Comparison between Hand Calculation and HAP programs for estimating total cooling load for Buildings

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A B S T R A C T

The purpose of this paper is to compare between (hand calculation) and HAP programs for building cooling load for thermal comfort, humidity comfort, ventilation, and air filtration. This project is developed to find the best way to apply the concept of (HVAC) system design in Erbil Polytechnic University Refrigeration and Air-conditioning Engineering Department. HAP uses the ASHRAE transfer function method for load calculations and detailed 8,760 hour-by-hour simulation techniques for the energy analysis. The aim of this study is to calculate and compare between hand calculations and HAP program. The building consists of two storeys with 19 zones to be conditioned. The international standard is used in the presented study. This paper estimates the cooling load for different climate conditions by using CLTD method for the building. Cooling load such as, people, lighting, infiltration and ventilation heat gain can be easily entered to the MS-Excel program. In addition to other data such as the cooling loads due to walls and roofs. The results show that there are similarities between the two methods. The maximum total cooling load deference between hand calculation and HAP program is 2.1%. Therefore, the hourly analysis program can be used for any building design to calculate the load and select the systems.

Nomenclatures

| Symbol | Description | Unit |
|--------|-------------|------|
| A | Area | m² |
| ACH | Air change per hour | m³/h |
| ASHRAE | American Society of Heating, Refrigerating and Air Conditioning Engineers | |
| CLTDc | Cooling load temperature difference correct | ºC |
| CLTD | Cooling load temperature difference | ºC |
| CLF | Cooling load factor | |
| DR | Daily range | |
| f | Factor for attic fan or duct above ceiling | |
| HVAC | Heating, ventilating, and air conditioning | |
| HAP | Hourly Analysis Program | |
| kW | Kilo wattage | kW |
| Kc | wall color correction | |
| Ks | roof color correction | |
| LM | Latitude & month applied to wall & roof | Degree |
| m₀ | Mass of ventilation | kg/s |
| Q sa | Sensible heat factor | W/m² |
| Q lh | Latent heat Factor | W/m² |
| SHG | Solar heat gain | W/m² |
| S.C | Shading coefficient | |
| Tavg | Average outside temperature | ºC |
| tmax | Maximum outdoor temperature | ºC |
| t₁ | Temperature room | ºC |
| TR | Tons of refrigeration | |
| U | Overall heat transfer coefficient | W/(m².ºC) |
| V | Volume | m³ |
| ṷ | specific volume | m³/kg |

1. INTRODUCTION

The main purpose of air conditioning profession is to provide a comfortable atmosphere for people or machines (computer centers, metrology laboratories….) inside a closed space. Therefore, cooling (decrease the temperature of the surrounding air), heating (increase the temperature of the surrounding air), humidifying (increase the moisture content in the surrounding air), dehumidifying (decrease the moisture content in the surrounding air) and ventilation and cleaning (renew and clean the air inside the space)
processes describe the main processes of the air-conditioning profession.

Human body temperature is normally estimated at 37 ºC. If the body needs to dissipate some of its heat to the surrounding and can't, it will overheat. Body feels comfortable when the heat level is transferring to the surrounding air at comfort rate. The rate of heat transfer depends on the properties of air surrounding temperature, humidity, and air velocity (ASHRAE 1997).

Air conditioner is an appliance or a mechanism designed to extract heat from humanly occupied space air temperature using refrigeration cycle. The earlier form of air conditioning was invented thousands of years ago in the form of wind shaft which was built on top of the roof in order to catch the wind and pass it through water and blow the cooled air into the building (ASHRAE 1997).

In business, industry, schools, hospitals, hotels, theaters, restaurants and homes air conditioning is no longer auxiliary but an essential part of modern living. There are four atmospheric conditions, which affect human comfort such as:

- Temperature of the surrounding (ambient) air.
- The humidity of the air.
- Air purity.
- Air moving.

True air conditioning system should meet all listed factors for human health.

1.1 Air Conditioning Systems

Air conditioning for people is the control of temperature, humidity, air movement and air cleanliness. Air conditioning systems can be categorized according to the terminal cooling medium which is going to be used for four basic system categories (ASHRAE 1995).

- All-air systems
- Air-water systems
- All-water systems and, direct expansion systems

1.2 Cooling load Calculation

Estimation of heat or rejected heat is usually based on steady-state heat transfer, and the results obtained are usually quite adequate, for cooling design, however. Transient analysis must be used. The instantaneous heat gain into a conditioned space is quite variable with time, because of the strong transient effect created by the hourly variation in solar radiation. There may be an appreciable difference between the heat gain of the structure and the heat removed by the cooling equipment at a particular time. This difference is caused by the storage and subsequent transfer of energy from the structure and contents to the circulated air, If this is not taken into account, the cooling and dehumidifying equipment will usually be grossly oversized (ASHRAE 1981).

The differentiate between heat gain, cooling load, and heat extraction rate. Heat gain is the rate at which energy is transferred to or generated within a space. It has two components, sensible heat and latent heat, which must be computed and tabulated separately. Heat gains usually occur in the following forms:

1. Solar radiation through transparent area.
2. Heat conduction through boundaries with convection and radiation from the inner surfaces into the space.
3. Sensible heat convection and radiation from internal objects.
4. Ventilation (outside air) and infiltration air.
5. Latent heat gains generated within the space. The cooling load is the rate at which energy must be removed from a space to maintain the temperature and humidity at the design values. The cooling load will generally differ from the heat gain because the radiation from the inside surface of walls and interior objects as well as the solar radiation coming directly into the space through openings which does not heat the air within the space directly. This radiant energy is mostly absorbed by floors, interior walls, and furniture, which are then cooled.
primarily by convection as they attain temperatures higher than that of the room air. Only when the room air receives the energy by convection does this energy become part of the cooling load (ASHRAE 1997).

1.3 THE SOFTWARE: HAP
Hourly Analysis Program (HAP) is a computer tool produced by Carrier, a company providing solutions for air conditioning, heating and refrigeration. The aim of this program is to assist engineers to designing HVAC systems for commercial buildings. It presents two tools in one: estimation of the loads and designing system, and simulation of the energy use and calculation of energy costs. The program is thus split in two parts: HAP system design features and HAP Energy Analysis Features (HAP Carrier 2005).

In the first part, HAP is able to perform the following tasks:
- To calculate design cooling and heating loads for spaces, zones, and coils.
- To determine required airflow rates for spaces, zones and system.
- To size cooling and heating coils.
- To size air circulation fans.
- To size chillers and boilers.

During the energy analysis, HAP executes the following tasks:
- To simulate hour-by-hour operation of all heating and air conditioning systems.
- To simulate hour-by-hour operation of all plant equipment.
- To simulate hour-by-hour operation of non-HVAC systems.
- To calculate the total energy use and energy costs based on the previous simulations.
- To generate tabular and graphical reports of hourly, daily, monthly and annual data.

HAP’s calculation method is made according to the ASHRAE’s standards. Moreover, it runs detailed 8760 hour-by-hour simulation for energy analysis purpose.

2. LITERATURE REVIEW
As HAP only provides differential integrated dry-bulb temperature, differential integrated enthalpy controls and differential non-integrated dry-bulb temperature control, the study is thus restricted to those three types. However, it would have been interesting to realize the simulation with a control taking in account integrated enthalpy and dry-bulb temperature (Zmeureanu et al., 1988).

Carrier’s Hourly Analysis Program HAP is designed for the practicing engineer, to facilitate the efficient day-to-day work of estimating loads, designing systems and evaluating energy performance. Careful attention has been given to design of the graphical user interface and to reporting features. Tabular and graphical output reports provide both summary and detailed information about building, system and equipment performance (HAP Carrier 2003).

Thermal load of building is important to find exact air conditioning equipment and air handling unit. Since it is important to achieve comfort operation and good air distribution in the air-conditioned zone. It should consider the highest temperature of the summer and lowest in the winters that occur in the location of the building. Building location construction materials and other interior loads must be considered for estimation of accurate thermal loads (Hani H.2013).

The effective design of central air conditioning can provide lower power consumption, capital cost and improve quality of a building. The result of the calculation of difference using CLTD method were compared with standard data by ASHRAE and CARRIER Fundamental Hand Books (SANDIP K.2014).

3. THEORETICAL ANALYSIS
The Erbil technical engineering college is in
Erbil city (latitude = 36.191 °N and Longitude = 44 °E). The building is not surrounded by any construction. Therefore, the building is directly open to atmosphere. 

The construction of the building as shown in figure and for finding the overall heat transfer coefficient (U) we use below equation (ASHRAE. 1997, chapter 28).

\[
U = \frac{1}{\sum R} = R \text{ for convection} + R \text{ for conduction} + R \text{ for radiation}
\]

\[
R \text{ for conduction} = \frac{\Delta x}{k}
\]

3.1 PROPERTIES OF COOLING LOAD CALCULATION

In Cooling load temperature difference method CLTD for air conditioned space we must choose:-

- Indoor design temperature.
- Outdoor design temperature.
- Daily range.
- Latitude and the day of the year.
- Roof and external walls color.
- Building and walls orientation.
- Overall heat transfer coefficient for roof, walls, and floor.
- People inside the space and their activities.
- Number and type of lights.
- Other electrical equipments.

Calculate average outdoor air temperature from below equation.

\[
T_o = t_o - \frac{DR}{2}
\]

For roofs and external walls (exposed to solar radiation):

\[
q(\text{wall or roof}) = U \times A \times CLTD_C
\]

For CLTD correction external walls:

\[
CLTD_C = (CLTD + LM) \times K_w + (25.5 - t_r) + (T_o - 29.4)
\]

For Correction CLTD Roofs:

\[
CLTD_C = [(CLTD + LM) \times K_r + (25.5 - t_r) + (T_o - 29.4)] \times f
\]

Cooling load for windows

By Radiation: \[Q = (\text{SHG mix} \times \text{CLF} \times A \times \text{S.C}) \]

By Conduction: \[Q = A \times U \times CLTD \]

Cooling load from people: \[Q = \text{No. of people} \times \text{sensible heat of people} \]

\[Q = \text{No. of people} \times \text{latent heat of people} \]

Cooling load from equipment equals total power or wattage in the zone

Cooling load for ventilation and infiltration are:-

\[Q_{Sh} = m_{vent} \times (h_A-h_{in}) \]

\[Q_{Lh} = m_{vent} \times (h_{out}-h_A) \]

And finally total cooling load = Q sensible heat + Q latent heat= (External wall + internal wall + Roof + Window + doors + S.H people+ S.H equipment + S.H Infiltration + S.H ventilation) + (L.H people +L.H Infiltration+ L.H ventilation)

4. HOURLY ANALYSIS PROGRAM (HAP)

This program is released as two separate, but they have similar products. The “HAP system design load” program provides system design and load estimating features. The full “HAP” program provides the same system design capabilities plus energy analysis features.

4.1 HAP SYSTEM DESIGN FEATURES.

HAP estimates design cooling and heating loads for commercial buildings in order to determine required sizes for HVAC system components. Ultimately, the program provides information needed for selecting and specifying equipment. The program performs the following tasks:

5. RESULTS AND DISCUSSION

The results show the cooling load calculation of different climate conditions by using CLTD method for a multi-story building which is a part of an institute. Cooling load items such as people, lighting, infiltration and ventilation can easily be entered to the MS-Excel program. The HAP can also be used to calculate cooling
load due to walls and roofs. The total floor area of the building is calculated as 952 m$^2$, as mentioned earlier.

Results were compared by the outcomes from HAP 4.2 program. It is shown that there is little difference (2.1 %) between the two results due to defining the thermal resistance for the used materials of the wall, roof, and windows. The results compared between hand calculation and HAP program. The results showed good agreement between them.

5.1 DESIGN PARAMETERS
The Erbil technical engineering college is placed in Erbil city (latitude=36.191 °N and Longitude = 44 °E). There is no existing building in front or behind of the building which means that the sides of the building are directly open to atmosphere:-
Region:- Middle East
Location:- Iraq-Erbil

5.2 CALCULATION OF HAP ANALYSIS:-
HAP programs windows only contain Baghdad and Mosul city when select Iraq. We select Mosul city because its weather properties are near Erbil, that can be changed according to the specific design conditions like design temperature, relative humidity and location as shown in the figure (1). All calculations are based on the maximum load in July because maximum ambient temperature is in 3pm 21 July.

5.3 Space parameters:
5.3.1 GENERAL:-
The program can indicate specific space conditions like: roof, door, lights, windows, people, equipments, internal and external walls as shown in figure (2).

5.3.2. INTERNAL LOAD:-
Defined as the loads of overhead lighting, task lighting, equipment, people, miscellaneous, and schedule for each one to enter as shown in figure (3).

5.3.3 Walls, windows and doors:
They are defined as the external walls area, number of windows, doors on walls, and theirs components. As shown in figure (4).

5.3.3.1 Walls components:
The walls are consisting of gypsum board, heavy concrete block and low concrete, and theirs thickness. To determine heat transfer coefficient of walls (U), in this study, the low concrete is converted to heavy concrete to determine nearest value of U to the theoretical U as shown in figure (5). Moreover, the roof component design and calculation are according to specific design or entire design as shown in figure (6).

5.3.3.2 Infiltration and partitions:
One air change per hour is selected for infiltration and the internal wall in the building is considered as a partitions. Finally the result of the cooling load, total cooling load of each zone of the building and difference between the hand calculation and HAP program have been demonstrated as showed in table (1) and figure (7). The result of one zone of the HAP program is shown in table (2), and the building architecture drawing of ground and first floor plan as shown in figure 8(a and b).

6. CONCLUSIONS
In this study, Refrigeration and Air conditioning Engineering Department building located in Erbil was considered for calculation of cooling loads. The hand calculation accuracy and features make it sufficient for real design of HVAC systems.

The main conclusions which can be drawn from the results of the present work are:-
1. The total cooling load for the Air conditioning of the building by hand calculation requirement is 95.7 TR. and total cooling load for HAP programs requirement is 93.6 TR.
2. For hand calculation method it is found that each TR can cover 9.94 m$^2$ floor areas.
While, for HAP program it is found that each TR can cover 10.17 m$^2$ floor areas. The HAP program can be used for any building design to calculate the load and select the systems.

| Zones | Total cooling Load by hand calculation (kW) | Total cooling Load by HAP (kW) |
|-------|--------------------------------------------|--------------------------------|
| Zone 1 | 5.21                                      | 5.8                           |
| Zone 2 | 3.64                                      | 6.4                           |
| Zone 3 | 9.6                                       | 9.1                           |
| Zone 4 | 4.35                                      | 4.4                           |
| Zone 5 | 0                                         | 0                             |
| Zone 6 | 0                                         | 0                             |
| Zone 7 | 33.61                                     | 33.4                          |
| Zone 8 | 32.87                                     | 33                            |
| Zone 9 | 4.4                                       | 5.4                           |
| Zone 10| 4.69                                      | 4.8                           |
| Zone 11| 11.22                                     | 11.2                          |
| Zone 12| 4.65                                      | 4.4                           |
| Zone 13| 18.46                                     | 23.4                          |
| Zone 14| 34.22                                     | 34.9                          |
| Zone 15| 29.57                                     | 25.2                          |
| Zone 16| 45.45                                     | 44.4                          |
| Zone 17| 36.36                                     | 34.5                          |
| Zone 18| 37.17                                     | 36.1                          |
| Zone 19| 19.02                                     | 17                            |
| Total (KW) | 336.49                                     | 329.4                          |
| Total (TR) | 95.68                                      | 93.66                          |

Table (1) Total cooling load of the building

Table (2) Design of zone 14 cooling load by HAP
Figure (7) Comparison of cooling load between hand calculation and HAP programs

Figure 8(a) Building architecture drawing of ground floor plan

Figure 8(b) Building architecture drawing of first floor plan

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