Development of a System Framework that Estimate Cooling Loads for Air-Conditioning System for Residential and Non-residential Buildings

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Abstract
Cooling Load estimation for air conditioning systems is done either by manual calculation or judgmental estimation based on experience of the air conditioning practitioner. While manual calculation is laborious, estimate based on judgment is liable to error due to gigantic, complex and dynamic nature of present day architectural designs. Load calculation through computer automation is likely to make a positive impact in the dynamic nature of air conditioning applications. This study developed computer software to handle simple and typical load estimate for air conditioning in Nigeria. The study has developed a system framework that estimate cooling loads for air-conditioning system for residential and non-residential buildings. It provides an effective and user-friendly way of introducing a residential cooling load calculation program to users. This software results compare favourably with the previous works and it can be used for educational purposes in air conditioning laboratory.
Keywords: Air-conditioning, Cooling loads, Residential buildings, System

1. Introduction

Cooling load calculation/estimation is the first step to control air-conditioning. Air conditioning is utilised to supply a controlled atmosphere to public buildings such as offices, halls, homes, and industries for the comfort of human being or for the proper performance of some industrial processes. Full air-conditioning implies that the purity, movement, temperature and relative humidity of the air be controlled within the limits imposed by the design specification (Pederson *et al*., 1997). For any air conditioning system to perform satisfactorily, equipment of the proper capacity must be selected based on the instantaneous peak load requirements. The type of control used is dictated by the conditions to be maintained during peak and partial load. Undersized equipment will not provide the required conditions while a greatly oversized one will lead to operating problems such as “hunting”. Load estimating in air-conditioning system design has been carried out manually in many quarters. A lot of time and energy are wasted when estimating the cooling loads in complex and intricate buildings of modern time (ASHRAE, 2001 & ASME, 2011).

Building cooling load components are; direct solar radiation, transmission load, ventilation/infiltration load and internal load. Calculating all these loads individually and adding them up gives the estimate of total cooling load. The load, thus calculated, constitutes total sensible load. Normal practice is that, depending on the building type, certain percent of it is added to take care of latent load. Applying the laws of heat transfer and solar radiation makes load estimations. Step by step calculation procedure has been adequately reported in the literature. It is a scientific and exact approach, but time consuming and lengthy. Overall heat transfer coefficients for all the components of building envelope are computed with the help of thermal properties of the building materials. For the design conditions and the building materials used, cooling load temperature difference, solar heat gain factors and cooling load factors are calculated (Mord, 2010 & Ansari *et al.*, 2005).

Principles of solar energy calculation are applied to determine the direct and in direct solar heating component of the building. The requisite data of building material properties, climate conditions and ventilation standard are also established and reported (Ahmed, 2012). First principle is applied to yields the rates of heat transfer through different building components. All these components, when added up, give the total cooling (or heating) load of a building. This lengthy procedure makes the theoretical approach more of academic interest, which quite often, the design engineers do not prefer. A widely popular method is by using load estimation forms; standard or developed by the designer/company. This approach saves both effort and time. Although it is an approximate method, it gives quite acceptable results for selecting suitable capacity of air conditioning units. The Air Conditioning and Refrigeration Institute (ACRI) load estimation form is used very popularly. There are many similar forms available commercially, which consist of tabulated data as function of design temperature difference. All the probable loads are included in these forms. These consist of direct solar radiation, transmission load through exposed walls (un-insulated and those with different degree of insulation), partition walls, all the possible types of walls, roof, ceilings, floors and outdoor air load. Sometimes, big companies prepare their own load estimate forms. A third method is by applying computer software, standard and commercially available or developed by the designer/company. Due to omnipresence of personal computers, the third method remains the most popular these days (ASHRAE, 1997 & Iu, 1999).

Cooling load estimation through computer application sounds reasonable to replace tedious and time consuming manual methods. To achieve this computer automation, software is developed, programming language tool is used in this work because of its simplicity and easily understandable by professionals. Besides, it is a versatile tool that has ability to handle large and complex problem of this kind (ASHRAE, (1995).

2. Methodology

The CLTD/SCL/CLF method is based on the transfer function method (TFM). It may be used to approximate the cooling load corresponding to the three modes of heat gain (conductive heat gain through surfaces such as windows, walls and roofs; solar heat gain through fenestrations; and internal heat gain from lights, people and equipment) and the cooling load from infiltration and ventilation (ASHRAE, 1995 & Ansari *et al.*, 2005).

The sources of the space cooling load, forms of equations to use in the calculations, appropriate references, are given as follow: (Ahmed, 2012 & Ansari *et al.*, 2005)

2.1 External Cooling Load

This is the rate at which heat is removed from the materials that envelope a building on the outside.

a. Roof: Roof is exposed to direct sunlight on the outside, hence, heat will be removed using equation (1)

$$Q = U * A * CLTD \quad (1)$$

Where Q = the rate of heat flow in watt (W), U = Thermal transmittance or design heat transfer coefficient (constant = 1.25W/m²K), CLTD = Cooling Load Temperature Difference (constant = 43ºC) and A = Area in m²

b. Wall: Heat penetrates through the walls and will have to be removed, the heat is from outside, hence external using equation (2 - 5)

North: $$Q = U * A * CLTD \quad (2)$$

West: $$Q = U * A * CLTD \quad (3)$$

East: $$Q = U * A * CLTD \quad (4)$$

South (internal): $$Q = U * A * (t_{new} - t_i) \quad (5)$$

Where t_{new} = adjoining unconditional space temperature, t_i = temperature of inside, Q = the rate of heat flow in watt (W), U = Thermal transmittance or design heat transfer coefficient (constant = 1.65W/m²K), CLTD = Cooling Load Temperature Difference, (constant = 6.8ºC for North, 10.9ºC for West, 19.9ºC for East) and A = Area in m²

c. Transmission through glass windows and doors: heat that penetrates through the glass windows and doors from the outside will be removed using equation (6)

$$Q = U * A * (t_o - t_i) \quad (6)$$

Where A = Area of north glass (windows + doors) + Area of east glass (windows + doors) + Area of west glass (windows + doors), t_o= outside temperature, t_i = inside temperature, Q = the rate of heat flow in watt (W), U = Thermal transmittance or design heat transfer coefficient, (constant = 5.7W/m²K),

d. Wooden door: Heat that penetrates through the wooden door from outside will be removed using equation (7)

$$Q = U * A * (t_{new} - t_i) \quad (7)$$

Where Q = the rate of heat flow in watt (W), U = Thermal transmittance or design heat transfer coefficient, (constant = 2.16W/m²K), and A = Area in m²

e. Roof asbestos sheet, flat roof with card board: Heat from roof asbestos sheet, flat roof with card board from outside through into the building will be removed using equation (8)

$$Q = U * A * CLTD \quad (8)$$

Where Q = the rate of heat flow in watt (W), U = Thermal transmittance or design heat transfer coefficient, (constant = 1.25W/m²K), CLTD = Cooling Load Temperature Difference, (constant = 43 ºC) and A = Area in m²

f. Solar load through glass windows and doors: Heat radiation is considered and removed, It is estimated as in equation (9)

$$Q = A * (SC) * (SHGF) * (SLF) \quad (9)$$

Where SC = shading coefficient, (constant = 0.53), SHGF = solar heat gain factor for external shaded windows/doors, (constant = 761), SLF = Solar load factor, (constant = 0.61 for West Glass, 0.21 for

East Glass, 0.98 for North Glass), A = Area in m² and Q = the rate of heat flow in watt (W)

g. **Partition walls and windows:** These are spaces that requires no cooling like toilet and store, which shares walls with spaces to be cooled. Heat through this place will be removed, it is estimated as in equation (10)

$$Q = U * A * (t_{new} - t_i) \quad (10)$$

Where t_{new} = adjoining unconditional space temperature, t_i = temperature of inside, Q = the rate of heat flow in watt (W), U = Thermal transmittance or design heat transfer coefficient, (constant = 1.65W/m²K) and A = Area in m²

2.2 Internal Cooling Load

This is the rate at which heat is removed from the materials and people that make up or inside a building.

a. **People:** People emit heat with respect to activity they are engaged in. This will be considered and heat removed as in equations (11 &12)

$$Q_S = N * S \quad (11)$$

$$Q_1 = N * L \quad (12)$$

Where N = Number of people, S = Sensible heat gain, (constant = 80), L = Latent heat gain (constant = 120), Q_s = the rate of heat flow in watt (W) – sensible and
Q_1 = the rate of heat flow in watt (W) – latent

b. **Lights:** Heat electrical lightings emit on the inside of the building will have to be considered and removed using equation (13)

$$Q_{light} = N * W \quad (13)$$

Where N = number of lights in space, W = Watts input from electrical plans or lighting fixture data and Q_{light} = the rate of heat flow in watt (W) – through light

c. **Appliances and Equipment:** other electrical appliances used in the building will be considered and the heat removed as estimated using equation (14)

$$Q = N * W \quad (14)$$

Where N = number of appliances and equipments in space, W = Watts input from electrical plans and Q = the rate of heat flow in watt (W)

d. **Ventilation and infiltration air load estimation:** Ventilation is the circulation of fresh air from outside to inside of a building. This has to do with the volume of the space and the air change rate. Infiltration is the amount of air that enters a space due to the opening through the building, it is calculated as in equations (15 - 17)

$$Q_{sensible} = (cfm * 1.08 * (t_o - t_i)) * 0.3 \quad (15)$$

$$Q_{latent} = (cfm * 1.08 * (w_o - w_i)) * 0.3 \quad (16)$$

$$Q_{air\ total} = Q_{sensible} + Q_{latent} \quad (17)$$

Where cfm = Air volume in cubic feet per minute (volume of room space x Air change per hour), t_o, t_i = outside, inside air temperature, ºC, w_o, w_i = outside, inside air humidity ratio, kg(water)/kg (dry air), $Q_{sensible}$ = the rate of heat flow in watt (W) – sensible, Q_{latent}= the rate of heat flow in watt (W) – latent and $Q_{air\ total}$ = the rate of heat flow in watt (W) – air total

2.3 Total Cooling Load

This is the sum of the external cooling and internal cooling loads get the total cooling load of a space. Nigeria is approximately categorised under Latitude 5 degree North and February 21 as the design month and day. Usually, the highest outdoor temperature occurs between 1pm and 4pm. The greatest solar heat gains are likely to occur sometimes between these hours. The aggregate solar heat gains for the roof and west facing glass were considered, in order to obtain the time when the peak gain will be experienced from the two sources. This is known as the design time or sun time. Flow chart diagram of cooling load calculation in sequential order is as presented Figure 2.

2.4 Summary of Load Calculation Procedure

a. Establish outside design conditions
b. Determine inside conditions
c. Determine the occupancy and use of the space

d. Calculate the heat gain through the building structure
e. Calculate internal heat gains (Occupancy, Lighting and Equipment)
f. Determine the ventilation and infiltration
g. Estimate the total sensible and latent heat loads, including a safety factor
h. Select the equipment.

3. Software Methodology

Adlak Cool Calc 1.0 was developed using Java programming language on a Windows 8.1 PC. The graphical user interface was developed using Java Swing. It's composed of:

- JFrame: responsible for the closable window
- JTabbedPane: used for different tabs used for the various inputs
- JPanel: a component used for holding other components and placed on the JTabbedPane
- JLabel: it was used for putting titles and labels.
- JTextField: it was used for accepting inputs from users
- JButton: it was used to perform actions such as calculate, next, back.
- JMenu: it was used for the menu area; the about, exit.

Once the application is ran (adlak.jar), it opens the app window where input is expected from the user. The application window first shows the tab responsible for collecting and calculating 'External cooling load': Roof. Once you enter the area, you will be required to press the 'Calculate' button. Immediately, the rate of heat flow for the roof is calculated and displayed in the textfield below, also the application stores this value in the memory, to be used subsequently for calculating the total result.

Next, the user is expected to press the 'Next' button, which leads to the next tab for the 'Wall' calculation. The same process described above continues till it get to the 'Total' tab. On getting to this tab, it computes the total of all the heat flows and displays the result in the textfield.

Some safety precautions were taken to ensure the calculations are not corrupt, which are:

- The Calculate button would not work if any of the fields is empty or contains values that are not numerical
- The Next button would not work if the current tab's 'Rate of Heat Flow' has not been calculated.
- A user can press the Back button to edit the input made in the previous tab. Note: for the changes to be effected, the user must press the Calculate button again.

Figure 1 shows the Graphical User Interface (GUI) of the developed software - Adlak Cool Calc 1.0 can carry out cooling load calculation for Lagos and Southern Nigeria. The subsequent versions will consider other countries worldwide.

4. Results and Discussions

To test software and compare results, a model building plan of Multipurpose Hall with the following characteristics were assumed. Desired indoor conditions: 24ºC DBT and 55% relative humidity, Outdoor conditions: 32ºC and 27ºC WBT.

Occupancy is 600 people, Hall windows (glass) are 3.5m x 2m, Double doors (glass) are 2m x 2m, Asbestos sheet flat roof with cardboard ceiling 4.5m from the floor and Overall building height is 5m.

Note that, U is thermal transmittance, CLTD is cooling load temperature difference, CLF is cooling load factor, SLF is solar load factor, SC is shading coefficient, SHGF is solar heat gain factor for external shaded windows, sensible heat gain, latent heat gain and BF is ballast factor are all constants in the software from ASHRAE database.

Values for U roof = 1.25W/m²k, U wall = 1.65W/m²k, U single glass = 5.7W/m²k, and so on.

4.1 Case Study 1

Result of carrier software for cooling load calculation of the multipurpose hall:
Central Cooling Coil Sizing Data: Total Coil Load is 273.1 kW and Sensible coil load is 127.4 kW

4.2 Case Study 2

Result of LG software for cooling load calculation of the multipurpose hall:
LG SPACE LOAD SUMMARY, SPACE NAME: Multipurpose Hall
COOLING: Sensible (W): Load: 368353.75, S.F: 1.00, Final: 368353.75 and
Latent (W): Load: 6763.27, S.F: 1.00, Final: 6763.27 and Total (W): 375116.02
HEATING: Sensible (W): Load: 640.98, S.F: 1.00, Final: 640.98

4.3 Case Study 3

Result of DAIKIN software for cooling load calculation of the multipurpose hall:

Sensible heat (W): 15600 W. Latent heat (W): 108001 W and Overall Total (W): 264002 W

4.4 Case Study 4

Result of manual rule of thumb for cooling load calculation of the multipurpose hall:
Area of the hall = 36 x 20 = 720 m² and then, 720 x 0.3 = 216 kW or 216000W and
Hence, Overall Total heat for Manual = 216000 W.

4.5 Case Study 5

In this present study, the results of ADLAK Cool Calc 1.0 obtained during cooling load calculation for the multipurpose hall are:
Total heat flow rate in Watt (W) – Roof =38700.0 W
Total heat flow rate in Watt (W) – Wall =9985.14 W
Total heat flow rate in Watt (W) – Transmission through glass =3283.2000000000003 W
Total heat flow rate in Watt (W) – Solar Load =16851.1274 W
Total heat flow rate in Watt (W) – Wooden door =0.0 W
Total heat flow rate in Watt (W) – Partition Walls and Windows =742.5 W
Total heat flow rate in Watt (W) – People =120000.0 W
Total heat flow rate in Watt (W) – Through light =720.0 W
Total heat flow rate in Watt (W) – Through light =7200.0 W
Total heat flow rate in Watt (W) – Appliances & Equipments =5000.0 W
Total heat flow rate in Watt (W) – Ventilation & Infiltration =60256.224 W
Overall Total heat flow rate in Watt (W) = 262018.1914 W

4.6 Comparison of the Cooling Loads

The comparison of different cooling loads (W) obtained by using different software for the same capacity is presented Figure 3. It is evident from Figure 3 that the present work, ADLAK COOL CALC software results compared favourably with the previous work.

5. Conclusions

The study has developed a system framework that estimate cooling loads for air-conditioning system for residential and non-residential buildings. It provides an effective and user-friendly way of introducing a residential cooling load calculation program to users. If given more time and resources, the sizing of air-conditioning equipment for the building and the design of air distribution system can also be incorporated in this program. Moreover, this software can be used as a reference for educational purposes.

6. Recommendation

The factors that must be critically looked into during load estimation process include orientation of building (location), space used, dimensions, column and beams, construction materials, surrounding conditions, windows, doors, people, lighting, ventilation, thermal storage and floor. But, for simplicity some values were assumed rather than read out accurate values from the database. CLF for lights were assumed 0.85. Following improvements can be made:

i. In future CLF values for lights can be evaluated from CLF tables of ASHRAE fundamentals handbook by providing provision for selecting room furnishing and equipment operation conditions.
ii. Only few predefined walls are available in this software. For ease of use custom input methods can be introduced. Vast different wall construction materials and their properties can be included in the database.
iii. Due to data unavailability only Nigeria nation design data were used for the development of the software. But all Countries design data can be included for more precise results on the basis of data availability.

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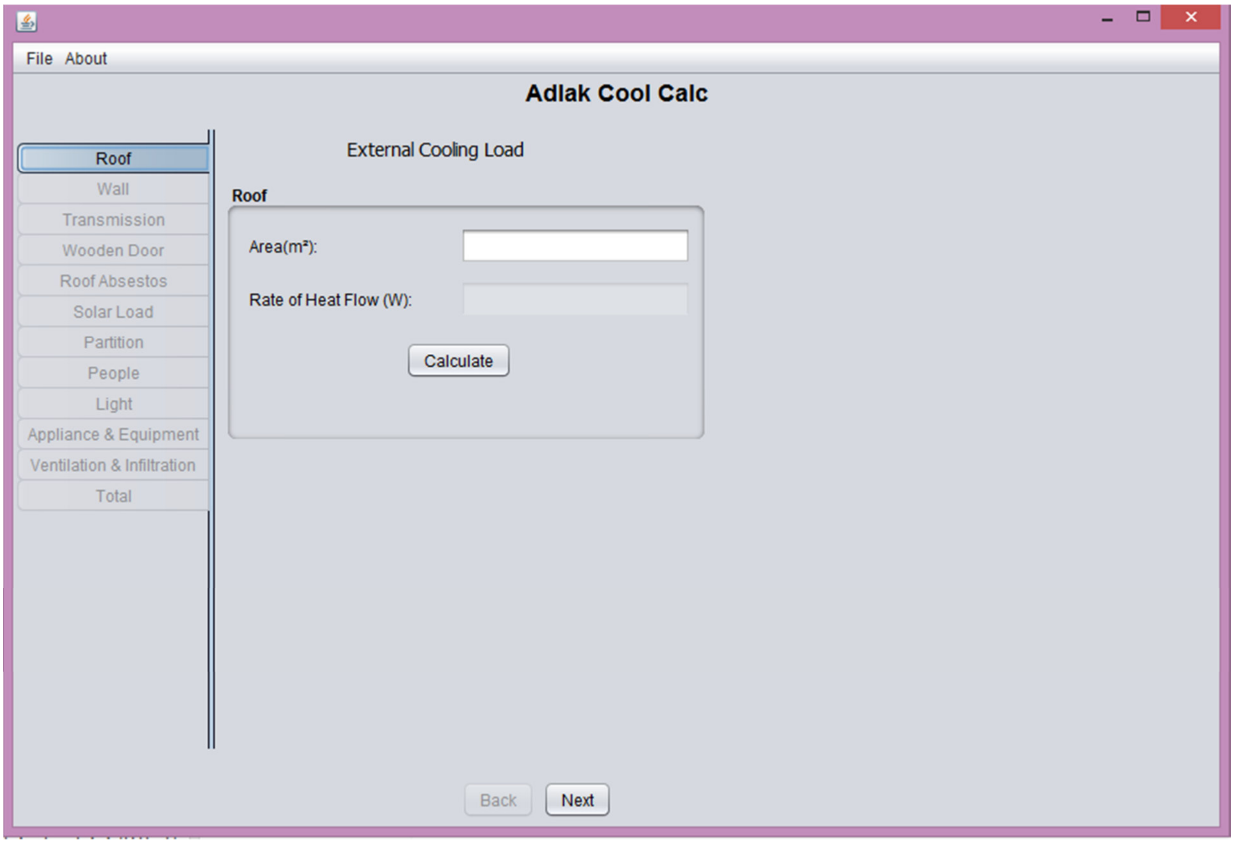

Figure 1. The Graphical User Interface (GUI) of the developed software -Adlak Cool Calc 1.0

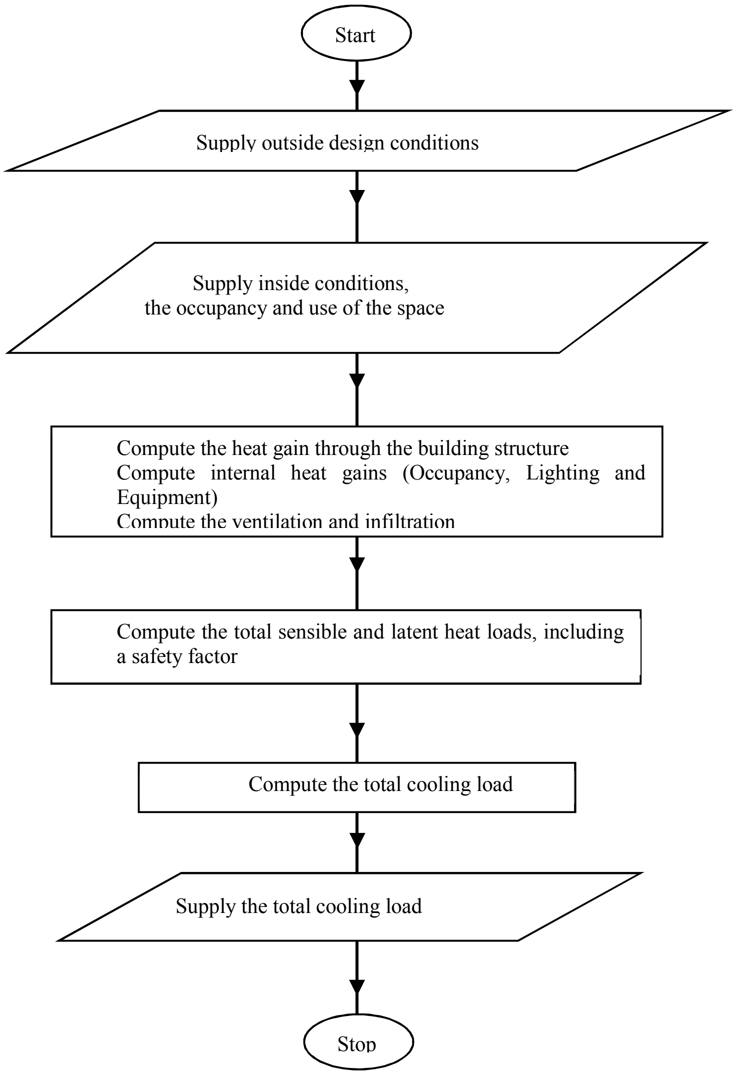

Figure 2. Flow chart of cooling load calculation

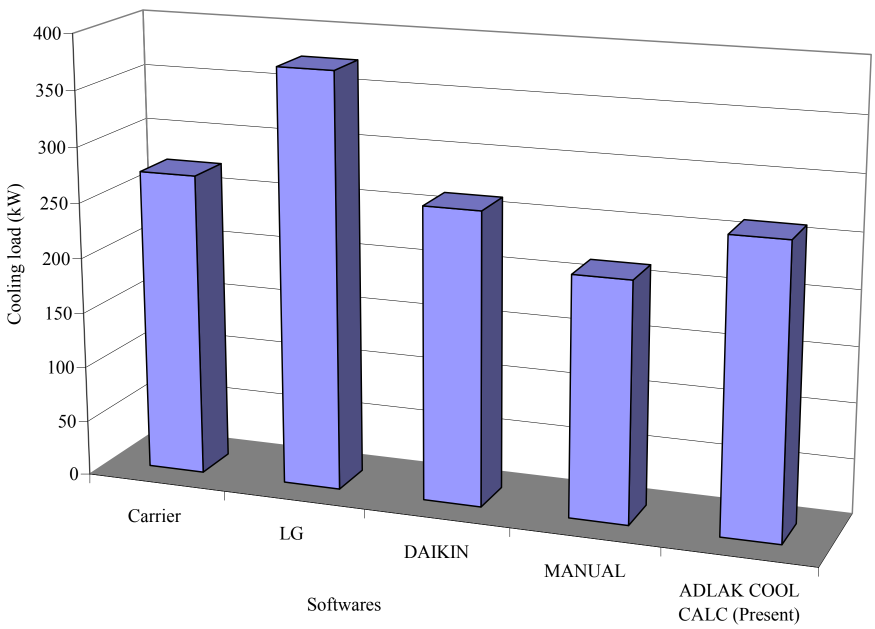

Figure 3. Graphical Comparison of the Cooling Loads

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