Red Sea University Journal of Basic and Applied Science
Vol (2) Special Issue (3) May-2017
ISSN: 1858-7658 (Online)
ISSN: 1858-7690 (Print)

Calculation of the thermal loads of building in Khartoum - Sudan

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Abstract. The aim of this paper to calculate the thermal loads of building in Khartoum capital of Sudan in order to provide a suitable working environment, Human comfort is essential now a day to improvement in the life style and increasing of atmospheric temperature. Cooling load items such as, people heat gain, lighting heat gain, infiltration and ventilation heat gain can easily be putted to the MS-Excel programmed. The programmed can also be used to calculate cooling load due to walls and roofs.

Keywords: HVAC, Cooling Load, Air Conditioning, Human Comfortless

Introduction

The multi-story building considered in this study is situated in Khartoum and located at 84.54E longitude and 22.12N latitude in Gabra, Khartoum. Khartoum is located in the middle of the populated areas in Sudan, it is lies between longitudes 31.5 to 34 °E and latitudes 15 to 16 °N.

The temperature in summer ranges from 25 to 40 °C from April to June, and from 20 to 35 °C in the months of July to October. In winter, the temperature declines gradually from 25 to 15 °C between March and November. The warm season lasts from April 8 to July 2 with an average daily high temperature above 39°C [1, 2].

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Table 1: Average high and low temperature (in ^{o}C/ ^{o}F) of Khartoum according to months

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max Temperature °C (°F)	32 (89.6)	34 (93.2)	37 (98.6)	40 (104)	42 (107.6)	42 (107.6)	38 (100.4)	36 (96.8)	38 (100.4)	40 (104)	36 (96.8)	33 (91.4)	37.3 (99.2)
Average Temperature °C (°F)	23.2 (73.8)	25 (77)	28.7 (83.7)	31.9 (89.4)	34.5 (94.1)	34.3 (93.7)	32.1 (89.8)	31.5 (88.7)	32.5 (90.5)	32.4 (90.3)	28.1 (82.6)	24.5 (76.1)	29.9 (85.8)
Average Min Temperature °C (°F)	16 (60.8)	17 (62.6)	19 (66.2)	23 (73.4)	26 (78.8)	27 (80.6)	26 (78.8)	25 (77)	25 (77)	25 (77)	21 (69.8)	17 (62.6)	22.3 (72.1)

The relative humidity typically ranges from 7% (very dry) to 87% (very humid) over the course of the year, dropping as low as 3% (very dry) and reaching as high as 100% (very humid).

The air is driest around May 10, at which time the relative humidity drops below 8% (very dry) three days out of four; it is most humid around August 19, exceeding 77% (humid) three days out of four[4-6].

Dew point is often a better measure of how comfortable a person will find the weather than relative humidity because it more directly relates to whether perspiration will evaporate from the skin, thereby cooling the body. Lower dew points feel drier and higher dew points feel more humid.

Over the course of a year, the dew point typically varies from -8°C (dry) to 24°C (very muggy) and is rarely below -15°C (dry) or above 26°C

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ISSN: 1858-7690 (Print)

(oppressive) [7].

There are two periods in the year that are most comfortable: The first is between May 25 and June 29 and the second is between October 2 and November 27. The air feels neither too dry nor too muggy during these periods [8-10].

Building Structures

The dimension of the building which is to be air conditioned is, 104.61×48m in size. It has seven floors included the ground floor. The exterior walls of building consists of 230 mm common bricks + air space + 230 mm common bricks with 13 mm cement mortar and 26 mm (13 mm both side) sand cement plaster. The interior walls of building are consist of 230 mm common bricks with 26 (13 mm both side) inch sand cement plaster. The roofs consist of 152 mm concrete poured in a metal sheet with 13 mm plaster. The windows consist of single glass materials of 12.7mm thick with frame panel [11].

External Cooling Load

The external loads consist of heat transfer by conduction through the building walls, roof, floors, doors, heat transfer by radiation through fenestration such as windows and skylights.

CLTD Correction

CLTD gained from the tables is to be adjusted for:

(a) Latitude-month correction.(b) Exterior surface color.(c) Indoor design temperature.(d) Outdoor design temperature.

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(e) Attic conditions.(f) U-values.(g) Insulation.

$$CLTD_{corr} = ((CLTD + LM)\,K + (78 - t_R) + (t_o - 85))f \text{ in } (^oF) \quad (1)$$

Where:

CLTD = Cooling load temperature difference from the tables in ^oF.

LM= Latitude month correction for walls or horizontal surfaces in ^oF.

K= color adjustment factor.

*K= 1.0 if dark colored or light in an industrial area.

*K=0.5 if permanently light-colored (rural area).

$(78 - t_R)$ = Indoor design temperature correction in ^oF.

$(t_o - 85)$ = Outdoor design temperature correction where (t_o) is the average temperature on design day in ^oF.

f =factor for an attic fan and or ducts above ceiling applied after all other adjustments have been made.

*f=1.0 if no attic or ducts.*f=0.75 if positive ventilation

Roof Cooling Load

Q= UA (CLTD) in (Btu/hr) (2)

U= roof design heat transfer coefficients in ($Btu/hr.ft^2.^oF$)

A=area calculated from building plans in (ft^2)

Table 2: Heat transfer coefficient for roof construction in $Btu/hr.ft^2.F$

Roof construction	Heat transfer coefficient
10-in Brick	U = 1.179961827

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20-in Concrete	U = 0.669232081
2-in Cement plaster	U = 10.21459492
1-in Asphalt layer	U = 13.10639958
Still air in the inside	hi = 1.40888
Air space between the layers	hr = 4.40275

Overall roof heat transfer coefficient (Uroof) =

$$\frac{1}{\frac{1}{Uconcrete}+\frac{1}{Ubrick}+\frac{1}{Uplaster}+\frac{1}{Uasphalt}+\frac{1}{hr}+\frac{1}{hi}} =$$

$$\frac{1}{\frac{1}{0.669232081}+\frac{1}{1.179961827}+\frac{1}{10.21459492}+\frac{1}{13.10639958}+\frac{1}{4.40275}+\frac{1}{4.40275}} = 0.28961 \text{ Btu/hr.ft}^2.^oF \quad (3)$$

Table 3: Total roof heat gain in Btu/hr

	10.00 AM	12.00 AM	2.00 PM	4.00 PM
APRIL	68869.73	70755.89	80186.67	97162.09
MAY	68869.73	70755.89	80186.67	97162.09
JUNE	68869.73	57552.79	66983.6	83958.99

Walls Cooling Load

Q= UA (CLTD) in (Btu/hr)

U= wall design heat transfer coefficients in (Btu/hr.ft^2.^{o}F)

A=area calculated from building plans in (ft^2)

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CLTD=cooling load temperature difference for the walls in (°F)

CLTD is to be adjusted for the same factors as roofs.

Overall wall heat transfer coefficient (Uwall) = $\frac{1}{\frac{1}{Ublock}+\frac{1}{Uplaster}+\frac{1}{hi}+\frac{1}{ho}}$

$$= \frac{1}{\frac{1}{0.580689894}+\frac{1}{4.021494913}+\frac{1}{1.40888}+\frac{1}{3.5222}} = 0.35367 Btu/hr.ft^2.^oF \quad (4)$$

Table 4: Total walls heat gain in Btu/hr

	10.00 AM	12.00 AM	2.00 PM	4.00 PM
APRIL	390192.3	390258.4	401163.1	416710.9
MAY	402761	404627	413732	429280
JUNE	423708.1	422088.3	428868.9	443254.8

Floors Cooling Load

Q= UA (ΔT) in (Btu/hr) , U= Design heat transfer coefficient in (Btu/hr.ft^2.^{o}F)

A= Areas calculated from building plants in (ft^2) ,ΔT= Design temperature difference in (°F)

Over all heat transfer coefficient for floor (U_{floor}) = $\frac{1}{\frac{1}{Uconcrete}+\frac{1}{Uplaster}+\frac{1}{Uporecelain}+\frac{1}{hi}}$

$$= \frac{1}{\frac{1}{0.892309442}+\frac{1}{10.21459492}+\frac{1}{0.510729746}+\frac{1}{1.140888}} = 0.25731065 Btu/hr.ft^2. ^oF \quad (5)$$

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Table 5: Total floor heat gain in Btu/hr

floor	371.63

Glass Cooling Load

$$Q_{conductioncn} = UA\,(CLTD) \text{ in } (Btu/hr) \qquad (6)$$

Table 6: Total conduction heat gain through glass in Btu/hr

10.00 AM	12.00 AM	2.00 PM	4.00 PM
27259.09	33272.3	38082.86	39285.51

Table 7: Total solar heat gain through glass in Btu/hr

	4:00 PM	2:00 PM	12:00 PM	10:00 AM
April	127780	141681.5	141147.4	125542
May	128195.9	142372.5	142133.1	126523
June	128477.6	142906.2	142896.6	127232

People Cooling Load

$$Q_{Laten} = N(\text{Latent HG}) \text{ in } (Btu/hr) \qquad (7)$$

Table 8: Total people heat gain in Btu/hr

Qs (Btu/h)	QL (Btu/h)	Qt (Btu/h)
24885	25675	50560

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Lights Cooling Load

Q= (Input)(CLF) in(Btu/hr) (8)

Input= Input rating from electrical plans or lightning fixture data. In (Btu/hr)

CLF= Cooling load factor for lights.

*CLF= 1.0 with 24 hours operation or if cooling is off at night.

Total lights heat gain in Btu/hr = 169157.9

Appliances Cooling Load

$Q_{Sensible}$ = (Heat Gain)(CLF) in (Btu/hr) (9)

Computer

It represents the CPU unit and its monitor. Cooling Load for a Computer in an office of medium/heavy work density = 135W = 460.35 Btu/hr

Laptop

A Laptop of 2.0 GHz processor, 2 GB RAM and 430 mm screen requires a cooling load of 36 W = 122.76 Btu/ hr

Printer

Cooling Load for a Printer in an office of medium/heavy work density =320W = 1091.2 Btu/hr

Scanner

Cooling Load for a Scanner of a medium/heavy work density = 100 W = 341 Btu/hr

Television

An LCD Screen generates less heat than a regular box TV.

Cooling Load for an LCD TV = 0.2*S – 20 in W

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Where S = Nominal TV Size in mm.

For 42 in TV, Cooling Load = 0.2*32*2.54*10-20 = 142.6 W = 486.266 Btu/hr

Projector

A projector requires a cooling load of 300W = 1023 Btu/hr.

Freezer

A Freezer (small size) requires a cooling load of 322 W = 1098 Btu/hr

Water Cooler

A water cooler requires a cooling load of 350W = 1193.5 Btu/hr

Table 9: Total appliance heat gain in Btu/hr

Floor	Heat gain in (Btu/hr)
First floor	22530.11*2
Second floor	19776.4*2
Third floor	16830*3
Total sum	135103.2

Ventilation and Infiltration Cooling Load

The external conditions such as speed of wind, direction of the wind, external atmospheric pressure and permeability of building materials to moisture must be known.

Sensible cooling load is the load that tends to increase the dry bulb temperature of the conditioned spaces.

Ventilation: is he amount of air fetched into the space

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ISSN: 1858-7690 (Print)

required by mechanical machines (fans). The entry of air into the conditioned space affects its internal situation and is often described as the change in moisture content of sensible load or latent load [13, 14].

$Q_{Sensible}$ = 0.35Qv(N)(ΔT)* 3.415179 in (Btu/hr) (10)

Q_V = Heat dissipated from a person in (m^3/hr)

N= Number of people and ΔT= Temperature difference in (^oC)

Q_{Laten} = 0.87Qv(N)(Δω)*(1000*3.415179) in (Btu/hr) (11)

Q_V= Heat dissipated from a person in (m^3/hr)

N= Number of people. Δω= Specific humidity difference in (kg of H_2O/kg of air)

Table 10: Total ventilation heat gain in Btu/hr

Floor	Sensible heat gain in (Btu/hr)	Latent heat gain in (Btu/hr)
First and Third Floors	28795.082*2	11061.799*2
cond and Fourth Floor	37078.598*2	14243.96*2
ifth, Sixth and Seventh Floors	20511.565*3	7879.6376*3
Total sum	193282.06	74250.431

Infiltration: is the non-conditioned air, which goes into the conditioned space inadvertently by natural factors such as wind, pressure changes lead to the entry of air by infiltration.

It depends on the amount

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ISSN: 1858-7690 (Print)

of air required for ventilation purposes, the nature of the building with respect to holes that slip through the air to the space.

$$Q_{Sensible} = 0.35(Y)(V)(\Delta T)*3.415179 \quad \text{in (Btu/hr)} \qquad (12)$$

Y= Number of air changes/hour.

V= Volume of the zone in m^3

ΔT= Temperature difference in (^oC)

$$Q_{Laten} = 0.87(Y)(V)(\Delta\omega)*(1000*3.415179) \quad \text{in (Btu/hr)} \qquad (13)$$

Y= Number of air changes/hour.

V= Volume of the zone in (m^3)

Δω= Specific humidity difference (kg of H_2O/kg of air)

Table 11: Total infiltration heat gain in Btu/hr

Floor	Sensible heat gain in (Btu/hr)	Latent heat gain in (Btu/hr)
First and Third Floors	89807.258*2	34499.983*2
Second and Fourth Floors	69605.207*2	26739.247*2
Fifth, Sixth and Seventh Floors	48415.183*3	18598.975*3
Total sum	464070.48	178275.39

Conclusions

In this paper, a multi-building an integrated part of a

ISSN: 1858-7658 (Online)
ISSN: 1858-7690 (Print)

research institution located in Khartoum, Sudan, was considered for calculating cooling loads. Cooling load temperature difference (CLTD) method was used to find the cooling load for each floor.

Cooling load items such as, people, light, infiltration and ventilation can easily be putted to the MS-Excel program. The program can also be used to calculate cooling load due to walls and roofs.

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