Modest Residential Building Cooling Load Components Analysis

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ABSTRACT: *In developing countries like Nigeria, the exacerbation of thermal discomfort in a living space is closely associated with high cost of air conditioning systems and the epileptic power supply. This paper therefore attempts to determine the contribution of each of the cooling load component of a modest residential building with the view of meliorating thermal comfort by manipulating the components that contribute significantly to the total cooling load of the building. To achieve the set objectives, the sources of heat load both internal and external were identified and their relative contributions to the total cooling load were determined. The results show that external heat load which encompasses heat gain through walls, windows, roof, and infiltration heat load, contributes about 87% of the total cooling load of the building. Significant reduction of the external cooling load by passive measures will not only make the occupants of the building to have relief comfort but can also reduce the size, cost and the power requirement of the air conditioning system to be used in the building. Amelioration of thermal comfort by mitigation of the external cooling load of a building using passive measures is recommended.*

Keywords: Cooling load, Components, Residential building, Comfort, Passive
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Introduction

Thermal comfort is an important parameter in the building design process as modern man spends most of the days indoors. In fact, to a very large extent, the quality of lives of human beings is a function of the quality of their indoor environment [1]. But in developing countries like Nigeria, the high level of poverty and constant epileptic and interrupted power supply largely hinder the common man from achieving thermal comfort.

Thermal discomfort experienced by occupants of a built environment especially during the hot season causes lower emotional health manifested as psychological distress, depression and anxiety as well as lower physical health manifested as heart disease, insomnia, headache and infection. To provide thermal comfort for the user of a building is fundamental. In hot and dry climates, the provision of thermal comfort to a very large extent is a function of the cooling load of a building envelope. The cooling load of a building depends primarily on both internal and external heat gains. The internal heat gain sources include the heat gain from people, appliance/equipment, lighting while the external heat gains are heat transmitted to the building interior through the roof, walls, and windows and by infiltration of the outside warm air. These sources of heat gains both internal and external contribute at different degrees to the total cooling load of a building. The contributions of these sources largely depend among other factors on the type of the building (residential, office, commercial, industrial), its orientation, extent of glazed and unglazed surface area, proximity of other buildings, and whether the building is new or old. In thermal analysis of building, the knowledge of cooling load is important for designing or selection of cooling systems. Also, it helps the user of a building to achieve thermal comfort by manipulating the cooling load components that can be manipulated. Therefore, the knowledge of the contributions of each component of the cooling load to the total cooling load of a building is imperative.

This paper therefore is an attempt to identify the cooling load components of a modest residential building, determine the contribution of each component to the overall cooling load and suggest ways of reducing the cooling components that contribute significantly to the total cooling load of the building.

Description of the Study Area

Modest residential building was considered for this study. The building is situated in Kano whose latitude and longitude are 12^0 01'N and 08^0 01'E respectively [2]. The building has perimeter walls measuring 4.62m long, 3.64m wide and 2.94m high. It has only one door located on the South wall and two equal windows located on the North and East walls. The windows are measured 1.24m high and 1.16m wide. The windows are of glazing type while the walls are block-plastered and are 190mm thick.

Methodology

The internal and external heat gain components of the building were identified and the relative contribution of each component to the total cooling load of the building was determined. The outdoor design temperature and relative humidity were considered from the past weather data for the months of March, April and May, since they are the hottest months in the study area. The weather data of Kano on the basis of usually prevalent conditions in the respective months were classified into five groups of average maximum dry bulb temperature (T_1) , relative humidity (RH_o) ,wet bulb temperature (T_3) and humidity ratio (ω_1) as shown in Table 1.0. The most frequent occurring conditions of $T_1 = 39.4^0C$, $RH_o = 8.1\%$, $T_3 = 17.4^0C$ and $\omega_1 = 0.0032\ kg/kg$ dry air, are selected for the analysis.

Table 1.0 Average Weather Data of Kano, Nigeria

Ambient Condition	$DBT_{max}(^{0}C)$	Total days	$T_1(^{0}C)$	RH_o (%)	$T_3(^{0}C)$	$\omega_1(kg/kg)$
A	$Less\ than\ 34$	3	32.4	9.4	13.7	0.0028
B	$34 \leq DBT < 37$	7	36.1	6.8	14.2	0.0020
C	$38 \leq DBT < 40$	23	39.4	8.1	17.4	0.0032
D	$41 \leq DBT < 42$	12	41.4	12.2	19.8	0.0058
E	$43\ \&\ Above$	–	–	–	–	–

Sources of Heat Gain

The two sources of heat gain identified are internal and external heat gains.

The internal heat gains identified were:

- Heat gain from lights
- Heat gain from appliance/equipment
- Heat gain from people

The external heat gains identified were:

- Solar heat gain
- Infiltration heat load

The indoor design dry-bulb temperature, T_2, of the building was taken to be 23^{0}C because at the operative temperature range of 23 – 27^{0}C most normally clothed people resting or doing light work feels comfortable [3]. Resting or doing light work is typical activity found in modest residential buildings.

Analysis of the Cooling Load

In determining the cooling load of the building, the following assumptions were made:

- The building occupancy is at full design capacity
- All building equipment and appliances are considered to be operating at a reasonably representative capacity
- Latent as well as sensible loads are considered

Heat Gain from Lighting

The heat gain from lighting is calculated based on equation 1.0.

$$\dot{Q}_{lighting} = W * F_{UL} * F_{SA} * CLF \ \ldots\ldots (1.0)$$

Heat Gain from Appliance/Equipment

Being a modest residential building, the appliances used in the building are refrigerator, TV, DVD, radio and ceiling fan. The heat gain from the use of each of the appliance is calculated based on equation 2.0 [4].

$$\dot{Q}_{appliance} = \left(\frac{P}{E_m}\right)_{ref} * F_{UM} * F_{LM} \ \ldots (2.0)$$

The peak heat gain from the use of all the appliances is calculated based on equation 3.0 [3].

$$\dot{Q}_{appliance,\ peak} = 0.5 * \dot{Q}_{appliance,\ total} \ldots (3.0)$$

Heat Gain from People

Heat gain from people has two components: sensible, $\dot{Q}_s$ and latent, $\dot{Q}_l$. The values of $\dot{Q}_s$ and $\dot{Q}_l$ were determined to be 70W and 45W respectively [4].

Sensible and latent heat gains from people are calculated based on equations 4.0 and 5.0 respectively.

$$\dot{Q}_{people,\ sensible} = N(\dot{Q}_S)(CLF) \ \ldots\ldots (4.0)$$

$$\dot{Q}_{people,\ latent} = N(\dot{Q}_l) \ldots\ldots\ldots\ldots\ldots (5.0)$$

The total heat gain from people is calculated based on equation 6.0 applying the factor of 0.7 to take care of the fluctuation in the occupancy [5].

$$\dot{Q}_{people} = 0.7(\dot{Q}_{people,\ sensible} + \dot{Q}_{people,\ latent}) \ldots\ldots (6.0)$$

Total Internal Heat Gain

The total internal heat gain of the building is computed from equation 7.0.

$$\dot{Q}_{internal,\ gain} = \dot{Q}_{lighting} + \dot{Q}_{appliance,\ peak} + \dot{Q}_{people,\ total} \ldots (7.0)$$

Heat Gain through the Walls

Consider the schematic of a plane wall such that there is steady rate of heat transfer through it. The total thermal resistance network, R_W, for the plane wall is expressed in equation 8.0 [3].

$$R_w = \frac{1}{h_i A_w} + \frac{L_w}{K_w A_w} + \frac{1}{h_o A_w} \quad \ldots\ldots \quad (8.0)$$

The steady rate of heat transfer through the walls, $\dot{Q}_W$, is calculated from equation 9.0.

$$\dot{Q}_w = \frac{T_1 - T_2}{R_w} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9.0)$$

Heat Transfer through the Roof

From the description of the residential building, the total thermal resistance network of heat transfer through the various sections of the roof, R_r, is expressed in equation 10.0 [3].

$$R_r = \frac{1}{h_i A_r} + \frac{L_z}{K_z A_r} + \frac{L_t}{K_t A_r} + \frac{L_a}{K_a A_r} + \frac{L_c}{K_c A_c} + \frac{1}{h_o A_c} \ \ldots (10.0)$$

Since the roof is 45^0 pitched, A_C and A_r are related by equation 11.0

$$A_r = \frac{A_c}{0.707} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11.0)$$

Therefore, the steady rate of heat transfer through the roofing, $\dot{Q}_r$, is calculated from equation 12.0

$$\dot{Q}_r = \frac{T_1 - T_2}{R_r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12.0)$$

Heat Gain through Windows

Heat gain through the windows has two components:

- Solar transmission
- Conductive

The cooling load equation for solar transmission through the glass of the window is calculated based on equation 13.0.

$$\dot{Q}_{win,\ solar} = SHGC \times A_g \times \dot{q}_{solar,incident} \ \ldots (13.0)$$

For the conductive component, the total thermal resistance network for conductive heat transfer through a plane glass window R_{win}, is calculated from equation 14.0.

$$R_{win} = \frac{1}{h_i A_g} + \frac{L_g}{K_g A_g} + \frac{1}{h_o A_g} \quad \ldots\ldots \quad (14.0)$$

The steady conductive heat transfer through the window glazing is calculated from equation 15.0.

$$\dot{Q}_{win,\ conductive} = \frac{T_1 - T_2}{R_{win}} \quad \ldots\ldots \quad (15.0)$$

The total heat transfer through the window

$\dot{Q}_{win,\ total}$, is calculated from equation 16.0.

$$\dot{Q}_{win,\ total} = Q_{win,\ conductive} + \dot{Q}_{win,\ solar} \ \ldots (16.0)$$

Infiltration Heat Load

The sensible and latent infiltration heat load of a building are calculated based on equations 17.0 and 18.0[3].

$$\dot{Q}_{infil,\ sensible} = \rho_a C_p (ACH)(V_b)(T_1 - T_2) \quad \ldots (17.0)$$

$$\dot{Q}_{infil,\ latent} = \rho_a h_{fg} (ACH)(V_b)(\omega_2 - \omega_1) \quad \ldots (18.0)$$

The total infiltration heat load is calculated from equation 19.0.

$$\dot{Q}_{infil,\ total} = \dot{Q}_{infil,\ sensible} + \dot{Q}_{infil,\ latent} \quad \dots (19.0)$$

Total External Heat Gain

The total external heat gain $\dot{Q}_{external,\ gain}$, is calculated from equation 20.0.

$$\dot{Q}_{external,\ gain} = \dot{Q}_{win,\ total} + \dot{Q}_r + \dot{Q}_w + \dot{Q}_{infil,\ total} \quad \dots (20.0)$$

Total Cooling Load

The total cooling load, $\dot{Q}_{cooling\ load,\ total}$, of the occupied space is determined from equation 21.0.

$$\dot{Q}_{cooling\ load,\ total} = \dot{Q}_{internal,\ gain} + \dot{Q}_{external,\ gain} \quad \dots (21.0)$$

Results

Table 2.0: Total Internal Heat Load of the Building

Parameter	Value
Heat gain from lighting, $\dot{Q}_{lighting}$	72W
Heat gain from appliances, $\dot{Q}_{appliance,\ peak}$	123.7W
Heat gain from people, $\dot{Q}_{people,\ total}$	91.8W
Internal heat gain, $\dot{Q}_{internal,\ gain}$	**287.5W**

Table 3.0: Total External Heat Load of the Building

Parameter	Value
Heat gain through windows, $\dot{Q}_{win,\ total}$	1235.8W
Heat gain through roof, $\dot{Q}_r$	137.1W
Heat gain through walls, $\dot{Q}_w$	372.8W
Infiltration heat load, $\dot{Q}_{infil,\ total}$	93.3W
External heat gain, $\dot{Q}_{external,\ gain}$	**1839W**

Table 4.0: Total Cooling Load of the Building

Parameter	Value
Internal heat gain, $\dot{Q}_{internal,\ gain}$	287.5W
External heat gain, $\dot{Q}_{external,\ gain}$	1839W
Total cooling load, $\dot{Q}_{cooling\ load,\ total}$	**2126.5W**

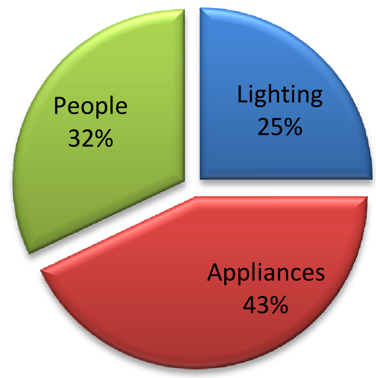

Figure 1.0 Components of Internal Heat Load

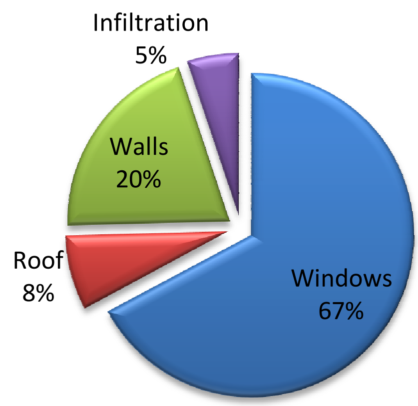

Figure 2.0 Components of External Heat Load

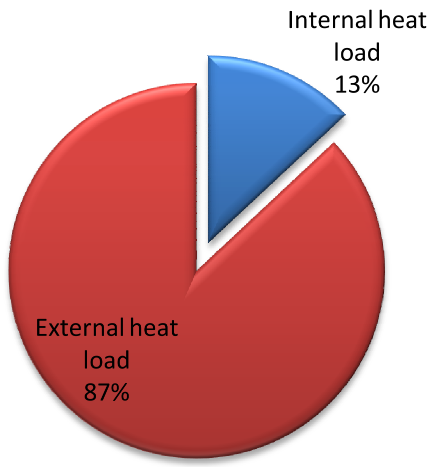

Figure 3.0 Total Cooling Load

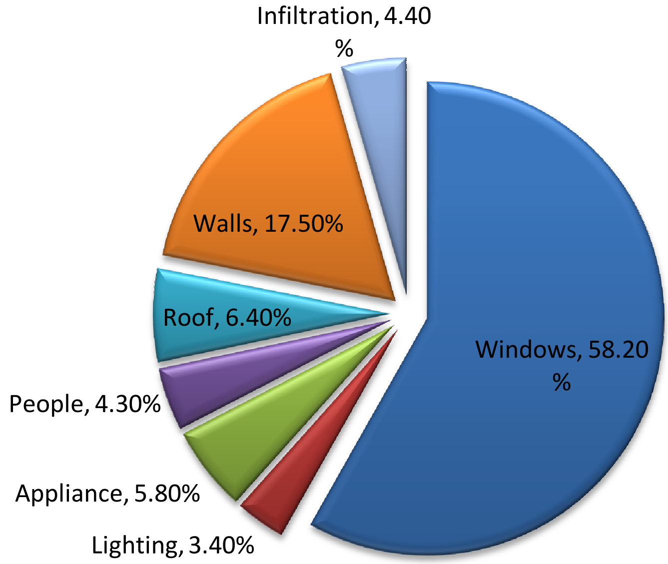

Figure 4.0 Contributions of the Cooling Load Components

Discussion

From the analysis of the modest residential building carried out, the total cooling load of the building was 2126.5W. The internal and external cooling loads contribute about 13% and 87% respectively of the total value of the building cooling load as seen on figure 3.0. The relative contributions of lighting, people, appliances, heat gain through windows, roof, walls, and the infiltration heat gain to the total cooling load of the building as shown in figure 4.0 are 3.4%, 4.3%, 5.8%, 58.2%, 6.4%, 17.5% and 4.4% respectively. This shows that the reduction in the external heat gains by the building will significantly reduce the total cooling load of the building. These external heat gains can easily be mitigated using passive measures such as shading devices, creation of microclimate, use of double-pane glass on windows, use of removable canvass on roofs, use of insulation in walls and roofs, proper orientation of buildings, etc. When the cooling load is significantly reduced, relief (lenitive) comfort can be achieve in the living space or smaller air conditioning systems of cooling capacity less than the estimated value of 2126.5W can be used to provide thermal comfort for the occupants of the space.

Conclusion

The knowledge of the contribution of each of the building cooling load component is imperative. Since the external heat load contributes about 87% of the total building cooling load, therefore, reducing the external heat load possibly by passive measures will go a long way in providing a measure of relief comfort for people who cannot afford air conditioning systems. Therefore, reduction of cooling load of the building using passive means will not only reduce the energy requirement for achieving thermal comfort but, will significantly reduce the size and cost of the air conditioning system if it is to be used for providing the thermal comfort.

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Nomenclature

$A_{c,r,w,win}$	Area of ceiling, roof, wall and window respectively, m^2
ACH	Air change per hour
CLF	Cooling load factor

C_p	Specific heat capacity of air, $J/kg\ K$
E_m	Equipment motor efficiency
F_{UL}	Lighting use factor, as appropriate
F_{SA}	Special ballast allowance factor, as appropriate
F_{UM}, F_{LM}	Motor use factor, Motor load factor
$h_{i,o}$	Combined convection and radiation heat transfer coefficients on the inner and outer Surfaces of the building, $W/m^{2\,0}C$
$K_{a,c,t,w,z}$	Thermal conductivities of air, ceiling, rafter and zinc respectively, W/mK
$L_{a,c.t,w,z}$	Thicknesses of air, ceiling, rafter, wall and zinc respectively, m
$R_{a,c,t,w,z}$	Thermal resistances of air, ceiling, rafter, wall and zinc, $^0C/W$
$\dot{Q}_w$	Heat transfer through wall, W
N	Number of people in space
V_b	Internal volume of the room, m^3
ρ_a	Density of air, kg/m^3
h_{fg}	Latent heat of vapourization, KJ/kg
$SHGC$	Solar heat gain coefficient
$\omega_{1,2}$	Humidity ratio of indoor and outdoor air, $kg\ water/kg\ dry\ air$
W	Watts input from electrical lighting
P	Horsepower rating from electrical appliance
$\dot{Q}_{s,l}$	Sensible and latent heat respectively, W

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