Influence of Solar Shading on Indoor Climate of Buildings

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ABSTRACT
The paper describes and analyses the influence of shading on the indoor climate of Maputo City buildings and its impact on thermal comfort to the occupants. The case study focuses on Maputo City – 3 de Fevereiro Guest House of Eduardo Mondlane University and is one example of how the temperatures within any buildings of Maputo City E-W orientation are influenced by the lack of adequately fixed shading devices. Mozambique is mainly a tropical country that is characterized by a strong solar radiation throughout the year. The elimination or reduction of the incident direct solar radiation on the external walls of the buildings could be a key method of reducing electrical energy consumption and increasing occupant thermal comfort. The main objective of the research was to evaluate the thermal comfort that was lost due to the lack or inadequate shading on buildings and to encourage designers and builders to use passive means to attain better conditions in the buildings. The simulation results showed that by using properly dimensioned external fixed shading devices on E-W orientated buildings in Maputo City, the indoor temperatures and the thermal comfort could improve significantly. The improvement in comfort hours during the hottest day and typical summer days is 33 % and 100 % respectively.

Keywords: Building envelop, Building orientation, Passive cooling, Simulation.

1.0 INTRODUCTION

The strong solar radiation observed in Maputo City-Mozambique from October to March make the indoor temperatures of non shaded buildings become very high and, consequently, such buildings are often not comfortable for occupants for most of the year. Thus, to minimize the negative impact, the occupant uses devices such as fans and air conditioners to get comfort. The rate of energy waste due to inefficient use is indeed significant, hence the amount of money spent for this purpose is enormous both for private and public consumers. Conflicts in terms of non-payment of electricity duty are common. Despite that fact, little work has been done to improve the energy performance in buildings. Solar shading can contribute positively to energy use in buildings by improving the shading coefficients of the envelope. The exterior shading of building is widely used and it is a very effective method to create lower direct solar radiation to the internal. The strategy leads to lower indoor temperature condition and reduced energy use for active cooling (Kolokotsa, 2007). There is a wide range of solar shading components. Most used devices for shading the buildings are; landscape feature; fixed shading devices; horizontal reflecting surfaces; solar control glass and interior glare control devices such as Venetian blinds or adjustable louvers and curtains. External shading is more efficient than internal shading devices which dissipate the heat to the air gap between the shading device and the glazing (Datta, 2001).

2.0 SIMULATIONS WITH DEROB-LTH PROGRAM

To understand the influencing parameters on the thermal comfort, a residential building was simulated. The program used for this purpose was DEROB-LTH. The program performs transient calculations of the heat balance for the building. The resolution in calculated values is one hour.

2.1 Simulated Apartments

The two apartments studied are part of the building with two storey located at eastern part of Maputo City, in Sommerschield neighbourhood, P. A. J. de Almeida Street. The building contains totally six apartments with three flats on each floor. The long axis of this building is approximately in E-W orientation, and the main facade of the building is in south orientation. The building has openings facing South and North. The studied apartments are located in the East. Its eastern facade is shaded by the stair compartment, and the west facade is adjacent to the next apartments. The apartment on ground and first floor are composed of living room, bedroom, kitchen, bathroom, corridor, laundry and storeroom. The apartment at the first floor has a balcony (see Figures 1 to 5). The structure of this building is composed of foundations, columns and beams. The foundation is constructed of concrete and blocks. The walls start from a shallow basement using 400x200x200mm hollow concrete blocks. The roof has 16^{o} pitch. Internal surfaces of the building are plastered and painted white and the external surfaces are plastered and painted with orange and brown colour. The openings to doors and single glazed windows are framed by wood structure. One panel of each window is made up of a mosquito net and a 4 mm thickness single glass. For simulation, the following U-values and g-values were considered for each building element shown in Table 1.

Table 1: U-values and g-values of the Building Elements

Building Elements	U-value (W/m^{2o}C)	Building Elements	U-value (W/m^{2o}C)
External walls	1.603	Ceiling of the Ground floor	2.895
Internal walls	1.909	Ceiling of the first floor	3.575
Floor	1.008	Roof	4.641
External doors	3.390	Glazing G-value	0.867

2.2 Plan Design, Section and the Volumes Identification

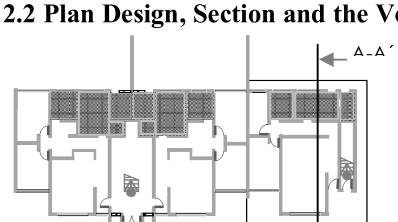

Figure 1: Ground floor

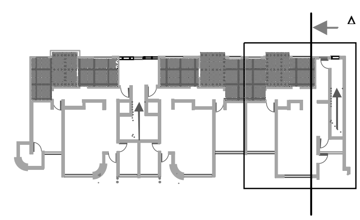

Figure 2: First floor

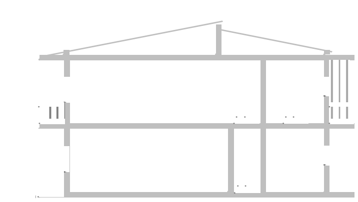

Figure 3: Section A-A'

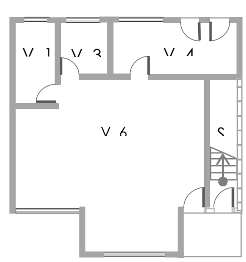

Figure 4: Ground Floor Volumes

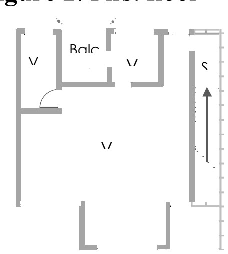

Figure 5: First Floor Volumes

2.3 Studied Parameters

When analyzing the indoor climate the following parameters where varied; shaded and non-shaded building with opened or closed windows. The dimensions used in fixed devices for shading were 1.75 meters.

Two representative days and six summer months were chosen to evaluate the thermal comfort. The 16th of December was chosen as the hottest day and 11th of October as a typical summer day. The duration of summer months are from October to March. The considered thermal comfort limits were from 22°C to 28°C.

3.0 RESULTS AND FINDINGS

3.1 Indoor temperatures in the volumes of the non-shaded and shaded Buildings

The following charts present the simulation results of the non-shaded and shaded buildings. In the charts, the curved lines represent the indoor temperature of the seven volumes and the outdoor temperature. The shaded area represents the comfort zone limits of the Maputo City.

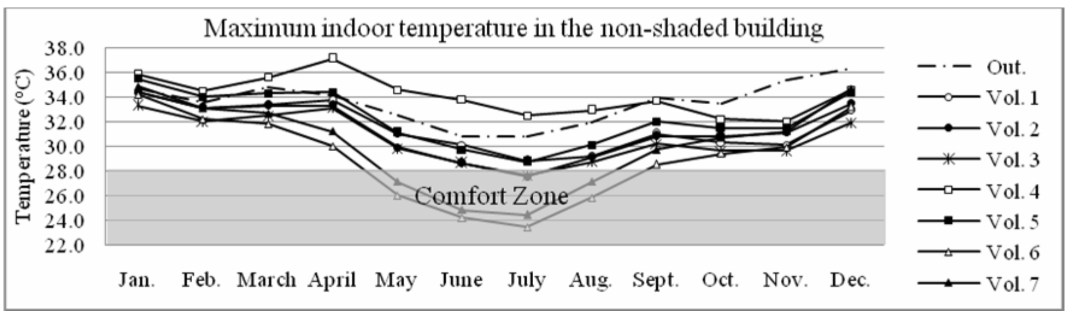

Figure 6: Maximum monthly indoor temperatures in the volumes of the non-shaded buildings.

Figure 6 shows that the volume 6 and 7 were comfortable from April to August whereas the remaining volumes and outdoor temperature were above the comfort zone. Volume 4 presented the highest and volume 6 the lowest indoor temperatures among the volumes.

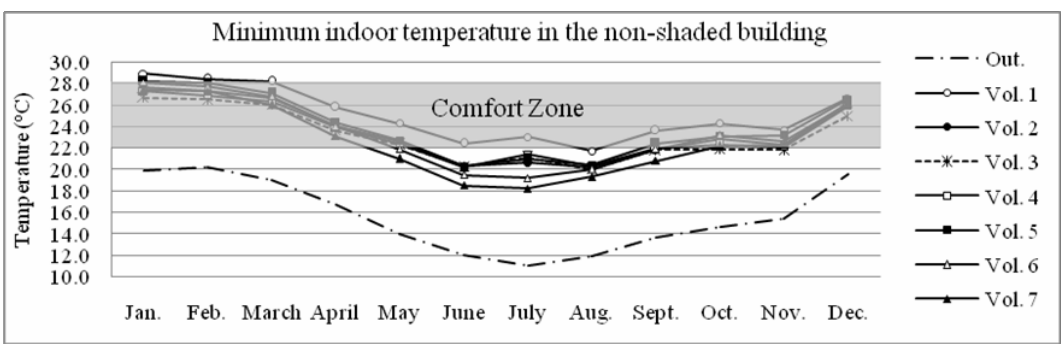

Figure 7: Minimum monthly indoor temperatures in the volumes of the non-shaded buildings

The lowest minimum indoor temperature was seen in volume 7 and, it was almost 6°C above the outdoor temperature. Volume 1 presented higher minimum temperature and it was comfortable since March until December. The minimum outdoor temperatures were under the comfort zone throughout the year. The other volumes were comfortable since September until April.

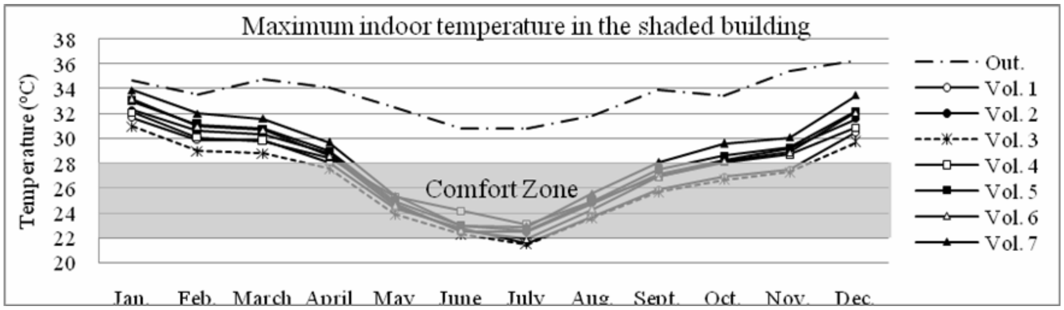

Figure 8: Monthly maximum indoor temperatures in the volumes of the shaded buildings.

Figure 8 shows that the lowest maximum temperature was observed in the volume 3 and the highest was seen in the volume 7. All volumes presented their maximum temperatures below 34°C. Volume 1 and 3 had comfort from April to November. Volume 2, 4, 5 and 6 were comfortable from April to October and the volume 7 was comfortable from April to September. The maximum outdoor temperatures were above the comfort zone during whole year.

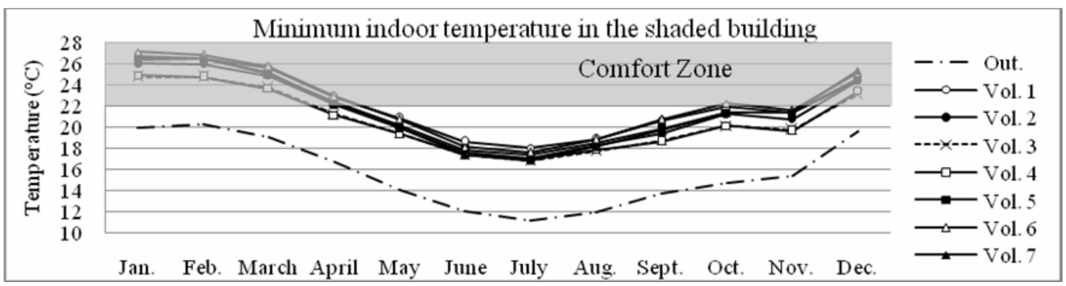

Figure 9: Minimum monthly indoor temperatures in the volumes of the shaded buildings

The difference of the annual minimum indoor temperature among volumes was little. The lowest minimum indoor temperature was seen in volume 3 and 4 and the maximum was observed in volume 6 and 7. The minimum annual outdoor temperatures were below the comfort zone and, it was almost 6°C lower than the minimum temperature of volume 3, 4 and 5. From November to April, all volumes were comfortable and, from April to October, they were uncomfortable.

3.2 Absorbed Radiation and Indoor Temperature in the Volume 4

To evaluate the performance in the shaded buildings, volume 4 was chosen because it was the most remarkable in terms of high temperature among the volumes of the non-shaded buildings.

During the hottest day and the typical summer days, the absorbed radiation that was absorbed by the exterior walls to the non-shaded volume was as expected higher than for the shaded volume. The absorbed radiation was reduced of about 3 times when using shading. Opening and closing windows did not influence in the absorbed radiation due to the g-value of the used glass (see the Figure 10).

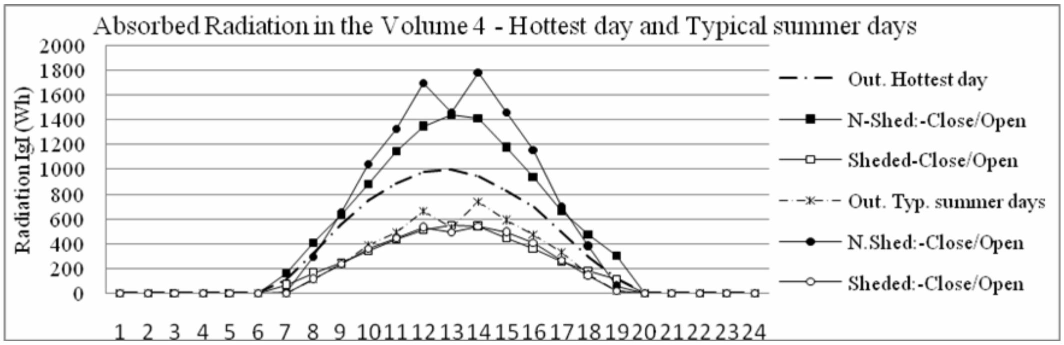

Figure 10: Outdoor global radiation and the absorbed radiation in the volume 4 in all environments

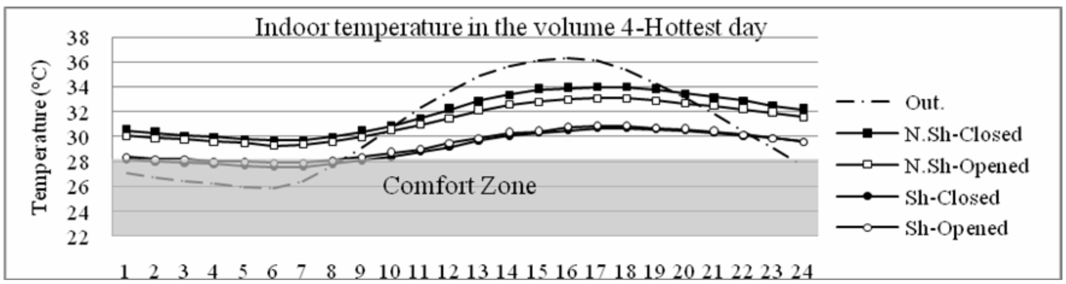

Figure 11: Hours of comfort observed in volume 4 during the hottest day in all environments.

The indoor environments of the shaded buildings as well as the outdoor temperature had about 8 and 9 comfort hours seen from 1 a.m. to 9 a.m. and from 0:00 to 9 a.m. respectively. The environments of the non-shaded buildings were uncomfortable and they had almost 3°C more than indoor temperatures of the shaded buildings. The peak indoor temperature of the shaded buildings was about 5°C under the peak outdoor temperature.

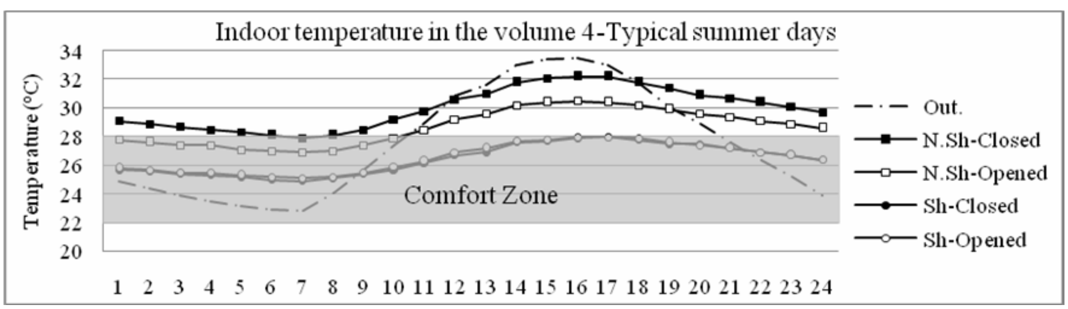

Figure 12: Hours of comfort felt in volume 4 during the typical summer days in all environments

During the typical summer days, the shaded building was comfortable throughout the day. The non-shaded building with closed windows was not comfortable and the environment with opened windows had 10½ hours of comfort observed from 0:00 to 10½ a.m. From 20.30 p.m. to 10.30 a.m., the outdoor was comfortable for about 14 hours.

3.3 Thermal Comfort Hours

To analyse the comfort hours in the all environments of the simulated volumes, months from October to March were considered as the summer months in order to conduct the study. All volumes of the shaded buildings had more hours of comfort than the volumes of the non-shaded buildings. The number of the outdoor comfort hours was higher than the number of the comfort hours in all volumes of the non-shaded building. In the shaded buildings, the thermal comfort hours of the volume 1, 2, 3, 4 and 6 were high. These volumes also had more hours of comfort than outdoor. Volume 5 and 7 had less hours of comfort than outdoor (see the Table 2).

Table 2: Comfort hours by the volumes of the non-shaded and shaded buildings

Environments/Volumes	Out.	Vol.1	Vol. 2	Vol. 3	Vol. 4	Vol. 5	Vol. 6	Vol. 7
Non-Shaded-Closed	2531	1007	1190	1907	1022	847	1380	1239
Non-Shaded-opened		1903	1827	2189	1852	1702	2025	1828
Shaded-Closed		2712	2521	3511	3066	2195	2074	1868
Shaded-opened		2789	2733	2958	2866	2324	2695	2230

4.0 ANALYSIS OF THE RESULT

4.1 Indoor temperature in the buildings

In all environments the results showed that the maximum indoor temperature of the volumes located at south part of the building with large area of its facades facing towards south had thermal comfort in the winter. The maximum indoor temperature of the volumes of the non-shaded buildings located at north part of the building having one or two facades facing north/east did not have the comfort but after it being shaded, they also observed comfort in the winter. Apart from the volumes located in the south, the maximum indoor temperatures of the volumes at first floor of the non-shaded building as well as the volume 4 were high than the indoor temperatures of the volumes at ground floor. The high indoor temperatures of the volumes at first floor were due to the high U-Value of the building materials used to the ceiling. The attic was not properly ventilated.

Volume 4 presented the highest indoor temperature among the volumes because this volume had two facades facing to the outdoor, one facing to north and another facing to east. The facade facing to the north was subject to solar radiation during the whole day and the east facade was exposed to solar radiation in the morning. This volume had great improvement in terms of comfort after the building was shaded. In general, the indoor temperatures of the volumes of the non-shaded buildings presented a great improvement after the building becomes shaded. The volume 6 presented the lowest indoor temperature among the volumes because this volume did not have any facade that was receiving direct solar radiation and above the ceiling is volume 7 that is shaded and enough ventilated.

4.2 Indoor temperature in the volume 4

In the hottest day, the environments of the non-shaded building were uncomfortable. This happened because this volume had two facades that were receiving solar radiation throughout the day. The area of the walls that were receiving the direct and diffuse radiation represents about 50% of the total area of the walls of the volume. The remaining 50% of the area of the walls was adjacent to the volume 3, 6 and of the stairs compartment. After the building being shaded, the indoor temperature of the volume had about 8 hours of comfort. This is an improvement of about 33% of comfort hours in that day. In the typical summer days, the non-shaded building with opened windows has 10½ hours of comfort. After the building being shaded the volume was 100% comfortable.

4.3 Thermal comfort hours in summer season

Comparing the non-shaded building and the shaded building both with closed windows showed that the minimum improvement was about 51% that was observed in the volume 7 and the maximum improvement was about 200% that was seen in the volume 4 and, the minimum improvement observed in the environments with opened windows was about 22% and the maximum was about 55% as that was seen in the volume 7 and 4 respectively.

Comparing the improvements achieved among the volumes and the outdoor comfort hours, the results showed that in the non-shaded building as well as volume 5 and 7 of the shaded building, the outdoor temperature had more hours of comfort. When the building was shaded the maximum improvement was about 39% that was observed in the volume 3. Volume 4 that was the worst in terms of indoor temperature before it being shaded was in second position in terms of comfort hours with 21% of the improvement than the outdoor comfort hours.

5.0 CONCLUSION

In the non-shaded buildings, the volumes situated at north part of the building having more than one facades facing to the north, east or west received and absorbed much solar radiation, and thus they presented high indoor temperature. The volumes located at south part of the building having their long facades E-W orientated only absorbed diffuse radiation hence their indoor temperature was more comfortable than other volumes. The annual indoor temperature of the volumes showed that the volumes under the ceiling of the first floor, had their indoor temperature high than other volumes because, the attic was not properly ventilated and the ceiling was not thermal insulated.

The simulated building also demonstrated that to shade the Maputo city buildings E-W orientation taking into consideration the same building materials that were used in the simulated building, the indoor temperature in the buildings could be felt for about 33% of the daily hours in the hottest day and in about 100% of the daily hours in typical summer days. The improvement that the building could achieve after being shaded represents about 33% in the hottest day, 129% in typical summer days and 200% during the summer season in relation of the previous results of the same building before being shaded. The performance of the building in term of comfort after being shaded compared to the available outdoor comfort hours, the building could increase in 0% in hottest day, 71% in typical summer days and 21% during the summer period.

6.0 ACKNOWLEDGEMENTS

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