

Computer software simulation of cooling loads determination in buildings

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Abstract

Accurate determination of the cooling load units in private and commercial buildings is an essential factor relating to human comfort as it corresponds to human efficiency and well-being of those that dwell or operate within such buildings. In this study, a computer simulation was developed for the determination of optimum cooling loads for air conditioning in a building. In the developed programme, input parameters used include building structure, air infiltration, number of occupants, number and types of doors and windows. The computer simulation developed considered all intricate parameters that may lead to drop in the cooling loads. The programme was versatile, easy to operate and suitable for the determination of appropriate cooling load in any building. Results show that the software programme developed can be applied to determine cooling loads for commercial buildings, worship centres and private homes.

Keywords: cooling load, temperature, heat gain, air conditioning, building

1. Introduction

Places of human dwellings, requires aesthetics, minimum comfort and security. Besides being aesthetically pleasing, the human environment must provide light, air and thermal comfort. In addition, proper acoustics and hygiene are important. People feel uncomfortable when they are either too hot, too cold or when the air produces unpleasant odour or is stale. Positive comfort conditions are those that do not distract by causing unpleasant sensations of temperature, drafts, humidity or other aspects of the environment. Ideally, in a properly conditioned space, dwellers should not be distracted of equipment noise, heat or air motion. The feeling of discomfort by humans is based on a network of sense organs such as the eyes, ears, nose, tactile sensors, heat sensors, and the brain. Therefore, thermal comfort is that state of mind that is satisfied with the thermal environment which is the condition of minimal stimulation of the skin, Aktacir *et al*; 2008, and Hui and Cheung, 1998. For human comfort and efficiency, the body requires a fairly narrow range of environmental conditions compared with the full scope of those found in nature. The factors that affect humans pleasantly or adversely include: temperature of the surrounding air, radiant temperatures of the surrounding surfaces, humidity of the air, air motion, odours, dust, aesthetics, acoustics and lighting. Of these, the first four relate to thermal interactions between people and their immediate environment. Provision and functionality of such facilities in buildings particularly air conditioner are required for optimum operations and interactions of people who inhabit such buildings, Ahmed, 2008.

Air conditioning system is required to carry away heat and refresh the enclosure, Kareem, 2008. Heat is a form of energy that flows from a point at one temperature to another point at a lower temperature. There are two forms of heat of concern in planning for comfort: sensible heat and latent heat. Sensible heat is an expression of the degree of molecular excitation of a given mass. Such excitation is caused by a variety of sources, such as exposure to radiation, friction between two objects, chemical reaction or contact with a hotter object.

Mechanical systems in building services comprise of fire protection, sewage disposal system, water storage system, plumbing and piping system, heating, ventilation and air conditioning system (HVAC). Although most building codes require load calculations for heating and cooling equipment installed in new buildings, the requirement is widely ignored and rarely enforced as reported by Ahmed, 2012. Most HVAC professionals never perform cooling load calculations; instead, installations of air conditioners are based on the rules of the thumb, Ahmed, 2012. The age-old rule of the thumb used by most professionals was based on one ton of cooling equipment for every 37.16 square meters of conditioned space. In a concession to recent improvements in insulation levels and window specifications, it has been suggested that one ton is required for every 55.74 square meters. This rule of the thumb most often result in either gross oversizing or under sizing of cooling

equipment. The estimates never accounts for orientation of the walls and windows, the difference in surface area between a one-story and a two-story homes of the same floor area, the differences in insulation and air leakage between different buildings, the number of occupants and many other factors, Ahmed, 2012. Using a rule of the thumb to size an air conditioner is no substitute for performing a room-by-room cooling load calculation. Room-by-room calculations are necessary for many reasons such as to properly size ductwork, to address unusual architectural features like rooms with large windows or openings, Li *et al*; 003.

Load estimations in air conditioning system have been carried most often manually which requires more time and energy. This procedure in itself may not give consideration to some factors that affects the cooling load determinations. Determination through the use of computer application becomes less burdensome and more accurate. To minimize time and be more accurate in the determination of cooling loads in buildings this software is developed using JAVA (Jdk, Netbeans-8) programming language tool was developed. Java as used in this work is simple, object oriented and highly portable. The program can run on any combination of hardware and operating systems with adequate runtime support.

2. Heating, ventilation and Air conditioning system

Heating, ventilating and air-conditioning (HVAC) is a mechanical and electrical system employed to provide thermal control or cooling loads in buildings, Peterson and Liley 2013.

Control of the thermal environment is a key objective for occupied buildings. In the modern building design context, thermal control expectations go far beyond survival and involve fairly complex thermal comfort and air quality concerns. HVAC system provides interior thermal conditions that a majority of occupants find acceptable. Occasionally this may simply require that air be moved at a particular velocity to enhance convective cooling and evaporation from the skin. Much more commonly, however, providing for occupant comfort will require that an HVAC system add or remove heat to or from building spaces. In addition, it is normally necessary for moisture to be removed from spaces during the hot season sometimes moisture will need to be added at another season. The heat and moisture control functions of HVAC systems provide the foundation for key system components, Aktacir *et al* 2008; Peterson and Liley 2013.

2.1 Heat gain

The main sources of latent loads are infiltration, perspiration and exhalation by occupants, cooking, laundry, showering and bathing. A home's latent load is normally assumed to be 30% of the total load while the actual latent load varies widely and depends on a home's infiltration rate, the climate, and the amount of moisture generated by occupants, Aktacir *et al*; 2008. Heat gain in commercial buildings is dominated by internal loads such as computers, lighting, and body heat. Compared to commercial buildings, most family homes have fewer electrical devices and occupants per square meter and have a building envelope with a bigger surface area per square meter of conditioned space; as a result, internal loads play less of a factor in homes than in offices, schools or commercial centres or halls.

Nevertheless, internal loads can be significant in homes and must be calculated. The sensible heat gain (body heat) emitted by one occupant is usually assumed to be 67 watts. The default assumption for a home's appliances is 469 watts while lighting is assumed to add another 469 watts as in Peterson and Liley 2013. A heat gain calculation requires that all of the heat flows into a building: internal and external, sensible and latent be added up. Because of thermal mass effects and the dynamic nature of heat gain, the cooling load of the air conditioning equipment will usually be less than the building's heat gain. Cooling load calculation methods consider the heat storage capacity of the building shell (a factor that delays heat flow through the building's walls and ceiling) and the heat storage capacity of internal furnishings (a factor that dampens the effect of short-term heat gains).

2.2 Air Conditioning

Air conditioning is the process of maintaining specific conditions of temperature, moisture content in air and dust level inside an enclosed space. The conditions to be maintained are dictated by the need for which the conditioned space is intended for. Air conditioning in office buildings, public auditoriums, private houses, classrooms, worship halls and other public building is meant for

providing comfort conditions for the occupants. In addition to the control of temperature and relative humidity for comfort conditioning, it is necessary to filter the air and maintain proper air circulation, Peterson and Liley 2013. Skin temperature varies according to the surrounding temperature and relative humidity. If the surrounding temperature is less than the body temperature, there is a flow of heat from the body to the surrounding. On a hot day when the surrounding temperature is higher than the body temperature, there is no heat flow from the skin to the surrounding and heat is felt by the person. The situation is worse if the outside is hot and humid because no evaporation of moisture can take place on the skin surface and the person feels hot and uncomfortable, Li *et al*; 2003 and Aktacir *et al*; 2008. In order to provide comfort by air conditioning, the temperature and relative humidity inside the room should be maintained at certain levels so that heat dissipation from the skin is steady, Gutkowski, 1996; Rajput, 2005.

The ability of air-conditioning system to maintain condition of comfort or condition required by a product or process has made its use inevitable for sustainable development especially in temperate regions, Li *et al*; 2003.

2.3 Human comfort

Human comfort whether at home, recreation centers or work places are of paramount importance to the health and wellbeing of people. Air conditioning is mainly used as human comfort medium. It is used more often in situations where the daily temperatures are high. Air conditioning controls the moisture, cools and cleans the air. Without proper estimation of cooling load, much energy will be wasted due probably to overload of the system.

Hourly dry bulb temperature for Ikeja and Ilorin were obtained by Olorunmaiye *et al*; 2012 which showed the average temperature of 32.4 °C and 35 °C for Ikeja and Ilorin respectively. The implication of the higher temperatures observed is that more energy will be needed for running refrigerators and air conditioning units. If the cooling load is higher than the heat gained by the building, the temperature will be lower. However cooling load for building varies and it depends on building specification, weather, location, user trend and surrounding condition, Hui and Cheung 1998. Air-conditioning system is designed with ability to subdue most common heat loads such as sensible and latent heat, Hui and Cheung, 1998. Load estimating in air-conditioning system design has been carried out manually particularly in Nigeria and many other developing countries of the world as reported by Ahmed, 2012 and Kareem, 2008. A lot of time and energy are wasted when estimating the cooling loads in complex and intricate buildings of modern time, Hui and Cheung, 1998 and Kareem, 2008.

3. Cooling load

To appreciate the theory behind cooling load calculations, it's useful to understand all of the ways that a building gains heat, Hui and Cheung 1998. Some heat originates from outside the building, which is external load, while some heat is generated inside the building which is internal load. When outdoor air is hot and humid, the moisture load that accompanies infiltrating air must be removed by the air conditioner. Similarly, moisture is generated by building occupants through the people taking showers, cooking, watering plants or mopping the floor which must also be considered when making cooling load calculations depending on the area being considered. Cooling load calculations are made for worst-case conditions. The heat-loss calculations are made for the coldest night of the year, cooling-load calculations assume late-afternoon conditions during the hottest month of the year. The outdoor design temperature is usually less than a location's record hot temperature, however; designing a system for record temperatures results in equipment oversizing, Li *et al*; 2003 and Olorunmaiye *et al*; 2011. Outdoor design conditions are location-dependent, different locations have different dry-bulb temperature and humidity conditions. Therefore, generalization of dry-bulb temperature and humidity conditions does not make for accurate determination of cooling loads. The usual indoor design conditions for cooling load calculations are a temperature of 24 °C and an indoor relative humidity of 50 %, Aktacir *et al*; 2008. Calculation methods assume that a representative number of appliances and lights are on, and that the building is fully occupied.

Summary of the factors that affect cooling load determinations are,

- i. The climate,

- ii. Orientation of the building, windows are not usually evenly distributed on all four orientations, rotating the orientation of a building design by 90 degrees can change the cooling load.
- iii. Latitude, because the sun angle changes with latitude,
- iv. The roof overhang width, as well as the distance between the top of the window and the soffit,
- v. The presence or absence of insect screens on windows as they affect solar heat gain, window screens are removable, most calculation methods assume that windows have no insect screens,
- vi. The presence or absence of curtains or blinds,
- vii. The building's air leakage rate, cracks or openings,
- viii. The mechanical ventilation rate,
- ix. The number of occupants, and
- x. The lighting and appliance specifications, energy-efficient appliances and lighting produce less waste heat than inefficient appliances and lighting.

3.1 Methods of Cooling load determination

Methods for the determination of cooling loads include Transfer Function Method (TFM), Cooling Load Temperature Differential/Cooling Load Factors (CLTD/CLF), Total Equivalent Temperature Differential/Time Averaging (TETD/TA), Heat Balance (HB), Radiant Time Series (RTS). Of these methods, the Transfer Function Method (TFM) developed by ASHRAE based on Stephenson and Mital's method is most widely used. Due to the intensive iterations process involved in the method, other computational methods which are less tedious have been adapted, Hui and Cheung, 1998.

3.2 Governing equations

The governing equations for the computation of cooling loads are based on the parameters contributing to its determination, Aktacir *et al*; 2008.

3.2.1 Heat gain by radiation

The total heat gain due to solar radiation is given as:

$$Q_{s,tot} = Q_{s,w} + Q_{s,g} \quad (1)$$

Where,

$Q_{s,w}$ - maximum heat gain through walls and roof,

$Q_{s,g}$ - mean hourly heat gain through windows during sunshine hours.

$$Q_{s,w} = 0.174 \times A \times e(T_h - T_e) \quad (2)$$

$$Q_{s,g} = \tau I_d A_{sun} + \tau' I_s A_{tot} \quad (3)$$

A - Area of both wall and roof,

e - emissivity of radiating body,

T_h - absolute temperature of radiating body,

T_e - absolute temperature of receiving body,

τ, τ' - transmissivity for direct and scattered radiation respectively,

I_d - direct radiation for vertical window (W/m^2),

A_{tot} - total area of the window (m^2),

A_{sun} - the surface area of the window exposed to solar radiation (m^2) and

I_s - the scattered radiation calculated for solar air temperature (W/m^2).

3.2.2 Heat gain through building structure due to heat transmission

Heat gained through the building structure can be expressed as;

$$Q_{B.S} = \sum_{i=1}^n (A_i U_i \Delta t_i) 24 / T_{cool} \quad (4)$$

Where,

A_i (m^2) -surface area of a part of building structure possessing a certain overall heat transfer coefficient U_i (W/m^2K) and exposed to a certain temperature difference Δt_i (K)

T_{cool} -time of cooling per day, hours.

$$U_i = \frac{1}{\frac{1}{\alpha_i} + \sum_{j=1}^m \frac{\delta_j}{K_j} + \frac{1}{\alpha_0}} \quad (5)$$

Where,

α_i -Heat transfer coefficient from inside the room (W/m^2K),

α_0 -Heat transfer coefficient from outside the room (W/m^2K),

δ_j -thickness of the layer of structure (m) and

K_j -Heat conductivity of the material of the layer of structure (W/mK).

$$\alpha_0 = 5.7 + 3.8 V \quad (6)$$

V -wind velocity

3.2.3 Heat gain through electrical lights

There are two commonly types of light bulb, the incandescent and the energy saving bulb. The energy saving bulb has low level of heat generation and energy consumption than the incandescent ones. Thus heat generated is determined by,

$$Q_l = \sum_{i=1}^n (P_{l(i)} F_{cl(i)}) n_{l(i)} \quad (7)$$

Where,

$P_{l(i)}$ - power of the lamp operating simultaneously with others, (W)

$F_{cl(i)}$ -cooling load factor of the tubes as in Table 1,

$n_{l(i)}$ - No of lighting points.

Table 1: Cooling Load Factor of Lamps (Gutkowski, 1996)

$T_{op}(hrs)$	2	4	6	8	10	12
F_{cl}	0.82	0.88	0.92	0.95	0.97	0.99

3.2.4 Heat generated by occupants

Sensible heat and moisture are emitted by humans in different states of activity. In high-density places, such as auditoriums and halls, these sensible and latent heat gains comprise a large fraction of the total load and are determined thus,

$$Q_0 = \sum_{i=1}^n (q_{ps} F_{cp(i)} + q_{pl}) n_{p(i)} \quad (8)$$

Where,

q_{ps} - sensible heat gain from one person, see Table 2, (W)

q_{pl} - latent heat gain from one person, see Table 2, (W)

$n_{p(i)}$ - number of persons staying in the room simultaneously.

$F_{cp(i)}$ - cooling load factor of the occupants depending on time of stay in the room as in Table 3,

T_{st} -Total heat gain from one person equals,

$$q_{pt} = q_{ps} + q_{pl} \quad (9)$$

Table 2: Sensible and Latent heat gains per person (Varkie, 2002)

Level of activity	Typical application	Heat gain per person	
		Sensible(W)	Latent(W)
Seated at rest	Theatre	71.8	30.8
Seated, light work	Office	71.8	45.4
Moderate office work	Office	73.3	58.6
Standing, walking slowly	Retail sales	73.3	73.3
Light bench work	Factory	80.6	139.2
Dancing	Nightclub/Church	89.4	159.7
Heavy work	Factory	169.9	264.9

Table 3: Cooling Load Factor of the Occupants (Gutkowski, 1996)

Time of stay (hr)	2	4	6	8	10	12	14	16	18
F _{cp}	0.58	0.71	0.79	0.84	0.89	0.92	0.94	0.96	0.97

3.2.5 Heat gain due to ventilation

The movement or introduction of air into and out of a building through specific openings can be determined thus,

$$Q_v = V_v \rho_a (h_A - h_R) \times 10^3 \quad (10)$$

Where,

V_v - volumetric flow rate of outdoor ventilation air (m³/s),

ρ_a - density of dry outdoor air (kg/m³),

h_A - enthalpy of outdoor air (kJ/kg) and

h_R - enthalpy of indoor air (kJ/kg).

$$V_v = \frac{V_R}{T_{op}} \quad (11)$$

Where,

V_R - volume of the room

T_{op} -period of operation per day in seconds

3.2.6 Heat gain due to infiltration of outdoor air

Outdoor air infiltration is the uncontrolled and often undesired leakage of air into the building through cracks and perimeter gaps in the windows and doors. Air rates due to infiltration through cracks are approximately selected thus;

Windows $Q_{iw} = 8.207 \times 10^{-4} \text{ m}^3/\text{s}$ (Gutkowski, 1996)

Doors $Q_{id} = 1.394 \times 10^{-3} \text{ m}^3/\text{s}$ (Gutkowski, 1996)

3.2.7 The heat gain due to infiltration through cracks

$$Q_{ic} = L_{tcr} a_i p_a (h_A - h_R) 24/T_{cool} \times 10^3 \quad (12)$$

Where,

$L_{t,cr}$ - length of crack

It is assumed that there is a crack of 0.02m long on the window and 0.01m on the door. (Gutkowski, 1996)

T_{op} -Total time of opening the door per day,

$T_{op} = 2 \text{ min}$ (assumption).

$Q_{id} =$

$$0.4 F_{pd} B \left[2g(\rho_R - \rho_A) \rho_R \rho_A H^3 \left(\rho_R^{1/3} + \rho_A^{1/3} \right)^{-3} \right]^{0.5} (h_A - h_R) \times 10^3 \times \frac{T_{op}}{T_{cool}} \quad (13)$$

3.2.8 Heat produced by moisture

Moisture sources within the building includes: shower areas, swimming pools or natatorium,

$$Q_m = M_m(I_o + C_v t_v) \times 10^3 \quad (14)$$

Where,

M_m - moisture gain,

I_o - latent heat of evaporation of water at $0^\circ\text{C} = 2501.6 \text{ KJ/kg}$

C_v - specific heat of water vapour = 1.925 KJ/kgK

t_v - room temperature, 24°C ,

It is assumed that moisture gain is 0.04 litres. (Gutkowski, 1996),

1 litre = 1kg

$M_m = 0.04 \text{ Litre} = 0.04 \text{ kg}$.

The total heat gained is the sum of all the heat gains thus:

$$Q_{tot} = Q_{s,tot} + Q_{B,s} + Q_l + Q_o + Q_v + (Q_{iw} + Q_{id}) + Q_{id} + Q_m \quad (15)$$

$$\text{Compression work} = \frac{\text{Re frigerating capacity}}{\text{Coefficient of Performance}} \quad 16$$

4. The computer program

Computer program was developed known as Java Development Kit (JDK). The input parameters interface is shown in fig 1, Graphical User Interface (GUI) for all the conditions of heat gains. The variable parameters simulated by the computer are the heat gain due to solar radiation through walls and roof and mean-hourly, heat gain through windows, outside heat gain through building structure due to heat transmission, heat produced by lighting bulbs, heat gain produced by occupants, heat gain due to ventilation, heat gain due to air infiltration through openings and heat gain produced by moisture as displaced in fig 2, space information while fig. 3 is the compression work. The flow chart for the computer simulation is shown in fig. 4.

4.1 Assumptions

- (a) Weather conditions are selected from a long-term statistical database,
- (b) The length of crack on windows is 0.02m and for doors is 0.01m,
- (c) Moisture gain is 0.04kg,
- (d) Coefficient of performance of a refrigerating system, normally 2.5,
- (e) Time of opening of doors per day of 8 hours working day (2minutes) and
- (f) Design indoor temperature of 24°C and outdoor temperature is 37°C .

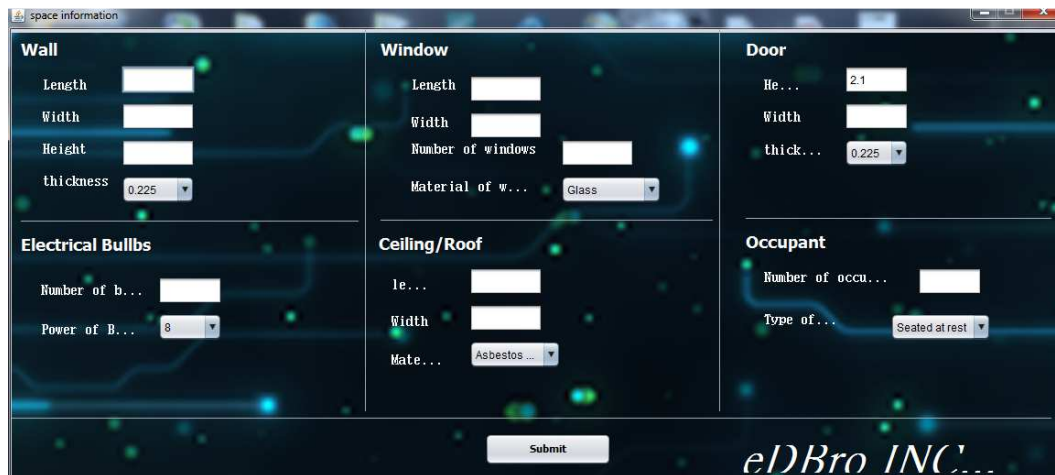


Fig.1 Graphical user interface

Fig.2 Space information

Fig.3 Compression work

5. Results and discussion

Figure 5 shows the cooling load as determined by the developed computer software. From this figure, there is close correlation between the established results by ASHRAE and the current work. The graph shows that the obtained results from the current software are very close for values between 8 and 13 hours. The deviation as seen from 14 to 17 hours may be as a result of input parameters errors. The trends obtained was in agreement with that of Aktacir *et al*; 2008. The maximum estimated cooling load obtained from the present study was 13.6 kW while that obtained by ASHRAE is 12.5 kW which makes that of the present study about 7.2 % higher. The differential which is minimal may also be attributed to the assumptions and design considerations made in the computer simulation.

The computer simulation of cooling loads is followed according to the flow chart in figure 4.

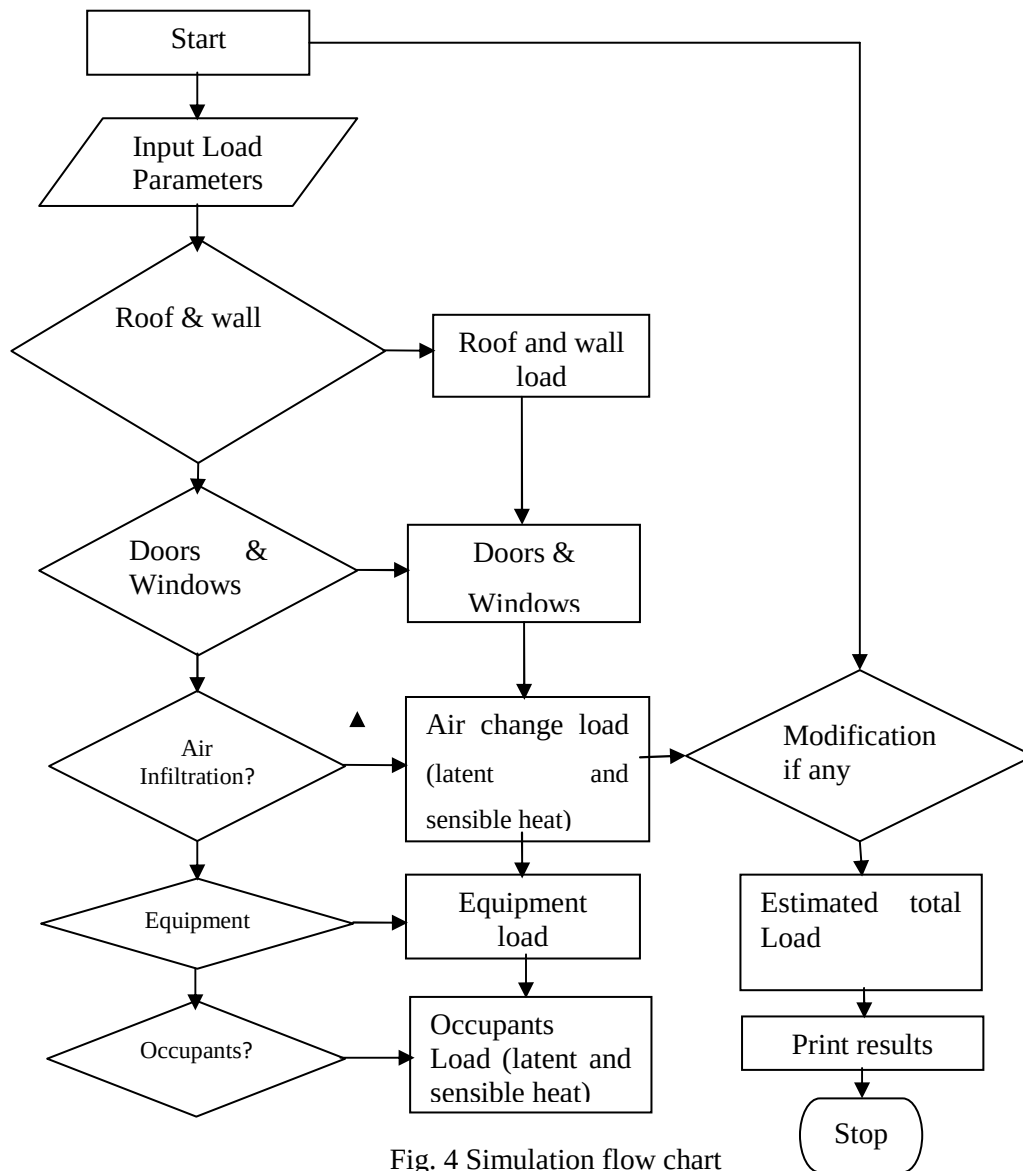
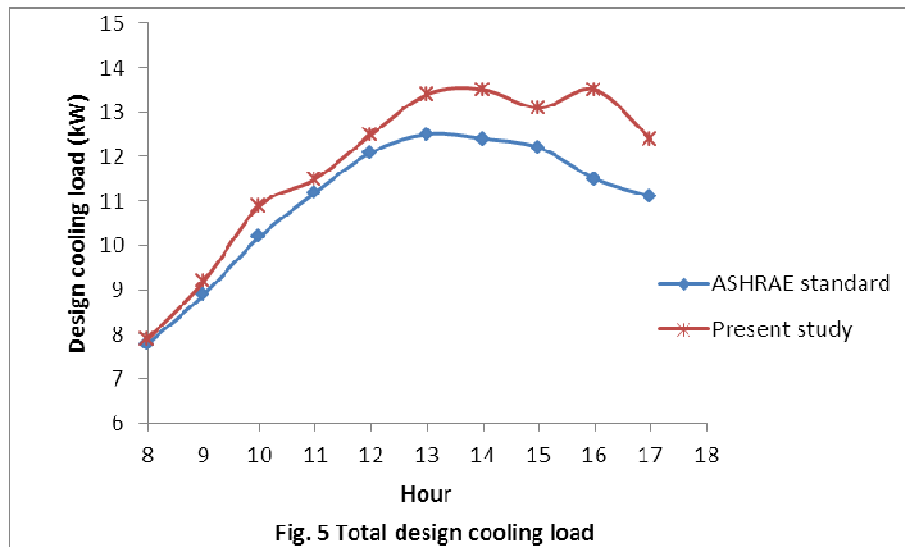


Fig. 4 Simulation flow chart

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6. Conclusion

The study developed a system through which cooling loads for air conditioning system for buildings (residential and commercials) can be determined. Using this developed program, both sensible and latent loads can be determined. The program is not only limited to residential buildings but can be applied to commercial buildings as all the heat load parameters required for its determination are included in the software. The software provides an effective and user friendly way of determining the cooling loads for buildings and can be run on computer windows. From the results obtained, the software developed can effectively be used to calculate the cooling loads in any buildings.

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