Implications of urban space aspect ratio on campus outdoor thermal comfort

(Case study, BUE campus, Cairo, Egypt)

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Abstract

Campus outdoor urban spaces consider effective spaces for students to take a walk or engage in recreation and social activities or studying. A comfortable thermal environment is extremely important for students to enjoy the outdoor urban spaces. Wherefore thermal comfort in urban spaces is a crucial issue, but the warmer urban climate may have some negative impacts on outdoor thermal comfort of student in campus. Therefore, the aim of this study was to investigate the effect of aspect ratio of urban space, which is one of most effective strategy to improvement outdoor thermal comfort. ENVI-met numerical simulation applied to examine a series of aspect ratio scenarios. ENVI-met run for main entrance space in BUE campus, Cairo, Egypt. The effects of aspect ratio on outdoor thermal comfort dealt with in detail. The results show that aspect ratio (H/W=3) could be considered starting point to respect outdoor thermal comfort.

1. Introduction

Campus life is well and active in open spaces, and functioning open spaces in campuses have become as appealing as classrooms to students. Therefore, the understanding of microclimate of campus outdoor urban spaces and thermal comfort impacts on students pioneers new methods to develop campus urban space[1]. However, outdoor thermal comfort quantification is rarely in area of investigation. Thermal indices, which developed to estimate outdoor thermal comfort not related to human thermal sensation directly. For this reason, it is difficult to be interpreted by urban designers. In the last few years, many studies of urban thermal comfort have proceed in different climatic zones in many urban outdoor spaces. Some studies dealt with outdoor thermal comfort in the subtropical climate[2], some other focused on temperate and cold climate[3], some others studies, and some other studies investigated the tropical climate[4]. Outdoor thermal environment influences directly on human outdoor thermal comfort, and built environment designing influences significantly on outdoor thermal environment[5]. Subsequently, the relationship between outdoor thermal comfort and urban design need to be understood. In order to improvement urban design guidelines by evaluating the modifying of outdoor climate in urban design process by using specific details. In addition, urban designer must have some methods for "predicting the impact of a particular change in a climatic element on the human comfort in outdoor''[6].

2. Outdoor thermal comfort

Thermal comfort in the ASHRAE Standard[7] defined as "that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation". Thermal comfort in this case indicates to a psychological and a subjective condition of the person mind.

2.1. Calculation of thermal comfort

Thera are six primary factors for defining parameters for thermal comfort[8]. Two factors are personal "metabolic rate, and clothing insulation", and the other four factors are environmental "air temperature, radiant temperate, air speed and humidity". Both of personal and environmental factors not dependent of each other, but they determine together human thermal comfort. "The most widely used indices in recent years for predicting thermal comfort are the PMV-PPD index"[9]. However, it is not suitable for outdoor thermal comfort prediction this is due to the variable thermal environment under outdoor conditions. In the following part, different outdoor thermal indices that have been used until now.

2.2. Outdoor thermal indices

There are several thermal indices, "perceived temperature (PT), predicted mean vote (PMV)[10], physiologically equivalent temperature (PET)[11], outdoor standard effective temperature (OUT_SET*)[12], and universal thermal climate index (UTCI)[13], have been developed to quantify human thermal comfort. All of last indices derived from the human energy balance. It was found that PET is the most index used for assessment of outdoor thermal[14]. Since PET takes into consideration both of environmental parameters AT, MRT, RH, and WS, and personal factors. It assumes a constant 80 W of activity level and 0.9 clo of clothing level for different person[15]. OUT_SET* index "is an outdoor version of standard effective temperature (SET*)". Predictive capabilities of OUT_SET* are still needed to be tested, so OUT_SET* is less widely used compared with PET. UTCI is a tool for outdoor thermal comfort at planning level. In addition to, it is suitable in sub-tropical regions[16], but the predictive ability of UTCI needed to calibrate in hot climates. Therefore, to evaluate campus outdoor thermal comfort, PET will apply in this study as a thermal index.

3. Effect of Aspect ratio on outdoor thermal comfort

This part will review the implications of aspect ratio strategy on outdoor thermal comfort. Serval researches have presented the impact of urban design on microclimatic parameters such as AT, RH, WS, solar radiation or mean radiant temperature in urban spaces, but very few studies focused on relationship between urban design and outdoor thermal comfort or human thermal sensation especially in outdoor campus environment. Recent researches have pointed out that shading strategy is an important method to improve daytime outdoor thermal comfort. Also agreed that physiological equivalent temperature (PET) is the base of outdoor thermal comfort investigation in terms of urban design implications. Emmanuel et al. (2007) based on PET index when used the software ENVI-met simulation tool to analysis the effect of different cases of urban design. Study result summarized that increase of aspect ratio of urban space from about one to three leads to a decrease in PET by about 10°C[17], and this a positive effect on outdoor thermal comfort. In addition, the result of Johansson and Emmanuel (2006) study in Colombo, Sri Lanka indicates that scattered urban form with low aspect ratios cannot provide comfortable thermal conditions, at variance of compact urban form with high aspect ratio[18]. In Freiburg, Germany, Ali-Toudert and Mayer (2007) conclude that the most significate strategy to mitigate summer heat stress was shading the pedestrian under hot conditions[19]. Another study in Freiburg, Germany, Herrmann and Matzarakis (2012) run a simulation to analysis the influence of the aspect ratio and in a typical urban. Results of the study shows that mean radiant temperature variation can over the range of 30°C and more, according to different aspect ratio options[20]. The literature review of above studies concluded that height-to-width ratio (aspect ratio) is the most important design parameters affecting PET in urban spaces. So the practical study would base on this strategy.

4. Case study

The case study conducted in Cairo in BUE campus allocated in El-Shourok city Figure 1. Located some 30 km from downtown Cairo, Choosing the British university as a case study, is based on its location in El-Shourok city since considers a new city with a hot arid climate, and this type of climate needs investigation of thermal comfort in urban space.

- The methodology which has been employed for effect of aspect ratio strategy on outdoor thermal comfort in BUE campus in Cairo, Egypt is presented as follows.

4.1. Study area

Study area is a main entrance space of the campus as shown in Figure 1. The entrance space is one of the most vital urban spaces in BUE campus. The space is made of interlock and asphalt. The buildings around the space are three have almost the same height (15 meter) and are 3 storeys. The base case of space orientation is SouthWest-NorthEast. There was vegetation in different areas of the space (trees and grass).

Figure 1. Study area (Entrance space) at BUE campus

Source: Author (2015)

4.2. Envi-met numerical modeling

The occupancy time of BUE university during 8 hours per day from 9 am to 4 pm, therefore The model was simulated for 8h starting at 9 am and ending at 4 pm. In addition to, the simulation was run on the hottest day during study period was 27 April 2015.

4.2.1 Base case of study area

Base case model constructed in ENVI-met software, Actual conditions of the study area are shown in Figure 2 and figure 3.

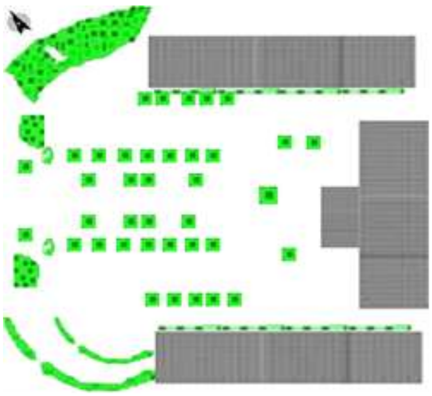


Figure 2. Model domain for the study area by author

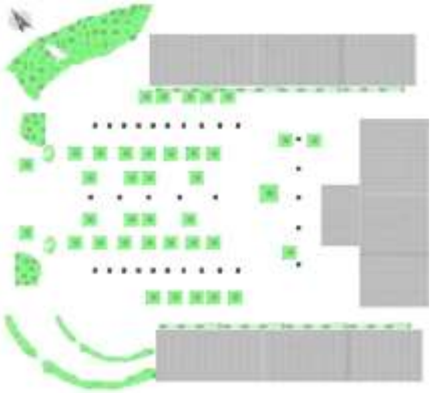


Figure 3. Receptors (extracted points) for the study by author

4.2.2 Different Aspect ratio scenarios

The following aspect ratio scenarios are analyzed for entrance space, different aspect ratio scenarios showen in Table 1. For comparison of different Aspect ratio scenarios, 30 points were extracted for analysis at entrance space as shown in Figure 4.

Table 1. Different aspect ratio scenarios for entrance space

Design scenario		Space orientation	Aspect ratio (H/W)	Vegetation
Base case		NorthE-SouthW	2.7	trees and grass in different zones
Aspect ratio (Height to Width)	case 1	North East-South West	1	trees and grass in different zones
	case 2		2	
	case 3		3	
	case 4		4	
	case 5		5	

4.3. Simulation results analysis

Envi-met simulation results analysis for base case and different scenarios of space aspect ratio are dividing into two results, the first one is microclimatic analysis and another is thermal comfort analysis.

4.3.1 Analysis of microclimatic results of space aspect ratio scenarios

Microclimatic results include four parameters analysis presented as follow:

- “Air temperature”
- “Mean radiant temperature”
- “Relative humidity”
- “Wind speed”

- **Air temperature analysis**

Result of air temperature analysis for different aspect ratio in Figure 4 shown that shallow space had higher air temperatures than deep space. Between the different scenarios, the maximum air temperature difference could be up to 0.90oC. Also can be seen that when aspect ratio reached to value 4. It was identical air temperatures in both cases of H/W of 4 and 5.

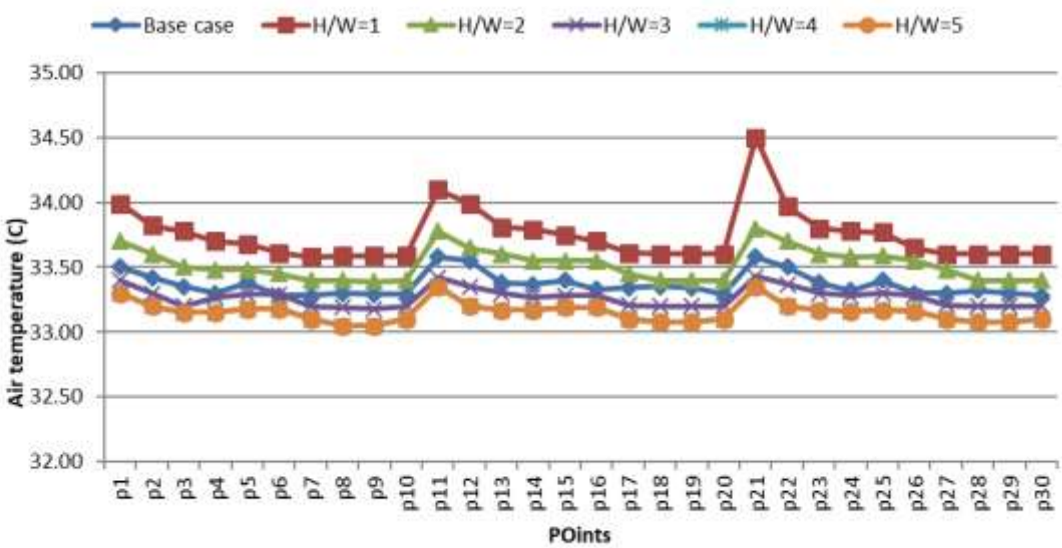


Figure 4. Air temperature for different aspect ratio

Source: Author

- **Mean radiant temperature analysis**

Also according to simulation results as shown in Figure 5, it is obvious that mean radiant temperature affected by the same conditions of aspect ratio which affected on air temperature, in addition to, no mean radiant temperature differences can be estimated when aspect ratio reached to value 3.

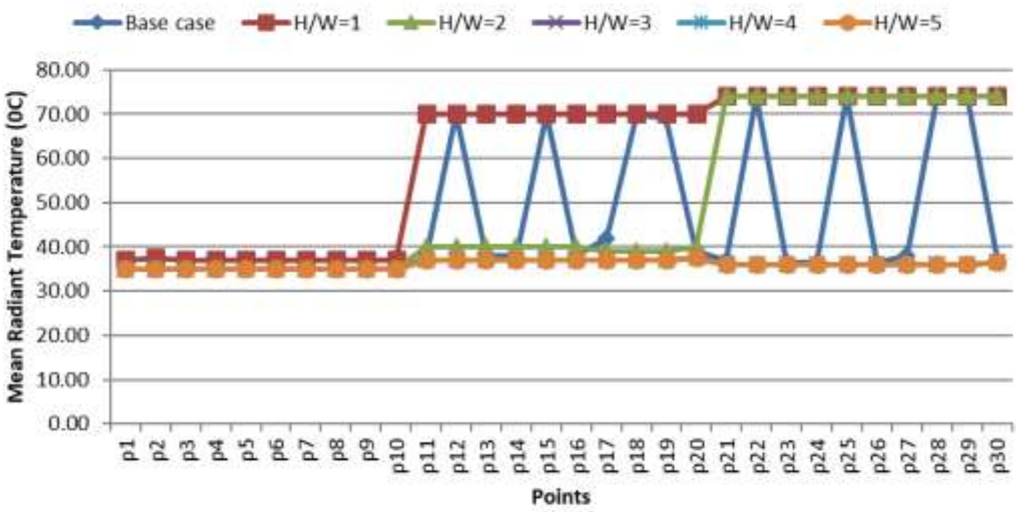


Figure 5. Mean radiant temperature for different aspect ratio

Source: Author

- **Wind speed analysis**

In the other side, The wind speed patterns for the 6 cases in Figure 6, were shown not much difference was found between the different aspect ratios. The result of wind speed affected by limitations of envi-met, where "ENVI-met cannot provide satisfactory results of wind speed due to its static bundary condition of the model".

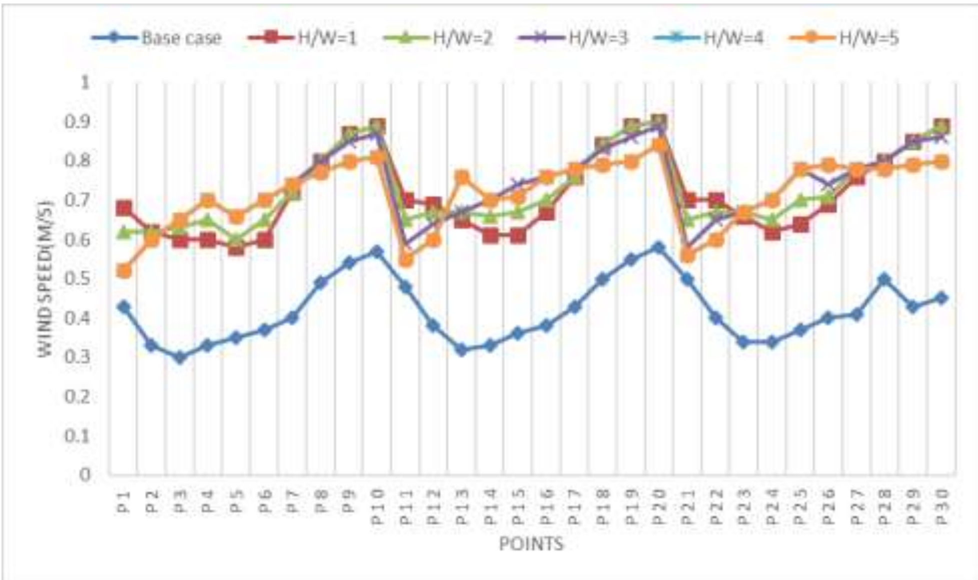


Figure 6. Wind speed for different aspect ratio

Source: Author

- **Relative humidity analysis**

The relatively humidity increased with the increase of aspect ratio as shown in Figure 7, the maximum humidity difference was less than 3%, wherefore the differences can be negligible between different aspect ratio cases.

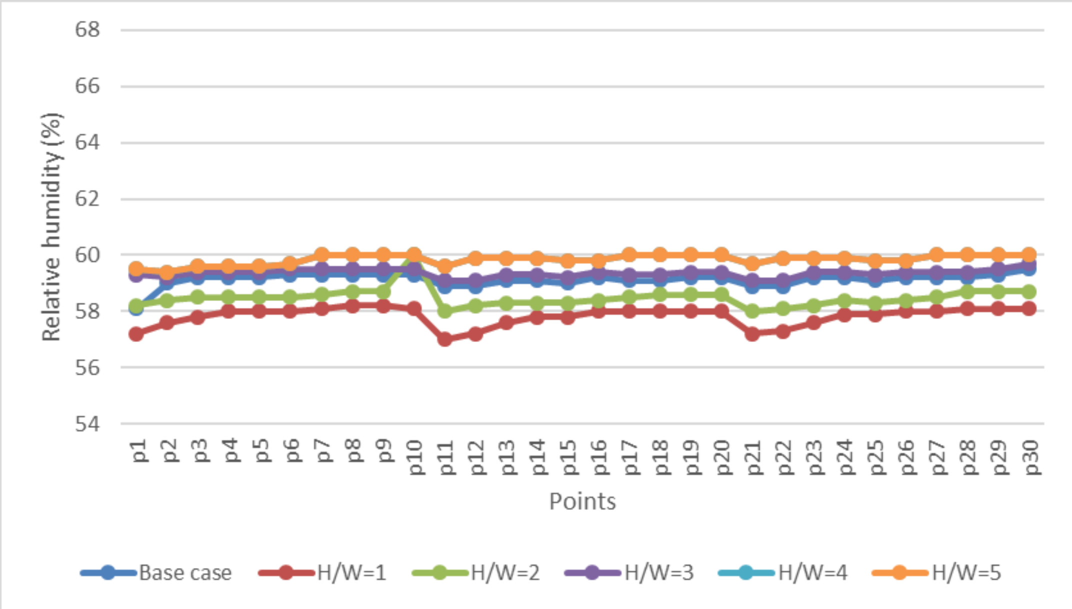


Figure 7. Relative humidity for different aspect ratio

Source: Author

4.3.2 Analysis of thermal comfort results of space aspect ratio scenarios

Thermal comfort result includes analysis of thermal sensation vote which predicted by scenarios simulation:

- Thermal sensation vote result
- Mean Thermal sensation vote result

The TSV (thermal sensation vote) index "predicts the mean response of a large group of people. Its values were based on the ASHRAE 7-point thermal sensation scale from -3 to +3, where +3 , +2, +1, 0, -1, -2, and -3 are hot, warm, slightly warm, neutral, slightly cool, cool, and cold respectively".

- **Thermal sensation vote analysis**

Analysis of the thermal sensation vote simulation (TSV) in Figure 8 shows that TSV(thermal sensation vote) decreased when aspect ratio increased, this result refers that space with deep depth better than shallow space with little depth in terms of thermal comfort conditions. However, the thermal comfort enhancemet can be negligible when H/W reached to value 3.

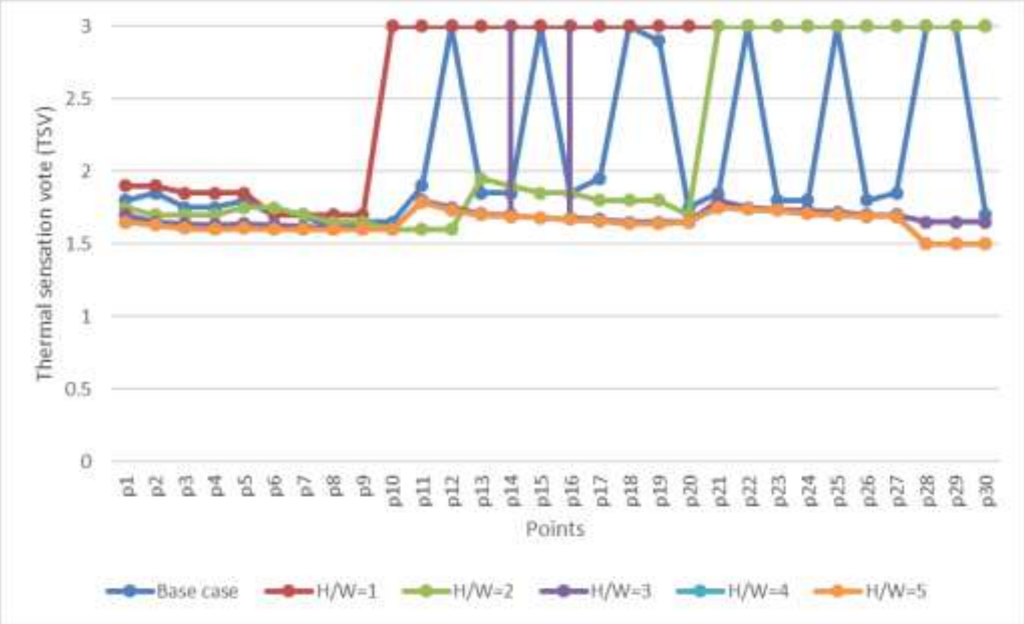
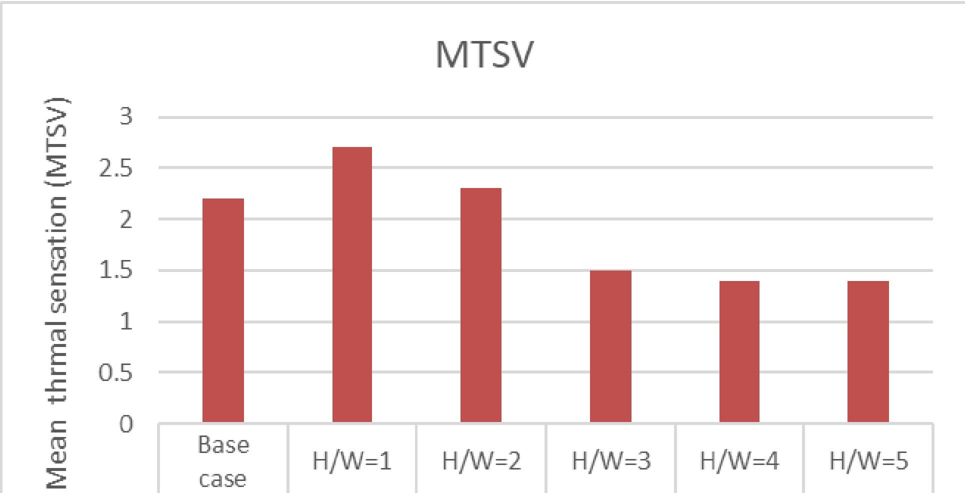


Figure 8. Thermal sensation vote (TSV) for different aspect ratio

Source: Author

- **Mean thermal sensation vote analysis**

MTSV was 2.7 for H/W=1, 2.3 for H/W=2, 1.5 for H/W=3, 1.4 for both cases of H/W= 4 and 5 as shown in Figure 9. Aspect ratio (H/W = 3) could be considered the starting point of the thermal comfort respect, this is due to, urban space recevies little sun radiation in case of aspect ratios of 3 or less.



	Base case	H/W=1	H/W=2	H/W=3	H/W=4	H/W=5
MTSV	2.2	2.7	2.3	1.5	1.4	1.4

Figure 8. Thermal sensation vote (TSV) for different aspect ratio

Source: Author

5. Results and conclusion

The increase of aspect ratio seems to be effective strategy in improving campus outdoor thermal comfort. This is due to that the findings illsurate that conditions of thermal comfort at 3pm were negative according to simulation result of base case of study area (MTSV=2.2) but improvements were possible by means of appropriate aspect ratio, since MTSV can reach to 1.4. Because of shading effect of surrounding buildings within urban space, which can reduce both of two climatic parameters at the same time (AT) air temperature and (MRT) mean radiant temperature. Wide urban space with aspect ratio =1 recorded the highest value 2.7 of MTSV which was highly uncomfortable thermal conditions. So it is recommended that shadow length of buildings should be longer than urban spaces in campus for achieving significant urban shading. In addition to the campus building in cairo egypt should be closer because of high angle of the sun. According to this study result, aspect ratio of 3 value must be considered starting point in hot condition with respect of campus outdoor thermal comfort. Furthermore, results points out that design strategies as aspect ratio with low wind speed and high relative humidity condition not necessarily lead to discomfort in outdoor thermal environment. In case of positive impacts of reduction of air temperature and mean radiant temperature overcome the negative impacts of low wind speed and high relative humidity, in these thermal conditions the outdoor thermal comfort can still be improved greatly. It would be better if additional shading alternatives as appropriate space orientation, tree planting is also an effective alternative to promote outdoor thermal comfort, and shading devices, particularly horizontal devices, are provided for shading. Therefore, Studies which, present more shading strategies for outdoor thermal comfort will be an interesting scope for future researches.

6. References

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