Influence of Building Orientation on the Indoor Climate of Buildings

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ABSTRACT
The paper describes and analyses the influence of the orientation of buildings on the indoor climate of Maputo City buildings and their impact on thermal comfort to the occupants. Case Study focuses on Maputo City - Urban district nr.1 as one example of how the indoor climates of many buildings of Mozambique cities were influenced by its orientation.

In Maputo city, about 70% of buildings were orientated in the way that all external facades of buildings allow to be irradiated by sun rays throughout the year. Thus, the indoor temperatures in these environments are high and consequently, the thermal comfort is affected. The main objective of the study was to evaluate and to gauge how much the thermal comfort was lost due to inadequate orientations of buildings and to encourage designers and builders to use passive means as the one of the key method for getting thermal comfort in the buildings. Through simulations were carried out the studies which results demonstrated that the temperatures within the volumes of the building NE-SW orientated were about 5 to 7^oC high than the outdoor temperature and about 2^oC more than the buildings E-W orientated throughout the year. For having whole approach about the orientations of the Maputo City buildings were simulated 24 different orientations of buildings. The results concluded that the indoor temperatures of the buildings NE-SW orientated have had their thermal comfort negatively influenced in about 11%-42% compared to the buildings E-W orientated and in about 6,4%-17% of the thermal comfort from outdoor.

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

1.0 INTRODUCTION

Most of the research which has been carried out within the field of architectural sustainability focuses on energy efficiency because it can be a key for sustainable buildings now and in the near future. Thus buildings orientations is one of the key methods that the designers could pay attention on. Maputo City is a sub-tropical city that is located about two degrees below Capricorn tropic. This localization could be an opportunity to be taken in account for designers in order to minimize the use of the building materials to obtain the adequate indoor temperatures in the buildings. The city is densely built and the predominant road network infrastructure is orthogonal and orientated on NE-SW and NW-SE axis. Many buildings of the city have their facades parallels to these road network infrastructures. According to (Holger, 1999), in hot and humid regions, the long axes of buildings should be E-W oriented in order to minimize the area of exposition of solar irradiation. Considering this statement, many buildings of Maputo City are not optimally oriented therefore, the indoor climate of many buildings are negatively affected. Due to this fact, the energy used for cooling and ventilating these buildings is high.

2.0 GENERAL DESCRIPTION ABOUT MAPUTO CITY

Maputo City has about 350,00km2 with nearly 1.272.000 of inhabitants. Climatically, the city is hot a humid with two seasons as the summer and winter. The summer is observed from October to March and the winter is from April to September. The summer is hot and humid. During this season, the temperature is constantly high (average about 29°C maximum and 21°C minimum) with less diurnal amplitude. The humidity is high (average about 80%). The winter is dry and cool. During this season the temperature is moderately low (average about 26°C maximum and 16°C Minimum) and the humidity is less (average about 60%). During the year, the wind is mainly observed from N, E and SE. The mean monthly wind speed observed by the Maputo meteorological station varies from 2m/s in the winter and 4m/s in the summer. (INAM, 2005).

2.1 Orientation of the Buildings in Maputo City

About 70% of Maputo City buildings have their long facades NE-SW or NW-SE orientated. These orientations followed the orientation of the road network infrastructures of Maputo City. This mesh of road network infrastructure followed the two first built streets in Maputo City (Former Lourenço Marques) which were perpendicular to each other and NE-SW and NW-SE orientated making the city to be identified by a mesh of orthogonal road.

2.2 Thermal Comfort for Maputo City

For this study were considered the thermal comfort values that were a result of calculation according to the Szokolay method. This method presents the thermal comfort zone based in thermal neutral temperature in function of medium external temperature and its comforts limits are based on Standard Effective Temperature (SET). After determination of the thermal neutral temperature, the obtained values should be decreased 2°C for the minimum thermal neutral temperature and increased 2°C for the maximum thermal neutral temperature. This method can be used for all sites only require the climate data of these places for applying the following formula:

$$\vartheta_n = 17{,}6 \times 0{,}31 \times \vartheta_m; \quad 18{,}5°C < \vartheta_n < 28{,}5°C \tag{1}$$

where;

$$\vartheta_n = thermal\ neutral\ temperature\ [°C]$$
$$\vartheta_m = medium\ external\ temperature\ [°C]$$

According to the Maputo City climate data, the average of the minimum and maximum temperature was 18.7 °C and 27.4 °C respectively. Thus applying the above formula, the comfort limits for Maputo City were found to be 22 °C to 28 °C. The obtained results are similar as the limits recommended by (OLGYAY, 63), thermal comfort values to the tropics and by (GIVONI, 92) thermal comfort for developing countries.

3.0 SIMULATION WITH DEROB-LTH

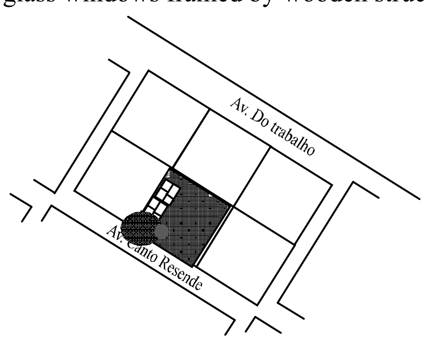
To understand the influencing parameters on thermal comfort, a residential building and 24 different orientations of Maputo City buildings were simulated with DEROB-LTH. DEROB-LTH is a dynamic and detailed energy simulation tool originally developed at Austin School of Architecture, University of Texas and further developed at Lund Institute of Technology. It has accurate models to calculate the influence of solar insulation and shading devices on the energy balance of a building. The building is modeled in 3-D, a necessary condition for accurate calculations of the distribution of solar insulation and temperatures in the room and its surfaces. The resolution in calculated values is one hour. DEROB-LTH can manage rooms with irregular geometries, buildings with several zones and calculate peak loads, energy demand, temperatures and thermal comfort for a building. (Källblad, 1993). The DEROB-LTH program also calculates the Global Operative Temperature in the buildings. Global Operative Temperature is the uniform temperature of a radiantly black enclosure in which the occupant would exchange the same amount of heat by radiation plus convection as in the actual no uniform environment, thereby experiencing thermal comfort, or thermal neutrality. (Källblad, 98-12-13).

3.1 Simulated Building

The building is a terrace house containing three identical dwelling units of about 45 m2 each. Each dwelling has four rooms: one living room, two bedrooms and a kitchen. The building does not have veranda and any other kind of solar protection. This building is located in the southeastern part of Maputo City in the Malanga neighborhood, Canto Resende Street, number 12. The long axis of this building is NE-SW oriented with the main facade facing SE. This form of orientation follows the general road network infrastructure orientation of the district.

3.2 Technical Description

The structure of this building is basically composed of foundation, columns and beams. The foundation used in this building is concrete and blocks. The walls start foundation level using 400x200x100mm of concrete blocks hollow. The roof is 22,5 % pitched. The inside and outside of the walls are plastered and painted yellow. The openings, oriented SE are doors and single glass windows framed by wooden structures.



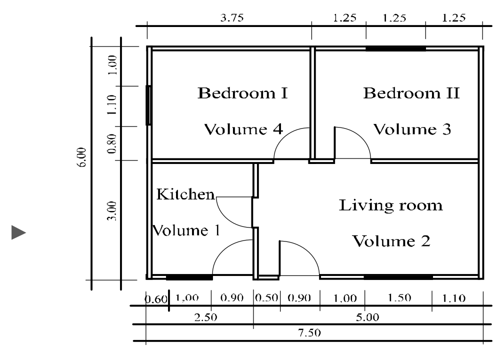


Figure nr.1: Site Plan Figure nr.2: Plan arrangement and volumes identification

3.3 Studied Parameters

Two main parameters as the orientation of the buildings and the indoor environments were considered. The two indoor environments considered were; building with closed and opened windows. In the study were also simulated 24 different orientations of buildings for Maputo City.

3.4 Days and Months Used for Analysis

Annual indoor temperature, two representative days and six summer months were chosen to evaluate the indoor temperature in the buildings. December, 16 was chosen as the hottest day and, October, 11 as the typical summer days. From October to March were considered as the summer months. The thermal comfort limits used for study were from 22^{o}C to 28^{o}C as boundaries.

3.5 Climate Data Used for Simulations

The Input climate data used to the DEROB-LTH simulation program is based on the climate data from (Meteonorm Version 6.0, 2007), which produce a Global Metrological Database for Engineers and Planners. The climate data created by Meteonorm Version 6.0, reports the average of the Maputo City climate data from 1981 to 2000. The available climate data containing information about global horizontal radiation, temperature, relative humidity, wind direction and wind speed.

4.0 RESULTS
4.1 Solar Radiation
The table 1 shows the maximum and average annual of the global radiation absorbed by volumes.

Table nr: 1. Absorbed solar radiation by the volumes of the building.

Solar radiation absorbed by the volumes	IgI (Wh)				
	Outdoor	Vol.1	Vol.2	Vol.3	Vol.4
Maximum	1122	640,5	970,4	1344,7	581,1
Average	205,1	70,7	107,0	193,8	67,7

4.2 Indoor Temperatures Within the Volumes of the Buildings NE-SW Orientated
The table 2 shows the maximum, average and minimum annual outdoor and indoor temperature of the building's volumes NE-SW orientated taking in consideration the two environments.

Table nr: 2. Indoor temperature of the building's volumes.

		Building with closed windows				Building with opened windows			
	Outdoor	Vol.1	Vol.2	Vol.3	Vol.4	Vol.1	Vol.2	Vol.3	Vol.4
Maximum	36,3	38,7	39,8	39,3	39,3	38,6	38,6	38,9	39,0
Average	23,6	27,0	27,5	28,1	27,5	26,0	26,2	26,4	26,2
Minimum	11,1	16,0	16,5	17,6	17,1	16,5	16,5	17,6	17,6

4.3 Indoor Temperature in the Volumes 2 NE-SW and E-W Orientated
To evaluate the indoor temperatures in the buildings NE-SW and E-W orientated, the volume 2 was used to be simulated in the hottest day of the year and in the typical summer days. The front facades of the buildings were facing to SE and south respectively.

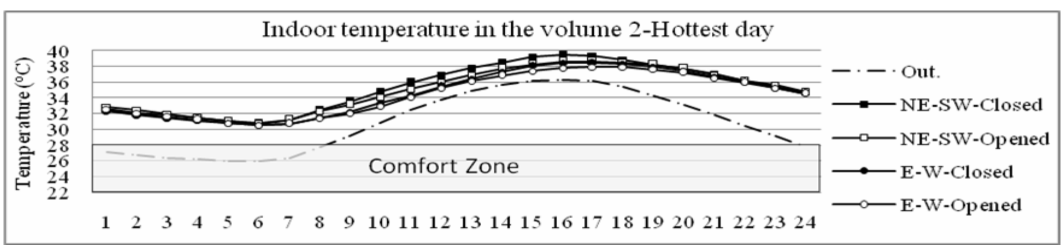


Chart nr. 1: Indoor temperatures of the building in the hottest day of the year.

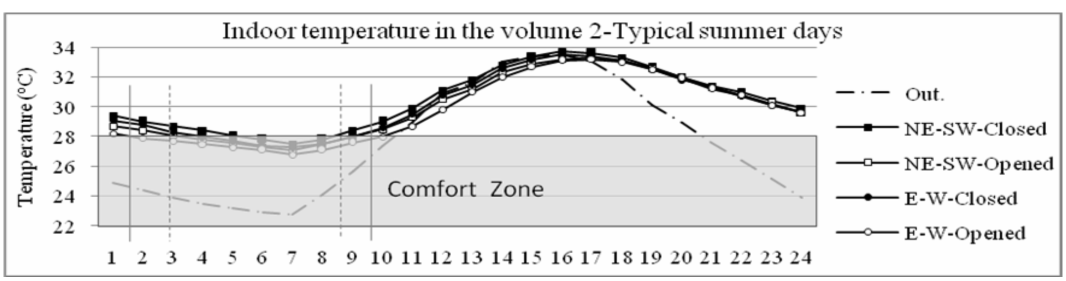


Chart nr. 2: Indoor temperatures of the building in the typical summer days.

4.4 Thermal Comfort Hours
To evaluate the comfort hours of the all volumes in the summer (from October to March) all environments of the buildings NE-SW and E-W orientated were simulated, see table 3.

Table 3: Comfort hours by the volumes of the buildings NE-SW and E-W orientated.

Environments		Building NE-SW orientated				Building E-W orientated			
	Out.	Vol.1	Vol.2	Vol.3	Vol.4	Vol.1	Vol.2	Vol.3	Vol.4
Cl. Windows		994	885	812	870	1063	1066	972	942
Op. Windows		1487	1471	1462	1476	1614	1633	1618	1554

4.5 Indoor Temperature in the Volume 2 Differently Orientated
For choosing the appropriate orientation in term of insolation for Maputo City buildings were simulated twenty four different orientations of the volume 2. This volume is a rectangle with 5.00x3.00 meters and it has two facades that are part of the envelop and the other two are internal walls which are adjacent to the volumes 1, 3 and 4. In the chart 5, the orientation 0^o is that the main facades of the building a facing north and the orientation 180^o are facing south.

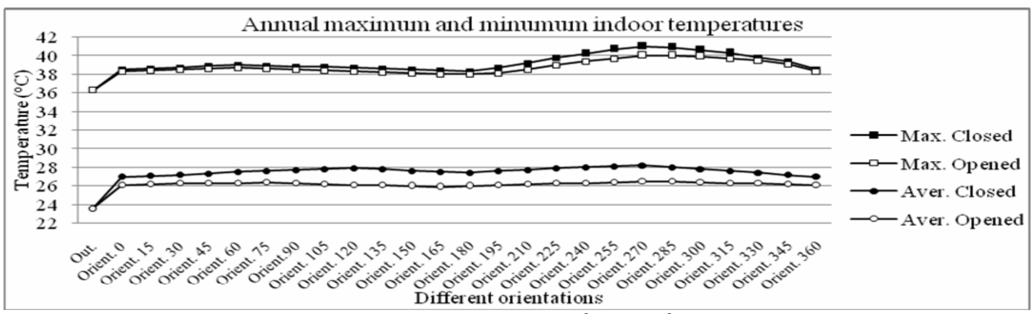


Chart 3: Different orientations of the volume 2 from 0^o to 360^o.

5.0 FINDINGS

5.1 Solar Radiation
In the maximum global radiation, the volume 3 absorbed more solar radiation than other volumes. The volume 4 absorbed less solar radiation.

5.2 Indoor Temperatures
The annual maximum indoor temperatures of the volumes were approximately the same although the volume 2 with closed windows was presenting the highest indoor temperature among them with about 40^{o}C. The maximum indoor temperatures were slightly fresh when the windows were opened and the minimum were slightly warm when the windows were closed. The maximum indoor temperatures of all volumes were about 4^{o}C high than the maximum outdoor temperature at peak times of day. In the hottest day, the environment of the two orientations did not have comfort although the building E-W orientated with opened window was almost 2^{o}C bellow than the building NE-SW orientated. In typical summer days, the indoor temperature of the building E-W orientated with opened windows presented 8½ hours of thermal comfort while the building NE-SW orientated presented about 6 hours. Mostly, the hours of comfort were observed at early hours of the morning and at morning. During afternoon and evening these studied buildings did not observe thermal comfort. The building orientated E-W provided an additional 2½ hours of comfort compared to the number of comfort hours of the typically NE-SW orientated model.

5.3 Thermal Comfort Hours

For each environment, the volumes presented almost the same numbers of comfort hours although the volume 4 presented the highest improvement. For both orientations, the thermal comfort hours of the environment with opened windows had more hours of comfort than those presented by the environments of closed windows. In the environments with opened windows of the two orientations, the volumes of the building NE-SW orientated have had around 1500 hours of comfort for each, the volumes of the building E-W orientated have had more than 1600 hours of comfort and the outdoor temperature presented 2531 hours of comfort. The outdoor temperature has had more than 900 and 1000 hours of comfort than the volumes of the building E-W and NE-SW orientated respectively.

5.4 Indoor Temperature in the Volume 2 Differently Orientated

The results of simulation of the volume 2 in different orientations had demonstrated that the buildings oriented from 15^o to 165^o and from 195^o to 345^o had their indoor temperatures higher than the buildings that were oriented from 0^o to 15^o and from 165^o to 195^o. The highest indoor temperature was seen in the orientation 90^o and 270^o i.e., N-S orientation and the lowest indoor temperature was observed in the orientation 0^o and 180^o i.e., E-W orientation. For all orientations, the environment with opened windows presented good results than the building with closed windows and, the outdoor temperature were better than the indoor temperatures of the volumes.

6.0 ANALYSIS

6.1 Solar Radiation

All volumes had two facades that were receiving the global radiation. The facades that were located at SE and NE were receiving the global radiation at morning and the facades located at NW and SW was irradiated at afternoon. The two facades of the volume 2 and 4 were irradiated in one period of the day and the volume 1 and 3 were irradiated by the whole day, one facade at morning and another at afternoon. Although the volume 1 has been irradiated twice, this volume has had interruption on its radiation that was almost seen in the transition of the morning to afternoon while the volume 3 was consecutively hence presented the highest absorption.

6.2 Indoor Temperatures

In general the indoor temperatures of the volumes were high although the indoor temperatures of the volumes with opened windows have observed a slightly reduction. This improvement was because of the influence of outdoor air temperature that was 4^{o}C less than the indoor temperatures of the volumes that by stack ventilation, the volumes were removing their heat and receiving the fresh air from outside. Due to low amplitude of the outdoor temperature associated at the high U-Value of the building envelop, the process of heat exchange between the outdoor and indoor temperature until to achieve the thermal balance took many hours. Thus the thermal comfort on the volumes were seen at early morning after the envelop has been lost their thermal heat. In the typical summer days, the outdoor temperature had about 14½ hours of thermal comfort, the volume E-W orientated had about 8½ hours of comfort and the volume NE-SW orientated had 6 hours of comfort. The difference between the volumes represents about 41,7% of the improvement of the volume E-W orientated compared to the previous orientation and about 17,2% of the improvement in relation of the outdoor temperature comfort hours.

6.3 Thermal Comfort Hours

The thermal comfort hours of the building E-W orientated had improvement in relation of the comfort hours of the building NE-SW orientated. The maximum improvement was observed in the volume 2 with about 162 hours of comfort more than the previous thermal comfort hours presented by the same volume when it was NE-SW orientated. This improvement represents about 11,1% of the gain on the building E-W orientated in relation of the hours of comfort of the building NE-SW orientated and about 6,4% in relation of the hours of comfort of the outdoor.

6.4 Indoor Temperature in the Volume 2 Differently Orientated

In the different orientation of the buildings, the building that was E-W orientated has presented about 2°C less than the building N-E orientated and about 1½ °C less than the building NE-SW orientated. This difference was observed because the rectangular buildings that had their long facades orientated beyond -2° to 2° of the E-W line are subjected to have all facades irradiated by sun rays and, the buildings that have their long facades orientated between -2° to 2° of the E-W line have advantage to see one of their facades shaded because one of its facades will be facing to south where it will never experiment direct solar radiation. In that orientation, the volumes that have one facades facing to south were privileged than those that had one facade facing north thus, the temperatures within the volumes at south were about ½ °C less than the volumes at north.

7.0 CONCLUSIONS

Independently of the orientation of the buildings, the buildings that have had not insulated nor shaded presented high indoor temperature when they have had their windows closed and they improved their indoor temperatures when they have had their windows opened but the buildings that have had the long facades E-W orientated had presented a good performance among all buildings orientations that were simulated. The way how the buildings of Maputo City were orientated, all facades of the rectangular buildings shapes were subjected to direct solar radiation throughout the year. Thus, the global radiations that was been absorbed by the volumes was high and consequently the temperatures within the volumes were great, reducing in that way the thermal comfort hours in the buildings making the environment of the volumes uncomfortable. The simulations results showed that many buildings of Maputo City were not ideally orientated. Thus, the indoor temperatures of these buildings were affected in about 11%-42% than the buildings E-W orientated and in about 6,4%-17% of the thermal comfort from outdoor.

8.0 ACKNOWLEDGEMENTS

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