A Simple Thermal Model for the Development Project "KIUMA" in Tropic Climate, Matemanga, Tanzania

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ABSTRACT: A thermal model is developed for a new development project "KIUMA" at Matemanga in Tunduru district of Southern Tanzania, which includes hospitals, residential buildings, education buildings and dining halls by using TRNSYS-15 simulation program. The work is done in the context of a lecture for educational purposes in the University of Dortmund to introduce thermal behaviour of the building in this tropic region with respect to different design variations. Simulations were carried out in two phases; reference case and improved variations. A rectangle shape model is chosen. The main design parameters influencing the thermal comfort according to their importance were orientation, ventilation strategies, thermal capacity and different roof insulation/ventilation. The climate of Matemanga is influenced by an altitude of 799 m and thus has cooler nights than other tropic regions in low altitudes. Some days the ambient temperature decreases by 12°C at nights even in the hottest month, October.
The results showed us that the optimal design can consist of followings: Daily minimum hygienic ventilation, maximum night ventilation with thermal mass heavy structure, rectangular building shape with large north-south surfaces, double layer roof structure or suspended ceiling. The results are graphically illustrated and compared to each other.

Keywords: Tropic design, optimum ventilation, thermal comfort

1. INTRODUCTION

Tropics can be classified into two main climatic zones: warm-humid and hot-arid. Warm-humid regions are the regions that have often more than 90 % relative humidity and annual mean temperature of about 23°C; it can rise to 38°C in summer. The hot-arid regions have an absolute humidity of 25 mb and high temperatures which is coupled by solar radiation [1].

As it is seen tropical climates generally show similar thermal characteristics: Heat is the dominant problem; annual mean temperature is not less than 20°C and significant part of the year buildings are awaited to keep indoor environment cool [2]. However, all these facts together are not valid for some of the tropical cities situated in high altitudes, like Matemanga with altitude of almost 800 m. Analysis of a simple building model was performed by using TRNSYS-15 to give students a preview of designing in such a specific tropic climate. Weather data were provided from METEONORM.

2. CLIMATE AND GEOGRAPHICAL CHARACTERISTICS OF MATEMANGA

2.1 Geographical Characteristics

The city is situated in southern Tanzania close to Mozambique with the longitude of Matemanga is 37.00- East and latitude is -10.75-North.

2.2 Climate of Matemanga

The climate of Matemanga is influenced by its high altitude. The city has moderate tropical climatic characteristics. Annual average air temperatures are between 20°C and 25°C. June and July are the coldest months with average temperatures of almost 19°C. October is the hottest month of year, which has the peak average temperature of 25°C. Matemanga receives the highest rainfall between January and March; average monthly precipitation value during this time is 200mm. On the other hand the dry season is from June to October. Relative humidity varies between 60% and 85% throughout the year in contrast to general approach of that most often the relative humidity more than 90% in tropical regions (Figure 1).

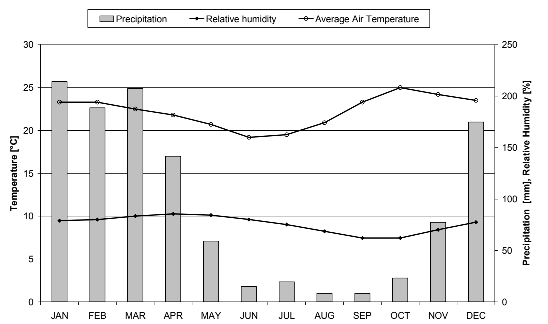

Figure 1: Monthly air temperature, precipitation and relative humidity values.

Although the city has tropical climate characteristics, low temperatures can also be seen sometimes by 12°C at nights, even in the hottest month. The differences between day and night ambient temperatures are almost 16°C in the hottest months of year, October. (Figure 2)

Solar radiation is received mostly from west, east surfaces of building envelope and roof due to sun position, which varies between 80° south and 57° north. After assessing sun position through the year shading strategies of this climatic region can be estimated. It is estimated that overhanging roof cantilevers will be enough to block direct radiation from south and north directions.

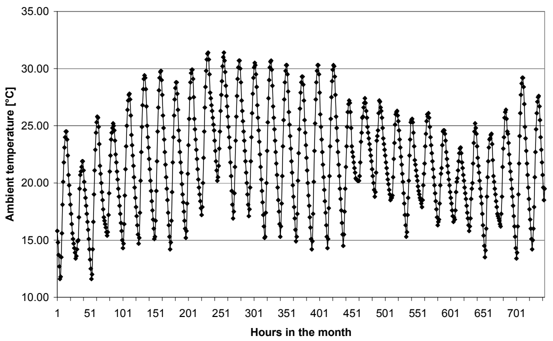

Figure 2: Ambient temperature in October (The hottest month)

3. DESCRIPTION OF MODEL BUILDING

As a building model, a section of the paediatrics yard is chosen from the proposed drawings of Kiuma community hospital, which was already built. It is rectangle in shape (18.23m*7.06m) and has large envelope surfaces facing to North and South. Windows are situated within the north and south envelope as well.
The building is made of 23cm brick external walls with lightweight suspended ceiling. Reflective aluminium is used as roof cover which is the real case. The building is raised 20cm to prevent rain water flow into the building (Figure 3). Different design variables are applied to this model building during the simulation process.

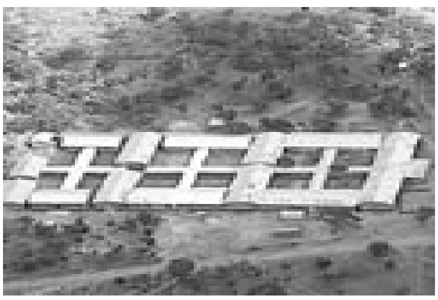

Figure 3: The hospital building in "Kiuma" project, a rectangle unit of this building were chosen as a model

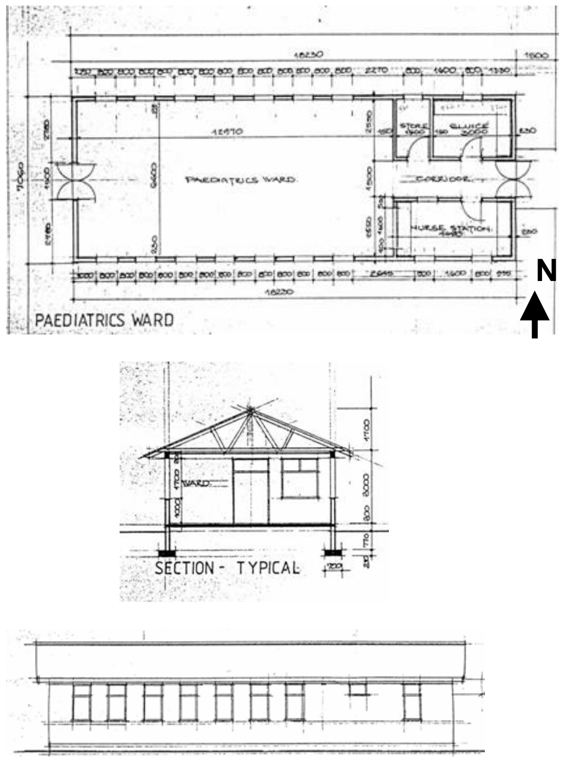

Figure 4: Plan elevation and section of the model building. (Source: Proposed Kiuma Hospital)

4. THERMAL MODEL AND THERMAL ANALYSIS OF THE SELECTED BUILDING

4.1 Methods

The thermal analysis of building model was performed by TRNSYS-15 simulation program. TRNSYS-15 is a modular transient simulation program developed by University of Wisconsin, USA. Weather data obtained from METEONORM, which has climatic data of over 7400 weather stations from different continents.

4.2 Strategies and Assumptions for the Simulations

The assessments of the thermal performance are carried out regarding two main cases; reference case and improved variations. Once the reference case is determined and simulated, some design strategies including different ventilation values, orientation variables and different envelope materials were used to improve thermal performance of building. Both reference case and other design variables to improve building model can be summarized as follows;
Reference case represents the "real" case. Reference case thermal model:

- roof structure: aluminium roof cover, plywood
- wall structure: Plaster, brick, plaster :25cm
- windows: single pane window is used
- not any shading device is used
- large surfaces and windows are faced S–N direction
- the windows are wide open during the night and day assumed as: 25 1/h

- suspended ceiling is used
- number of users; 30 people during the day, 20 patient during the night

Following variables are investigated and changed;

- air-change values are decreased to 2^{-h} during the day and 5^{-h} at night
- the large surfaces of the building are faced E-W direction
- shading device is applied in case of rotating the building E-W

The idea of covering roof with aluminium is not an improvement but rather the real situation. In "KIUMA" project and in the region significant numbers of buildings have aluminium roof cover, this hospital unit model as well. That's why the roof cover is considered as aluminium cover.

After evaluation of all these variables worst case and best case variables are determined and compared each other to indicate influence of the passive design variables.

4.3 Analysis of the results

Analyses of the results assessed with regard to ventilation, orientation, different wall materials and roof structure variables

Ventilation strategy was played significant role in thermal performance of the building in this climatic region. High ventilation rate of 25^{-h} during the day by opening the windows widely resulted in high indoor temperatures almost equal to ambient temperature. However, adjusting the ventilation rate to daily hygienic air-change of 2^{-h} and high night ventilation of 4^{-h} – 5^{-h} performed as the best improvement. In that case the building with thermal mass building envelope absorbs heat during the day, with minimum hygienic ventilation, both strategies aim to prevent hot ambient temperature flow to indoor environment. In addition night ventilation provides to exhaust the heat released from thermal mass elements during the night to get cool night ambient temperature. In case of applying no ventilation the temperature varies between 18°C and 22°C (Figure 4). This fact was the starting point in choosing smaller ventilation rates during the daytime. The air change values of 2^{-h} during the night and 5^{-h} during the night time are the hygienic values that can also supply enough drought

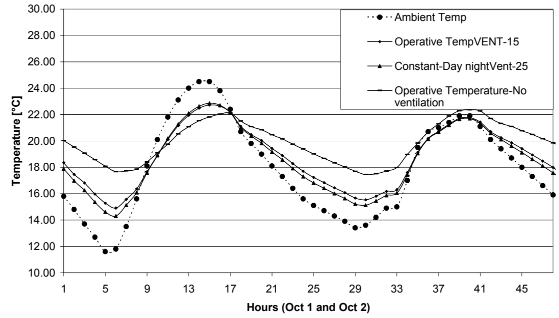

Figure 5: Influence of different ventilation strategies

Since the model building has an aluminium reflective roof cover, the heat gain from roof is high due to thermal transmittance features of metal material, although the roof cover reflects some of the coming solar radiation. In simulations two types of solutions for this problem are monitored. These two suggested solution were double layer roof structure, which houses an air barrier between two layers of roof structure, and suspended ceiling with enough roof ventilation. Both improvements are showed better performances than the case of using just aluminium roof cover. For both suggested design improvements the roof ventilation should be used to sweep trapped hot air between the roof layers and roof space.

Changing orientation of model building was another variable. Large surfaces of building envelope with nine windows from both sides were rotated 90° in order to compare both S/N and E/W orientation influences on indoor operative temperature. In case of rotating buildings large surfaces to South-North, indoor operative temperature is reduced thanks to lower solar heat gain. Rotating those surfaces to W-E orientation resulted in temperature increases in the morning and evening because of high solar heat gain through the windows and large surfaces.

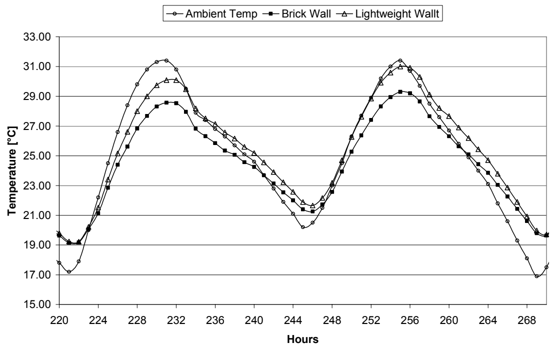

Figure 6: Performance of the brick and lightweight walls

The simulations are carried out for two wall construction types as well. One of them is a thermal mass wall made of brick and plastered from both sides. Lightweight wall made of insulation covered plywood from both sides. Thermal mass structures performed better than lightweight structures during the day and at night if it is sufficiently ventilated to eliminate disadvantage of the thermal mass wall during the night. Thermal mass structure has 2°C lower daytime indoor temperature than lightweight structure (Figure 5).

In conclusion, optimal case and worst case strategies for model building were assessed and compared in a diagram.

In optimal case, daytime hygienic ventilation of 2^{-h} with higher night ventilation 5^{-h} are applied. The large surfaces of building faced South and North.

The worst case has very high day and night air-change rates of 25^{-h}. it is assumed the windows are open in significant part of the day (Figure 6).

Combination of these improved design variables without using any mechanical solution gave students a preview of passive design in general and designing in this tropic climate specifically.

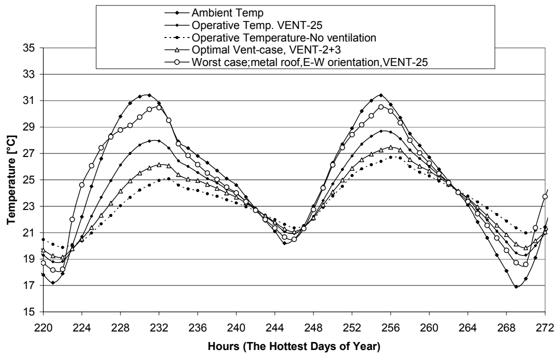

Figure 7: Comparison of the worst and optimal case of design variables

The Figures 7 and 8 indicates the relation between temperature and relative humidity in dry season October and in January the month Matemanga receives the highest precipitation. Increasing ventilation rates during the night resulted decrease in relative humidity but increase in room temperature comparing to outdoor temperature and relative humidity. On the hottest day, in the midday, indoor relative humidity and temperatures are almost 50% and 27°C respectively, when ambient air temperature is 4-5°C higher and outdoor relative humidity 10-12% smaller. Comfort temperature varies according to the countries in tropics. Although we don't calculate thermal comfort range of Matemanga, we can refer ASHRAE Fundamentals (ASHRAE 2001), where the comfort range for typical summers and winter of temperate climate defined as 20.5°C-23.5°C at over 60% relative humidity in winter and 22.5°-27°C at 60% relative humidity in summer. With the help of these comfort zone definitions, it can be concluded that thermal comfort for the simulated model is within the comfort limits in summer and winter.

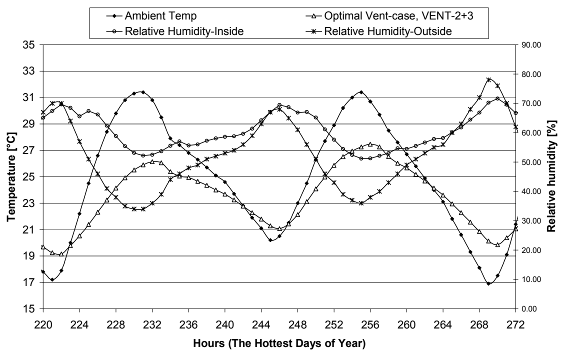

Figure 8: Indoor and outdoor temperature and relative humidity for the two hottest days

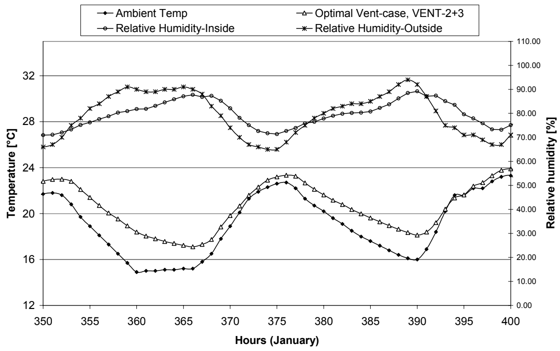

Figure 9: Indoor and outdoor temperature and relative humidity in the January.

5. CONCLUSION

The architect builds in tropics must battle against heat, strong solar radiation and in general high levels of air humidity to provide comfortable living spaces for the users without using any mechanical system [3] This work showed that the design variables which are generally thought and applied to the buildings in most of the tropical regions can not be successful for some tropical regions situated in high altitudes. Some of the findings can be summarized as follows;

- In contrast to general acceptance of applying high ventilation rates in tropic buildings, closing windows during the day with minimum hygienic ventilation keeps indoor climate cooler in such a tropic climate than that in case of high ventilation. High ventilation applied at night to cool down faster.
- To reduce influence of high solar heat gain through roof, double layer roof structure or suspended ceiling can be used as adequate solutions with the help of sufficient ventilation.
- Thermal mass perform better than lightweight structure during the day.
- Short and east and west envelope surfaces with smaller window areas for minimum solar heat gain.

ACKNOWLEDGEMENT

This work is prepared as a part of lecture named "Tropic Design" to inform and give architecture students of University of Dortmund a brief preview of designing in such a climate zone. The simulation of a sample building was just a small component of this lecture. The aluminium roof cover is not an suggested idea but rather in reality the building itself has aluminium roof cover.

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