Heat Gain Study of a Residential Building in Hot-Dry Climatic Zone on Basis of Three Cooling Load Methods

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***Abstract*—The paper presents the study on theoretical heat gain for a residential building located in hot-dry climatic zone of India. The location is city Kota (25.10^0 N, 75.83^0 E). To determine heat gain, three different methods have been used. The aim of the paper is to study the heat gains and also to compare the three different methods. First method is CLTD/GLF method which is taken from ASHRAE 1997, second method is CLF/SCL/CLTD method which also taken from ASHRAE 1997 and third method is RLF method which is taken from ASHRAE 2013. After that comparative study has been done of all three methods. For the study a typical middle income group residential house has been considered. The model house is taken of size 12 m x 15 m with three windows of size 1 m x 1m each and one door of size 1 m x1.5 m. The walls are brick wall and roof is taken of RCC. From the analysis it is found that CLTD/GLF method predicts heat gain towards lower side whereas CLTD/SCL/CLF method values are higher and RLF values lies in between being more close to CLTD/SCL/CLF method. An important point to notice on comparison of results is that all methods predict around 50% heat gain through roof for this building structure. Another major contribution to heat gain (around 30%) is through walls. The window to wall ratio for the building is 1.9% and therefore the effect of heat gain through windows is only around 8%. Other factors contribute only a minor percentage to the overall heat gain. Thus, from the results it can be concluded that in order to reduce the heat gain and cooling load, major attention must be paid on roof and wall heat gain along with the other factors. Suitable passive measures can be identified on the basis of heat gain study.**

***Index Terms*—Heat Gain, Cooling Load, ASHRAE Methods, Comparative Study, Residential Building, Passive Measures.**

I. INTRODUCTION

Heat gain of a building can occur through walls, roof, doors, floor and window glazing by conduction, convection and radiation. Heat gain mainly occurs due to direct exposure of building envelope by solar radiation. There are other reasons of heat gain also which include household kitchen equipments, electrical equipment like computer, TV, lighting devices, infiltration, ventilation and number of occupants in the building etc. Thus, heat gain may be classified as external heat gains and internal heat gains. Further, the heat gain can be also described as sensible heat gain and latent heat gain. Sensible heat gain is associated with temperature increase and may be due to conduction, convection and/or radiation in the space. Latent heat gain is associated with water vapor/moisture (phase change) and is due to breathing of occupants, equipment, and ventilation/infiltration of air. For a building to be comfortable for occupants without wastage of energy, it is important that heating and cooling loads are clearly estimated. Heating load for a building may be defined as the amount of heat required to be supplied to the building in order to maintain it in thermal comfort range. Similarly cooling load may be defined as the amount of heat which should be removed from the building in order to maintain it within thermally comfortable range.

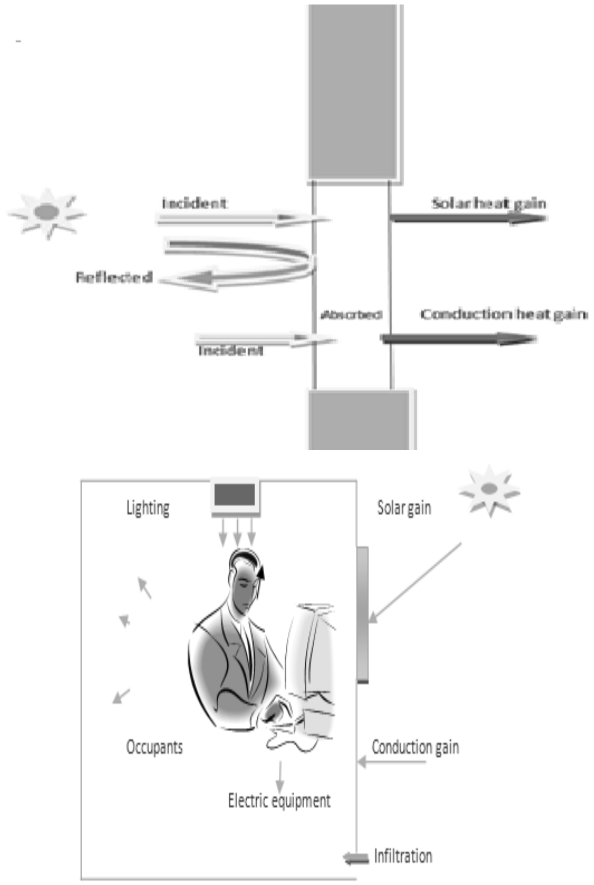

Fig. 1. External and internal heat gain for a building

A number of studies have been conducted on heat gain and cooling load estimation. M.Gr. Vrachopoulos et al. presented the method for determining the thermal and cooling load in Athens. They evaluated density of building, size of cover, weight, volume and consumed energy [1]. Cooling load of building can be determined if heat gain of building is known. S.L. Wong et al. determined the heat gain in Hong Kong and observed increasing trend in heat gain of building envelope. They analyzed from the study that the average annual cooling load in duration 2009-2100 can reach 6.1% and 9.85% which is greater than in duration

Published on September 26, 2019.
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1979-2008 for low and medium forcing [2]. By estimating heat gain of building over consumption of electricity for a particular space can be reduced because it gives an idea that how much electricity consumption is required for one place. It also prevents too much cooling and too heating of the place because some places require more energy and some places require less energy. Many studies have been done to decrease the cooling load of buildings. Mehdi Baneshi, Hiroki Gonome and Shigenao Maruyama discussed the cooling load of single stage single family home in three different climates and with different cool black paints. They observed a decrement in peak and annual cooling load by 6-13% and 6-14% respectively [3]. Lighting load can be reduced by using fluorescent lamp in place of tungsten lamp. By 'make air tight and ventilate right' approach the cooling load can be decreased [4]. Vinod Kumar Venkiteswarana, Jason Limana and Saqaff A. Alkaffa studied various passive measures for reducing cooling load including wall insulation by polystyrene, single low-emissivity window glazing and white painted roof, and compared the results. They found that wall insulation is the most effective method for Malaysian climate and also it is cost effective too [5].

To calculate heat gain due to lighting a simple lighting heat gain model is used in ASHRAE's new cooling load calculation [6]. Deepak Kumar Yadav et al. determined cooling load in different climatic conditions using Cooling Load Temperature Difference (CLTD) method. A tutorial room was selected for the study [7]. Eng. Essa S. Ben-Essa determined cooling load for one storey villa with basement located in Kuwait using CLTD method and discussed result [8]. Felix A. and Emmanuel A. estimated cooling load of a building situated in Ghana using transfer function method (TFM) and then compared the result with the result of cooling load estimated by computer programme [9]. Baisong Ninga,b, Youming Chena investigated a cooling load calculation model integrated operation of radiant and fresh air system. For that they used heat balance method. They also investigated cooling load calculation method using Chinese standard on radiant system [10].

Yu Wang et al. studied the effect of climate change on cooling load of residential building. They also studied the effect of climate change with respect to the age of the occupants. They observed that the climate change effect is more pronounced for people under the age of 55 [11]. Yuanda Cheng et al. studied the different cooling load calculation methods used over 20 years and concentrated on STRAD system [12]. E. Catalina Vallejo-Coral evaluated the CLTD values for flat roofs and walls of buildings for different climatic zones in Mexico. For this they used complex finite Fourier transform, then compared the result with ASHRAE CLTD values. They found 10ºC difference between them with the ASHRAE values on higher side [13]. Anurag Kumar Singh et al. estimated heat gain for library in Delhi using CLTD/CLF method. The estimated heat gain for library came out to be 48614.91 W [14]. M. D. Suziyana et al. calculated the heat gain of computer laboratory and an excellence centre using CLTD/CFL/SCL method. They obtained the heat gain values for computer laboratory and excellence rooms as 20458.6 W and 33541.3 W [15]. Hani H. Sait did hand calculation using CLTD method to determine thermal load of building and then results were compared with the outcomes from HAP 4.2 program [16]. Wan Sharizatul Suraya W.M.Rashdi, Mohamed Rashid Embi investigated the relation between building design and cooling load for this they used computer simulation analysis program Autodesk Ecotect [17]. G. Evola, L. Marletta used solar response factor to determine solar gain through glazing and compared the results with EnergyPlus [18]

Heat gain for a building and cooling load are strongly interconnected. Cooling load is used to design a heating, ventilating and air conditioning (HVAC) system to remove heat from a space to provide a specified condition of thermal comfort within that space. Cooling load is directly dependent on the modes and amount of heat gain by various components of the building envelope and therefore cooling load calculations make use of estimation of heat gain. American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) have given various methods to determine cooling load on basis of heat gains such as

A) CLTD/ GLF method B) CLTD/SCL/CLF method C) TETD/TA method D) TFM method F) RLF method

A. CLTD/ GLF method

This method is used to determine heat gain only for residential buildings. This method is very simple and one of the earliest method. In this method sensible gain is determined using cooling load temperature difference (CLTD) and glass load factor (GLF). Latent load is determined using latent factor with the help of psychometric chart. CLTD is a theoretical temperature difference used for estimating heat gain taking into account combined effects of the inside-outside air temperature difference, daily temperature and solar radiation variation and thermal mass of building.

B. Transfer Function Method (TFM)

In this method heat gain is determined using conduction transfer function coefficient and then heat gain is converted into cooling load using room transfer function coefficient.

C. CLTD/SCL/CLF method

In this method CLTD is used to determine external conduction gain and SCL (solar cooling load) is used to determine solar gain through glass. SCL is to be added for more accuracy. CLF (cooling load factor) is used to determine internal conduction gain. In this method hourly values of heat gain can be calculated by using hourly CLTD values. This method is modified form of TFM method.

D. Total Equivalent Temperature Difference/Time Averaging (TETD/TA)

In TETD method the TETD values are calculated as a function of sol air temp and maintained room temperature with the use of response factor technique. Here a number of representative wall and roof assemblies can be taken. The internal heat gain elements are added to it and after that time averaging technique is used to convert heat gain into cooling load but this can be solved only with help of computer due to its complexity.

E. Residential Load Factor (RLF)

In RLF method the procedure consists of two steps, in the first step the cooling load factor and heating load factor (CFs and HFs) are determined for each component then these factors are used to estimate cooling load in second step. The load contribution of various components is determined separately and then added. RLF is simple procedure which is hand manageable and can be used with spread sheet application [19].

Estimating heat gain and cooling load of a building is one of the most important steps towards better designing of a building in hot dry climatic zone. It helps in choosing measures which can lead to improvement in thermal comfort with optimized energy usage. For the present study Kota, a city situated in hot dry climatic zone of India has been chosen. This paper discusses the estimation of heat gain of a residential building of Kota through three different methods- CLTD/GLF method and CLTD/SCL/CLF method and RLF method. The aim is to develop an understanding of the heat gains due to various loads which can be used in subsequent studies to suggest measures for improved thermal performance of the building. It does not focus on designing of an HVAC system, the main aim is to improve design of buildings and identify feasible passive measures on the basis of this study. In the first section of the article, heat gain is determined by GLF method, in second section CLF method is used, after that in third section estimation is done by RLF method. The results with respect to various components of building and internal loads have been presented for all the three methods in form of tables. The three methods have been comparatively studied and the results have also been comparatively analyzed.

II. Structural Details of a Residential Building for Kota

For studying the heat gains a single family detached house located at Kota (25.10°N latitude) of dark color has been assumed. The construction and occupancy details are presented in Fig. 2 and table I.

The size of house is 15 m x 12 m which is usually owned by middle income group. Here it is assumed that the house contains two bedrooms, one kitchen, one living room, one bathroom and one storage room. The size of both bedrooms is 9x3 sq. meter. One bedroom has window on south of 1 m x 1 m and other bedroom has window on east of 1 m x1 m. Both bedrooms have one attached bathroom of size 3 m x 3 m. The size of living room is 9 m x 9 m. Living room has door on north of 1m x1.5 m meter. The size of kitchen is 3 m x7 m. Kitchen has west side window of 1 m x1.m. All windows are operable. The size of storage room is 5 m x 3 m.

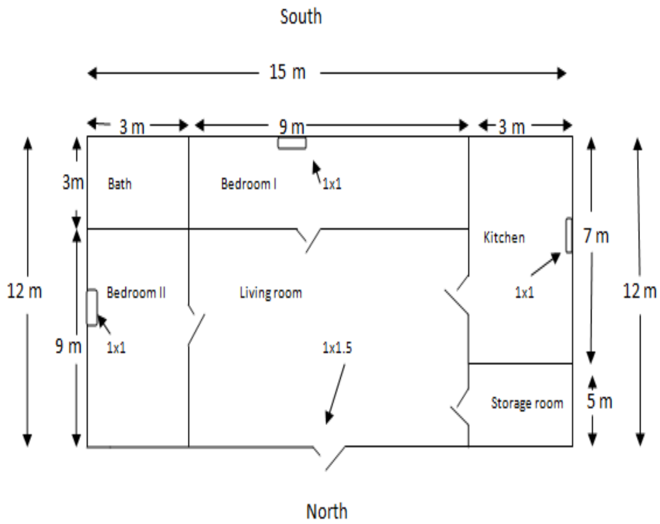

Fig. 2. Dimensions and plan of the residential building taken for study

TABLE I: Construction Type Of House

Component	Details
Roof construction	RCC roof of 150 mm with cast concrete of 100 mm. (U- factor 3.44 W/m²K)
Wall construction	Double brick (common red burnt brick) wall of 230 mm with cement plaster of 13 mm both side.(U- factor 4.9 W/m²K [20]
Floor construction	Clay tile (100 mm)
Fenestration	Regular single glass glazing with wood frame
Door	Plywood of 60 mm thickness.(U- factor 2.9 W/m²K).
Ceiling height	3 m throughout
Outdoor design condition	Temperature of 41°C dry bulb with almost 13 K daily range and relative humidity is 30% with humidity ratio .0147kg/kg [21].
Indoor design condition	Temperature of 24°C dry bulb temperature and 50% relative humidity with humidity ratio .0092 kg/kg.
Occupancy	Four persons

The humidity ratio is taken from psychometric chart. It is assumed that the house has no overhang. The construction of the house is considered as medium.

III. Estimation of Heat Gain Through CLTD/GLF Method

This method uses CLTD values to calculate heat gain through the opaque structure such as walls, roof and floor. Glass load factors are used to find heat gain through windows [22]. Here following equations are used to find out the heat gain.

Glass and window areas $$q = (GLF)A \quad (1)$$

Door $$q = U_d A(CLTD) \quad (2)$$

Above grade exterior walls $$q = U_w A(CLTD) \quad (3)$$

Partitions to unconditioned space $$q = U_p A(CLTD) \quad (4)$$

Ceiling and roofs $$q = U_r A(CLTD) \quad (5)$$

Exposed floor $$q = U_f A(CLTD) \quad (6)$$

Infiltration $$q = 1.2Q\Delta t \quad (7)$$

$$Q_{fr} = ACH \times (room\ volume) \times \frac{1000}{3600} \quad (8)$$

Latent Factor (LF) $0.65+35*H_o$ (9)

U- factor for wall is taken from [20], GLF, CLTD for wall, roof and door and ACH are taken from [22].

Total cooling load = LF x (Sum of individual sensible cooling load components) (10)

Where
q = sensible cooling load(W)
Δt = design temperature difference between outside and inside air(K)
A = area of applicable surface(m^2)
U = U-factor for appropriate construction(W/m^2K)
Q_{fr} = volumetric airflow rate(L/s)
ACH = air change per hour(1/h)
GLF = glass load factor(W/m^2)
CLTD = cooling load temperature difference (K)
LF = latent load multiplier
H_o - outdoor design humidity ratio (vapor kg/dry air kg)

Internal load due to people is assumed 67 W per person. The appliance and light load of 470 W is divided between the kitchen and adjoining room and the laundry and adjoining room. It is assumed that 50% of the kitchen appliances load is picked up in the living room.

TABLE II: HEAT GAIN OF LIVING ROOM

Heat gain process/component	Heat gain (kW)
Infiltration	0.749
Occupants	0.268
Appliances	0.235
Transmission heat gain	
North wall	1.250
North door	0.044
Roof	7.801

TABLE III: HEAT GAIN OF KITCHEN

Heat Gain Process/components	Heat Gain (kW)
Infiltration	0.194
Occupants	0
Appliances	0.235
Transmission heat gain	
West wall	1.568
South wall	0.529
Roof	2.022
West window	0.322

The infiltration is determined using (7) and (8). The heat gain through walls is determined using (3) and the heat gain through roof is determined using (5). The heat gain through window or glass area is determined using (1). GLF is selected for single glass glazing with no shade inside. The design temperature is taken 41^0 C.

TABLE IV: HEAT GAIN OF BEDROOM I

Heat Gain Process/components	Heat Gain (kW)
Infiltration	0.250
Occupants	0
Transmission heat gain	
South wall	1.528
Roof	2.600
South window	0.211

TABLE V: HEAT GAIN OF BEDROOM II

Heat Gain Process/components	Heat Gain (kW)
Infiltration	0.250kW
Occupants	0 kW
Transmission heat gain	
East wall	2.038 kW
North wall	0.441 kW
Roof	2.600kW
East window	0.322 kW

TABLE VI: HEAT GAIN OF STORAGE ROOM

Heat Gain Process/components	Heat Gain (kW)
Infiltration	0.138
Transmission heat gain	
North wall	0.441
West wall	1.176
Roof	1.444

TABLE VII: HEAT GAIN OF BATHROOM

Heat Gain Process/components	Heat Gain (kW)
Infiltration	0.083 kW
Transmission heat gain	
South wall	0.529 kW
East wall	0.705 kW
Roof	0.866 kW

From table II to VII the sensible heat gain of different places of house are shown. The table VIII show total sensible heat gain of each place. The ventilation heat gain is determined separately.

TABLE VIII: SENSIBLE HEAT GAIN

Room	Total sensible load (q_{rm}) in kW
Living room	10.35
Kitchen	4.87
Bedroom I	4.59
Bedroom II	5.65
Storage room	3.20
Bathroom	2.18
Total	30.84

Sensible heat gain due to ventilation

$$q = 1210 \text{x} airflow \Delta t \quad (11)$$

Multiplying the number of people in the space by the .01 m^3/s of outdoor air required per person in the space

Ventilation airflow = 4x0.01 m^3/s/person = 0.04 m^3/s. The ventilation heat gain can be determined using equation (11) with airflow 0.04 m^3/s and Δt as 17^0C. The value for sensible heat gain as a result of ventilation is q = 0.823 kW

Thus total sensible heat gain = 31.66 kW.

The total heat gain is the sum of sensible and latent heat gain. The calculation for latent heat gain is shown below in form of latent cooling factor (L.F.).

Since the temperature outside is assumed to be 41^{0}C and relative humidity is 30% so from psychometric chart (chapter 6 ASHRAE 1997) the humidity ratio of outside is 0.052049 kg vapor/kg dry air. Then

L.F = 0.65+ 35*H_o [22]

L.F = 0.65+35x0.0147 = 1.16

Hence total cooling load= sensible load (31.66) x LF = 36.73 kW.

IV. Heat Gain Estimation Through CLTD/SCL/CLF

In previous section the CLTD / GLF method is used to determine residential heat gain. This method is used for residential buildings only. Through CLTD/ SCL/CLF method both residential and nonresidential heat gain can be determined. In this section it is used to determine heat gain for the same residential building shown in Fig. 2. Following are the equations that are used to determine heat gain.

Conduction through roof, wall and glass

$$q = UA(CLTD) \quad (12)$$

Solar load through glass

$$q = A(SC)(SCL) \quad (13)$$

People $$q_{sensible} = N(sensible\ heat\ gain)CLF \quad (14)$$

$$q_{latent} = N(latent\ gain) \quad (15)$$

Ventilation and infiltration

$$q_{sensible} = 1.23Q_v(t_o - t_i) \quad (16)$$

$$q_{latent} = 3010Q_v(H_o - H_i) \quad (17)$$

Corrected CLTD values $(CLTD)_c = CLTD(Table) + (25.5 - t_i) + (t_{ave} - 29.44)$ (18)

$$t_{ave} = t_o - \frac{t_{daily\ range}}{2} \quad (19)$$

Where

SC- shading coefficient

SCL- solar cooling load factor either considering no interior shade or with shade

CLF- cooling load factor by hour occupancy

H_o – outdoor humidity ratio (from psychometric chart)

H_i – indoor humidity ratio (from psychometric chart)

Q_v- ventilation /infiltration air flow (L/s)

The CLTD value should be corrected according to location condition. Equation (18) and (19) shows the corrected value of CLTD.

In above expressions CLTD value for glass is taken from [23], CLTD values for wall and door are taken from reference [24], SCL values for glass is taken from [23], SC value is taken from [22], CLF value is taken from [22] and it is taken 1 due to 24 hour occupancy, sensible heat gain and latent heat gain from people are taken for sitting and activity level related to very light work [22].

Table IX shows the CLTD values for walls which are used to calculate conduction heat gain presented in table X. Table X, XI and XII shows the conduction heat gain through wall, roof and door. It is determined using (12). Here heat gain is calculated at different hours of the day from1 pm to 6 pm in July month Table XIII shows the conduction gain and solar gain through glass. Tables XIV and XV present the internal heat gain and total internal heat gain.

TABEL IX: CLTD values for walls

Time (pm)	South wall CLTD	North wall CLTD	East wall CLTD	West wall CLTD
1	12.61	15.61	26.61	16.61
2	13.61	16.61	30.61	17.61
3	14.61	17.61	32.61	17.61
4	16.61	19.61	34.61	19.61
5	18.61	20.61	36.61	22.61
6	20.61	22.61	36.61	26.61

TABLE X: Conduction Heat Gain Through Wall

Time (pm)	South wall q (W)	North wall q (W)	East wall q (W)	West wall q (W)
1	2718.72	3327.27	4583.61	2848.62
2	2934.32	3540.42	5249.62	3020.12
3	3149.92	3753.57	5592.62	3020.12
4	3581.12	4179.87	5935.62	3363.12
5	4012.32	4393.02	6278.62	3877.62
6	4443.52	4819.32	6278.62	4563.62
Ave.	3473.32	4002.25	5653.12	3448.87

TABLE XI: Conduction Gain Through Roof

Time (pm)	CLTD	q (W)
1	33.61	20811.31
2	38.61	23907.31
3	42.61	26384.12
4	46.61	28860.91
5	49.61	30718.51
6	51.61	31956.91
Av.		27106.51

TABLE XII: Conduction Gain Through Door

Time (pm)	CLTD	q (W)
1	25.61	111.40
2	27.61	120.10
3	30.61	133.15
4	32.61	141.85
5	35.61	154.90
6	36.61	159.25
Av.		136.78

TABLE XIII: Conduction And Solar Gain Through Glass

Time (pm)	CLTD	q (W)	South SCL	q(W)	East SCL	q (W)	West SCL	q(W)
1	18.61	109.98	32	32	59	59	53	53
2	19.61	115.89	31	31	56	56	84	84
3	20.61	121.80	30	30	52	52	112	112
4	20.61	121.80	28	28	47	47	130	130
5	19.61	115.89	29	29	41	41	130	130
6	18.61	109.98	18	18	33	33	91	91
Av.		115.89		28		48		100

TABLE XIV: Internal Gain

People					
No. of occupants	Sensible heat gain	CLF	$q_{sensible}$(W)	Latent heat gain	q_{latent} (W)
4	70	1	280	45	180
Heat gain from ventilation/ infiltration					
No. of occupants	Total Airflow rate(L/s)	Δt (^{0}c)	ΔH_o (kg water/kg dry air)	$q_{sensible}$ (W)	q_{latent} (W)
4	40	17	0.0055	836.4	662.2
Light and appliances - The light and appliances load is assumed 470 Watt.					

TABLE XV: TOTAL HEAT GAIN

Total sensible load	Total latent load
45460.92 W	842.2 W

V. HEAT GAIN ESTIMATION THROUGH RLF (ASHRAE 2013)

Here same building structure model as mentioned in table I and fig. 2 is used but heat gain is estimated through ASHRAE RLF method. The RLF method is reported to be transparent, simple and more accurate. Following equations are used in this method [25].

$$q_{opq} = A \times CF_{opq} \quad (20)$$

$$CF_{opq} = U(OF_t \Delta t + OF_b + OF_r DR) \quad (21)$$

$$q_{fen} = A \times CF_{fen} \quad (22)$$

$$CF_{fen} = U(\Delta t - 0.46\, DR) + PXI \times SHGC \times IAC \times FF_s \quad (23)$$

$$PXI = T_x E_t \quad (\text{unshaded fenestration}) \quad (24)$$

$$IAC = 1 + F_{cl}(IAC_{cl} - 1) \quad (25)$$

$$A_L = A_{es} \times A_{ul} \quad (26)$$

$$Q_i = A_L IDF \quad (27)$$

$$Q_v = 0.05A_{cf} + 3.5(N_{br} + 1) \quad (28)$$

$$Q_{vi} = Q_v + max(Q_{unbal}, Q_i + 0.5Q_{unbal}) \quad (29)$$

$$q_{vi,s} = 1.23Q_{vi}\Delta T \quad (30)$$

$$q_{ig,s} = 136 + 2.2A_{cf} + 22N_{oc} \quad (31)$$

$$q_{vi,l} = 3010Q_{vi}\Delta W \quad (32)$$

$$q_{ig,l} = 20 + 0.22A_{cf} + 12N_{oc} \quad (33)$$

$$q_l = q_{vi,l} + q_{ig,l} \quad (34)$$

Where

q_{opq}= opaque surface cooling load(W)

A = net surface area(m^2)

CF_{opq} = surface cooling factor (W/m^2)

U = construction U-factor ($W/m^2.K$) (for window it is taken from table 2 chapter 17 and for wall it is taken from carbse tool)

Δt =cooling design temperature difference (K)

IAC_{cl} = interior attenuation coefficient for a completely closed configuration

A_L = effective leakage area

A_{es} =building exposed surface area (m^2)

A_{ul} = unit leakage area (cm^2/m^2) (table 3 chapter 17, house is considered to be averaged)

Q_i = infiltration airflow rate (L/s)

IDF = infiltration driving force (L/ s-cm^2) (table 5 for design temperature 41 which is almost near by 40)

Q_v = required ventilation flow rate (L/s)

A_{cf} = building conditioned floor area (m^2)

N_{br} = no. of bedrooms (not less than 1) (it is considered to be 4)

Q_{vi} = combined flow rate due to infiltration/ventilation (L/s)

Q_i = infiltration leakage rate without mechanical pressurization (L/s)

$q_{vi,s}$ = sensible ventilation/infiltration load (W)

Q_{unbal} = unbalanced airflow rate (L/s)

$q_{vi,l}$ = latent ventilation/infiltration load (W)

ΔH = indoor/outdoor humidity ratio difference (kg_w/kg_{da}) (psychometric chart)

$q_{ig,s}$ = sensible cooling load from internal gain (W)

$q_{ig,l}$ = latent load from internal gain (W)

q_l = total latent load (W)

OF_t, OF_b, OF_r = opaque surface cooling factors (table 7 , considered as a ceiling /roof assembly)

DR = cooling daily range (K)

α_{roof} = roof solar absorptance (table 8, material considered to be metal and dark)

q_{fen} = fenestration cooling load (W)

A = fenestration area (including frame), (m^2)

CF_{fen} =surface cooling factor (W/m^2)

PXI = peak exterior irradiance with inclusion of shading modifications

SHGC = fenestration solar heat gain coefficient (table 2 for single glass glazing and wood frame)

IAC = interior shading attenuation coefficient (there is no shade is assumed inside so it is takes as 1)

FF_s = fenestration solar load factor (table 13 single family detached)

PXI = peak exterior irradiance, (W/ m^2)

E_t, E_d, E_D = peak total irradiance, diffuse irradiance and direct irradiance (W/ m^2) (table 10)

T_x = transmission of exterior screen such as insect screen or shade screen

F_{cl} = shade fraction closed (0) to open (1)

Table XVI shows the heat gain through opaque. OF_t, OF_b and OF_r, values are taken for roof, ceiling assembly and CF is calculated using (21). Daily temperature range is taken as 13 K and heat gain through opaque surface is determined using (20).

TABLE XVI: OPAQUE SURFACES FACTOR

Component	U-factors ($W/m^2.k$)	OF_t	OF_b	OF_r	CF	Cooling load (W)
Roof	3.44	1	27.47	-0.36	136.88	24638.8
Wall	4.9	1	8.2	-0.36	100.55	15836.63
Door	2.9	1	8.2	-0.36	59.508	89.262

Table XVII shows the heat gain through fenestration. Fenestration is assumed of single glazing with wood frame. PXI is calculated from (24). SHGC is taken for single glazing wood frame window. IAC is taken 1 because it is assumed that there is no shade inside. FF_s is taken for single family detached house. CF is calculated using (23). Heat gain is calculated using (22).

TABLE XVII: FENESTRATION SURFACES FACTOR

	U-factor ($W/m^2.k$)	T_x	PXI	SHGC	FF_s	CF	Cooling load (W)
West	5.05	0.64	472.96	0.64	0.56	225.16	225.16
South	5.05	0.64	161.92	0.64	0.56	113.86	113.68
East	5.05	0.64	472.96	0.64	0.56	225.16	225.16

Table XVIII shows the heat gain through infiltration. A_{ul} is selected for averaged house. A_L is determined using (28). IDF is taken for design temperature 40 ^{0}C which is almost nearby 41^{0}C. Q_i is determined using (27). Q_v is determined using (28). Q_{vi} using (29). $q_{vi,s}$ is determined using (30).

TABLE XVIII: INFILTRATION/VENTILATION

A_{es}	A_{ul}	A_L	IDF	Q_i (L/S)	Q_v (L/S)	$Q_{vi,}$ (L/S)	$q_{vi,s.}$ (W)
342	2.8	957.6	0.043	41.18	19.5	60.68	1268.82

Table XIX shows internal heat gain. $q_{ig,s}$ is determined using (31). $q_{vi,l}$ is determined using (32). $q_{ig.l}$ is determined using (33) and q_l is determined using (34).

TABLE XIX: INTERNAL GAIN

$q_{ig,s}$	$q_{vi,l}$	$q_{ig,l}$
598 W	1004.56 W	95.6 W

Table XX presents the total sensible and latent load estimated through RLF method.

TABLE XX: TOTAL LOAD

Sensible load (q_s)	Latent load (q_l)
42,995.51 W	1100.16 W

VI. COMPARATIVE STUDY

A comparison of the relative points of difference and similarity between the three methods used in the previous sections is presented in form of table XXI for better understanding.

It can be seen from the table that in CLTD/GLF method the heat gain through walls and roof is calculated using CLTD values which are specified in tables, whereas in SCL method the specified CLTD value is corrected using (18) and (19).

In RLF method direction is not mentioned while calculating heat gain through wall. Heat gain is calculated for overall wall but in both previous methods heat gain is calculated separately according to direction. In RLF method OF_t, OF_b and OF_r is specified. Same is the case for door.

For windows in GLF method the glass load factor includes both solar and conduction gain and is specified in form of tables. In SCL method conduction and solar gain are calculated separately for the windows. For conduction gain corrected CLTD values are used and for solar gain SCL values are used which are specified. In RLF method FF_s and SHGC values are specified which are taken according to the type.

For occupants in GLF method occupant load is assumed 67 W per person while in SCL method and RLF method latent and sensible load are calculated separately for internal gain which includes occupants and appliances both. For appliances in GLF and SCL method appliances load is assumed 470 W.

In GLF method infiltration and ventilation is calculated separately. In SCL and RLF method sensible and latent load is calculated separately but includes both ventilation and infiltration. Both methods use same formula but in the SCL method the flow rate is assumed while in RLF method the flow rate is calculated. In GLF method latent factor is calculated separately.

TABLE XXI: COMPARATIVE STUDY

CLTD/GLF method	**CLTD/SCL/CLF method**	**RLF method**
• In this method heat gain is calculated room by room. CLTD value is specified in tables for calculation of heat gain of wall, roof and door. The values must be chosen from that specified values accordingly. • When calculating heat gain for window GLF values are specified in tables. In this method GLF includes both conduction gain and solar gain. They are not calculated separately. • In this method people heat gain is assumed of 67 W per person and internal heat gain is assumed 470 W. • Infiltration and ventilation is calculated separately. Infiltration is calculated room by room. For that ACH value is taken from table which is specified for tight, medium and loose construction. • Ventilation load is calculated by considering air flow rate 0.01 m^3/s per person. • In this method latent load factor is calculated which is dependent on outdoor humidity ratio and construction type. • For obtaining the value of total cooling load sensible load is multiplied with latent load factor.	• In this method heat gain is calculated from wall to wall and window to window according to the direction. • Here CLTD values for roof, wall and door is specified in table according to latitude but can also be corrected. • Here CLTD values are taken for estimating conduction gain through window and SCL value to find solar gain through window. SCL value is dependent on latitude. • The CLTD, SCL and CLF values taken in this method include both the effect of time lag in conductive heat gain through opaque exterior surfaces and the time delay due to thermal storage. • In this method people heat gain is calculated according to their activity. Sensible and latent gain is calculated separately and appliances load is assumed 470 W. • Ventilation load and infiltration load is calculated together in which sensible and latent load is calculated separately. Infiltration latent load depends on humidity ratio difference. • The total latent load is sum of latent load due to people and latent load due to infiltration/ventilation.	• RLF method has been developed as a simplified procedure from the Residential Heat Balance method. Several thousand ResHB cooling load results have been used to derive RLF. A range of climate and building types were analyzed. Statistical regression techniques were used to find values for load factors • In this method CFs is calculated for opaque (wall, roof and door) and fenestration (window). • CF of opaque is dependent on OF_t, OF_b, and OF_r values which is specified in tables according to surface type. • CF of fenestration is dependent on T_x, E_t, SHGC, FF_s, F_{cl}, IAC_{cl} which are specified. • Infiltration/ventilation sensible load is dependent on A_{es}, A_{ul}, A_L and IDF which are specified. • Latent infiltration load is dependent on humidity ratio difference. • Internal gain is calculated separately for sensible and latent gain. • Latent gain is sum of internal latent gain and infiltration latent gain.

The results obtained through the three methods have been compiled in table XXII for comparison.

TABLE XXII: COMPARATIVE ANALYSIS

Component/process (Area)	Heat gain (W) CLTD/GLF method		CLTD/SCL/CLF method		RLF method	
	Sensible	Latent	Sensible	Latent	Sensible	Latent
Walls (157.5 sq.m.)	10205	-	16578	-	15837	-
Roof (180 sq.m.)	17333	-	27107	-	24639	-
Door (1.5 sq.m.)	44	-	137	-	89	-
Window (3sq.m.)	855	-	524	-	564	-
Occupants/internal gain	268	-	280	180	598	96
Appliances	470	-	470	-	-	-
Infiltration	1664	-	836	662	1269	1004
Ventilation	823	-				
Latent factor	-	1.16				
Total latent load	-	-	-	842	-	1100
Total sensible load	31662	-	45932	-	42996	-
Total Load	36728		46774		44096	

VII. Results and Discussion

Table II to VIII present the sensible heat gain estimation of residential building in Kota using CLTD/GLF method. This method selected one by one room for heat gain estimation. The sensible heat gain of building without ventilation load is 30.84 kW. The ventilation load in form of sensible heat gain is calculated separately and it is 0.823 kW. The latent factor of building is estimated using (9) and it is 1.16. The total heat gain is estimated using (10). The calculated total heat gain is 36.73 kW.

Interesting point to observe from the results for heat gain through walls was that maximum heat gain is through east wall. The reason can be attributed to the fact that in the mornings when sun is on the east wall the temperature gradient is higher and as a result the conduction gain is more. From CLTD/GLF method heat gain cannot be calculated on hourly basis and this method is used only for residential building. The CLTD/SCL/CLF method can be used for both residential and non-residential building and heat gain per hour can be calculated. Similar observation regarding east wall can be seen from this method also. The tables (IX) to table (XV) present the heat gain estimation for building using CLTD/SCL/CLF method. This method estimates heat gain by selecting one by one component of the building. Table (X) shows the conduction gain through wall from1 pm to 6 pm. The average conduction gain through south wall is 3473.32 W, conduction gain through north wall is 4002.25 W, and conduction gain through east wall is 5653.12 W and through west wall is 3448.87 W.

Table XI shows the conduction heat gain through roof. The total conduction heat gain through roof is 27106.51 W. Table XII shows the conduction heat gain through door and the total heat gain is 136.78 W. Table XIII shows the conduction heat gain through glass and it is 347.67 W. The solar heat gain through glass is 28 W for south, 48 W for east and 100 W for west. Table XIV presents the internal heat gain due to occupant, infiltration and light, appliances. The sensible heat gain due to residents of the building is 280 W and latent heat gain for this method is 180 W. Due to infiltration the sensible heat gain is 836.4 W and the latent gain is found to be 662.2 W. The heat gain due to light and appliances is assumed to be 470 W. The total heat gain calculated is 46774 W.

From table XVI to XX the heat gain of building estimated using RLF method is presented. Table XVI presents the heat gain through opaque surfaces and it is 24638.8 W for ceiling, 15836.63W for wall, 89.26 W for door. Table XVII presents heat gain through fenestrations and it is 225.16 W for west, 113.68 W for south, 225.16 W for east. Table XVIII presents the heat gain due infiltration or ventilation and sensible heat gain due to infiltration is 1268.82 W and latent gain is 1004.56 W. Table XIX shows the internal heat gain including sensible and latent gain. Sensible load is 598 W and latent gain is 95.6 W. Table XX presents the total sensible and latent heat gain with the total gain as 44096 W.

From comparative study of all the three methods it can be seen that CLTD/GLF method predicts heat gain towards lower side whereas CLTD/SCL/CLF method values are higher and RLF values lies in between being more close to CLTD/SCL/CLF method. An important point to notice on comparison of results is that all methods predict around 50% heat gain through roof for this building structure. Another major contribution to heat gain (around 30%) is through walls. The window to wall ratio for the building is 1.9% and therefore the effect of heat gain through windows is only around 8%. Other factors contribute only a minor percentage to the overall heat gain. Thus, from the results it can be concluded that in order to reduce the heat gain and cooling load, major attention must be paid on roof and wall heat gain along with the other factors. In this study the major heat gain occurs from wall and roof and less heat gain is through windows as window area is less. There are various passive measures including insulating layers on wall and roof, white paint on roof, cool coatings, inverted earthen pots on roof, roof pond etc. which can help to reduce heat gain through roof and wall and enhance thermal comfort of buildings [26,27]. The heat gain from window can be reduced by applying low e coating on window glazing, by using overhang, curtains, awnings and also with the help of shading by trees.

VIII. Conclusions

The paper presented the study of heat gain for various components of a typical middle income group residential house in hot dry climatic region in India. For the heat gain study three different methods (CLTD/GLF, CLTD/SCL and RLF methods) were used and compared. From the study it can be concluded that methods which are used in the study are simple and can be used in manual calculation or spreadsheets. The advantage of this study is that the heat gain over various components/processes of building such as roof, walls, windows, infiltration, appliances, occupants etc. can be calculated. CLTD/GLF and CLTD/SCL methods give results of wall heat gain with orientation whereas RLF method results do not specify direction of walls and window. CLTD/GLF method uses specified values whereas CLTD/SCL method has flexibility of allowing variations. CLTD/GLF method predicts heat gain towards lower side whereas CLTD/SCL/CLF method values are higher and RLF values lies in between being more close to CLTD/SCL/CLF method. It is very useful study to get the basic knowledge about heat gains of building and it also helps in better designing of the building with less heat gain by applying suitable passive techniques. Here in this study the windows were of small size so major contribution in heat gain is due to walls (30%) and roof (50%). Therefore, for this type of building structures in hot dry climatic zone passive measures focusing on reduction in heat transfer from walls and roof should be adopted such as insulation, nocturnal cooling, roof ponds, roof garden, cool coating, reflective surfaces etc. If windows of larger area are taken in that case the heat gain through window will also increase so to cut down the heat gain through window the passive measures for window such as low e coating on window glazing, by using overhang, curtains, awnings, shading by trees etc. can be used.

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