CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF MECHANICAL ENGINEERING

Department of Environmental Engineering

Master's Thesis

Energy Consumption of AC system

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FACULTY OF MECHANICAL ENGINEERING CTU IN PRAGUE

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Monitoring of air-conditioning system in library building in Prague is the is the main task if this thesis. Evaluate the sizing of AC system and analyse data from AC system monitoring.

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Ashrae Fundamentals 2013, ISBN 9781936504466, Atlanta 2013

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III. THESIS ASSIGNMENT RECEIVED

The student is aware that the thesis has to be accomplished through an independent and unassisted student's work, supported only by recognized consultations. Literature and other information resources as well as consultants' names have to be acknowledged in the thesis.

24/04/2017 M. Praveen

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Statement

I declare that I have worked out this thesis independently assuming that the results of the thesis can also be used at the discretion of the supervisor of the thesis as its co-author. I also agree with the potential publication of the results of the thesis or its substantial part, provided I will be listed as the co-author.

In Prague: ______________________ Signature: ______________________

Acknowledgement

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Abstract

The Main aim of this thesis work is energy consumption especially about air conditioning in a library building. Studied about air conditioning and heat gains in a building for different applications. Total heat gains have been calculated from the radiation, conduction and heat generated within by people, lights, computers and other sources in a building. The aim is to analyze this gain and compared with the real consumption in a building with different climate year to determine the overall energy consumption for cooling.

List of Symbols

Symbol	Description	Unit
ρ	Density	kg/ m^3
v	Volume flow rate	m^3/s
ΔT	Temperature difference	K
H	Heat transfer Coefficient	W/ m^2K
S	Surface area	m^2
I	Intensity	W/ m^2
¥	Shading Coefficient	-
c	Specific heat capacity	kJ/kg.K
N	Number of hour	h
t_i	Indoor temperature	◦C
t_e	External temperature	◦C

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1 Introduction

Air-conditioning is a process that simultaneously conditions air; distributes it combined with the outdoor air to the conditioned space; and at the same time controls and maintains the required space's temperature, humidity, air movement, air cleanliness, sound level, and pressure differential within predetermined limits for the health and comfort of the occupants [2].

The majority of home and smaller commercial air conditioning systems circulate a compressed gas refrigerant in a closed "split" system to cool and condition inside air. The refrigerant has to be re-cooled and condensed, and outside air is the medium most often used to accomplish this. The term "split" simply means that components are divided into inside and outside portions as opposed to being located together in a "package" unit. The refrigerants, widely recognized by the trademark "Freon'', helps cool and dehumidify the inside air. In a "forced air" system, an internal blower circulates the conditioned air through ducts to the rooms where the cooler air is needed. The air ducts generally run either below the ceiling and inside the rooms (conditioned air) or in the attic (unconditioned air). An outside fan pulls air across the external parts of the system to cool and condense the refrigerant.

The types of buildings which the air-conditioning system serves can be classified as:

• Institutional buildings, such as hospitals and nursing homes

• Commercial buildings, such as offices, stores, and shopping centers

• Residential buildings, including single-family and multifamily buildings

• Manufacturing buildings, which manufacture and store products

1.1 Types of Air-Conditioning Systems

In institutional, commercial, and residential buildings, air-conditioning systems are mainly for the occupant's health and comfort. They are often called comfort air-conditioning systems. In manufacturing buildings, air-conditioning systems are provided for product processing, or for the health and comfort of workers as well as processing, and are called processing air-conditioning systems. Based on their size, construction, and operating characteristics, air-conditioning systems can be classified as the following [2].

Individual Room or Individual Systems. An individual air-conditioning system normally employs either a single, self-contained, packaged room air conditioner (installed in a window or through a wall) or separate indoor and outdoor units to serve an individual room is "Self-contained, packaged" means factory assembled in one package and ready for use.

Space-Conditioning Systems or Space Systems. These systems have their air-conditioning—cooling, heating, and filtration—performed predominantly in or above the conditioned space. Outdoor air is supplied by a separate outdoor ventilation system.

Unitary Packaged Systems or Packaged Systems. These systems are installed with either a single self-contained, factory-assembled packaged unit (PU) or two split units: an indoor air handler, normally with ductwork, and an outdoor condensing unit with refrigeration compressor(s) and condenser. In a packaged system, air is cooled mainly by the direct expansion of refrigerant in coils called DX coils and heated by a gas furnace, electric heating, or a heat pump effect, which is the reverse of a refrigeration cycle.

Central Hydronic or Central Systems. A central system uses chilled water or hot water from a central plant to cool and heat the air at the coils in an air handling unit (AHU). For energy transport, the heat capacity of water is about 3400 times greater than that of air. Central systems are built-up systems assembled and installed on the site. Packaged systems are comprised of the only air system, refrigeration, heating, and control systems.

Air Systems. An air system is also called an air handling system or the air side of an air-conditioning. Its function is to condition the air, distribute it, and control the indoor environment according to requirements. The primary equipment in an air system is an AHU or air handler; both include fan, coils, filters, dampers, humidifiers (optional), supply and return ductwork, supply outlets and return inlets, and controls.

1.2 Air Handling Unit

An air-handling unit (AHU) is the primary equipment in an air system of a central hydronic system; it handles and conditions the air and distributes it to various conditioned spaces. In an AHU, the required amounts of outdoor air and recirculating air are often mixed and conditioned [4]. The temperature of the discharge air is then maintained within predetermined limits by means of control systems. After that, the conditioned supply air is provided with motive force and is distributed to various conditioned spaces through ductwork and space diffusion devices. Many air-handling units are modular so that they have the flexibility to add components as required. An AHU basically consists of an outdoor air intake and mixing box section, a fan section including a supply fan and a fan motor, a coil section with a water cooling coil, a filter section, and a control section. A return or relief fan, a heating coil, a precooling coil, and a humidifier may also be included depending on the application.

1.2.1 Classifications of Air-Handling Units

Air-handling units may be classified according to their structure, location, and conditioning characteristics [4].

Horizontal or Vertical Unit. In a horizontal unit, the supply fan, coils, and filters are all installed at the same level. Horizontal units need more floor space for installation, and they are mainly used as large AHUs. Most horizontal units are installed inside the fan room. Occasionally, small horizontal units may be hung from the ceiling inside the ceiling plenum. In such a circumstance, fan noise and vibration must be carefully controlled if the unit is adjacent to the conditioned space.

In a vertical unit, the supply fan is not installed at the same level as the coils and filters but is often at a higher level, Vertical units require less floor space. They are usually smaller, so that the height of the coil section plus the fan section, and the height of the ductwork that crosses over the AHU under the ceiling, is less than the head room (the height from the floor to the ceiling or the beam of the fan room). The fan room is the room used to house AHUs and other mechanical equipment.

Draw-Through Unit or Blow-Through Unit. In a draw-through unit, the supply fan is located downstream from the cooling coil section, and the air is drawn through the coil section. In a draw-through unit, conditioned air is evenly distributed over the entire surface of the coil section.

Outdoor AHU or Mixing AHU. Most mixing AHUs can be used to condition either outdoor air only or a mixture of outdoor air and recirculating air, whereas an outdoor air AHU is used only to condition 100 percent outdoor air. An outdoor air, or makeup air, AHU is a once-through unit; there is no return air and mixing box. It may be a constant-volume system or a variable-air-volume (VAV) system if the number of occupants varies. In an outdoor-air AHU, the cooling coil is usually a six- to eight-row depth coil because of the greater enthalpy difference during cooling and dehumidification in summer. Freeze protections for water coils are necessary for locations where the outdoor temperature may be below 32°F (0°C) in winter. A heat recovery coil or a water economizer precooling coil is often installed in makeup air AHUs for energy savings.

Single-Zone AHU or Multizone AHU. A single-zone AHU serves only a single zone. A multizone AHU serves two or more zones. A zone can be a large perimeter or an interior zone or one of the many control zones which connect to a multizone AHU through ducts and terminals.

A multizone AHU with a hot and cold deck is now often used for a dual-duct VAV system. Another kind of multi zone unit which has many separate warm air ducts and cold air ducts with associated warm and cold air dampers for each of the zones became obsolete because this kind of multi zone unit wastes energy, needs complicated control, and is expensive.

1.3 Radiant Cooling

A radiant cooling system is a temperature-controlled surface that cools indoor temperatures by removing sensible heat and where more than half of heat transfer occurs through thermal radiation. Heat will flow from objects, occupants, equipment and lights in a space to a cooled surface if their temperatures are warmer than that of the cooled surface and they are within the line of sight of the cooled surface. The process of radiant exchange has a negligible effect on air temperature, but through the process of convection, the air temperature will be lowered when air comes in contact with the cooled surface. Most radiant cooling applications have been based on aluminum panels suspended from the ceiling, through which chilled water is circulated.

Radiant cooling systems typically use chilled water running in pipes in thermal contact with the surface. The circulating water only needs to be 2-4 °C below the desired indoor air temperature [5]. Heat is removed by the water flowing in the hydronic circuit once the heat from different sources in the space is absorbed by the actively cooled surface – ceiling, floor or walls. Radiant cooling has many types and one of the types is Slab cooling method.

1.3.1 Advantage of Radiant cooling

Less energy required to transport heat transfer medium (water) when compared to conventional HVAC where the air is used. The addition of radiant cooling capabilities minimally increases the initial cost of radiant heating and has many advantages during operation. Radiant cooling transforms the piping network from a heating system to a year-round building comfort system. Therefore, many commercial buildings utilize Radiant Cooling Systems. Hot, dry climates offer the greatest advantage for radiant cooling as they have the largest proportion of cooling by way of removing sensible heat. Much of the energy savings is also attributed to the lower amount of energy required to pump water as opposed to distribute air with fans. By coupling the system with building mass, radiant cooling can shift some cooling to off-peak night time hours.

2 Introduction to Building

The Czech technical library opened in 2009 and it is in the middle of the Czech Technical University at Dejvice, in Prague. This oval-shaped building has 6 floors and is provided with a large open atrium with stairwells and lifts enabling access to all public areas. The building covers in total an area of 5 000 m^2. The atrium has an illuminating roof and is provided with the ability to open windows for natural ventilation. The ground floor is accessible from four sides and is a kind of "inner city" surrounded by a café, bookshop, exhibition spaces and Conference Hall. One entry is accessed from the main class of the University campus, on the opposite side of the building was a leisure park area.

In the underground floors, there is a parking located. The main part of the building is the public library which reaches over the 2nd until the 5th floor. The building consists of a steel concrete frame, with some of the concrete sub-layers are pre-stressed to enable large distances between the columns at every floor. The internal walls consist of a gypsum partition or glass while the building envelope is a double skin facade made of glass.

For calculating, Split the building into 8 segments externally, namely South, north, east, west, north-west, north-east, south-west and south-east and 2 zones internally, namely Office part and Library part.

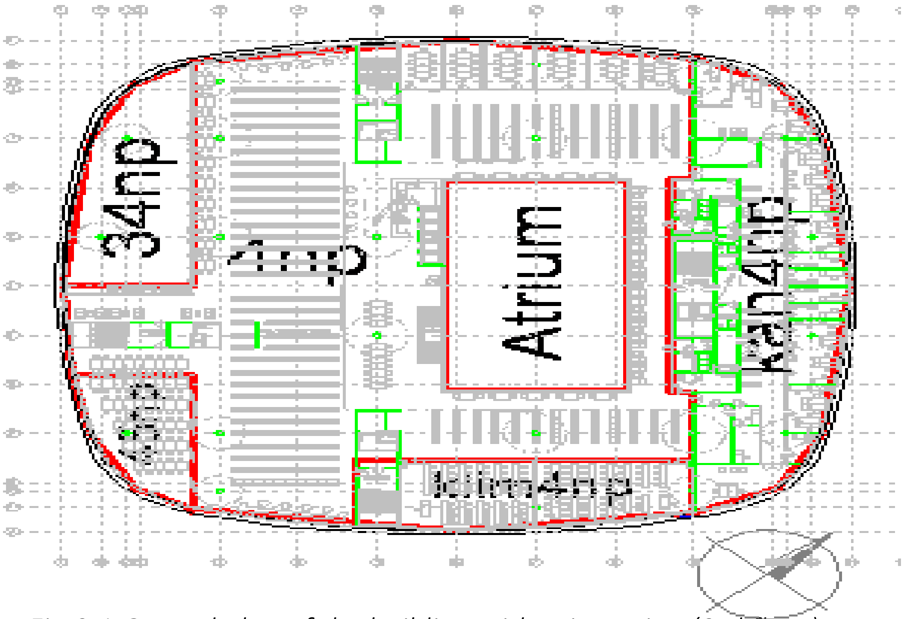

Fig 2.1 Ground plan of the building with orientation (3rd floor)

2.1 Orientation of Building

The library part (Large area) is located in the south-east, the south-west and north-east facades. This minimizes the energy consumption. The office part is located on the north-west. This reduces the thermal load of the solar radiation and will result in more balanced lighting (especially for offices) during the day, throughout the year. In order to minimize the energy consumption, the location of the large rooms in the outer external cladding with the orientation of the south-east, south-west and optimized desktop transparent fills in a 2 NP-6 NP, the floor which does not exceed 50 to 70 % of the external cladding of the respective area. The transparent area of the external cladding is fitted with effective protection against heat gains from the external environment (outside screening).

2.2 HVAC system

Concerning the HVAC system, the building is divided into three main parts. First, there is the system for the main library hall and study rooms, in which heating/cooling pipes are embedded in the concrete massive ceiling. The thermal mass of this ceiling slab is therefore cooled or heated by water. As a result, the supply airflow can be limited to the fresh air requirements. The inlet water temperature in the case of cooling in the summer has to be high enough to avoid condensation at the ceiling. With a temperature of supply water between 16 °C and 20 °C the surface of the ceiling will be free of condensation. In the concrete slabs at a depth of 150 mm is fed at night (from 20:00 to 8:00) cooling capacity 40 W/m^2, which corresponds to the temperature of the cooling water 18/21 °c, with a spacing pipe 150 mm. Surface cooling ceilings are less than the total area of the ceiling (about 71 %).

In the computer rooms, restaurants and shops there is a common fan-coil system applied, because of the needed cooling capacity. In the computer labs, the set temperature of 26 °C (the assumption of the use of air conditioning) for the operation of the library (7: 00-21: 00). A computer simulation to determine the necessary significant cooling air conditioning performance necessary for compliance with this temperature. In the offices was considered no cooling.

There is one cooling source for both slab cooling and the fan-coil system. This chiller will provide cold water for the slab cooling at night (off-peak period) and for the fan-coil system during the day (peak gains). This way the chiller capacity gets significantly decreased.

2.2.1 Ventilation

A hybrid ventilation system is installed in the building in order to minimize the mechanical ventilation, the ventilation is pure natural during the transitional period. 200 of the 500 windows in the study and library zone are equipped with an electric motor to open and close the window automatically. These windows are controlled by sensors which will open the window after exceeding the limit of the concentrations of $C0_2$ or temperature required in the room. This will reduce the costs of electric energy of the mechanical ventilation system. The additional air-conditioning switches on only in case the natural ventilation is insufficient to cool the building. In summer, there is also made use of night cooling.

2.2.2 Floor heating

An underfloor heating system is used in the premises at 1NP and the service in the lobby at 2NP. The system combines the function of the heating and cooling of the space. It is designed for heating the temperature of 40/32 °C and cooling 16/19 °C. Underfloor heating power is 125 kW. The involvement of the system is by using the three-way valve and a pump.

The main distribution system underfloor heating the object from the engine room shall be kept horizontal distributions under the ceiling of the basement of the steel pipes.

2.2.3 Slab Cooling

From the second floor until the sixth floor the concrete core of the building is thermally activated, for both heating and cooling. The pipes are embedded in the concrete ceiling and are able to pre-cool or pre-heat the building. It combines radiant cooling with the accumulation of cold in the massive concrete slabs. The main distribution of the system is placed in the engine room, under the ceiling of the basement. At the places of the connections to the horizontal branches shut-off and control valves are installed to regulate and balance the system.

The concrete core activation system is restricted to 28 °C in case of heating and 16 °C in case of cooling. The 16 °C in case of cooling is the maximum, concerning the condensation risk at the ceiling of the activated concrete. Two parallel connected pumps of each 7.5 kW provide a mass flow of 110 000 kg/h.

Each section of pipe units corresponds to the sections of the concrete procedure. In each section, there are several lines long 80 m total number of circuits is 970. End of lines is decorated either in the double floor or under the ceiling (6 floors), where they are connected to the Distributor/collector. In total, placed approx. 49 000 m of the pipeline.

Because of the radiant cooling during cooling degree days, the ventilation is restricted to the minimum required airflow for hygiene. The air is supplied in all rooms of the library and naturally extracted through the top of the atrium. In the computer rooms, restaurants and commercial places, additional fan-coil units are installed. A prerequisite is the use of pre-cooling at night of the concrete activation parts, so the cooling liquid can be used for the fan coil units during the day. This reduces the required cooling capacity.

2.3 Size of AC system

UNICO chiller was used in the library building. This chiller is installed on the roof and placed on a floating base to minimize the spread of noise and vibration to the building structure. The control is placed on the unit itself and will control to a constant output temperature of the heating/cooling water. The cooling capacity of the unit is 751.7 kW. The used refrigerant is R134a. The temperature gradient of the chilled water is 6/12 °C. The UNICO chiller is equipped with two parallel connected pumps of each 7.5 kW.

Table 2.1 Overview of technical parameters of cooling units

Description	Capacity	Unit
Cooling capacity	751.7	kW
Number of compressors	2	KS
Total wattage of compressors	277.5	kW
Number of fans	10	KS
Total power consumption of fans	14	kW
Number of pumps	2	KS
Total wattage of pumps	15	kW
Cooling factor (COP)	2.59	-

3 Heat Gains

We have Internal heat gains and external heat gains in a building. Heat gain is usually calculated for the purposes of cooling systems design. In such a situation, the system employed for the purpose of providing artificial cooling should be able to combat or deal with the warmest conditions at its peak capacity.

3.1 Internal Heat Gains

Internal heat gain is the sensible and latent heat emitted within an internal space from any source that is to be removed by air conditioning or results in an increase in temperature and humidity within the space. t_i = 25 °C.

Following sources are in main cases [3]:

I. **Occupants:** All bodies including humans lose heat to their surroundings due to their metabolic activity, which is related to the activity of the subject is performing (i.e. sedentary, sleeping, dancing etc). The heat can be released as sensible or latent heat. The sensible heat release is due to the higher temperature the surface of the skin can have in respect to the surrounding environment, while the latent heat is released by means of respiration and sweating. Standard Energy needed for a person to feel good will be 70 W.

Heat Gain from occupants = No. of people * Energy/person

Table 3.1. Heat Gain from occupants- G1 method

Occp Gain	6th Floor	5th Floor	4th Floor	3rd Floor	2nd Floor
Office(kW)	0.7	0.98	0.77	0.63	0.7
Library(kW)	2.8	4.2	4.06	5.18	1.4

II. **Lighting:** All the electrical energy used by a lamp is ultimately released as heat. The energy is emitted by means of conduction, convection or radiation. When the light is switched on the luminaire itself absorbs some of the heat emitted by the lamp. Some of this heat may then be transmitted to the building structure, depending on the way the luminaire is mounted. The radiation energy emitted from a lamp will result in a heat gain to space only after it has been absorbed by the room surfaces. This storage effect results in a time lag before the heat appears as a part of the cooling load.

Table 3.2. Heat Gains from Lighting- G1 method

Ligh. Gain	6th Floor	5th Floor	4th Floor	3rd Floor	2nd Floor
Office(kW)	7.4	7.4	7.4	7.4	7.4
Library(kW)	35.3	34.3	32.8	35.3	5.9

III. **Office equipment:** Personal computers and associated office equipment result in heat gains to the room equal to the total power input. The heat gain from computers showed little reduction when idle versus operational. The exception was computers equipped with the Energy Star energy saver feature. This feature will place a computer in a "sleep mode" if it remains idle for a pre-set time. The internal heat gains can be estimated from basic data but care must be taken to allow for a diversity of use, idle operation and the effects of energy saving features of the equipment.

Table 3.3. Heat Gains from Office Equipment

Eqi. Gain	6^{th} Floor	5^{th} Floor	4^{th} Floor	3^{rd} Floor	2^{nd} Floor
Office(kW)	1.2	1.68	1.32	1.08	1.2
Library(kW)	1.53	2.88	3.07	3.45	1.4

Total Internal Heat Gain = Heat Gain from occupants + Lighting + Equipment

Total Internal Heat Gain = 221 kW

3.2 External Heat Gains

It receives heat gain by two ways,

I. **Radiation Gain:** We receive radiation gain into the building through windows. We have 8 segments in a building. Each direction of the segment has its own intensity value which is standard at the time. Shading Coefficient (¥) will be 0.15. For single glazing, the value of shading coefficient (¥) will be 0.6.

Radiation Gain = I* S * ¥

II. **Conduction Gain:** We receive conduction gain into the building through walls and windows. Conduction gain through windows will be the surface of glazing and conduction gain through walls will be the total surface of wall minus surface of the glazing. Indoor Temperature will be 25°C and external temperature depends on the direction of the segment facing to the sun. Standard Heat transfer coefficient (H) will be 0.3. The external heat gain at 14:00 hours was given below.

Conduction Gain = S * H * ΔT

Total External Heat Gain = Radiation Gain + Conduction Gain through window + Conduction gain through walls

Total External Heat Gain = 161 kW

3.3 Calculation

To calculate External part of the building, split into 8 segments and Internal part will be divided into two zones- Library part and Office part. For Total Heat Gains, Internal Office part will be added with 3 segments of external part and Internal library part will be added with remaining 5 segments of external parts. From 2nd Floor till 6th Floor I have calculated the heat gains. Below mentioned gains are sample at 14:00 hours only for G1 method.

6th Floor; Office part:	Library part:
Total Internal Heat Gains: 9.3 kW	39.6 kW
Total External Heat Gains: 8.1 kW	23.0 kW
5th Floor; Office part:	
Total Internal Heat Gains: 10.0 kW	41.4 kW
Total External Heat Gains: 8.7 kW	30.1 kW
4th Floor; Office part:	
Total Internal Heat Gains: 9.5 kW	39.9 kW
Total External Heat Gains: 10.7 kW	25.0 kW
3rd Floor; Office part:	
Total Internal Heat Gains: 9.1 kW	43.9 kW
Total External Heat Gains: 7.0 kW	20.5 kW
2nd Floor; Office part:	
Total Internal Heat Gains: 9.3 kW	8.7 kW
Total External Heat Gains: 6.8 kW	20.6 kW

Total Heat Gains in 6^{th} floor = 80 kW

Total Heat Gains in 5^{th} floor = 90.2 kW

Total Heat Gains in 4^{th} floor = 85.1 kW

Total Heat Gains in 3^{rd} floor = 80.5 kW

Total Heat Gains in 2^{nd} floor = 45.4 kW

Data which have been collected from library building was related to daily, monthly and yearly usages. So, Total gains must be calculated for a day in which it has maximum gains of a year in theoretical. Working hours in the building was taken from 8.00 to 19.00 hours standardly. Results of total gains have been shown below for each one hour of the G1 method.

Table 3.4 Total Gains for a whole day – G1 method

Time(h)	External Gain (kW)	Ventilation Gain (kW)	Internal Gain(kW)
1	-36.97	-119.98	0
2	-40.17	-130.35	0
3	-41.08	-133.32	0
4	-40.17	-130.35	0
5	-26.81	-119.98	0
6	38.61	-102.212	0
7	96.99	-81.47	0
8	129.62	-56.29	221.15
9	142.70	-29.62	221.15
10	145.46	-2.96	221.15
11	154.05	22.22	221.15
12	158.26	42.95	221.15
13	162.11	60.73	221.15
14	161.11	71.10	221.15
15	165.05	74.06	221.15
16	156.65	71.10	221.151

17	129.21	60.73	221.15
18	77.39	42.95	221.15
19	16.19	22.22	221.15
20	-0.91	-2.96	0
21	-9.13	-29.62	0
22	-17.34	-56.29	0
23	-25.10	-81.47	0
24	-31.49	-102.21	0

4 Analysis of data

I have been performing the analysis to compare the real data usage with the theoretically calculated values of a day where we occur maximum gain. I have taken four different methods as G1, G2, G3 and G4 to show the results with the real values. For all the methods, Cooling factor was used as 3.

G1 = Total capacity of 300 people, Flow rate of 44000 m^3/hr

G2 = Total capacity of 300 people, Flow rate of 20000 m^3/hr

G3 = Total capacity of 800 people, Flow rate of 56000 m^3/hr

G4 = Total capacity of 800 people, Flow rate of 28000 m^3/hr

The analysis is made on August 21st of the year for a whole day. Theoretically, August 21st is the maximum gain according to the climate data. External gain has been common for all the methods and for internal gains people occupied the building from 7 am to 19 pm and remaining period has no people occupied. To demonstrate the gains, I have selected the graphical method.

Now I have shown G1 methods graphically for external gain, Internal gain, Ventilation and Total gains in a row.

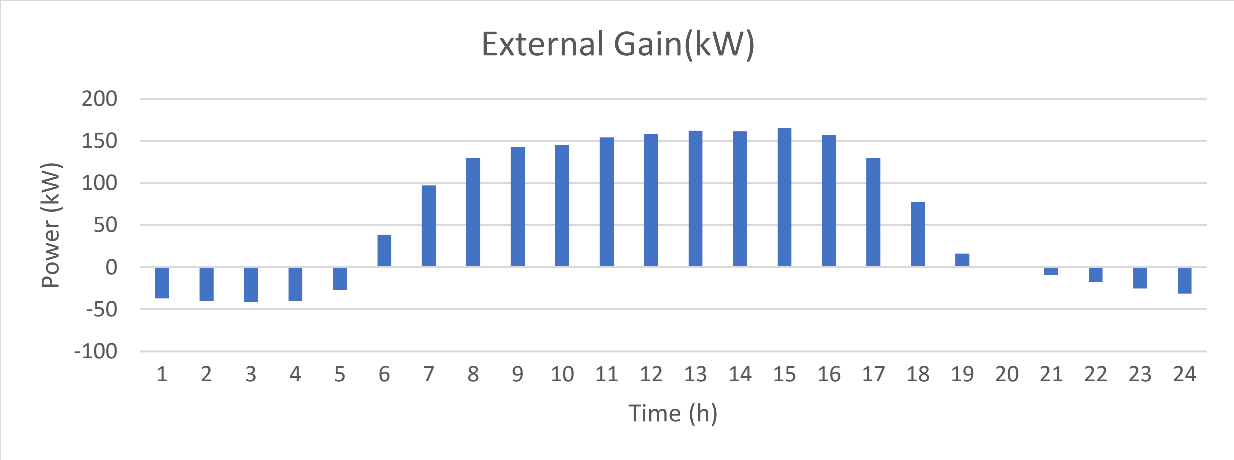

Fig 4.1 External gain of a building for G1 method

People capacity will vary from time to time and day to day according to their requirements. I don't have exact data for the occupancy in a building. Maximum 800 people can occupy in a library building. I use two occupancy methods to evaluate results, one with 300people and another with 800 people. It was shown in different methods below.

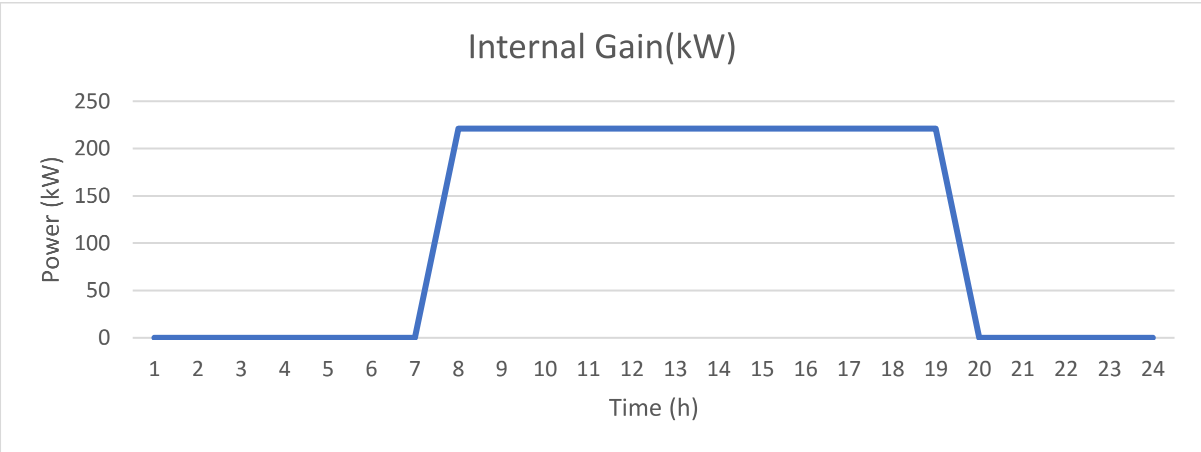

Fig 4.2 Internal gain of a building for G1 method

Ventilation gain has been calculated using an external temperature and internal temperature with flow rate and capacity of air. External temperature is less than the internal temperature during the night time and higher during the daytime. Below graph shows the ventilation gain on a day. The internal temperature of a building is 25 ∘C. External temperature will vary for every hour, so it was given in below table.

$$Q = V.c.\,\rho.\Delta t \text{ (kW)}$$

Table 4.1 External Temperature of a building

Time(h)	1	2	3	4	5	6	7	8	9	10	11	12
t_e (∘c)	16.9	16.2	16	16.2	16.9	18.1	19.5	21.2	23	24.8	26.5	27.9
Time(h)	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
t_e (∘c)	29.1	29.8	30	29.8	29.1	27.9	26.5	24.8	23	21.2	19.5	18.1

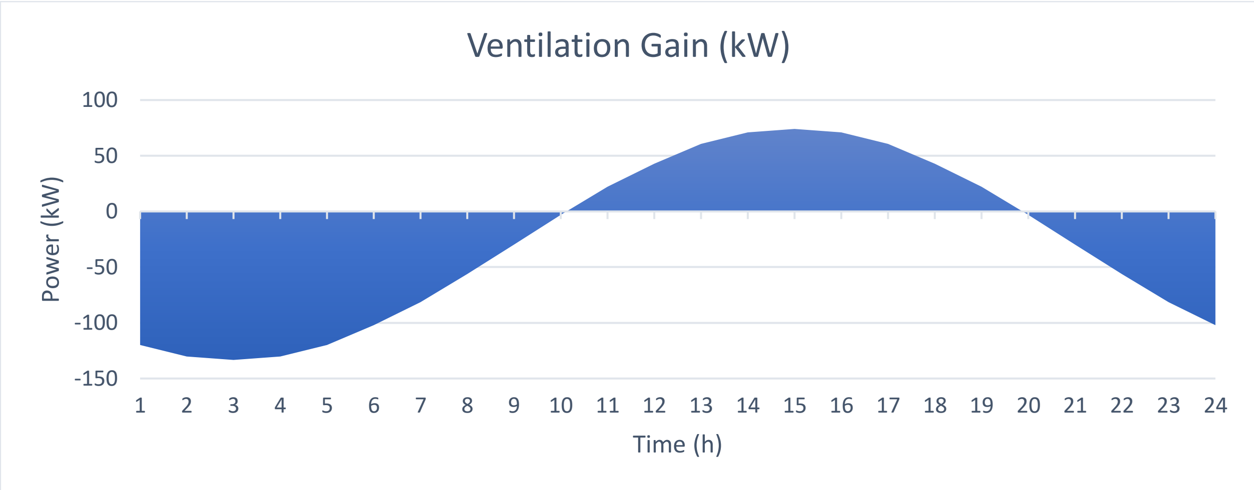

Fig 4.3 Ventilation gain of a building for G1 method

External gain, Internal gain and Ventilation gain all together referred as total gain. The total gain graph used to give the gains in percentage or it shows which has higher gain on an hourly basis. Negative power between 20 pm till 7 am in the morning. All the remaining hours has positive gains.

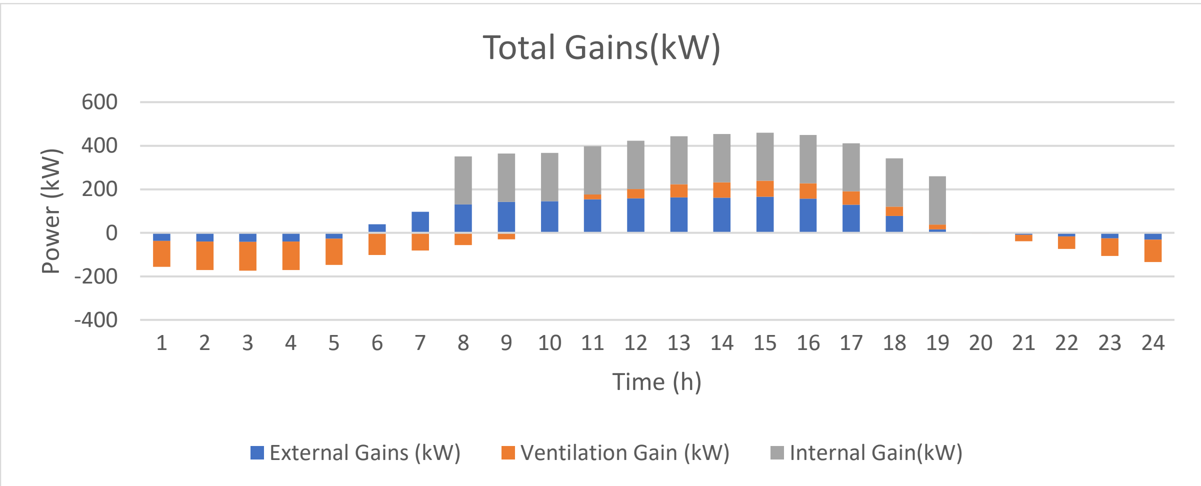

Fig 4.4 Total gain of a building for G1 method

Calculated value will now be compared with real data from the year 2012 which has a maximum load in August i.e., 05.08.2012. From the below graph, it was clear that the cooling process is high during night time because of slab cooling and almost constant during the day time in a building.

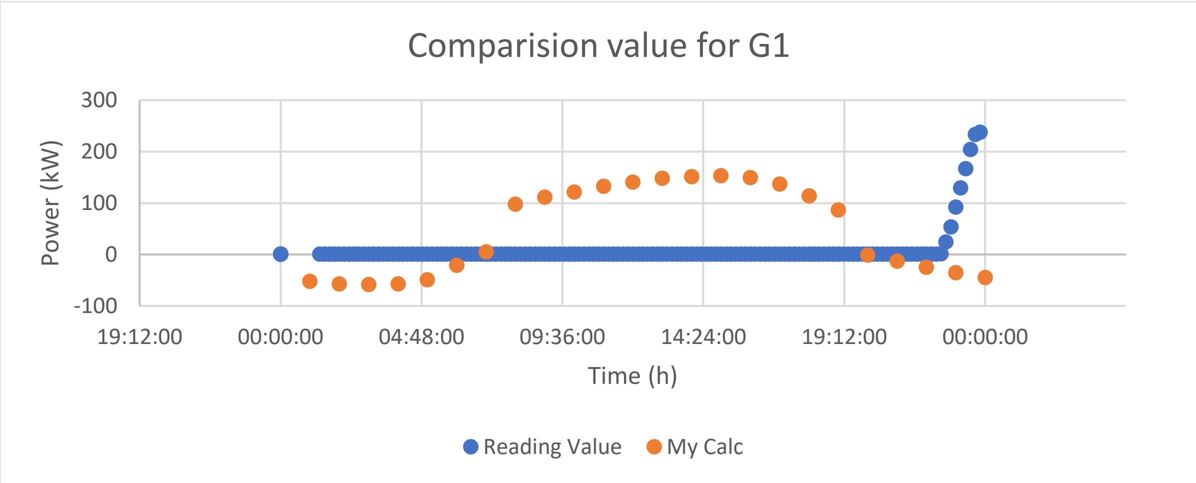

Fig 4.5 Comparison of real and calculated in a building for G1 method

The above results are the comparison of real data and calculated values of the G1 method. In this method, the calculated gain values have acquired more power than the realistic consumption for cooling. This comparison is for specific day or year which has no influences on other days in a month or year because consumption may vary according to the needs of a people or thermal comfort standard in a building.

The comparison has been made of different methods on different date and year. Now, a G2 method is applied to the real data. G2 method data are same as the previous method but the flow rate is half of it. Flow rate selected for this one is 22000 m^3/h and I have same 300 people in a building so the internal gain remains same as G1, the external gain is same throughout all the methods. Ventilation gain is calculated for every hour with respect to the temperature difference. A graphical method is shown the power for every hour.

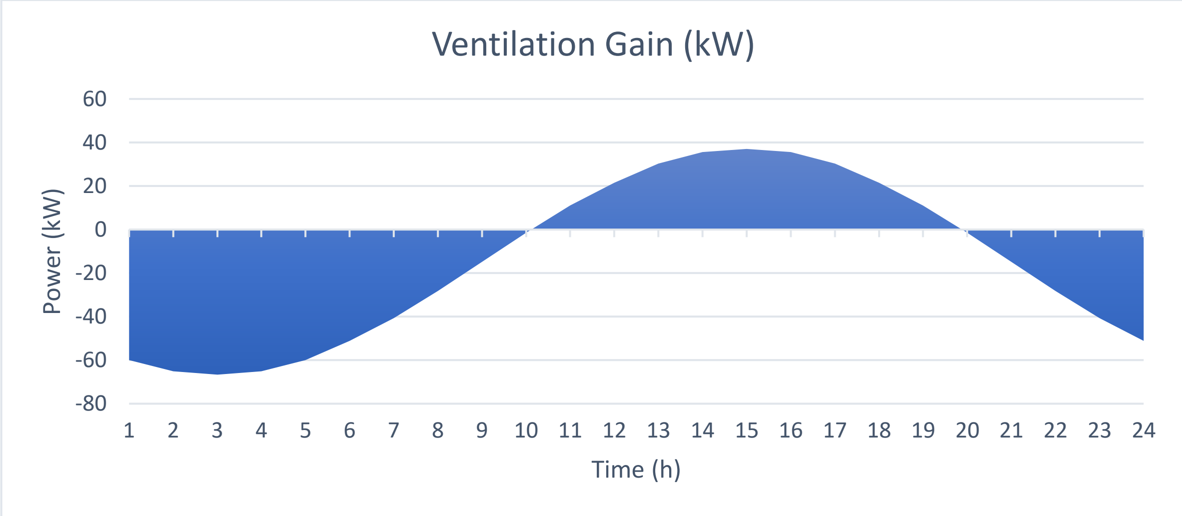

Fig 4.6 Ventilation gain of a building for G2 method

No major difference between G1 and G2 method because ventilation gain differs slightly. So, the total gain value has no minor change in the graph but still, it looks like a G1 process. With this method, I came to know that the gains have a small effect when the flow rate is changed. Graph of Total gain for the G1 method is already displayed in above steps. Now directly I can compare the data between calculated and reading from the building. The graph is shown below to explain the cooling power consumption.

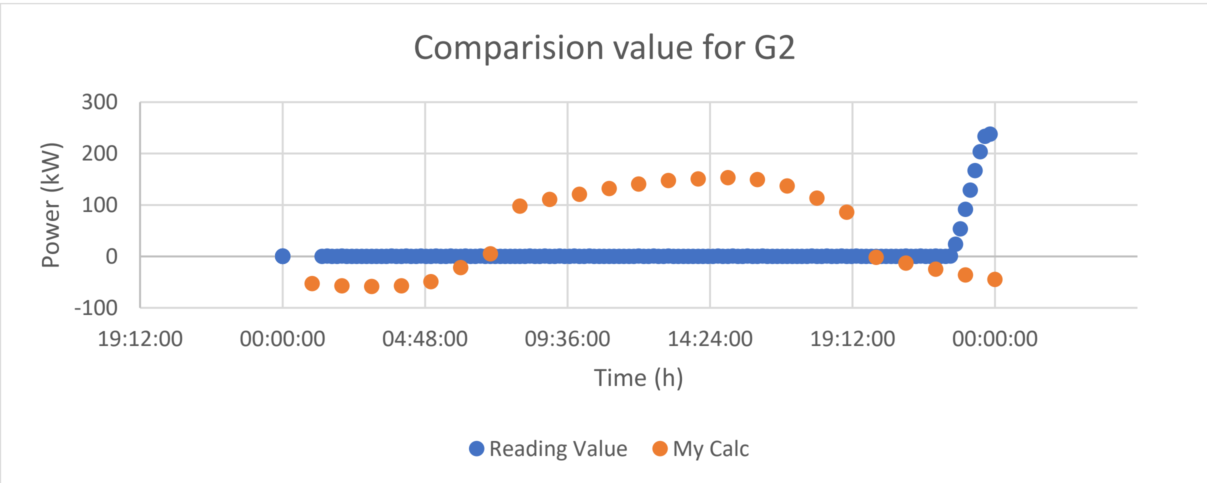

Fig 4.7 Comparison of real and calculated in a building for G2 method

G3 method is different from previous two methods. G1 and G2 method have 300 people in a building whereas G3 method has considered 800 people for the analysis. The energy needed for a person is 70. The flow rate for this method is 56000 m^3/h. Total gain has been shown in graph and calculation was done like previous methods.

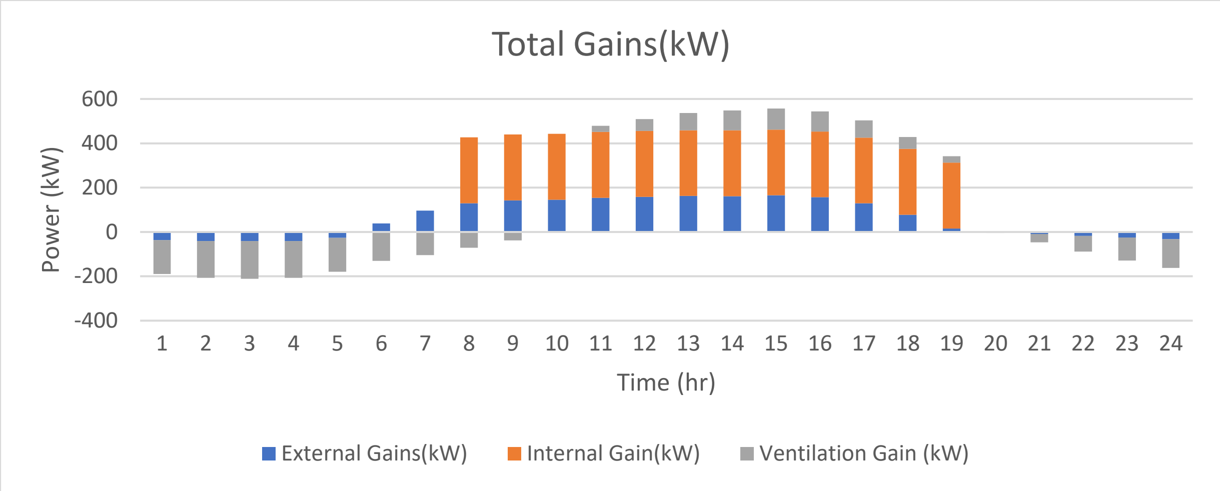

Fig 4.8 Total gain of a building for G3 method

The comparison has made between real and calculated gains, the consumption in a building and calculated gain on a maximum day of a year is almost same. This calculated day is compared with real consumption on a day and it may vary for different day or according to the capacity in a building the consumption is even higher.

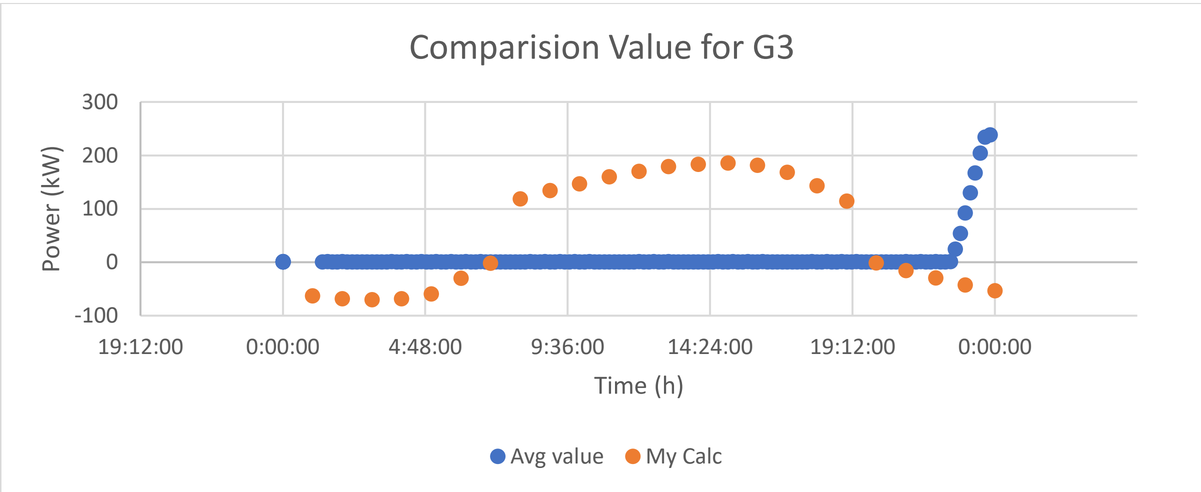

Fig 4.9 Comparison of real and calculated in a building for G3 method

G4 method has considered 800 people for the analysis. The energy needed for a person is 70. But Flow rate is half of G3 method. For this method, the flow rate is 28000 m^3/hr. Total gain has been shown in graph and calculation was done like previous methods.

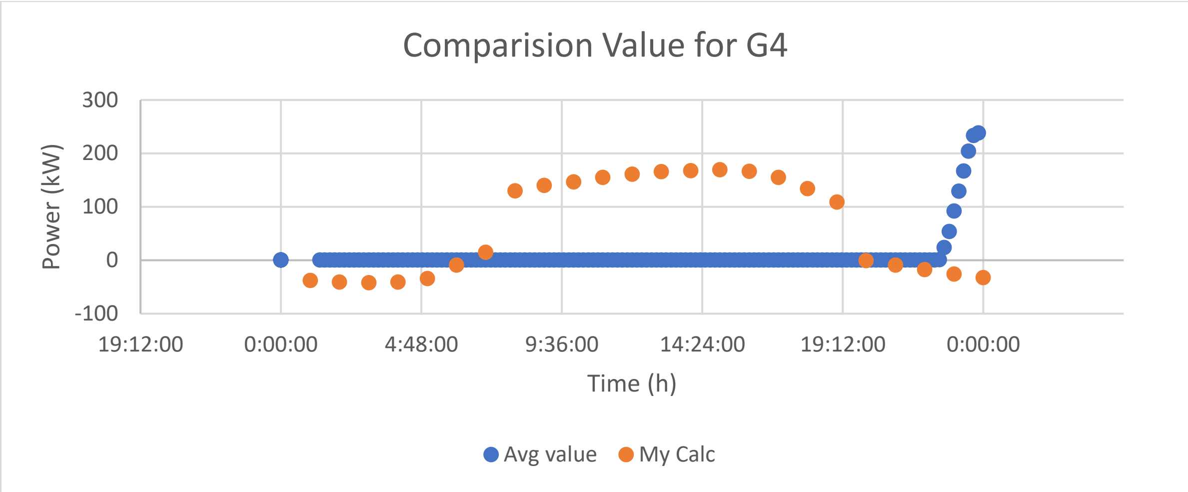

Fig 4.10 Comparison of real and calculated in a building for G3 method

4.1 Maximum consumption of chillers

2013: 18/06/2013

According to the collected data and information from the building, the year 2013 is the most humid occurring takes place. So, the power consumption of chillers should be very high compared with other years. From the data, 18/06/13 is the maximum consumption of chillers. This maximum day was compared with the calculated methods followed G1, G2, G3 and G4 respectively.

From 12 am till 4 am in the morning the consumption was almost nothing because no occupancy was occupied at that time. From 5 am in the morning the power usage was started to make or feel the person good in a building when they enter. Different ways are carried for cooling, for example, Power is ON before the person enter the building or Power is ON when the person is entering or Power is ON after the person enter the building. Due to high humid, the calculated gain is very less compared with the consumption.

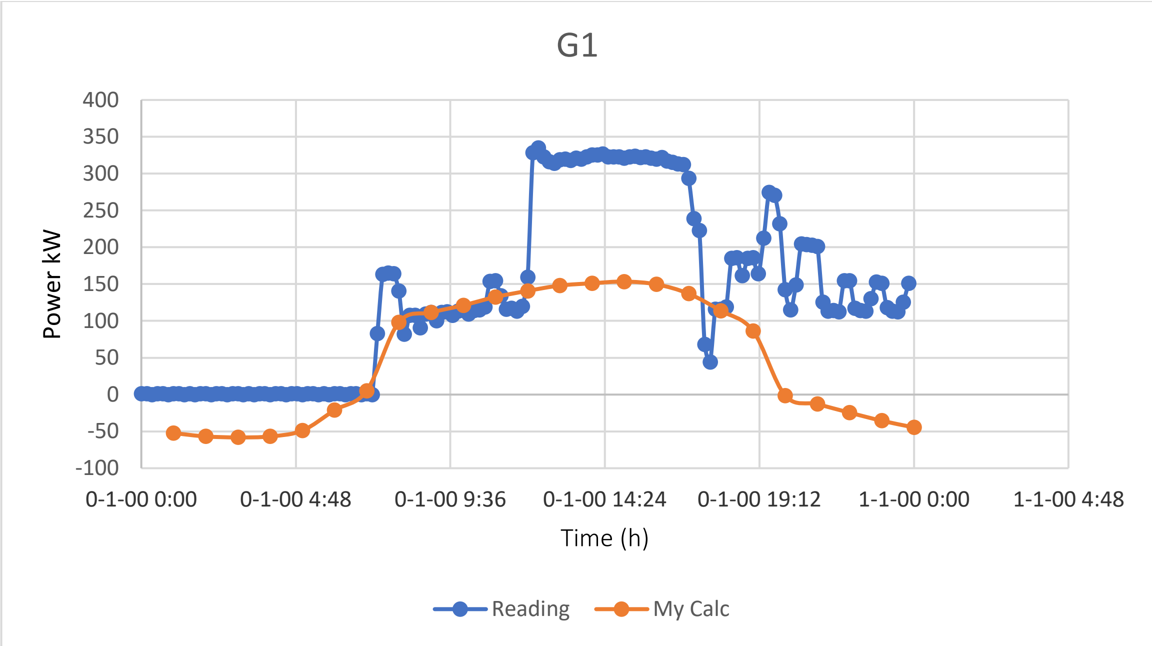

Fig 4.11 Comparison of max consumption and calculated on 18/6/13

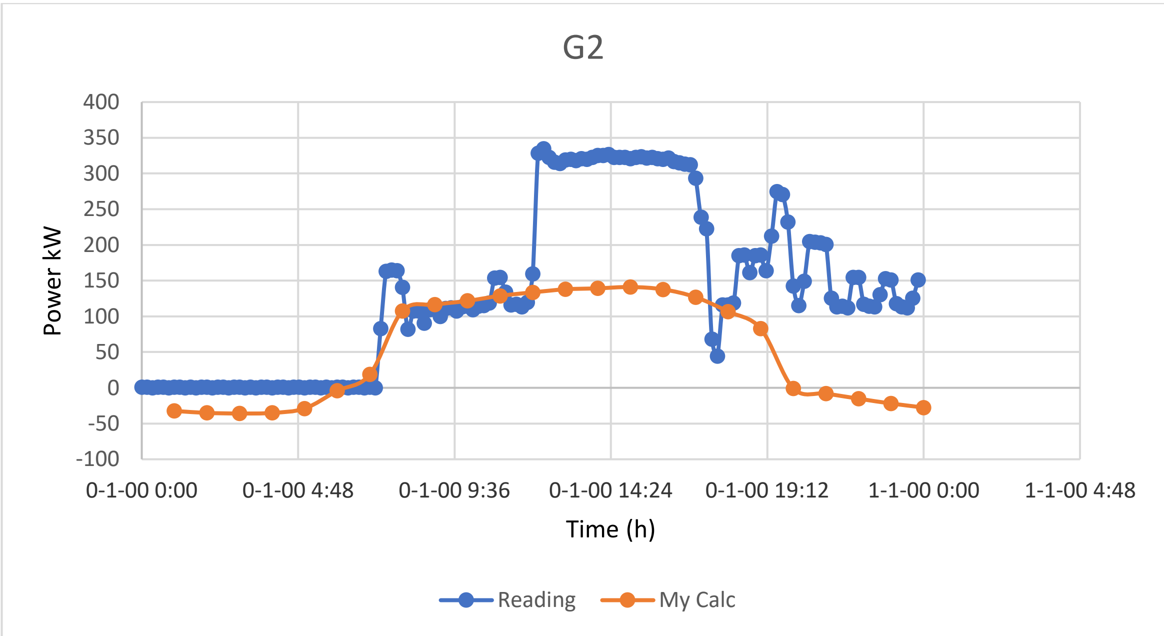

Fig 4.12 Comparison of max consumption and calculated on 18/6/13

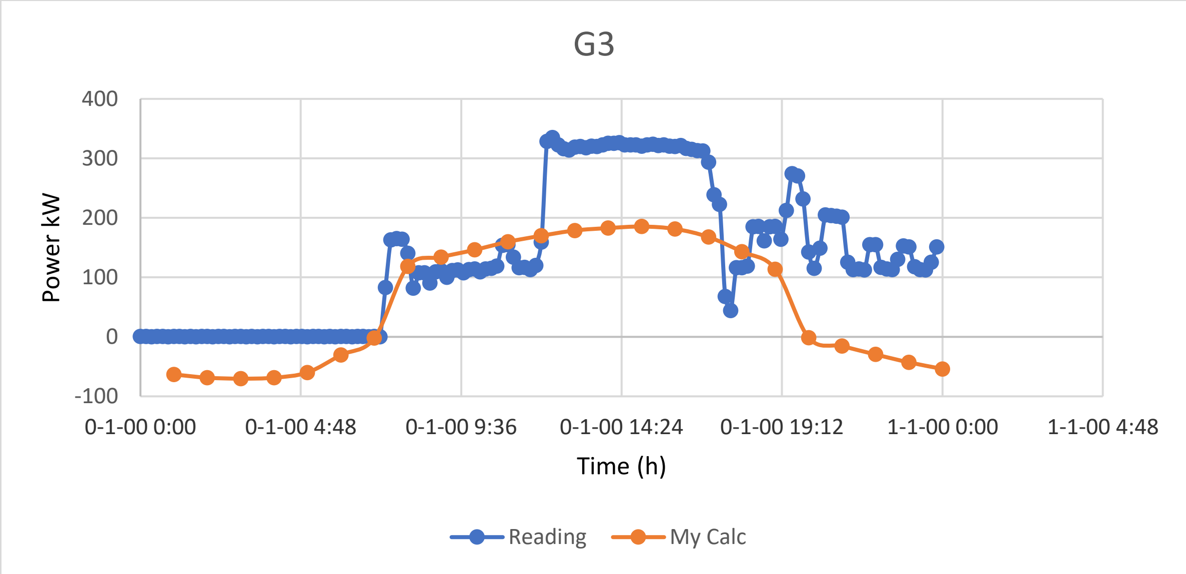

Fig 4.13 Comparison of max consumption and calculated on 18/6/13

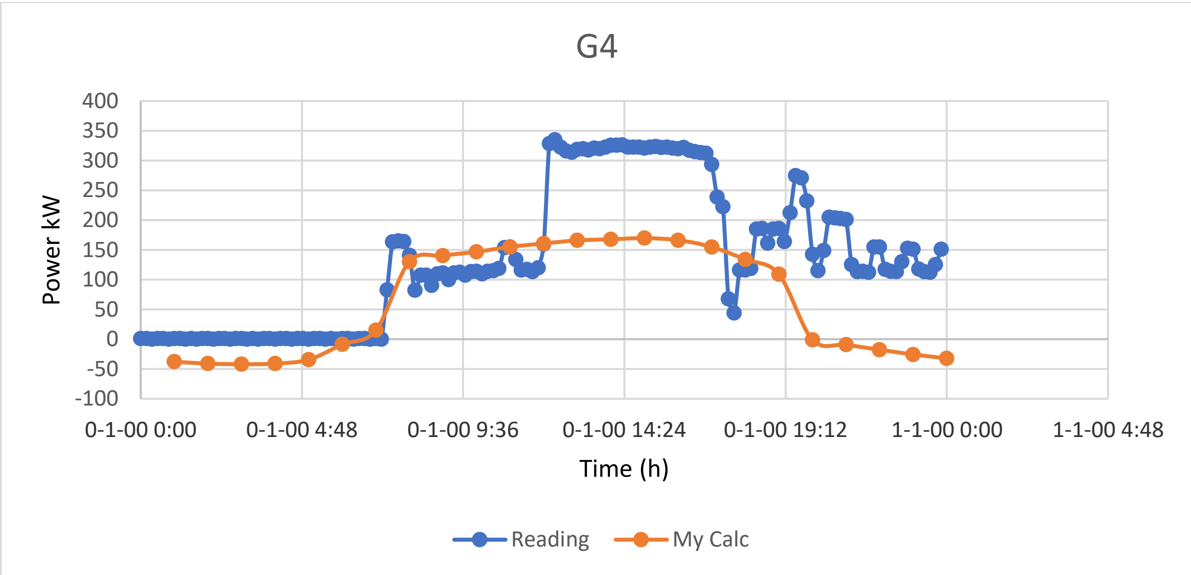

Fig 4.13 Comparison of max consumption and calculated on 18/6/13

Maximum consumption of chillers is very high compared with calculated values. In 2013 during the summer season the consumption will be very high. Everything depends on how the temperature response on a year or a season. Different days in a year was analyzed briefly in another sub-topic below.

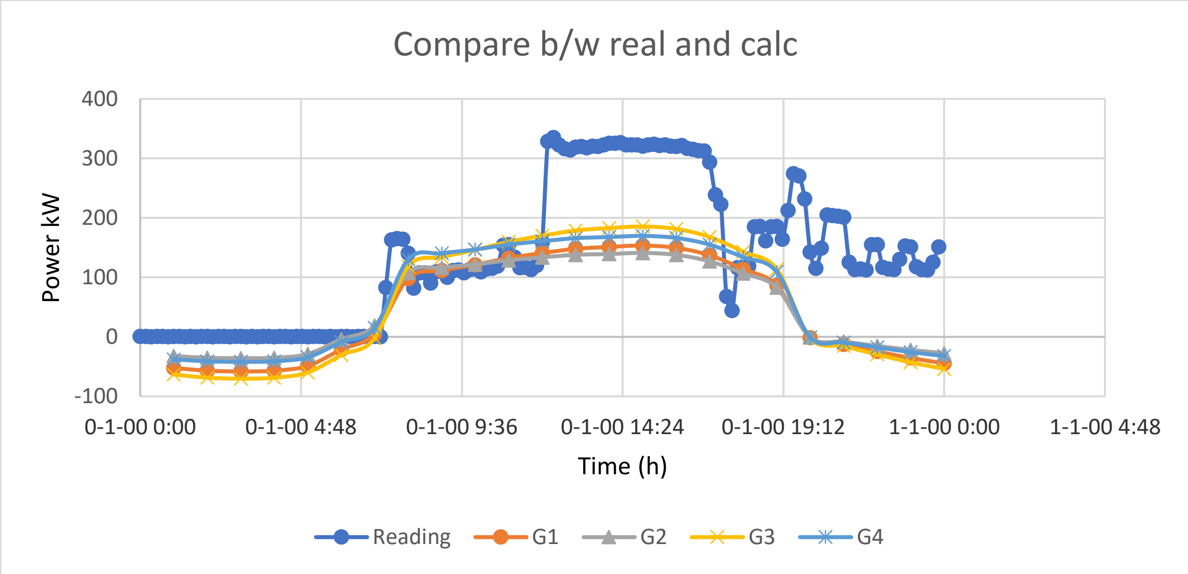

Fig 4.14 Comparison of max consumption and calculated on 18/6/13 for all methods

2012: 21/05/12

In 2012, maximum day power consumption was quite good with the calculated values. Power was used during day time and fully switched off during night time. Slab cooling was used to cool the building and reduces the consumption of power. In this day power is consumed only in the day time and almost calculated gains matched the real data from the building.

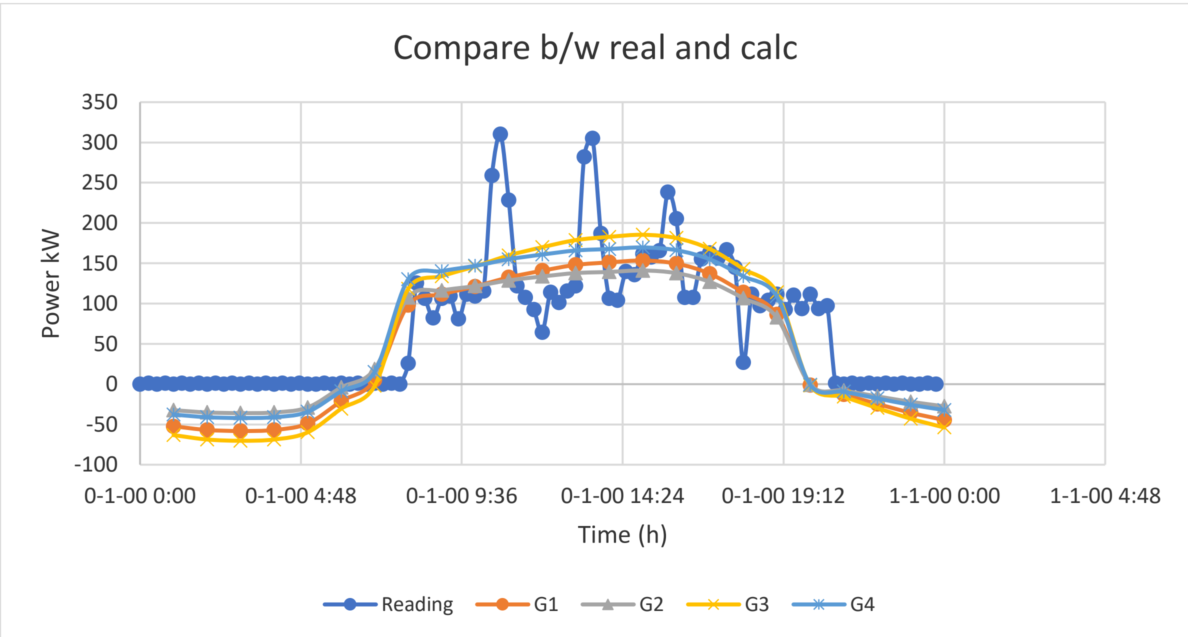

Fig 4.15 Comparison of max consumption and calculated on 21/05/2012

2014: 10/06/14

In 2014, chiller consumption was used throughout the day. Even in night time, chiller used to keep the building in cooling. Particularly on this day, the usage of people in a building during the night may be enormous.

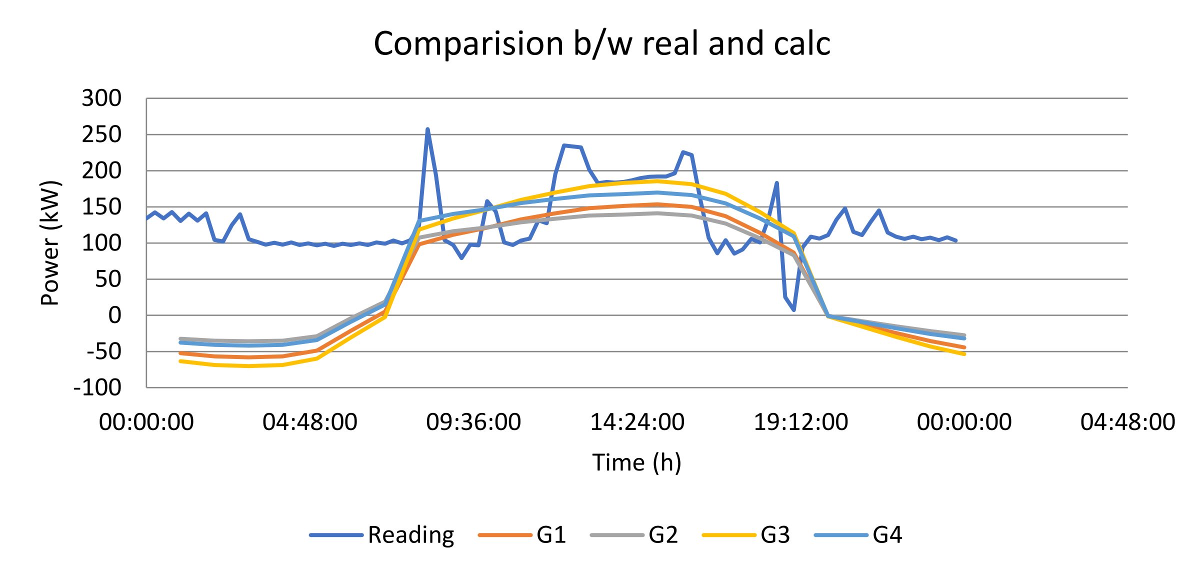

Fig 4.16 Comparison of max consumption and calculated on 10/06/2014

4.2 Monthly Analysis in Different years

2010:

Detailed data is not available for this calendar year and so monthly data is provided from the building of how much power was consumed in every month. I have compared this monthly data with the calculated gains and conclude the necessity of that month and whole year required for the cooling process. Monthly data was transformed to the average daily data with some compensation factor of working days in a month.

In 2010, June and July are the two extreme months which needed the cooling process. Power consumption was provided for a whole month whereas our calculated gain is just for one day. So, the need is to compensate somehow and finding the comparison effectively. Approximately in a month, we have 22 working days. Power consumed for one month should be divided by twenty-two, so we get for one day. From January till May and August until September the consumption was less than 100 kWh/day which is 10 times less than July and almost 7 times less than June.

I have considered 300 and 800 people in a method but It may differ in a building during summer season because it was a vacation period in university. That's the reason we have a slight difference in the comparison. Power consumption in July is almost equal to the G1 method.

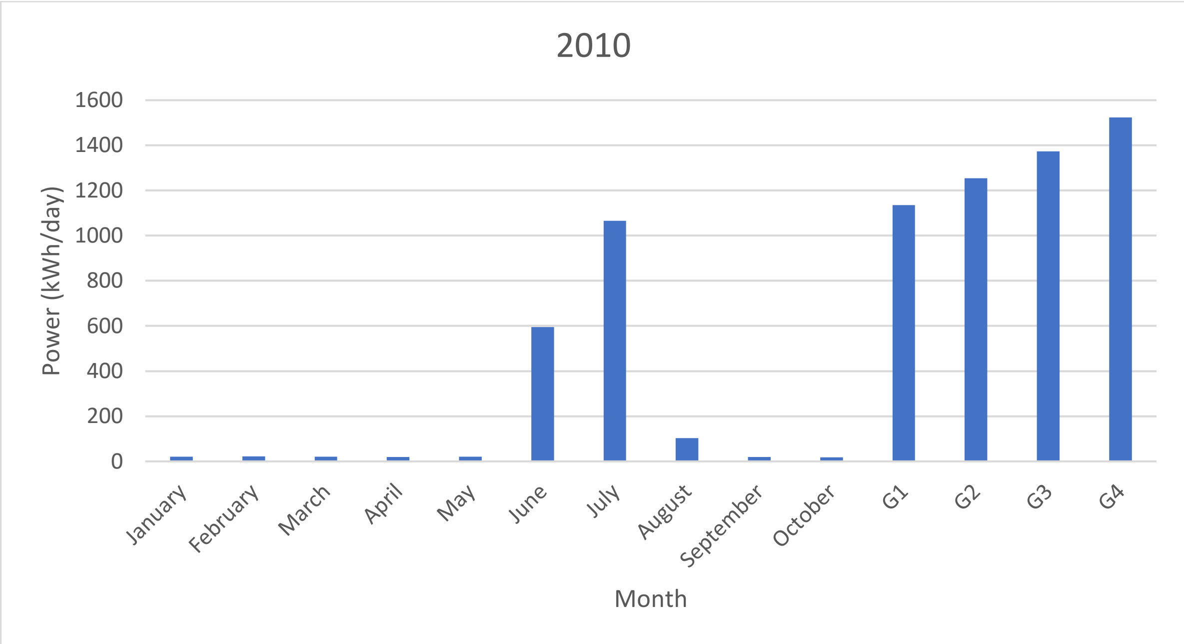

Fig 4.17 Monthly analysis in 2010 for all methods

2011:

In 2011, June and August are the two extreme months which needed the cooling process. Power consumed in this year was less compared with 2010. Calculated gain has the higher edge in 2011 real data. From October till May the power consumed was less than 100 kWh/day but in period June and August the consumption is maximum but it depends on the people occupied in a building. Maybe in July, we have less number of occupancy because it is a summer season.

In 2010, July has peak usage whereas in 2011 August has peak usage. Climate data will always vary from year to year but in 2011 July has less power consumption. It may be climate condition or people occupied in the building.

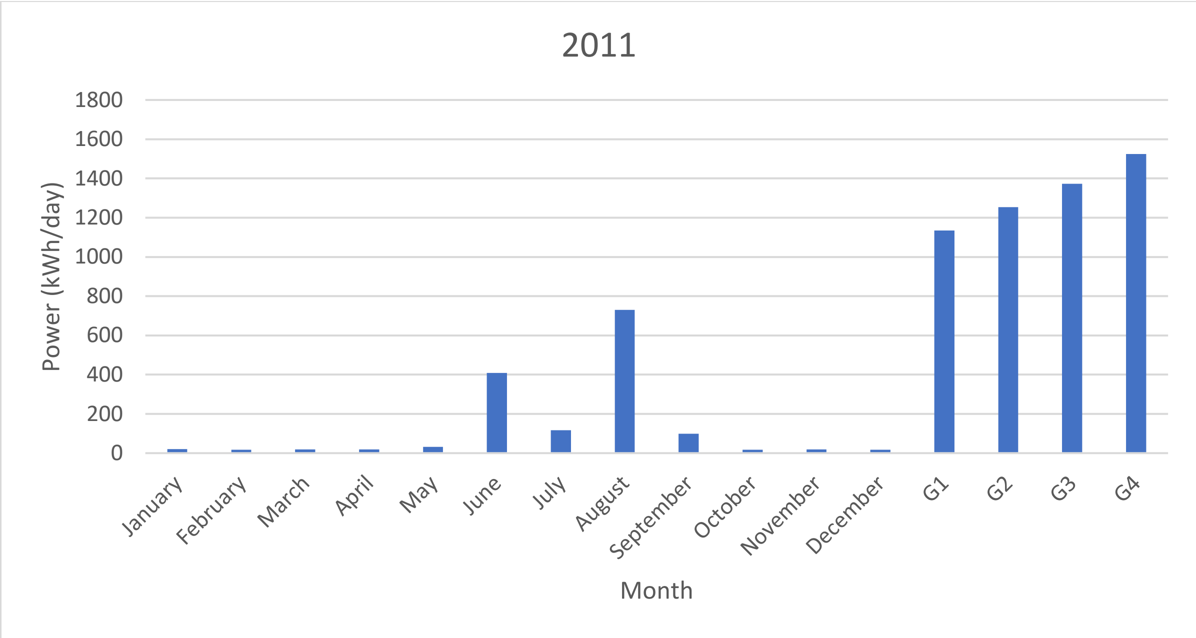

Fig 4.18 Monthly analysis in 2011 for all methods

2012:

In 2012, from May itself the power consumed becomes enormous due to the requirements in a building for a cooling process. From May till August the usage was almost same in this year particularly.

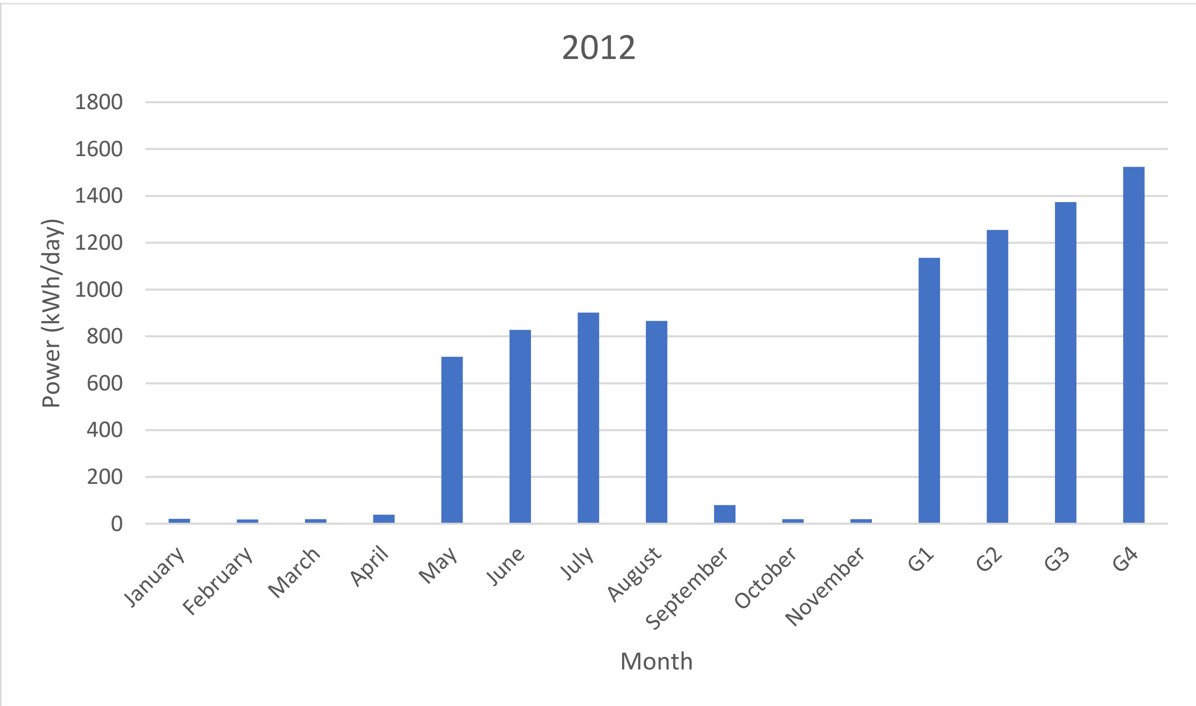

Fig 4.19 Monthly analysis in 2012 for all methods

2014:

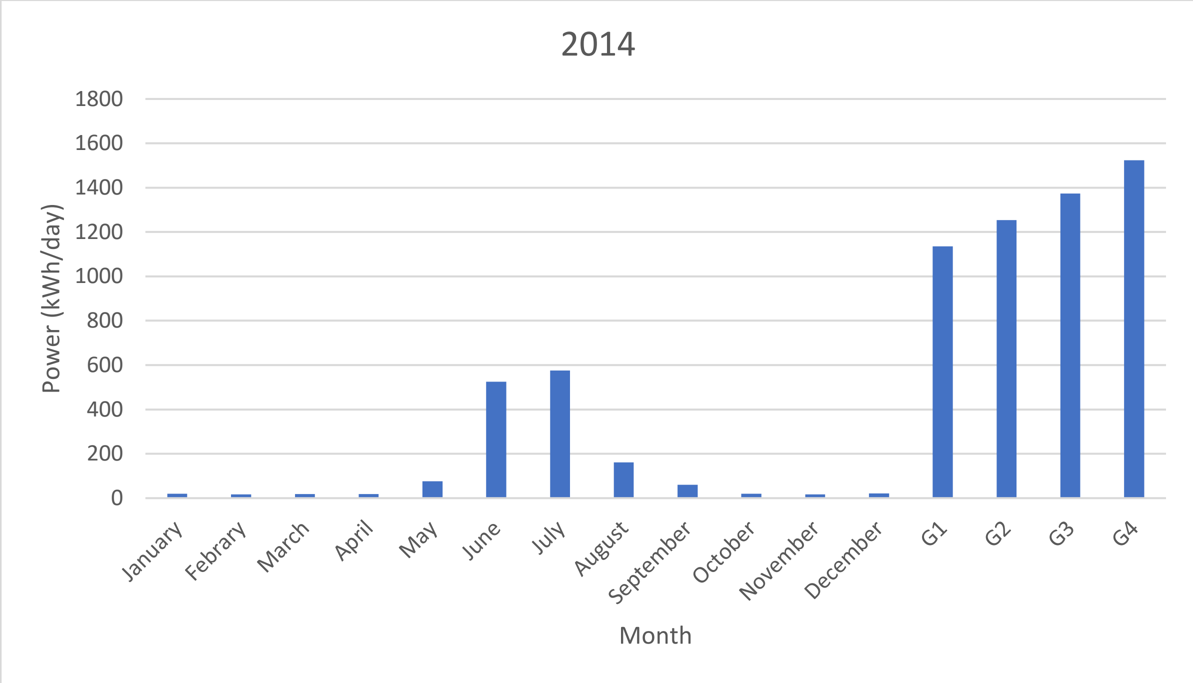

Fig 4.20 Monthly analysis in 2014 for all methods

2015:

In 2015, real consumption of power is very high compared with the calculated G1, G2, G3 and G4 methods. July and August are the high usage months whereas from October to may it was consumed very less due to winter season effects. In this monthly analysis of different year, 2015 has the highly consumed cooling process from the records excluding 2013 because I don't have data for that year in monthly order.

Moreover, In 2015 the real consumption is high than the calculated. This is due to night ventilation was not fully used in this year and 2016. If minimal night ventilation is applied means, the real consumption is similar or almost same usage to the calculated values. Let me show the case of 10 %-night ventilation was used in graphical methods (G1) follows the result of monthly analysis for 2015 and 2016. Minimal night ventilation is applied only during night time and full flow in the day time.

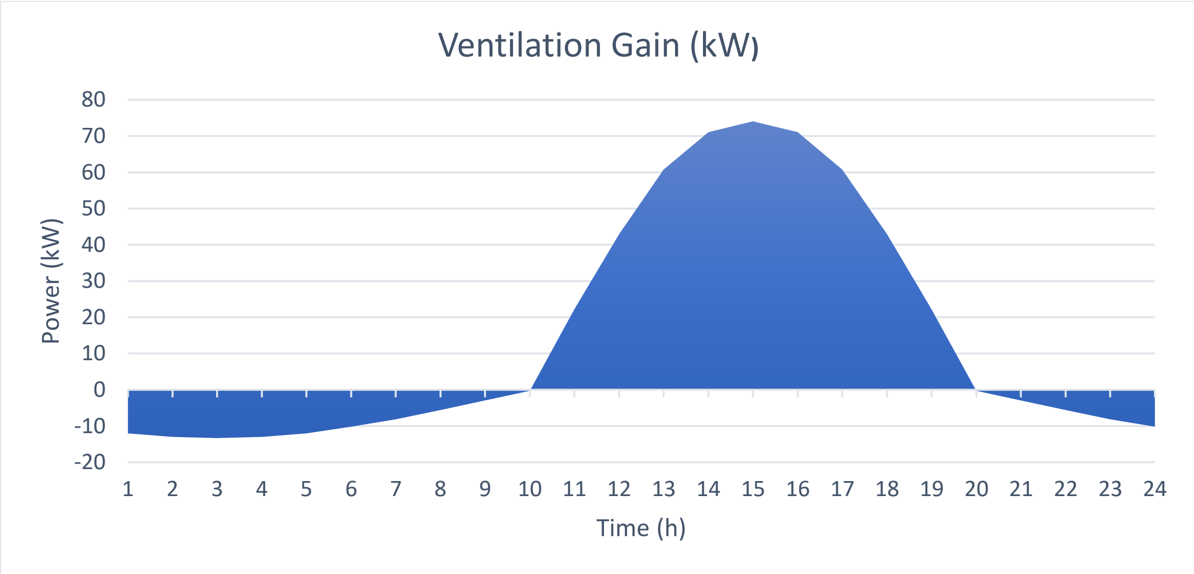

Fig 4.21 Ventilation gain in 2015 & 2016 for G1 method

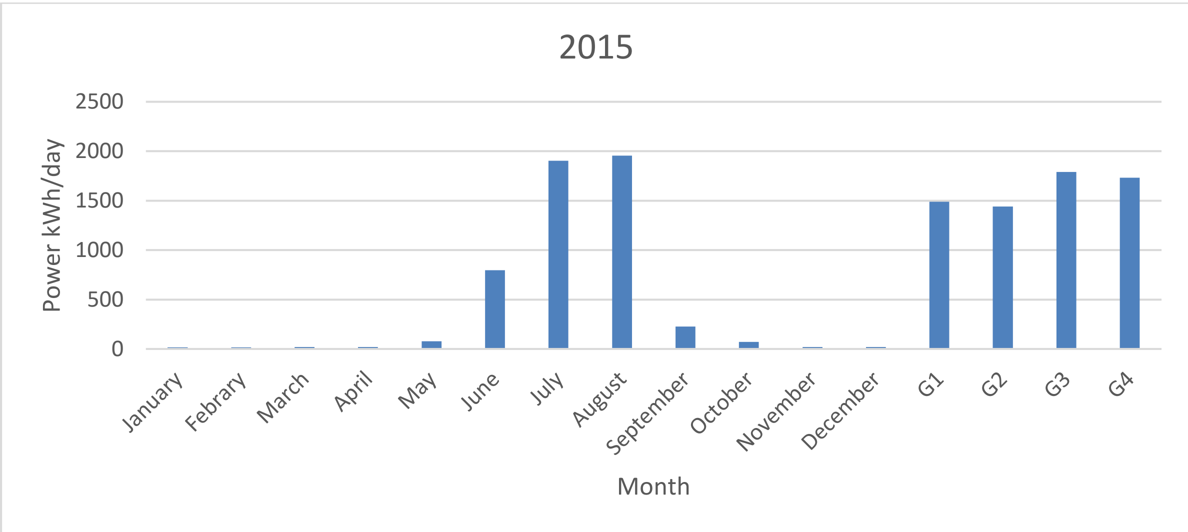

Fig 4.22 Monthly analysis in 2015 for all methods

2016:

This year analysis is also quite same as 2015. The same 10 %-night ventilation was applied during night time and full flow is allowed during daytime. Ventilation gain in this year is same as Fig 4.21. Results for 2016 monthly analysis is given below.

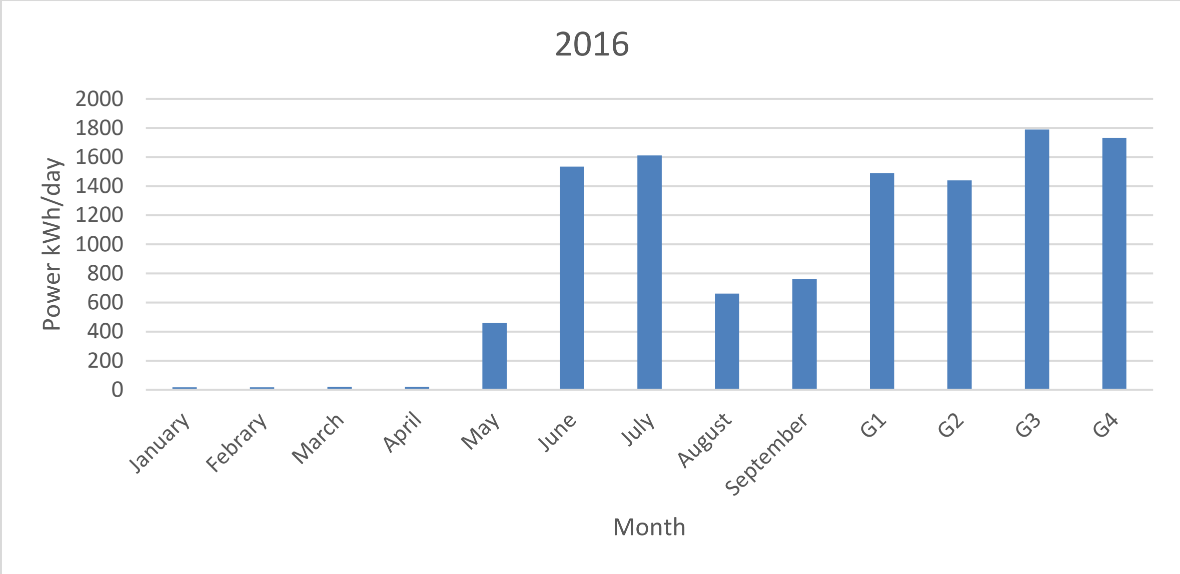

Fig 4.23 Monthly analysis in 2016 for all methods

4.3 Analysis on different dates in a year

2012:

From the data collected, I have analyzed the maximum capacity date with the calculated values. In this topic, the analysis is based on the different date in a year which is compared with the calculated values for finding the cooling capacity needed in a year.

On 08/06/12 the power consumption for cooling is taken during daytime only. Even though it is June month, the occupancy might be high on those time still the consumption was less with the calculated values. Calculated value is the day of maximum gain expected in a year but the real day is the common one and the usage of power was less due to the temperature or fewer people occupied in a building.

On 21/08/12 the power consumed takes place for a whole day without any OFF mode. It happens because slab cooling takes place on this occasion and so the cooling effect was high on the whole day.

On 11/09/12 the calculated value and the real value is quite similar. Daytime is fully occupied by the occupancy and cooling effect is needed in a building but during night time there will be no occupancy or a person in a building for such cooling effect.

On 28/07/12 this day must be noted carefully. In day time, there is very less consumption than other days which I compared previously. Slab cooling is highly effective on these days because the building was cooled using slab method in the night time. This helps the building to keep the temperature low that maintains the building during day time. Slab cooling is used to minimize the power consumption and this day shows exactly the same.

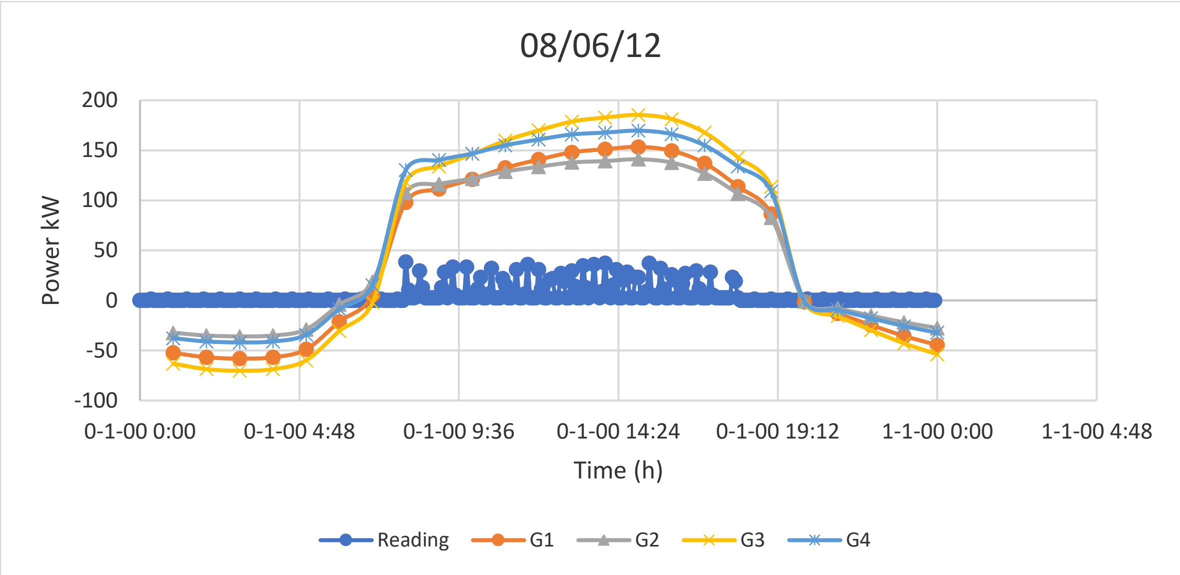

Fig 4.24 08/06/12 analysis for all methods

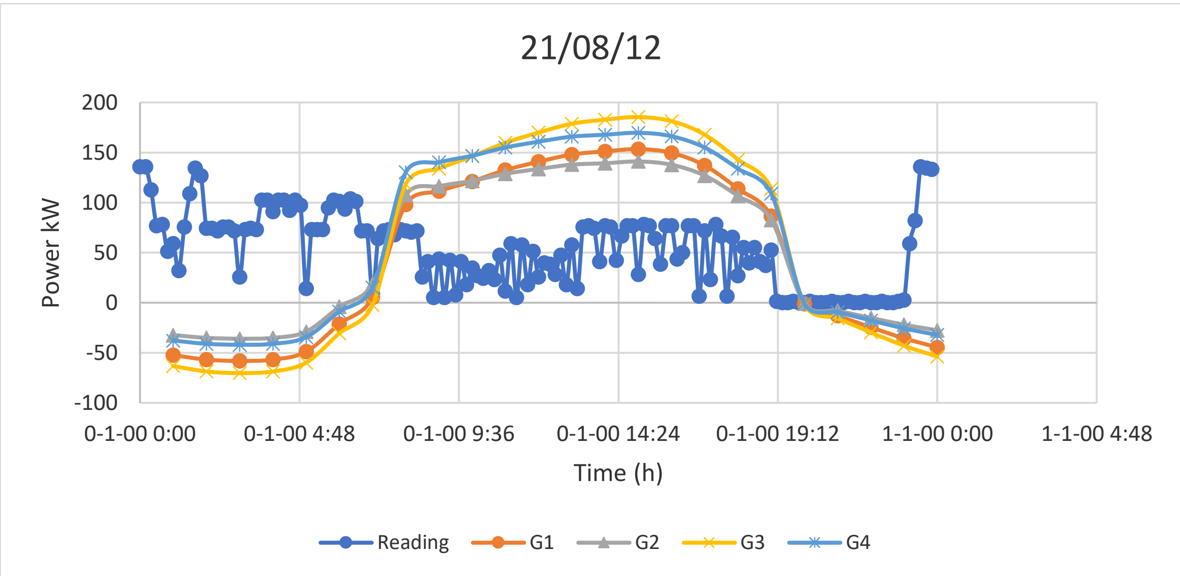

Fig 4.25 21/08/12 analysis for all methods

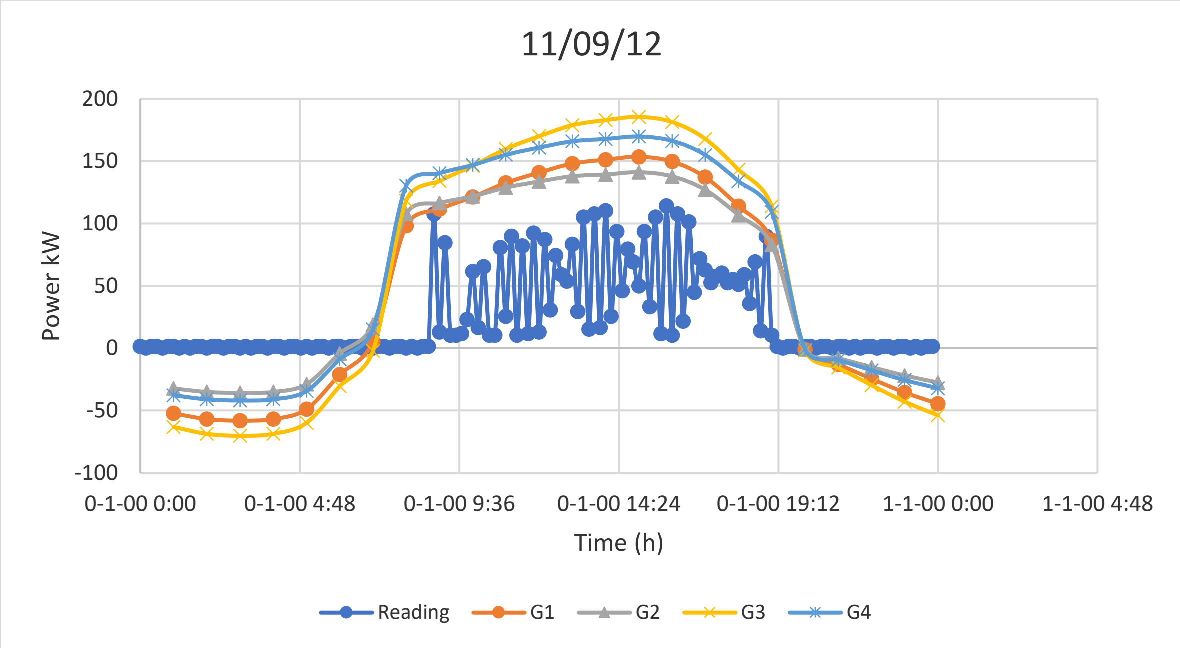

Fig 4.26 11/09/12 analysis for all methods

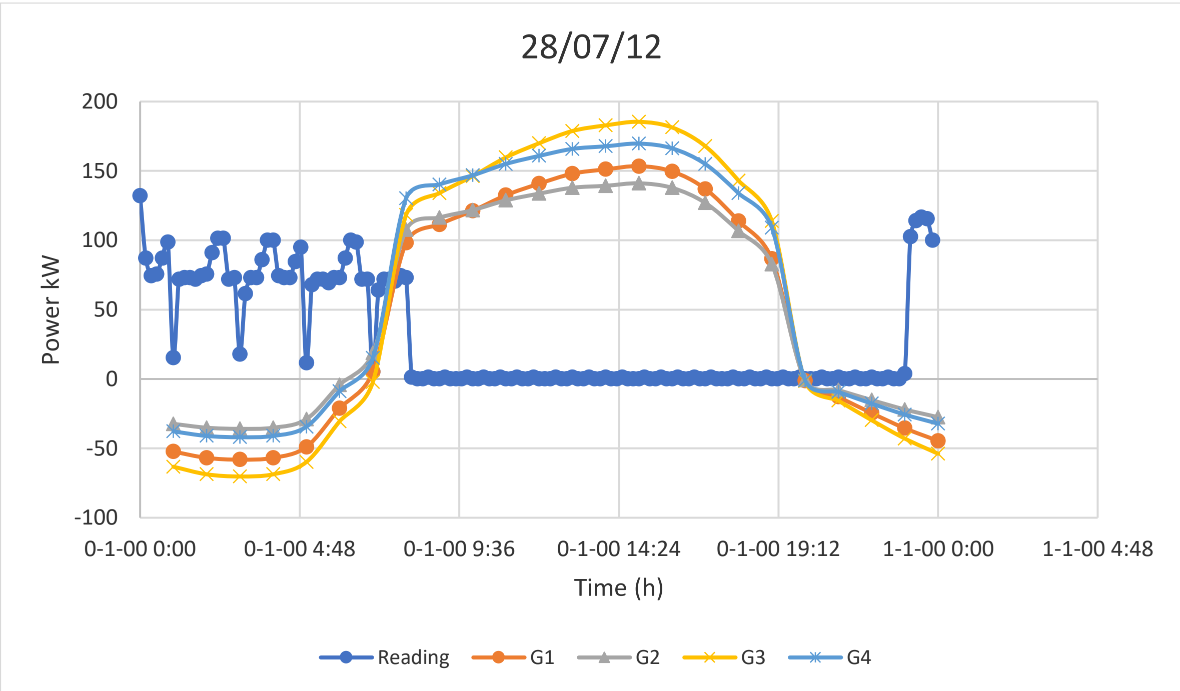

Fig 4.27 28/07/12 analysis for all methods

2013:

This year is a slightly different year than other years. It is the unstable year because the humidity is very high. So, I have chosen two days in the same month in a gap of two weeks. This two days will show the difference in the real values highly.

On 16/07/13 and 03/07/13, let us compare the power consumption on this two days. Firstly, the 16/07/13 the power consumed is high then the calculated value. But In 03/07/13 the power consumed is very low then the calculated value. In the previous topic, the maximum day was discussed in this year and the consumption is even high than these days.

On 03/07/13 the power consumption was very less for the whole day. This is due to the gains in a building and especially the usage is limited on this day.

Graphical representation was shown below to explain the power consumption between different days in the same year.

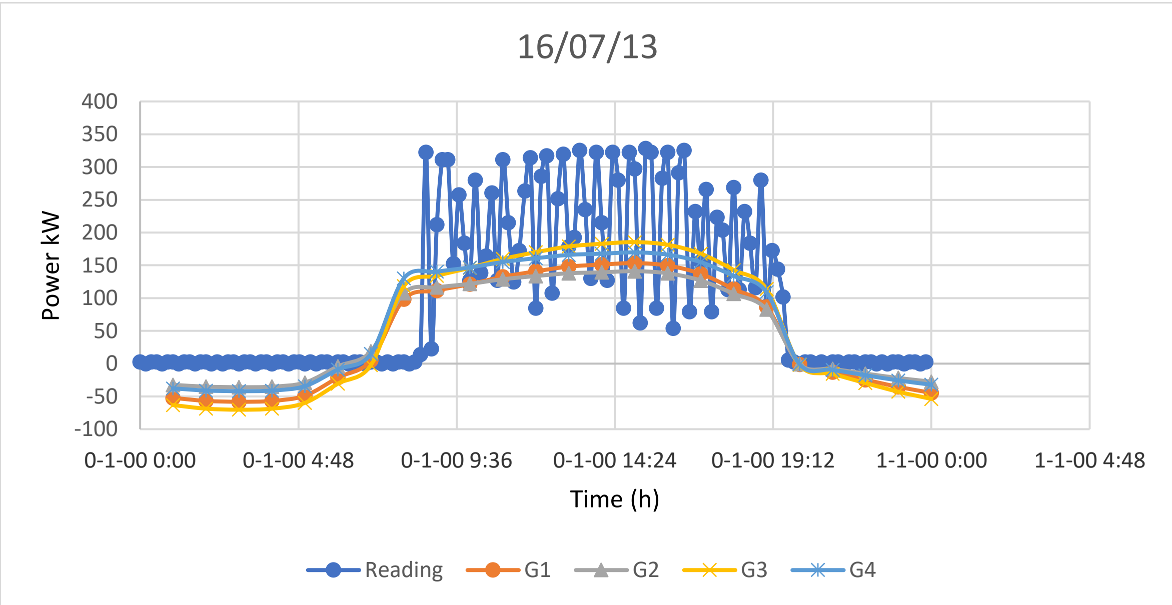

Fig 4.28 16/07/13 analysis for all methods

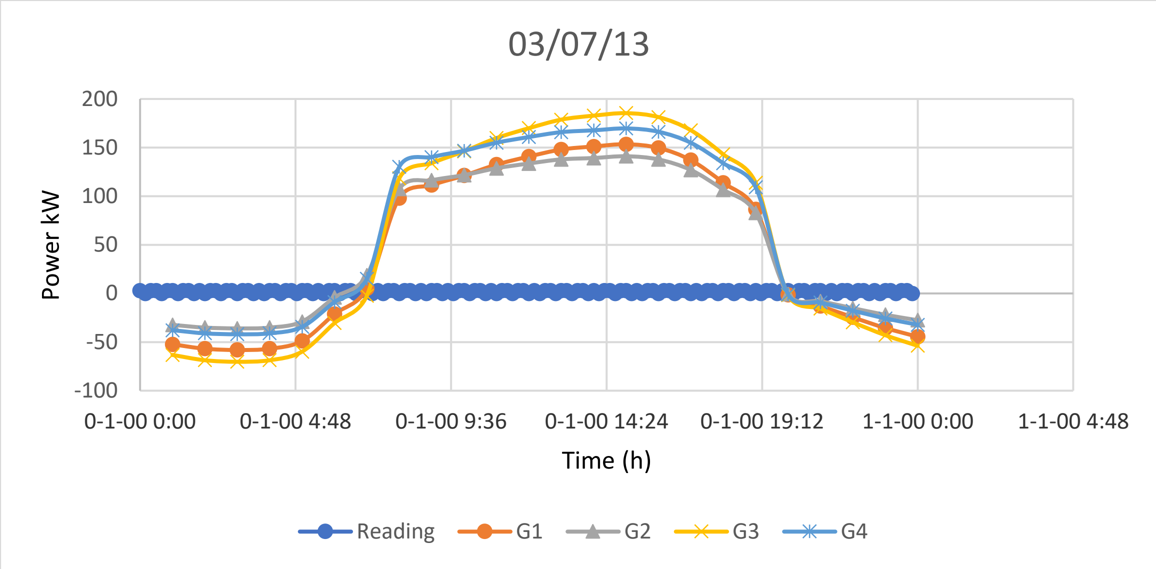

Fig 4.29 03/07/13 analysis for all methods

4.4 Comparison with Nominal capacity

Few occasions in a year, the power consumption used was equal to nominal or higher. Mostly the nominal capacity always is on top because the usage in a building needs to be very high to achieve the nominal capacity of a building. Some of the months were selected in a year and analyze that with the nominal capacity value.

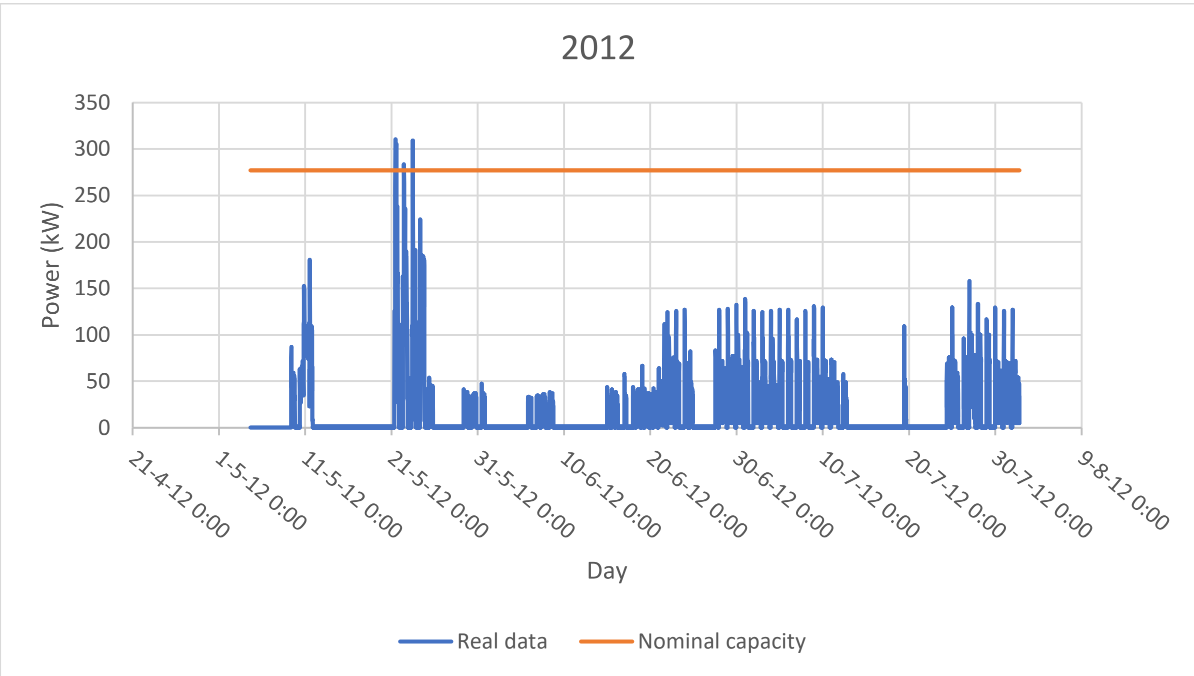

Fig 4.30 2012 analysis with nominal capacity

In 2012 during May month the real consumption was equal and sometimes higher than the nominal. All the other months in a year has a less power usage than the nominal capacity in a building. From this analysis, some days in a month or year might reach the nominal values listed. Detailed data is not available for 2015 and 2016 to compare it with nominal capacity.

5 Bin Method

This method was used to yield annual energy consumption. For different temperature and for different intervals, this method will be useful for steady state calculation. The consumption will be calculated for several values of outdoor temperature and that will be multiplied by the number of hours in the interval.

Calculated yearly consumption values can be compared with the reading values from the building. For this method, the interval was chosen between 30 ◦C to 15 ◦C. Evaluate the average temperature for three intervals from 30-25 ◦C, 25-20 ◦C, 20-15 ◦C and < 15 ◦C. Between this interval I will get the number of hours(N) for each. Reference year should be selected and daily average temperature should be calculated to compare with the real consumption from the building.

For 30 ◦C – N is 111

For 25 ◦C – N is 336

For 20 ◦C – N is 419

For 15 ◦C – N is 333

For different temperatures, I have estimated the gains and it should be multiplied by a number of hours in an interval to get an annual consumption. It is just approximation whereas here just determined from 15 ◦C. So, total consumption for the whole year will be shown with two different analysis below.

Reference year has been selected to compare it with annual consumption in different years. To obtain a daily average temperature from the whole year, reference was taken for months, days and hours. The months was chosen from May to September, weeks are only working days (Monday to Friday) and the working period between 8.00 to 19.00 hours.

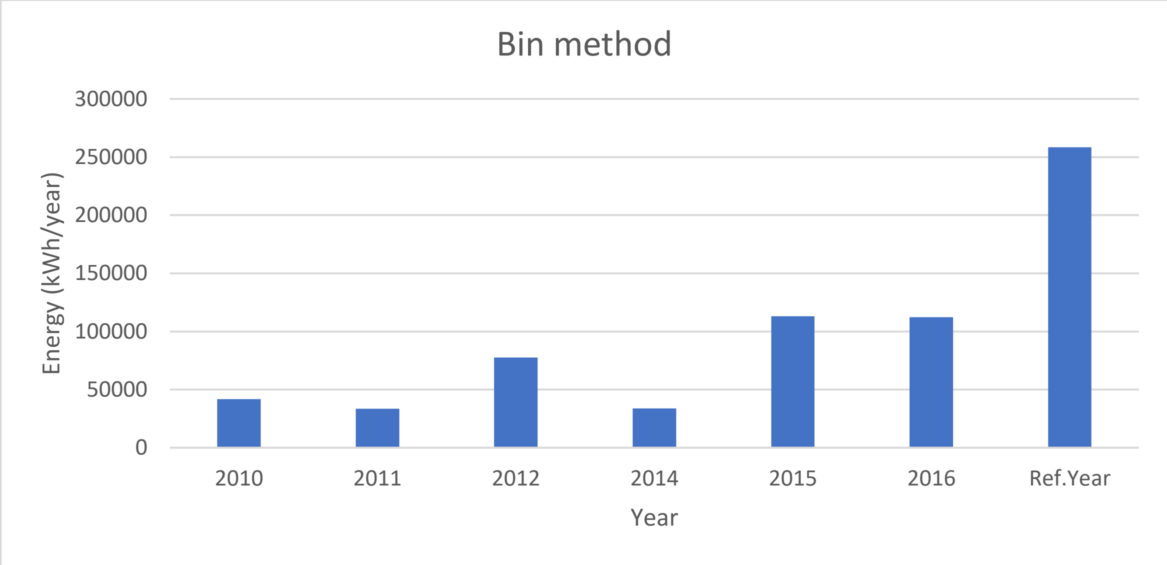

Fig 5.1 Bin analysis method-1 with different year

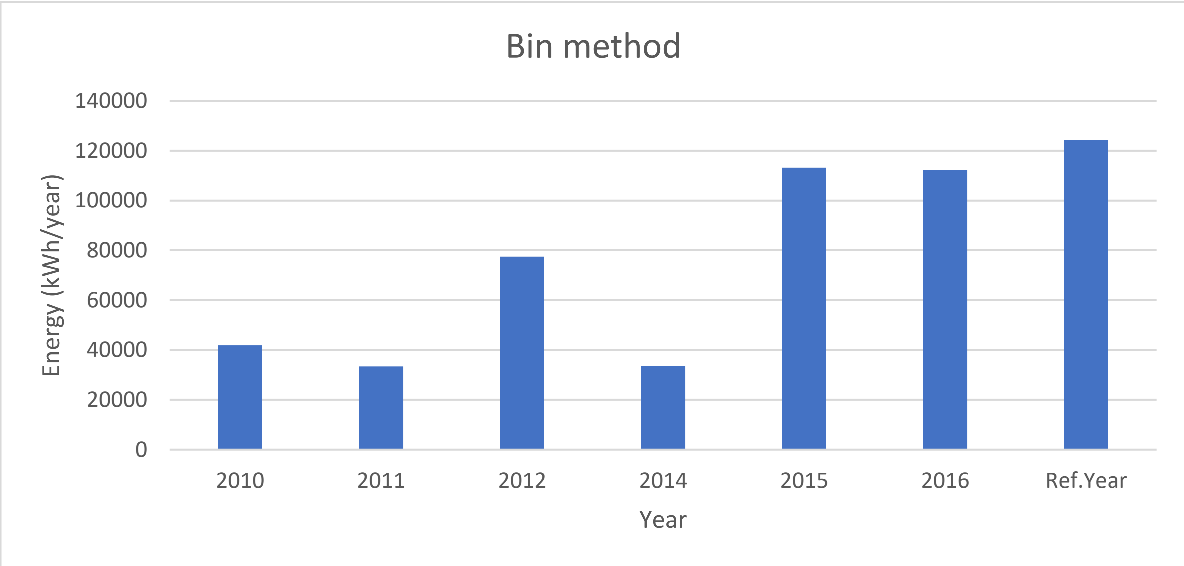

Fig 5.2 Bin analysis method-2 with different year

Bin analysis method-2 was similar like method-1 but the change in value is only on internal gains. Bin method-1 have an internal gain of 221 kW and I have selected 50 % of 221 kW for Bin method-2 and all the remaining gains are same without any alteration.

Bin analysis method- 1 gives annual reference year consumption higher than the real values. This happens because the calculation made for whole year and temperature has chosen constantly but the temperature will vary with seasons and occupancy might also make a huge difference in the consumption. Now the analysis of method-2 was quite near to the real values. This is due to the internal gains was selected 50 % from the method-1. So, the occupancy and temperature will make the difference in the overall annual consumption.

6 Conclusion

From this project, I can conclude that the internal heat gains in a building play a vital role to size a new heating-cooling system. I have calculated heat gains on a maximum day in a year theoretically. The data collected from the library on daily, monthly and detailed was analyzed with calculated heat gains. By comparing daily data, different days gives power consumption differently because of the usage in a building. When comparing with monthly data, May, June, July and August are the extreme requirement for the cooling process in a whole year. In the monthly analysis, the calculated values are higher than the real consumption. Bin method was introduced to calculate the annual consumption in the building. In bin method, it is necessary to decrease the internal heat gains of 50 % from G1 method because the reference year gives high value than the real consumption. After decreasing internal gains, reference year gives good annual consumption with the real values.

7 Reference and Bibliography

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8 Annex

Find in the annex, a CD with the thesis report in PDF.