space (Charabi and Bakhit, 2011; Shabaan and Khudhayer, 2015). The overextended horizontal expansion of the urban spaces face problems of high heat stress due to high solar radiation and ambient air temperature. Most of the above pieces of literature highlighted the importance of shade as one of the prime factors that contribute to restore thermal comfort at the urban space and attract pedestrian activities. Some of these studies investigated the impact of the proportions of the urban space through the effect of the aspect ratio. However, little attention has been devoted to the identifying the proportional limits of the urban space to keep feasible shade for pedestrian. Accordingly, the following are the objectives of this study:

1. To identify the expansion limit of the urban space that keeps a feasible shade for the pedestrian.
2. To establish guidelines to the urban designers for the effective configurations of the urban space in terms of shading. These guidelines could be utilized in the design of the futuristic urban space and provide amendments to the existing urban space.

2. Methodology
Shading requirements were established through climatic analyses of Muscat regions. The urban space was abstracted into a floor surrounded by four walls. The abstracted space was then classified into four typologies (single, double, triple and quadruple walls). The four typologies were coded by the number of surrounding walls and their locations relative to the floor within two cardinal directions at 45° intervals. The assessment tool
was developed to calculate the shading efficiency at the urban space floor level. The shadow length that was derived using Hoffmann’s Shading Calculations Tool (Hoffmann, 2015) and then inputted in the solar angles’ equations. The obtained data were then correlated with algorithms to identify the wall’s shadow direction for each typology. Then, the shaded area for eight hours interval was calculated on October 21. The shading efficiency is the percentage of the shaded area to the total space’s floor area and calculated in three intervals morning, midday and afternoon. The equations and algorithms were laid down in Microsoft Excel to create the assessment tool. This tool was utilized to calculate the average shading efficiency for all typologies in two directions (n = 0 and 45) along three intervals (morning, midday and afternoon). The following procedures were adopted to identify the FEL for each typology:

1. The width (X) and the length (Y) of the floor were equally expanded in the range (0.5/0.5–4.0/4.0).
2. The average shading efficiency was calculated for the floor of the expanded typologies along three intervals (morning, midday and afternoon).
3. The threshold of the shaded floor was assumed to be 50 percent as feasible average of shading efficiency. This threshold represented the horizontal line to intersect each of the three-line graphs of the three intervals (morning, midday and afternoon). Then, vertical lines were dropped from the intersections to the proportion’s axis (0.5/0.5–4.0/4.0) to indicate the FEL that satisfy the threshold shading efficiencies.

A detailed analysis for the resulted FELs has been conducted to identify the effective configurations. Finally, some critical guidelines were established that could be utilized in the design of the futuristic urban space and provide amendments to the existing urban space.

3. Scope and limitations
   Some limitations and constraints were imposed on the tested typologies in order to reduce the variables and concentrate on simple, clear criteria to standardize the results. Thus, urban space was simplified into a rectangular form with a uniform height. The more complex urban forms can be handled by dividing these forms into several effective configurations that were extracted in this research.

4. Shading requirements
   In previous study, Shabaan and Khudhayer (2015) analyzed the climate of Muscat using Building Bioclimatic, and they concluded that the overheated period spans from March 21 to October 21 and the comfort period is short spanning from November 21 to March 21, and shading is required throughout the year even in the short comfort period. The overheated period is divided into two parts: middle and edge periods, presented in Table I.

   In the middle period, the temperatures reach 45°C and relative humidity 85 percent, so comfort cannot be attained even in the shade, and it is unlikely that pedestrians would use public urban spaces. This work, therefore, concentrated on the provision of shading at the edges of the overheated period and took October 21 as a case study for calculations and analyses.

<table>
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<td>Middle-overheated period</td>
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</table>

Table I. Analyses of the climate of Muscat by building bioclimatic
5. Urban space typology
The urban space was geometrically abstracted in this study into hypothetical box formed by a floor and surrounding walls that represented the elevations of the surrounding buildings. A survey was conducted by the authors on the geometric configuration of Muscat urban and the public urban spaces, and geometric typologies were classified into four fundamental typologies: single, double, triple and quadruple walls spaces (Figure 1).

The research consecrated on the shading of the floor of the urban space as it’s occupied by pedestrian for various activities. The floor of urban spaces described by a code of two parts: number of surrounding walls (B), and their locations relative to the floor within two cardinal directions at 45° intervals, and grouped in the following typologies:

- single wall floor (1B/N, 1B/NE, 1B/E, 1B/SE, 1B/S, 1B/SW, 1B/W and 1B/NW);
- double walls floor (2B/N, S, 2B/NE, SW, 2B/E, W, 2B/E, W and 2B/NW, SE);
- triple walls floor (3B/W, N, E, 3B/NW, NE, S, 3B/N, E, S, 3B/NE, SE, SW, 3B/E, S, W, 3B/SE, SW, NW, 3B/S, W, N and 3B/SW, NW, NE); and
- quadruple walls floor (4B/NE, S, W and 4B/NE, SE, SW, NW).

6. Developing the assessment tool for shading efficiency
6.1 The theoretical concept for calculating shading efficiency
Shading efficiency is calculated at urban space floor level as related to pedestrian activities. The theoretical concept for calculating shading efficiency is based on assuming that the shaded area on space’s floor is produced simultaneously by the four surrounding walls north, east, south and west when the space floor is directed to North (Figure 2(a)). When the space floor is directed to Northeast-southwest (Figure 2(b)), the shadows are produced by northeast, southeast, southwest and northwest walls. In real life, only one or two walls produce shadow at any moment. For example, when the sun is behind the NE corner, shadows are created by the north and east walls. The values of Ln and Le are inputted into the equation, whereas Ls and Lw are inputted as 0.0. When the sun is behind the east wall, shadows are formed by the east wall; in this manner, just the Le value is inputted into the equation, whereas Ln, Ls and Lw are entered as 0.0. Meanwhile, when the sun is behind the southeast corner, shadows are created by the east and south walls. In this case, particularly, the values of Le and Ls are inputted into the equation, whereas Ln and Lw are inputted as 0.0. If the sun is behind the south wall, then shadows are created by the south wall, and only the value of Ls inputted, whereas Ln, Le and Lw are inputted as 0.0. The process of producing shadows is repeated in reflected pictures of past cases when the sun is in the southwest, west and northwest corners (Figure 2(c)).

The Shadow length (lp) and the azimuth angle (AZ) for eight hours intervals (8:00–16:00) on October 21 are obtained from the Muscat location using an online shadow calculation tool developed by Torsten Hoffmann (Hoffmann, 2015). Figure 2(d) illustrates the interface of this tool. The Shadow length (lp) is the shadow of the vertical pole at the corner of space (Figure 2(e)) and the azimuth angle (AZ) is the compass direction from which the sunlight is coming. It is like a compass direction with north = 0°, east = 90°, south = 180° and west = 270°. The wall shadow length (L) is calculated from Equations (1) and (2), where AZ is the azimuth, Ø is the wall’s orientation, L is the wall shadow length, HSA is the horizontal shadow angle, lp is the shadow length, and h is the wall height:

\[ L = \sin(HSA) \times lp \]  
\[ HSA = AZ - \varnothing \]

If X is the floor width and Y is the floor length, Ln, Lne, Le, Lse, Ls, Lsw, Lw and Lnw are shadow lengths due to N, NE, E, SE, S, SW, W and NW walls, respectively. The equation
to calculate shading efficiency for the floor (FS) when the floor directed to the north ($N = 0$) is as follows:

$$\text{Floor shading efficiency} = \left( \frac{\text{Floor area} - \text{Sun exposed area}}{\text{Floor area}} \right) \times 100\%,$$
The equations of calculating floor shading efficiency of urban space is laid down in Microsoft Excel formula to create the assessment tool. This tool is utilized to calculate the average shading efficiency (AFS) of floor for two directions \( n = 0 \) and \( n = 45 \) in three intervals (morning, midday and afternoon) for any space expansions interactively.

### 6.2 The process to identify floor expansion limit (FEL)

Solar altitudes are high in tropical regions (such as Muscat), and the vertical elements provide limited shade as compared with horizontal canopies. Accordingly, it would not be
feasible to aim at a full urban space shading by the surrounding buildings. Thus, a medium level of 50 percent average floor shading efficiency was set as the threshold of feasible shading efficiency (TFS) for comparing the urban spaces shading performance (Figure 3a). Additional shade could be provided by horizontal canopies and landscape elements and that will be the topic on the next research work.

The abstracted urban spaces box forms were described by the proportion of width/length/height \((X/Y/Z)\) and were grouped geometrically as follows:

- Group 1: very deep urban space when \(X/Y/Z \leq 0.5/0.5/1\).
- Group 2: deep urban space when \(X/Y/Z \leq 1/1/1\).
- Group 3: medium urban space when \(1/1/1 \leq X/Y/Z \leq 2/2/1\).
- Group 4: shallow urban space when \(X/Y/Z \geq 3/3/1\).

Generally, Group 1 addresses the high-density city center with high-rise buildings, and this is not in the scope of this study. Group 2 relates to limited proportion of public spaces and space within a single building (such as the courtyard). This study is concerned with the problems of the uncontrolled sprawl of the urban fabric in Muscat; thus, it concentrates on Groups 3&4. Some limitations and constrains were imposed on the tested typologies in order to reduce the variables and concentrate on simple clear criteria to standardize the results. Square space with uniform walls with the height of one unit was introduced as a basic module and was rotated at \(45^\circ\) intervals starting from North to test eight cardinal positions. The floor edges \((X/Y)\) were equally expanded in the range of \(0.5/0.5\) to \(4.0/4.0\). TFS represented the horizontal line at 50 percent to intersect each of the three-line graphs, and then vertical lines were dropped from the intersections to the X-axis to indicate the FEL that satisfy the threshold shading efficiencies (Figure 3(b)).

7. Results and discussion
The results of the shading efficiency calculations showed that each wall generates shadow on the floor in a static and dynamic trend instantaneously. The static trend occurs when the expansion is parallel to the wall and the shade remains constant. The dynamic trend occurs when the expansion is perpendicular to the wall and the shading efficiency decreases with expansion. The FEL is governed by the dynamic axis, and the floor can have one or two dynamic axes.
The floors with single and double walls have one dynamic axis, whereas the floors with triple and quadruple walls have two dynamic axes.

### 7.1 Floor with single wall

Figure 4 illustrates the FEL for the floor within two cardinal directions at 45° intervals for the floor with single wall typologies. These typologies were categorized into three groups (northern, intermediate and southern group). The northern group (1B/N, 1B/NE, 1B/NW) was located above the E/W line. This group produced insignificant shading efficiency because most of the walls shadow the area outside the floor (Figure 4(b)). The 1B/NE & 1B/NW produced FEL 0.70/0.70/1, whereas the 1B/N produced 0/0/0. The intermediate group (1B/E and 1B/W) located on E/W line produced shadow either in morning or afternoon only with FEL 2.75/2.75/1.00, whereas at midday with FEL 0/0/0. The southern group (1B/E and 1B/W) located on E/W line produced shadow either in morning or afternoon only produced FEL 0.70/0.70/1, whereas the 1B/N produced 0/0/0. The intermediate group (1B/E and 1B/W) located below E/W, 1B/SE and 1B/SW produced morning and afternoon shadow with FEL 1.70/1.70/1.00, whereas at midday with FEL 1.00/1.00/1.00. The 1B/S produced morning and afternoon shadow with FEL 1.7/1.7/1, whereas at midday with FEL 1.4/1.4/1. The 1B/SE & 1B/SW produced higher FEL but for a limited period, whereas 1B/S produced less FEL but continued all day.
7.2 Floor with double walls
The effectiveness of each wall of the pair depends on its location relative to the E/W line as explained earlier in the single wall group. The wall that belonged to the northern group provided insignificant FEL, whereas the wall that belonged to the southern group provided most of the FEL. Thus, the shading performance of the 2B/N.S was the same as 1B/S because N-wall was ineffective. The FEL of 2B/NE.SW could reach 3.4/3.4/1.0 proportion in the afternoon, whereas the threshold could only be achieved by 1.0/1.0/1.0 proportion at midday hours and 0.70/0.70/1.0 at morning hours because the NE-wall was ineffective (Figure 5).

7.3 Floor with triple walls
In the triple wall space, there were one, two, or three effective walls. The walls SE and SW were effective for 3B/NW.NE.SE and 3B/SW.NW.NE, respectively. Two effective pairs of walls were in two configurations: parallel or perpendicular. The parallel pair W.E was the effective configuration for 3B/W.N.E. The perpendicular pairs E.S, SE.SW, SE.SW, and S.W were the effective configurations for 3B/N.E.S, 3B/NE.SE.SW, 3B/SE.SW.NW and 3B/S.W.N respectively. However, all the three walls were effective in the 3B/E.S.W (Figure 6).

Figure 5. The FEL the floor with double walls typologies
7.4 Floor with quadruple walls
Not all the walls contributed to the shading performance of the quadruple space. Shadow for the 4B/N.E.S.W space was produced by the E, S and W walls only, with no contribution from the N-wall. The SE and SW walls produced shadow in the 4B/NE.SE.SW.NW space, whereas the effect of NE and NW walls is negligible.

All resulted FELs are given in Table III for comprehensive comparison among all typologies. The study found out that the performance of the effective walls was the driving force that governed the performances all other space typologies. It was concluded the shading efficiencies of various urban space typologies was not due to the accumulative performances of all surrounding walls but instead due to the combination of some critical effective walls. Accordingly, the double wall space had effective combinations of one wall and two walls. The triple walls space had effective combinations of one wall, two parallel walls, two perpendicular walls, and three walls. The quadruple walls space attained the highest FEL and were classified into two typologies. The first was 4B/N.E.S.W walls typology with effective U-shaped (E, S and W) walls combination that achieved the proportions 3.8/3.8/1.0 in the morning and afternoon, with 1.6/1.6/1.0 proportion in the midday period. The second was 4B/NE.SE.SW.NW walls typology with effective V-shaped (SE and SW) walls combination that achieved the proportions 3.5/3.5/1.0 in the morning and afternoon and 1.75/1.75/1.0) at the midday period.

8. Conclusions and recommendations
In the hot, arid climate, it would be not appropriate to recommend one type of optimally shaded urban space form, due to the dynamic, interactive variations between the shading patterns and daily pedestrian activities. Therefore, some flexible feasible guidelines were presented that enable the urban designer to select the appropriate space proportions to
provide the necessary shade at the specified zones and periods of pedestrian activities. It was found that comfort could not be attained in the shaded urban space in the middle of the overheated period due to high air temperature and humidity, causing pedestrian activities to be limited to indoor public spaces. Therefore, this work concentrated on the

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<th>Dynaxis</th>
<th>FEL (Morning)</th>
<th>FEL (Midday)</th>
<th>FEL (Afternoon)</th>
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<td>3.8</td>
<td>1.6</td>
<td>3.8</td>
<td>3.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.6 3B/SE.SW.NW</td>
<td>SE.SW</td>
<td>X,Y</td>
<td>3.5</td>
<td>1.75</td>
<td>3.5</td>
<td>2.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.7 3B/S.W.N</td>
<td>S&amp;W</td>
<td>X,Y</td>
<td>1.7</td>
<td>1.5</td>
<td>3.8</td>
<td>2.33</td>
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<tr>
<td>3.8 3B/SW.NW.NE</td>
<td>SW</td>
<td>X,Y</td>
<td>0.7</td>
<td>1</td>
<td>3.4</td>
<td>1.70</td>
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<tr>
<td>4.1 4B/N.E.S.W</td>
<td>E&amp;S&amp;W</td>
<td>X,Y</td>
<td>3.8</td>
<td>1.6</td>
<td>3.8</td>
<td>3.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.2 4B/NE.SW.SW.NW</td>
<td>SE&amp;SW</td>
<td>X,Y</td>
<td>3.5</td>
<td>1.75</td>
<td>3.5</td>
<td>2.90</td>
<td></td>
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</tr>
</tbody>
</table>

Table III. The FEL for the floor within two cardinal directions at 45° intervals for all typologies (single, double, triple and quadruple) and the dynamic and static FEL at the X and Y axes for the three periods of the day.
achievement of shading in the last part of the overheated period and took October 21 as a case study for calculations and analyses. However, the surrounding buildings in hot climate regions could provide limited shade at the urban space peripheral zones due to the high solar altitudes; thus, it was decided to target at 50 percent threshold shading efficiency. The study presented a new approach that can evaluate and provide a solution for the shading performance in the urban space. This approach gives schematic milestones for the new urban space and modifications to the existing urban space to return it to its effective configuration.

The study concluded two effective typologies could be used for the new design of the urban space. The first was U-shape combined from E, S and W walls with 3.8/3.8/1.0 FEL in the morning and afternoon and 1.6/1.6/1.0 FEL in the midday period. The second was V-shape (SE and SW) walls combination with FEL 3.5/3.5/1.0 in the morning and afternoon and 1.75/1.75/1.0 FEL at the midday period. Regarding the overextended existing urban space, the study suggested to improve this space by segmenting it into multiples of U-shaped (E, S, and W) or V-shaped (SE and SW) walls combination within the FEL relevant to the time of the pedestrian activity. The segmentation could be achieved by various landscape elements such as rows of vertical trees (Khudhayer et al., 2017). The trees are considered as space dividers to keep the overextended space within FEL. The above findings related to standardized urban spaces of equal heights. However, higher shading efficiencies could be attained by raising the heights of the effective walls adjacent to some peripheral zones as related to the time and type of pedestrian activities. Additional shade could be provided at the middle zones by horizontal canopies and landscape elements, and this will be the topic of future research work.

References


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