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Quantifying the impact of solar gain control measures on residential house cooling loads in hot humid climate of Kenya.

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Kenya Energy conservation Cooling Loads
Building envelope Solar gain control

1. Introduction

The main concern in hot and humid region of Kenya is attaining comfortable indoor thermal conditions and managing cooling loads. Due to Kenya's mid-latitude location and high solar irradiance, solar heat gains contribute significantly to the thermal loads. The cooling degree days for the case study location –Kenya coastal town Mombasa is 2917.

Use of HVAC systems in Kenya is still very limited because of affordability issues, however it is expected that due to improving economic situation, the demand for more comfortable living conditions will lead to increase in use of HVAC systems and therefore increased electricity consumption is expected.

This is a parametric study by computer simulation with the following objectives ;(1) To quantify impact of various building envelope solar gain control strategies on cooling loads in residential buildings in hot and humid climate of Kenya. (2) Investigate and analyze correlation between shading factors and cooling loads. (3) Propose the appropriate solar gain control strategy suitable for Kenya context.

2. Methodology

This parametric study used building energy simulation software, ENERGY PLUS™, a single zone case study house was modelled, the selected detached residential house represents a typical modern residential house in Kenya in terms of spatial design and code compliance (Figure 1, Table 1).

The house Location is Mombasa Kenya (Lat.4S, Long.39E) in a suburban area. The total floor area is 111.6m^2 and total net volume of the building is 279m^3, it is assumed that there are no neighboring structures or vegetation that could shade the house.

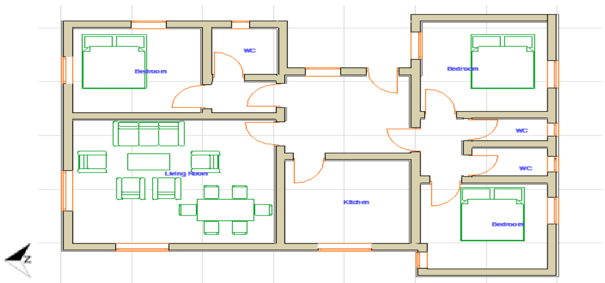

Figure 1 Floor plan of the case study house

Table 1 Construction layers & U values of the base case

Building elements	Construction layers	U value W/m^{2}K
Walls(external & partition)	20 mm cement plaster +200mm concrete block +20 mm cement plaster	2.59
Roof assembly	Galvanized iron sheet+5mm PVC ceiling	5.07
Floor	200mm concrete slab+20mm cement plaster	3.42
Window	3mm flat glass	5.89
Door	50mm block board	3.13

The test cases of various envelope configurations in Table 2 were simulated, the parameters of envelope configurations were varied and cooling loads of each were obtained.

Table 2 Simulation test case and conditions

Case	Test conditions	Abbreviation
1	No roof insulation.	N0-Base case*
2	25mm roof insulation(R=0.83m^{2}K/W)	N25
3	50mm roof insulation (R=1.66 m^{2}K/W)	N50
4	75mm roof insulation (R=2.5 m^{2}K/W)	N75
5	Roof paint (a=0.23)	RP
6	Low E Glass (T=0.63)	LoE glass
7	0.5m overhang projection	0.5OH
8	Fenestration shading –Internal	IS
9	Fenestration shading –external	ES

**base case other conditions-0.3m overhang, ventilation rate -0.5ACH.*

A simple HVAC system was modelled for the purpose of obtaining cooling loads, temperature set points is between 18^{0}C and 28^{0}C based of ASHRAE 55. The HVAC system is scheduled based on assumed single family household lifestyle schedule, switched on during waking hours 6.00am to 11pm and switched off during sleeping hours from 11pm to 6am [4].

3. Results and discussion

3.1 Indoor thermal condition

Relation between frequency and operative temperature is shown in Figure 2. In the base case, the percentage frequency of indoor operative temperatures equal or above 28^{0}C was 30%. Roof insulation and reflective paint had significant impact on indoor thermal conditions, 25mm insulation (R=0.83) or roof paint (a=0.23) reduced percentage frequency to 12% and 75mm insulation (R=2.5) reduced further to 5%.

3.2 Cooling loads

The annual cooling load for the base case was found to be 11.9GJ. Figure 3 indicates that peak loads are observed from January to March and from November to December with monthly peak of

ケニアの蒸暑地域における住宅の遮熱対策による冷房負荷削減効果の定量化　　ケンボイ　スタンレー*，齋藤宏昭**

approximately 1.4GJ. During the day, peaks loads are observed from 2pm and 4pm with hourly load maximum of approximately 5MJ.

Cooling load significantly reduced when roof insulation board was used, 25mm roof insulation reduced annual cooling by 42%, 50mm roof insulation caused 47% reduction while 75mm insulation caused 51% reduction (Figure 4). Use of white paint on the roof reduced cooling load by 35%, varying the size of overhang from 0.3m to 0.5m reduced cooling load dismally by 3%, using low emissivity glass or window curtains on the window reduced cooling by also gave reduction of approximately 3%.

3.3 Definition of solar gain coefficient – 'M value'

M value is a solar gain coefficient that takes into account the site exposure factor, envelope solar penetration rate and shading coefficient of shading device [3]. The M value is expressed as;

$$\mathrm{M_i} = \mathrm{sc_i} \times \mu_i \times \eta_i \times A_i \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$M = \frac{\Sigma M_{ij}}{A_f} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

where

$M_i =$ *component M value* (m^2)

$sc_i =$ *shading coefficient*

$\mu_i =$ *exposure factor.*

$\eta_i =$ *penetration rate.*

$A_i =$ *surface area* (m^2)

$A_f =$ *floor area* (m^2)

The cooling load has a direct proportionality to M value in Figure 5, and a lower M value indicates good solar shading effect and vice versa. The relationship is expressed as:

$y = 39147x + 2681.6$

where y *is cooling load in MJ and* x *is Mvalue.*

4. Conclusions

1. Roof insulation and reflective roof paint offers the best solar control strategy in reducing cooling loads and improved thermal condition, however it is noted that in a hot season high insulation is counterproductive.
2. From the cost point of view, reflective paint could be potentially cheaper in achieving better indoor thermal comfort and reduced cooling energy.
3. Envelope and fenestrations shading has small impact on overall cooling load, however can be used in combination to with roof insulation as complimentary measure.

References

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3. BRI-(2009), Design guidelines for Low energy housing with validated effectiveness. Building Research Institute, Japan.
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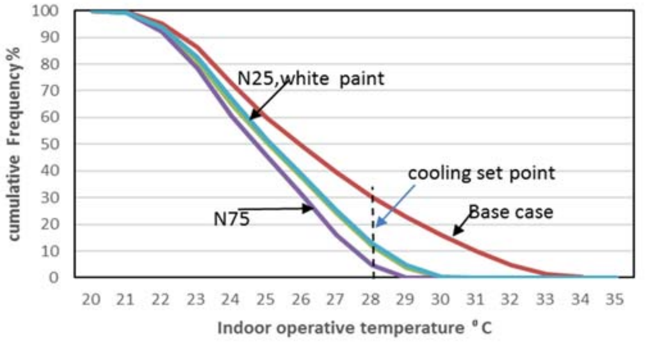

Figure 2 Reverse cumulative frequency distribution of indoor temperatures.

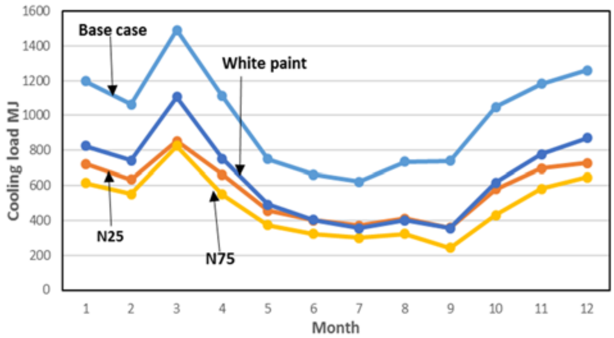

Figure 3 Monthly cooling loads

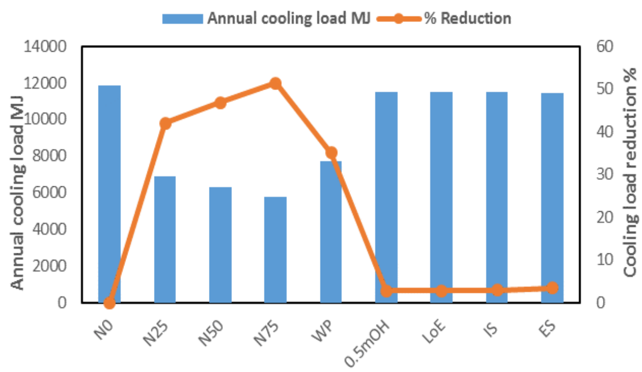

Figure 4 Annual cooling loads and percentage reduction

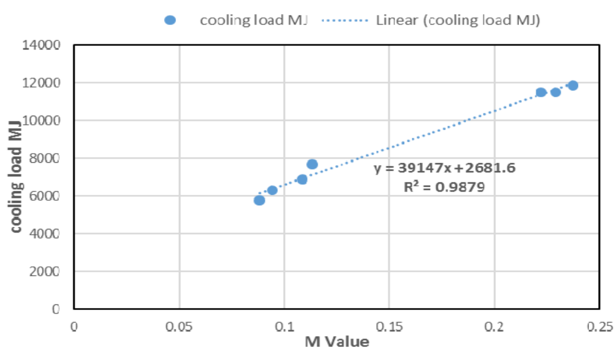

Figure 5 Relationship between M Value and cooling loads.

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