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# Effect of Orientation on Optimization of Urban Pedestrian Street Shading Efficiency in Muscat Region

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***Abstract:*** *This work addresses the problem of environmental comfort of outdoors pedestrian shopping street in the maritime desert climate of Muscat, Oman, by providing maximum shade. Street canyon was abstracted into theoretical long channel formed of floor and building facades( walls). Street shading efficiency was developed as a function of orientation and street profile ( height/ width). Proportions of profile was neutralized , and the work was concentrated on effect of variation of orientations. Street profile shadow charts were developed and used to for the calculation of shadow patterns and shading efficiencies . It was concluded that that N/S street have the highest average shading efficiency, followed by NE/SW and NW/SE streets, while E/W street has the lowest. Detailed of efficiencies of street floor and walls during various parts of the day were also presented in order to be synchronized with pedestrians peak and low shopping activities.*

***Key words:*** *pedestrians shopping streets. shading efficiency, street orientation, profile, shadow patterns, street canopy*

## 1. Introduction

Planning of future sustainable urban patterns in Muscat is developing a trend of shifting some of the shopping activities from air conditioned Malls to outdoors pedestrian shopping streets. This work contributes towards this trend by addressing the problem of hot climate by providing maximum shade to improve pedestrians shopping streets comfort conditions much can be learned from traditional Omani architecture. The concept of traditional shaded Suq at Nizwa (Figure 1) is reflected on in students Pedestrian Street at Sultan Qaboos University (Figure 2).

Fig.1: Traditional Suq at Nizwa
(Source: Author)

Fig. 2: Student"s pedestrian street
(Source: Author)

Masdar city in Abu Dhabi is another example that addresses the concept street shading through profile proportioning and proper street orientations [2]. The authors designed the Master Plan of Al-Khodh Valley Science and Technology Park in Muscat with the concept of shaded pedestrian streets [1] to improve social interaction between researchers and developers (Figure 3).


Fig. 3: Science and Technology Park Master Plan in Muscat [1]

Street pedestrians model in Ghardaia, Algeria concluded that the spatial distribution of physiologically equivalent temperature (PET) depend strongly on aspect ratio and street orientation [3]. Another study concluded the increase of H/W ratio from about 1 to 3 leads to a decrease in PET by about 10 $^{0}$C [4]. Numerical simulations of „solar access indices' were proposed by [5] , and presented urban design guidelines. Analyzes of the effect of street geometry and orientation contributed to the evaluation of the layout and urban canyon environment [6]. Street climate was assessed the in Constantine Algeria, and it was concluded that for streets oriented north–south, the floor canyon shading increases with increasing street H/W ratio[7]. Shishegar concluded that the decrease of the H/W ratio causes an increases solar access in the street [8]. Study of thermal properties of confined urban spaces in Santa Cruz in indicated temperature decrease of 8$^{0}$c for narrow streets (H/W = 5)[9]. Study of profile ratio H/W of 0.5 and 1for street orientations of N-S and E-W concluded that streets of a N-S more efficient than E-W orientation [10]. It can be concluded that further research is needed to address the effect of orientation in hot climate regions with particular reference to Muscat, Oman.

## 2. Research Methodology

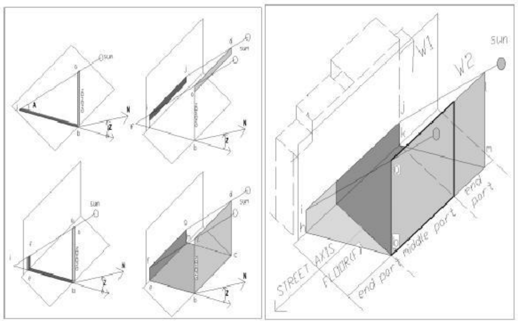
Shading requirements were established through climatic analyses. Street is abstracted into theoretical long channel floor (F) and two simple long walls (W1&W2). Street profile is neutralized to proportion of (W1/F/W2:1/1/1) in order to concentrate on the comparative shading efficiencies for various orientations. Higher shading efficiencies may obviously be obtained by narrower and deeper street profiles but this is to left for the designer. Orientation is identified by longitudinal "street axis", and four orientations at 45$^{0}$ intervals are studied at (E/W, N/S, NE/SW, NW/SE). Solar azimuths, altitudes with vertical and horizontal shadow angles were calculated, and used for developing profile shadow charts(SPSC). Street shading efficiencies were calculated and plotted for various parts of the day in relation to times of peak and low pedestrian activities. The findings were compared to arrive at optimum orientation.

## 3. Shading requirements

Analyses of the climate of Muscat region indicated that it is maritime desert climate that combines high temperatures, high humidity, dusty conditions, and low precipitation . Overheated period spans from April to October with a need for shading of outdoors spaces. Comfort period spans from November to March and even then shading is preferable.

## 4. Geometry of street shadow patterns

The development of shade of gnomon (ab), horizontal bar(ad), and wall (abcd) on floor and wall is given in (Figure4a). Street was subdivided into three zones; middle rectangular zone , and two trapezoidal end zones which represent very small portion and to be neglected (Figure 4b). Shading performance is further studied in relation to pedestrians activities during the day: Morning hours(sunrise to 10:00), Midday hours(10:00 to 14:00), and Afternoon hours(14:00 to sunset).



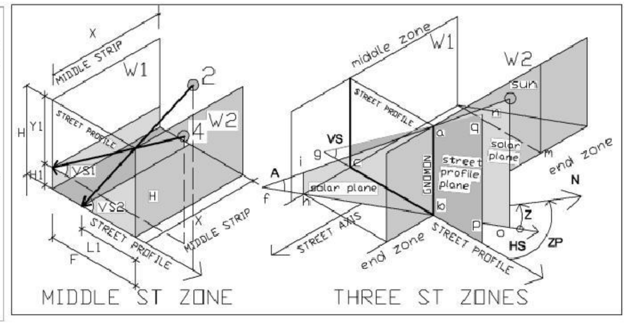




Fig. 4a Fig. 4b

Fig. 4: Shadow patterns of gnomon and street profile

In (Figure 4b) the triangle (fno) is defined as "*Solar plane*" containing solar altitude(A). The sectional plan perpendicular to street axis is the "*Street profile"* contains "*Vertical Shadow angle*-VS" which is the projection of the of the altitude angle (A) from the solar plane on the street profile, and was used for the calculation of street profile shadow charts (SPSC).

## 5. Development of equations for shading efficiency

Azimuth (Z) and altitude (A) for Muscat latitude 23.5° N are obtained from standard equations. Horizontal Shadow angle (HS) and Vertical Shadow angle (VS)are:

$$HS = Z - ZP \quad (1)$$

$$VS = \arctan(\tan A / \cos HS) \quad (2)$$

where: (ZP) is street profile azimuth from North

Solar movement across the street profile is into two parts ( Figure5) .The " *First part of the day*" is from sunrise until it is crosses the street axis, then the "*Second part of the day*" is from then until sunset. Two general cases of solar positions (2 &4) for first part of the day, and (6&8) for second part of the day were used for calculations The shaded area is made of three rectangular strips of equal width (X) (Figure 5):

### 5.1. Solar position -2 as sunray strikes the wall W1

Shading efficiency= shaded area / total area

Wall-1/ shading efficiency: $EW1 = ((H1*X) / (H*X))*100\% = (H1/H)*100\ \%$ (3)

Floor shading efficiency : $EF1 = ((F * X) / (F * X))*100\% = 100\ \%$ (4)

Wall-2/ shading efficiency: $EW2 = ((H * X) / (H*X)) *100\ \% = 100\%$ (5)

### 5.2. Solar position-4 as sunray strikes the floor only

Wall-1/ shading efficiency: $EW1 = ((H1*X) / (H*X))*100\% = (0 / H)*100\ \% = 0\ \%$ (6)

Floor shading efficiency : $EF1 = ((L1 * X) / (F * X))*100\% = (L1/F)*100\ \%$ (7)

Wall-2/shading efficiency: $EW2 = ((H * X) / (H*X)) *100\ \% = 100\%$ (8)

H1: shadow height on wall(W1) (measured upward from wall lower edge)

L1: shadow length on floor (measured from base of gnomon wall) .

H: street wall height ( walls are assumed to be of equal height), F : street floor width.

It can concluded that shading efficiency is reduced to calculation shadow lengths only.

### 5.3. Equations of shadow lengths

First part of the day:

$Y1 = F * \tan VS$, then $H1 = H - Y1$, $L1 = H * \cot VS$ ( where VS is +ve) (9)

Second part of the day:

Y2=F * tan VS, then H2=H-Y2, L2= H * cot VS (where VS is –ve, but use absolute value) (10)

Y1,Y2: sun patch drops on walls (measured <u>downward</u> from wall upper edge )

H1,H2: shadows climbs on walls (measured <u>upward</u> from wall lower edge of street floor)

L1,L2: shadow length on floor (measured from base of gnomon wall) .

## 6. Plotting of shadow patterns and shadow efficiencies

Street profile shadow charts (SPSC) were plotted for profile with proportion 1/1/1 for the four street types , a sample for 15May/30 Oct is shown (Figure 6). H1,H2,L1,L2 were measured from the shadow patterns and used to calculate and plot shading efficiencies (EW1,EF, EW2) the four street types( Figures 7-11). Average street efficiency is calculated and plotted as: EAV =( W1+EF+EW2)/3.

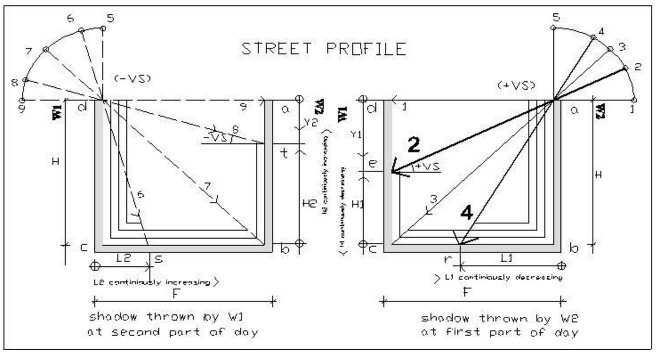



Fig. 5: movement across profile

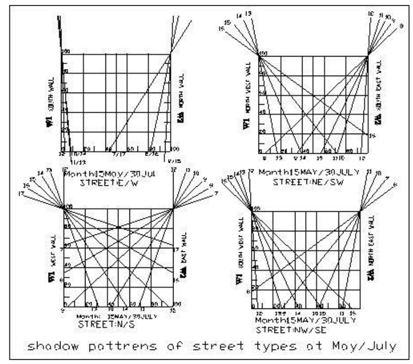



Fig. 6: Shadow charts for 15May/30July

## 7. Discussion of Results

Comparison of monthly average shading efficiencies of street orientations is given in (Figure 7) and detailed discussion of each orientation follows (Figures8-11). Equivalent score was used (Table 1) noting that: N=none, F= full. The following appreciations are used: wall shading efficiency (EW), floor shading efficiency (EF), Average street efficiency (EAV). Detailed shading efficiencies are further discussed in relation to pedestrians activities during the day: Morning hours (sunrise to 10:00), Midday hours(10:00 to 14:00), and Afternoon hours(14:00 to sunset).

TABLE 1: Conversion of shading efficiencies from percentages to scores

| Type | None | V- low | Low | Medium | High | V- high | Full |
|---|---|---|---|---|---|---|---|
| | N | VL | L | M | H | VH | F |
| Efficiency% | 0 | < 20% | 20-39% | 40-59% | 60-79% | >80% | 100 |


Fig. 7: Annual comparison of shading efficiencies of various orientations

### 7.1. Street of NE/SW orientation

NW-wall :EW is none at morning hrs, none to high at midday hrs, full at afternoon hrs.
Floor : EF is high to med at morn hrs, med to none at midday hrs, med to high at afternoon.
SE-wall : EW is full at morning hrs, full to none at midday hrs, none at afternoon hrs.
EAV : high at morning and afternoon hrs, med at midday hrs. Generally: EF of SE wall is higher than NW wall , and EF in the following decreasing order : SE wall, FL, NW wall but with limited variations (Figure 8).

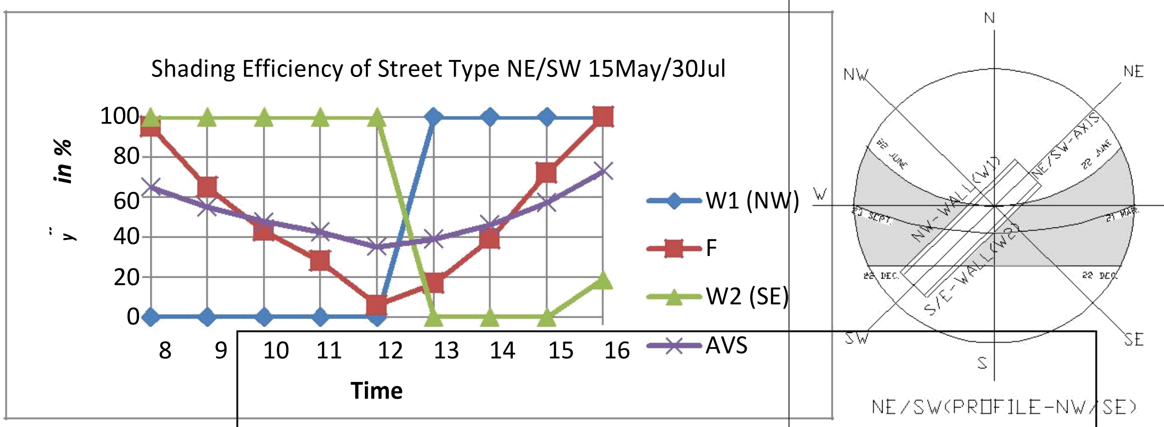



Fig. 8: Shading efficiencies of NE/SW Street

### 7.2. Street of NW/SE orientation

SW-wall : EW is none at morning hrs, none to high at midday hrs, full at afternoon hrs. Floor: EF is high to med at morning hrs, med to none at midday hrs, med to high at afternoon. NE-wall: EW is full at morning hrs, full to none at midday hrs, none at afternoon hrs
EAV: EF is high to med at morning and afternoon hrs, med at midday hrs
Generally: EW of SW wall is higher than NE wall
Efficiency in decreasing order: SW wall, FL, NE wall but limited variations (Figure 9).

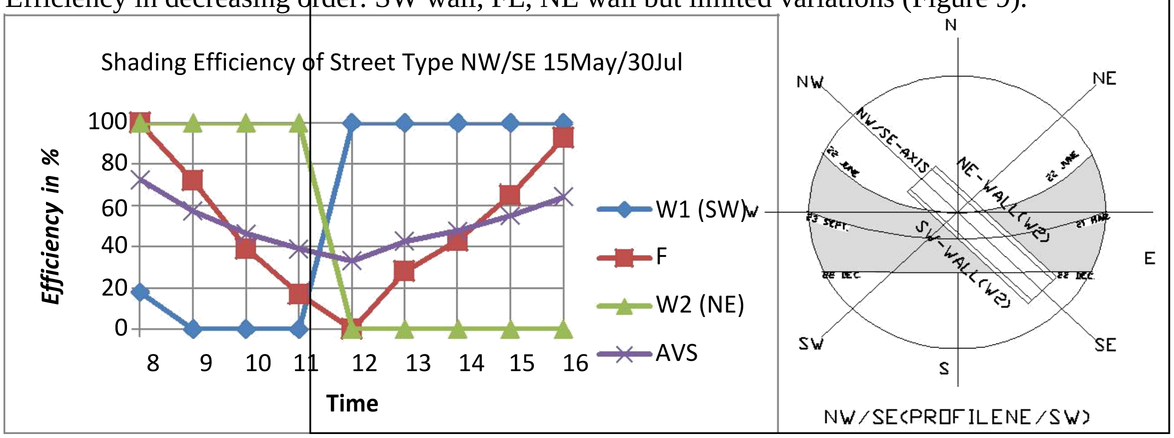



Fig. 9: Shading efficiencies of NW/SE Street at 15May/30 July

### 7.3. Street of E/W orientation

S-wall :EW is low at morning hours, V-high at midday hrs, low at afternoon hrs.
Floor: EF is V-low at midday hours and V-low at morning and afternoon hours.
N-wall: EW is full to none at morning and afternoon hours, none at midday
EAV: is generally low throughout the day (Figure 10).

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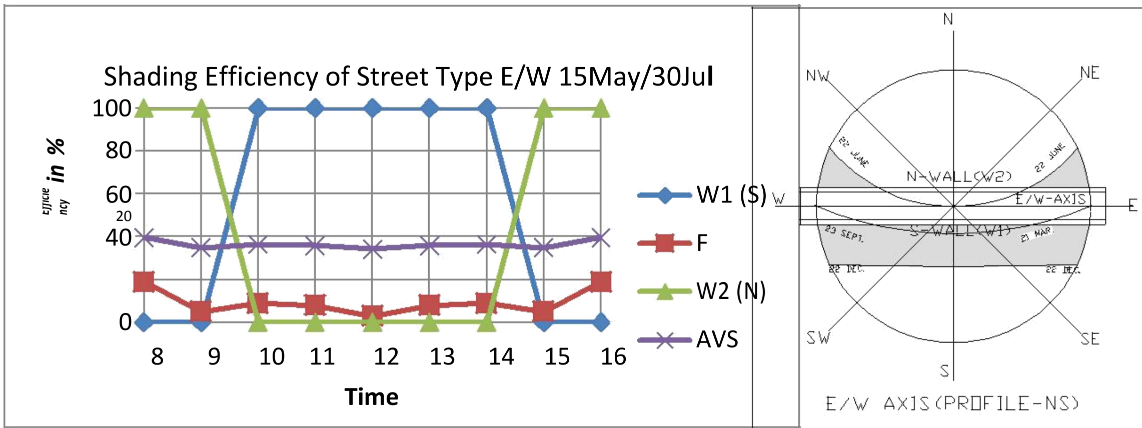


Fig. 10: Shading efficiencies of E/W Street at 15May/30 July

### 7.4. Street of N/S orientation

wall: EW is low at morning hours, none to medium at midday hrs, full at afternoon hrs
Floor: EF is low at midday hour, low →medium at morning and afternoon hours
E-wall: EW is full at morning hours, high at midday, low at afternoon
E&W walls interchange EW at morning and afternoon hours due to symmetry
EAV: generally high but drops to low at midday hours (Figure 11) .

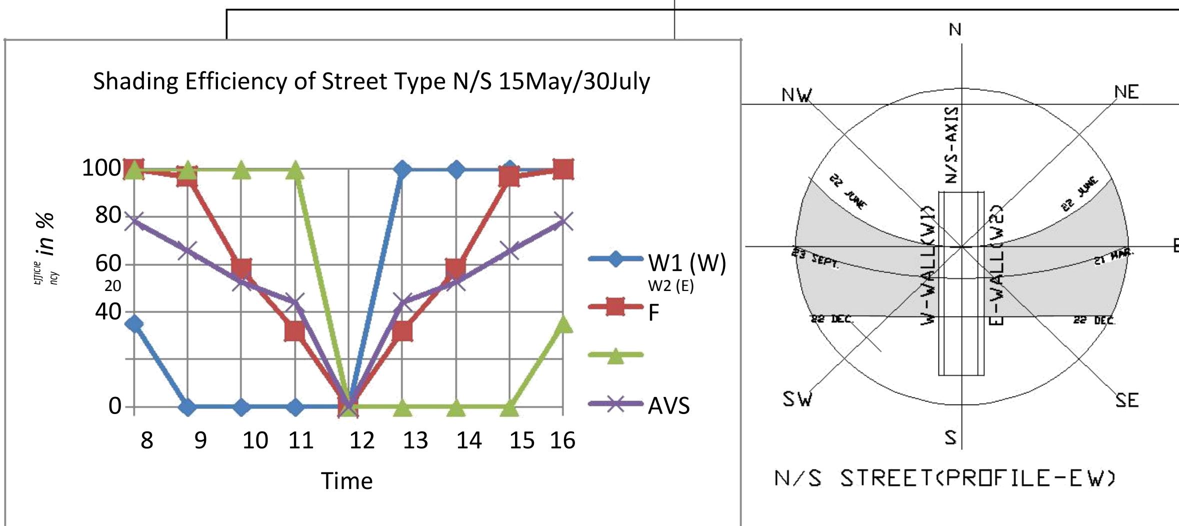


Fig. 11: Shading efficiencies of N/S Street at 15May/30 July

## 8. Conclusions

1-Comparsion of general average shading efficiencies during the overheated period indicates that N/S street have the highest average shading efficiency, followed by NE/SW and NW/SE streets, while E/W street has the lowest. The high shading efficiency of N/S street is due to long shadows of E-wall and W-wall during mid-morning and mid- afternoon hours. E/W street has the lowest shading efficiency because the sun path of high altitude closely follows the street axis allowing little shading effects of its walls.

2- Average shading efficiencies at the comfort period of all the street types follows the same hierarchy as above but with higher amplitude. It should be noted that shading is also preferable in the comfort period.

3-Studies were also conducted on street floor shading efficiencies in order to relate it to pedestrians peak and low shopping activities. It is concluded that floor efficiency of N/S street have the highest EF but it deteriorate at midday hours. NE/SW and NW/SE streets are next in order , while E/W street is the lowest.

4-Detailed performances of shading efficiencies of walls and floors were established at morning , midday, and afternoon hours. It presents guidelines to the planner to optimize pedestrian low and peak activities as related to the availability of shade at each specific street profile and orientation.

5-Prevailing wind in Muscat is around N/E, which seem to coincide with the optimum shading orientations of N/S , NE/SW and NW/SE streets and support the cooling effect.

## 9. Acknowledgement

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