STRATEGIC GUIDELINES FOR SELECTION OF BEST ENERGY EFFICIENT AIR CONDITIONING SYSTEM/EQUIPMENT FOR COMMERCIAL BUILDINGS IN SRI LANKA.

Kukulege Aruna Kelum Perera

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Master of Science in Building Services Engineering

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

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By

K.A.K. Perera

Supervised by

Prof.R.A.Attalage

This Dissertation was submitted to the Department of Mechanical Engineering of the University of Moratuwa in partial fulfillment of the requirement for the Degree of MSc in Building Services Engineering.

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Prof. R.A.Attalage

Department of Mechanical Engineering

University of Moratuwa

Abstract

Air conditioning was considered a luxury in earlier days and now it becomes a general requirement due to urbanization, new constructions, modern architecture, regulations and standards etc. In early days there were no limitations on space and also there were lot of greenery which supports concepts such as natural ventilation.

Therefore importance of establishing proper procedure for AC system development is great and this study aims at developing a systematic procedure for selection of efficient AC system/equipment for different type of commercial buildings.

Literature review discuss broadly on technologies, standards and regulations, energy efficiency, Calculation techniques and tools, Building envelope improvements which is the flat form for development of a methodology to achieve research objective. Methodology developed consist of three phases namely Design, Testing and Commissioning, Operation and Maintenance. In Sri Lanka focus is mainly given for design phase and neglect T & C, O & M phases which is so critical for success of the project.

Once methodology established guidelines have been developed for easy reference so that even layman can understand approach required for development of efficient AC system for his new building. Real time case study presented for better understanding of proposed methodology and further improvement on the study can be done by monitoring applications.

Finally recommendations were given based on research study outcome for real time applications.

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LIST OF ABBREVIATION

Abbreviation		**Description**
AABC	:	Associated Air Balance Council
AC	:	Air Conditioning
ACMV	:	Air Conditioning & Mechanical Ventilation
AHU	:	Air Handling Unit
ANSI	:	American National Standards Institute
ARI	:	Air Conditioning & Refrigeration Institute
ASHRAE	:	American Society of Heating, Refrigeration and Air Conditioning Engineers
BAS	:	Building Automation System
BCHP	:	Building Cooling Heat and Power
BMS	:	Building Management System
BOQ	:	Bill Of Quantities
BREEAM	:	Building Research Establishment Environmental Assessment Methodology
BSRIA	:	Building Services Research and Information Association (UK)
BTU	:	British Thermal Units
CCHP	:	Combined Cooling, Heat and Power
CCTV	:	Closed Circuit Television
CEB	:	Ceylon Electricity Board
CHPDH	:	Combined Heat and Power District Heating
COP	:	Coefficient Of Performance
DC	:	Direct Current
DOE	:	Department Of Energy
EER	:	Energy Efficiency Ratio

FCU	:	Fan Coil Unit
FLA	:	Full Load Amperage
FPT	:	Functional Performance Test
HCFC	:	Hydro Chloro Fluoro Carbons
HPHX	:	Heat Pipe Heat Exchanger
HVAC	:	Heating Ventilation and Air Conditioning
IAQ	:	Indoor Air Quality
IEQ	:	Indoor Environmental Quality
IPLV	:	Integrated Part Load Value
ISO	:	International Organization for Standardization
LCA	:	Life Cycle Assessment
LEED	:	Leadership in Energy & Environmental Design
LPD	:	Lighting Power Densities
MERV	:	Minimum Efficiency Reporting Value
MJ	:	Million Joules
NEBB	:	National Environmental Balancing Bureau
NGO	:	Non Governmental Organization
NPLV	:	Non Standard Part Load Value
NPV	:	Net Present Value
O & M	:	Operation & Maintenance
OTTV	:	Overall Thermal Transmittance Value
PMV	:	Predicted Mean Vote
PPB	:	Parts Per Billion
PPD	:	Predicted Percentage Dissatisfied
RH	:	Relative Humidity
SC	:	Shading Coefficient
STP	:	Standard Temperature and Pressure

T & C	:	Testing & Commissioning
TAB	:	Test, Adjust, Balance
TDS	:	Total Dissolved Solids
TMY	:	Typical Meteorological Year
TR	:	Tones of Refrigeration
VAV	:	Variable Air Volume
VOC	:	Volatile Organic Compound
VRV	:	Variable Refrigerant Volume
VSD	:	Variable Speed Drive
WPU	:	Water Cooled Package Units
WWR	:	Window to Wall Ratio

CHAPTER 1:INTRODUCTION/BACKGROUND:

1.1 Background:

Air Conditioning is becoming a basic requirement especially in city areas due to urbanization and new constructions. Because of space restrictions and looking forwards optimized building foot print, most of new constructions are of multi storied buildings and difficult to achieve thermal comfort levels within the building employing ventilation. Most of the old government offices were provided with ventilation systems which was adequate at that time to meet occupant comfort requirements.

Normally 50-60% of energy is consumed for air conditioning in commercial and industrial buildings[1]. Therefore energy efficiency of the air conditioning system is a key factor in designing of AC systems and energy efficient installations are rewarded with certification like Leadership in Energy and Environmental Design (LEED), Beaufort Region Environmental Assessment and Monitoring (BREAM), International Organization for Standardization (ISO) for energy efficiency etc.

This study aims at developing a systematic procedure for selection of efficient AC system/equipment for different type of buildings based on life cycle cost analysis. In the design of AC system for buildings, load characteristic, operating pattern, client specific requirement, site limitations must be considered before finalizing AC equipment. All above points are related with technical aspects and operational cost (energy consumption).

The building stock is divided into three categories based on floor area available as below.

- Small
- Medium
- Large

Small : Cinema Theatre, Super Markets, Office Premises

Medium : Shopping Complexes, Factories, Data Centre

Large : High rise buildings, City hotels, Large Factories

The most energy efficient AC system for above three categories are different and each has its technical and operational advantages. Thus selection of optimum suited system for a facility is based on so many factors and energy efficiency is having great weight in final decision making. The life cycle cost analysis is a great tool which can be used to make a final decision.

Most of the time client looks at investment cost and never enlightened on operational cost factor. A comprehensive life cycle cost performed with computer simulations shows that operational cost is a major component that we have to be considered and looked at the initial stage not later. This information must be important not only to Engineers but also to Architects to provide provisions for best suited AC systems (i.e Plant rooms, duct shafts, etc.).

1.2. Why Air Conditioning is needed in Modern Commercial Buildings?

Air conditioning as it is known it, providing thermal comfort by mechanical methods, first appeared in buildings about a hundred years ago [2]. The ability to control temperature, humidity and air purity made urban development possible in the most inhospitable of locations. Together with electric lighting, air conditioning also eliminated restrictions on plan form and fenestration that architects had been constrained to work under since antiquity. The description "fully air conditioned" is almost synonymous with large prestigious buildings, particularly commercial offices.

The internal environment used by these early office workers was determined largely by building features such as fenestration, plan form and story height. Protection from extremes of climate was restricted to passive measures such as opening windows and lowering shades when it was hot. Although electricity was common by 1900s, the cost and output of the lighting meant that office work was carried out from day light available. The ability to illuminate the full depth of the office, was therefore one of the most important provisions. Although it limited the maximum width of the office between outside wall and internal corridor, it also meant that natural ventilation was available from window openings. The provision of adequate daylight to offices and the consequent area of glazed wall and restriction in depth of offices from windows are the major obstacles to architects attempting to provide the maximum of floor space from building plots. Early days keeping cool did not seem to be a major concern. The priority appeared to be adequate ventilation for sanitary purposes and elimination of excessive humidity. Using air conditioning conjunction with new electrical artificial lighting offered great opportunities to transform buildings. Buildings could be designed without the constraints of passive measures to provide comfortable internal environments irrespective of the type and size of the enclosure and to create offices of infinite depth without regard for fenestration.

Adequate supply of fresh air requirement is another important factor for consideration and nowadays Ac designs are mostly based on ASHRAE 62.1 guidelines. On the other hand air conditioning necessitates ducts, plant room that occupies valuable internal spaces.

1.3. Cost of Energy and Usage for Air Conditioning:

Power consumed by an air conditioning system of a commercial building is significant and recent tariff increases by The Ceylon Electricity Board caused building owners to look for ways to reduce their power consumptions drastically. Ceylon Electricity Board (CEB) expected to boost its revenue by 72.2% amounting Rs: 69.9 billion from domestic consumers and 11.3% amounting Rs: 126.1 billion per annum from industrial users [3]. Above figures shows that impact on end users is significant and immediate measures must be taken to maintain their operating costs at a manageable level. Otherwise cost of production for a good or service would not be can't affordable to general public or buyers in case of international trades would loss competitive edge.

There was a significant increase in electricity tariff for last 10-15 years due to various reasons such as drought, food shift, fuel price increase etc and trend is that this would continue at an average 10% tariff increase per year since CEB is more depend on thermal power generation to meet increase in demand. Below Figure 01 shows power consumption distribution of a residence and main contributor is air conditioning. Air Conditioning system power consumption is varies from 40-60% from highly efficient system to average AC installation.

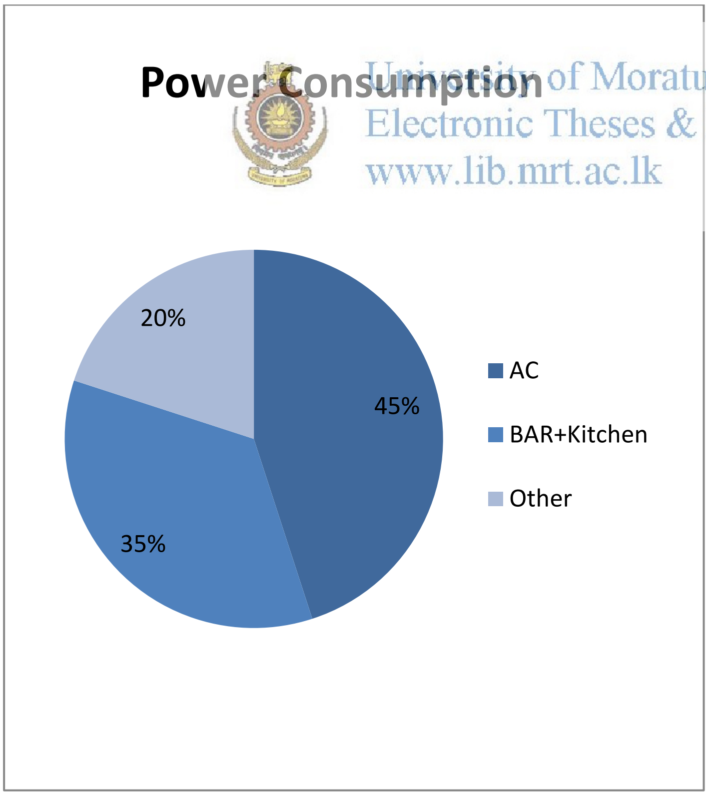


Figure:1-1:Power Consumption Distribution of a Residence

(Source:Co-Energi report on ENERGY ANALYSIS AND AC SYSTEM IMPROVEMENTS OF RESIDENTIAL COMPLEX IN COLOMBO)

Therefore relationship between Energy usage and type of AC system of a commercial building is very critical and nowadays building owners are more interested on new technologies which would help to cut down AC system operating costs.

1.4. Statement of The Research Problem:

Demand for air conditioning in modern commercial buildings is increasing and due attention must be given on this as a developing country since a reasonable amount of electricity is used by equipment related with air conditioning systems. Note that we are mainly depending on thermal power plants to generate electricity required to meet Peak Demand and government of Sri Lanka incur heavy cost for importation of fuel required for this. As per import statistics, More than 40% of our country's gross income is being spent on fuel import, transportation and production of thermal power. Therefore every effort must be taken to improve utilization of power as a nation and government has already initiated measures for this.

Since air conditioning systems consume a significant portion of electricity, steps must be taken to encourage installation of best energy efficient AC systems for new buildings and retrofit existing old system with properly designed new AC systems to meet international standards such as ASHRAE. To achieve above goal, one of the salient point is to establish "Strategic Guidelines for Systematic Selection of Best Energy Efficient Air Conditioning System/Equipment for Commercial Buildings in Sri Lanka". So that consideration must be given on Design, Testing & Commissioning, Operation & Maintenance at the initial level so that client must be able to understand all aspects related with Ac system upfront. In year 2008 Sri Lankan Building Code was introduced mainly given focus on building efficiency and this code however does not cover energy consumption process of equipment that are in the buildings other than in the form of building elements[4]. Therefore considering above facts now it is high time to develop a comprehensive strategic design guidelines for air conditioning system designs.

1.5. Research objectives and methodology:

1.5.1. Main Objective :

To Develop strategic guidelines to identify energy efficient AC system for small, medium and large scale buildings to be employed at the building design stage.

1.5.1.1. Specific Objective 1:

To establish current energy efficient practices/ technologies used in comfort Air Conditioning internationally which can be considered, incorporated in our designs.

1.5.1.2. Specific Objective 2:

To explore internationally accepted thermal comfort, IAQ and energy efficiency measuring criteria and strategies for enhancing Air Conditioning system energy performance which can be adopted in local AC system designs.

1.5.1.3. Specific Objective 3:

To evaluate factors associated with the selection of appropriate Air Conditioning system (Environment condition, Client requirements, Architectural limitations, Load profile, etc.) for buildings and develop a method to short list 2-3 suitable systems for the facility of interest.

1.5.1.4.Specific Objective 4:

To identify different building envelope types used in building construction and study it's impact on building cooling loads.

1.5.1.5.Specific Objective 5:

Develop and present strategic guide line

1.5.2. Methodology for Specific Objective 1:

Data shall be collected through following steps and then establish industry norms in energy efficient standards, regulations, practices and technologies used in comfort Air Conditioning. Same shall be incorporated in new designs to develop energy efficient AC designs.

- Conduct literature survey
- Obtain details of available installations
- Ascertain expert opinion
- Site Visits
- Obtain latest technology innovations info from AC equipment manufacturers (YORK, CARRIER, TRANE, DUNHAMBUSH, MACQUAY)
- Study on Limitations of available technologies and installations
- Study impact of BAS system on AC system efficiency.

1.5.3. Methodology for Specific Objective 2:

Need to study internationally available guidelines and standard related with thermal comfort, indoor air quality. Therefore would refer the followings.

- ASHRAE 90.1 volume
- LEED Energy efficiency guide lines
- Code of practice for energy efficient buildings-2008
- ASHRAE 62.1 volume
- ASHRAE 55 volume

1.5.4. Methodology for Specific Objective 3:

Following steps shall be adopted to evaluate factors associated with the selection of appropriate Air Conditioning system.

- Refer technical literature
- List out key factors considered in AC system design
- Develop data sheet which will automatically generate suitable AC system based on input data (design data).
- Select appropriate AC system for facilities from each category

1.5.5. Methodology for Specific Objective 4:

To identify different building envelope types used in building construction, following steps shall be adopted.

- Conduct literature survey
- Obtain details of available installations
- Obtain architects and engineers opinion
- Study impact of Building envelope on AC load.
- Study on available modeling techniques
- Perform thermal simulation for selected two buildings of each category.
- Select best system based on simulation result

Limitations:

1. Availability of consistent data for load calculation and life cycle costing.
2. Case analysis will be performed for existing facilities and therefore have to stick with available layouts.
3. Technology is evolving and there should be a mechanism to identify those initiations and incorporate with new designs.

1.6 Organization of the report:

Chapter-1 has discussed about background, the rationale of the dissertation, research problem statement and research objectives and methodology of the study.

Chapter-2 of the report discussed literature on Basic concepts of thermal comfort, IAQ for health and energy performance and their interrelation, Study on recently proven technologies, Emerging technologies, Best practiced technologies, Energy efficient alternative technologies, Internationally accepted energy efficient standards & guidelines, Factors associated with selection of an appropriate air conditioning system, Different building envelopes for Energy optimization and Building load and energy simulation techniques.

Chapter-3 discussed the detailed methodology adopted of the study to achieve the objectives of the research. Design Approach to achieve main and specific objectives, Testing & Commissioning, Operation and maintenance of air conditioning system has been discussed in this chapter.

Chapter - 4 presents the guidelines with respect to Design Stage, Equipment Sizing & Selection Stage, Operation & Maintenance.

Chapter-5 shows application of proposed methodology as a case analysis. Here we are discussing the advantages of adopting this methodology for commercial buildings.

Chapter - 6 is giving recommendations and conclusion with key message.

CHAPTER 2: LITERATURE REVIEW

2.1. Chapter Introduction:

Here we discuss about basic concepts and factors associated with air conditioning system design for commercial buildings and also on emerging and proven technologies, available internationally accepted standards and guidelines for air conditioning systems, importance of building envelope optimization for better performance of AC system. Further discussed about available cooling load simulation tools which can be used during design phase of the project and this is a key factor for consideration.

2.2 Basic concepts of thermal comfort, IAQ for health and energy performance and their interrelation:

2.2.1. Thermal Comfort:

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is personal, different from person to person(ANSI/ASHRAE Standard 55). This standard is to maintain thermal comfort for occupants of buildings or other enclosures which is one of the important goals of HVAC (heating, ventilation, and air conditioning) design engineers. Thermal neutrality is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. The main factors that influence thermal comfort are metabolic rate, clothing insulation, air temperature, mean radiant temperature, air speed and relative humidity. Psychological parameters such as individual expectations also affect thermal comfort.

Predicted Mean Vote (PMV) model stands among the most recognized thermal comfort models and it can be applied to air conditioned buildings. It was developed using principles of heat balance and experimental data collected in a controlled climate chamber under steady state conditions. Similar to ASHRAE Standard 55 there are other comfort standards like EN 15251 and the ISO 7730 standard[5].

2.2.2. Factors influencing thermal comfort:

Since comfort levels varies from person to person in terms of physiological and psychological satisfaction, it is hard to find an optimal temperature for everyone in a given space. Laboratory and field data have been collected to define conditions that will be found comfortable for a specified percentage of occupants.

There are six primary factors that directly affect thermal comfort and are categorized in to two groups as follows.

- Personal factors-Metabolic Rate and Clothing Level
- Environmental factors-Air Temperature, Mean Radiant Temperature, Air Speed and Humidity

Even if all these factors may vary with time, standards usually refer to a steady state to study thermal comfort, just allowing limited temperature variations.

2.2.3. Thermal comfort models:

As discussed earlier the thermal static model PMV/PPD can be used to model Thermal Comfort levels of air conditioned space. The PMV/PPD model was developed by P. O. Fanger [5] using heat balance equations and empirical studies about skin temperature to define comfort. Standard thermal comfort surveys ask subjects about their thermal sensation on a seven point scale from cold (-3) to hot (+3). Fanger's equations are used to calculate the Predicted Mean Vote (PMV) of a large group of subjects for a particular combination of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation. Zero is the ideal value, representing thermal neutrality, and the comfort zone is defined by the combinations of the six parameters for which the PMV is within the recommended limits -0.5 to +0.5. Although predicting the thermal sensation of a population is an important step in determining what conditions are comfortable, it is more useful to consider satisfaction of occupant. Fanger developed another equation to relate the PMV to the Predicted Percentage Dissatisfied (PPD). This relation was based on studies that surveyed subjects in a chamber where the indoor conditions can be precisely controlled.PPD method treats all occupants the same and disregards location and adaptation to the thermal environment.

ASHRAE Standard 55-2010 sets the requirements for indoor thermal conditions. It requires that at least 80% of the occupants be satisfied. Based on PMV analysis CBE Thermal Comfort Tool for ASHRAE 55 allows to input the six comfort parameters to determine whether a certain combination complies with ASHRAE 55. The results are displayed on a psychometric or a temperature-relative humidity chart and indicate the ranges of temperature and relative humidity that will be comfortable with the given the values input for the remaining four parameters.

2.2.4. Elevated air speed method:

ASHRAE 55, 2013 accounts for air speeds above 0.2 m/s separately than the baseline model. Since air movement can provide direct cooling to occupants, especially if they are wearing lightly even higher temperatures can be more comfortable than the PMV model predicts. Air speeds up to 0.8 m/s are allowed without local control, and 1.2 m/s is possible with local control. This elevated air speeds would result comfortable levels within occupied space even at fairly high temperatures.

2.2.5. Local thermal discomfort:

Although thermal comfort is usually discussed for the body as a whole, thermal dissatisfaction may also occur just for a particular part of the body, due to local sources of unwanted heating, cooling or air movement.

2.2.6.I AQ for health:

Air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants is termed as Indoor Air Quality. IAQ can be affected by gases (including carbon dioxide, carbon monoxide, radon, volatile organic compounds), particulates, microbial contaminants (mold, bacteria) or any mass or energy stressor that can induce adverse health conditions. Source control, filtration and the use of ventilation to dilute contaminants are the primary methods for improving indoor air quality in most buildings.

IAQ is part of Indoor Environmental Quality(IEQ), which includes IAQ as well as other physical and psychological aspects of life indoors (e.g., lighting, visual quality, acoustics, and thermal comfort).Environmentally Sustainable Design concepts also include aspects related to the commercial and residential heating, ventilation and air-conditioning (HVAC) industry. Among several considerations, one of the topics to attend to is the issue of indoor air quality throughout the design and construction stages of a building's life. Demand control ventilation can be used to reduce energy consumption while maintaining adequate air quality instead of setting a fixed air replacement rate. Carbon dioxide sensors are used to control the rate dynamically, based on the emissions of actual building occupants.

For the past few years, there have been many debates among indoor air quality specialists about the proper definition of indoor air quality and specifically what constitutes "acceptable" indoor air quality.

One way of maintaining quality of indoor air is by replacement with outside air at a constant frequency. In halls, gym, dining, and physiotherapy spaces, the ventilation should be sufficient to limit carbon dioxide to 1,000ppm. According to ASHRAE Standards, ventilation in classrooms is based on the amount of outdoor air per occupant plus the amount of outdoor air per unit of floor area, not air changes per hour. Since carbon dioxide indoors comes from occupants and outdoor air, the adequacy of ventilation per occupant is indicated by the concentration indoors minus the concentration outdoors. The value of 615ppm above the outdoor concentration indicates approximately 15 cubic feet per minute of outdoor air per adult occupant doing sedentary office work where outdoor air contains 385ppm, the current global average atmospheric CO_2 concentration. In classrooms, the requirements in the ASHRAE standard 62.1, Ventilation for Acceptable Indoor Air Quality, would typically result in about 3 air changes per hour, depending on the occupant density. Occupants may not be the only source of pollutants, so outdoor air ventilation may need to be higher when unusual or strong sources of pollution exist indoors. When outdoor air is polluted, then bringing in more outdoor air will aggrevate the situation and occupants will show symptoms related to outdoor air pollution. Generally, countryside outdoor air is better than indoor city air. The use of air filters can trap some of the air pollutants. Air filters are used to reduce the amount of dust that reaches the wet coils. Dust can serve as food to grow molds on the wet coils and ducts and can reduce the efficiency of the coils.

Moisture management and humidity control requires operating HVAC systems as designed. Moisture management and humidity control may conflict with efforts to try to optimize the operation to conserve energy. As an example, Moisture management and humidity control requires systems to supply Make Up Air at lower temperatures, instead of the higher temperatures to conserve energy in cooling-dominated climate conditions. High humidity fresh air must be carefully treated before supplying to indoor space since high humidity give rise to mold growth and moisture indoors are associated with a higher prevalence of occupant respiratory problems. The "dew point temperature" is an absolute measure of the moisture in air. Some facilities are being designed with the design dew points in the lower 50's °F, and some in the upper and lower 40's °F. Some facilities are being designed using desiccant wheels with gas fired heater to dry out the wheel enough to get the required dew points. On those systems, after the moisture is removed from the makeup air, a cooling coil is used to lower the temperature to the desired level. Normally air conditioned commercial buildings are often kept under slightly positive air pressure relative to the outdoors to reduce infiltration. Limiting infiltration helps with moisture management and humidity control.

Dilution of indoor pollutants with outdoor air is a way of maintaining Indoor Air Quality subjected that outdoor air is free of harmful pollutants. Ozone in outdoor air occurs indoors at reduced concentrations because ozone is highly reactive with many chemicals found indoors. The products of the reactions between ozone and many common indoor pollutants include organic compounds that may be more odorous, irritating, or toxic than those from which they are formed. These products of ozone chemistry include formaldehyde, higher molecular weight aldehydes, acidic aerosols, and fine and ultrafine particles, among others. This suggests that ozone should be removed from ventilation air, especially in areas where outdoor ozone levels are frequently high.

2.2.7. Energy performance:

Typical range of annual energy performance of local commercial buildings for cooling are as follows.

- Office building with water cooled package AC system: 140-160 kWh/m²/year
- Office building with Chilled water AC system: 90-120 kWh/m²/year
- Office building with high efficient chilled water AC system: 50-70 kWh/m²/year

While high-performance buildings are the obvious choice in today's sustainability-focused industry, it was only a short 40 years ago that the first standard for energy efficiency was established, setting the engineering engine of sustainability into motion in 1970's. Since being developed in response to the energy crisis in the 1970s, ASHRAE Standard 90.1 now influences building designs worldwide. It has become the basis for building codes, and the standard for building design and construction. Since its inception in 1975, Standard 90.1 has been widely adopted as the benchmark for energy efficiency in buildings. Standard 90.1 has been a major break through in the building industry, and there's no doubt that its influence is even greater today than it was 40 years ago. In 2004 the ASHRAE 90.1 standard applied to the building envelope, and majority of mechanical and lighting systems in the energy efficient buildings and new constructions would be covered by the standard. The standard would also be applied to additions to existing buildings and their systems as well as alterations to an existing buildings system. ASHRAE 90.1 standard would be applied to the building envelope if building heating system capacity is greater 3.4 btu/h-ft2 or be cooled by a cooling system that has an output capacity greater than 5 btu/h-ft2. The buildings that are exempted from ASHRAE 90.1 are single family homes, multifamily of three stories or less homes, manufactured or modular homes, buildings that do not use electricity or fossil fuels, and equipment and building systems that are used for industrial, manufacturing, or commercial purposes.

The updated version of the ASHRAE 90.1-2007 covers many sections of a building which include building envelope, HVAC, hot water, and lighting. The building envelope has to be categorized into 3 different categories of conditioned space as follows.

(a) nonresidential conditioned space,

(b) residential conditioned space, and

(c) semi heated space.

Each one has different requirements to meet. Mandatory provisions that building envelopes have to comply are insulation, fenestration and doors, and air leakage. The requirements for these provisions are in the ASHRAE 90.1 manual. Each section of the building envelope such as, Roof, Walls, and Floor have different requirements for each of the mandatory provisions. The HVAC system has many different requirements to be met. Since there are many types of HVAC systems each with different requirements. The HVAC section has the most requirements because there are so many different types of systems. ASHRAE 90.1 document has multiple tables that give minimum efficiency requirements for each system.

ASHRAE 90.1-2010 edition, was changed significantly including definitions, tables, and sections. Energy savings compared to 90.1-2004 were approximately 25 percent including plug loads and approximately 31 percent excluding plug loads.2010 edition scope was expanded to include defined industrial processes such as, economizers for data centers, included skylights, solar reflectance, thermal remittance, air barriers, and solar orientation under building envelope. Minimum efficiency requirements for many HVAC equipment were revised. Other revisions affect the maximum fan power limits, pump head calculation, chilled water pipe sizing, radiant panel insulation, single-zone VAV, and supply air temperature reset. Energy recovery is required for many more HVAC systems. Several reheat exceptions were removed or modified. Restrictions were placed on overhead air heating. Economizer requirements were added for more climate zones and smaller systems. Class A is now required for all duct sealing.

2.3. Technical Factors Associated with Selection of an Appropriate Air Conditioning System:

2.3.1. Environmental Conditions of Location:

Location of the building is critical in finalization of type of AC that is most suited to be used. One very important factor is the closeness to the sea there by making the environment corrosive. Such locations will generally not be suitable for the use of air cooled systems. This is due to the fact that the aluminum fins of the condenser coil perish rather fast due to corrosion and oxidation due to the salt laden atmosphere. In situations where the environment is highly corrosive, water cooled units will be the obvious answer provided the required volume of water of acceptable quality is available.

On the other hand there could be situations where water cooled units cannot be used due to the very bad quality of water or non availability of the required volume of water. In such situations air cooled units have to be considered provided corrosion is not a major factor. In certain instances where the buildings is located in a very remote area the maintainability of the equipment will also be a factor to be considered as the availability of technicians with the required skills may be a problem and also the time involved in sending technicians. In such situations we may compelled to design a very simple system.

2.3.2 Client requirements:

The client's requirement is essentially the starting point for any system design. However it is necessary for the designer to educate the client especially on the available options. The duty and the responsibility of the designer is to discuss in detail all possible options. The advantages and disadvantages of all the possible systems that could be used, must be explained to client and selection of appropriate AC system must be based on detailed analysis ,even life cycle costing must be performed to decide on best option for the facility.

2.3.3 Architectural limitations:

This is an extremely important aspect in the selection of systems and equipment. The ideal way is the AC system design engineer to be involved with the building design from the conceptual design stage. If this is followed, necessary spaces, heights, and paths for AC system installation shall be available. This gives a lot of flexibility for AC system design. Unfortunately this situation does not exist most of the time. Often air-conditioning is thought about at the last moment. The building designs have all being finalized, space and height allocations already fixed and possibly the building is under construction when air-conditioning is thought about. This will limit the AC system designer in the number of options that could be considered. Very often it is observed that the required spaces are not available even to consider installing the most suitable system. Under such circumstances compromised solutions have to be implemented. Such compromised solutions are not the best and often are the worst possible choice technically.

In selecting the most suitable system, it is important to consider the geographic distribution of the spaces to be air conditioned. If a ducted air distribution system is to be considered, then the availability of space to locate supply ducts and the possibilities for the return air to be directed back to the AC plant needs to be considered. In such centralized systems space will also have to be found to house the AC unit which very often has to be either within the conditioned space or adjacent to the conditioned space. In the case of geographically remote and detached spaces to be considered to be included in one system with ducted air distribution, the space availability to locate both supply air ducting and return air ducting is an absolute necessity. The possibility to use the ceiling plenum as the return air path is another aspect that needs to be looked at.

The acceptability of a common temperature for the entire area of the need for individual temperature control for separate areas such as cubicles will play an important part in deciding the type of system. A conventional ducted system will work where a common temperature is acceptable for the entire area. When individual control is needed, then the use of VAV Boxes (Variable Air Volume) with the ducted air distribution needs to be considered. In this system VAV Boxes are used to control the air flow in to each separate section. Due to the possibility of reduction of air flow at a number of outlets at the same time, a variable speed drive is required for the fan motor to avoid excessive air flow being pushed through the outlets that remain opened. If the separate locations requiring air-conditioning is too far spread out and does not have any clear path for locating ducts, then the use of ducted air distribution system will not be possible. This problem will further be compounded if the different areas used at different times and require individual temperature controls. (e.g. hotel, large office complex with many full height cubicles, etc.). In such situations, one has to consider the use of a chilled water system. The primary requirement for using a chilled water system will be the availability of a space to locate the central equipment and clear parts for routing the chilled water distribution pipes.

In smaller installations having many different segregated rooms requiring air-conditioning, especially where the load is shifted from one place to another during the day, the use of VRV (Variable Refrigerant Volume) systems can be considered.

2.3.4 Load profile & operation patterns:

This is another very important aspect that needs to be looked at before selecting a system. Very often, in a building where different area to be air conditioned, different areas have different operation patterns. On the other hand there will be a situation where a multi storey commercial building is occupied by many clients, operating an office, where each floor is occupied by one client. In this scenario the operating pattern of all offices are pretty much the same. When equipment is to be selected for a system for a system with varying operating patterns, systems such as split units, VRV systems and chillers may have to be considered.

When selecting equipment for a building with fairly uniform operating pattern, a system with multiple package units with separate units feeding separate floor can be considered. If the system is water cooled then a common cooling tower will have to be provided with the necessary circulating pumps also being common.

2.4 Study on Proven Technologies:

2.4.1 Building Management Systems:

A Building Management System (BMS) is a computer-based control system installed in buildings that controls and monitors the building's mechanical and electrical equipment such as ventilation, lighting, power systems, fire systems, and security systems. A BMS consists of software and hardware where the software program, usually configured in a hierarchical manner, can be proprietary, using such protocols as C-bus, Profibus and so on. Vendors are also producing BMSs that integrate using Internet protocols and open standards such as BACnet, LonWorks and Modbus. Building management system greatly enhance system controllability and responsiveness to changes such as environmental changes, load variations etc. [6].

Building Management Systems are most commonly implemented in large projects with extensive mechanical, electrical, and plumbing systems. Systems linked to a BMS typically represent 60% of a building's energy usage which included all mechanical equipment and lighting.

Functions of Building Management Systems are as follows. The four basic functions of a central, computer-controlled BMS are Controlling, Monitoring, Optimizing and Reporting

A BMS normally comprises of

- Power systems
- Illumination system
- Electric power control system
- Heating, Ventilation and Air-conditioning HVAC System
- Security and observation system
- Magnetic card and access system
- Fire alarm system
- Lifts, elevators etc.
- Plumbing system
- Burglar alarms, CCTV
- Trace Heating
- Other engineering systems
- Home Automation System
- Fire alarm and Safety system
- Manage the sensors of alarm

2.4.1.1. Benefits of BMS:

2.4.1.1.1. Building tenant/occupants:

- Good control of internal comfort conditions
- Possibility of individual room control
- Increased staff productivity
- Effective monitoring and targeting of energy consumption
- Improved plant reliability and life
- Effective response to HVAC-related complaints
- Save time and money during the maintenance

2.4.1.1.2. Building owner:

- Higher rental value
- Flexibility on change of building use
- Individual tenant billing for services facilities manager
- Central or remote control and monitoring of building
- Increased level of comfort and time saving
- Remote Monitoring of the plants (such as AHU's, Fire pumps, plumbing pumps, Electrical supply, STP, WTP etc.)

2.4.1.1.3. Maintenance Companies:

- Ease of information availability problem
- Computerized maintenance scheduling
- Effective use of maintenance staff
- Early detection of problems
- More satisfied occupants

Generally Air Conditioning system consumes significant portion of energy of any facility and it varies from 40% low to 60%high for less efficient AC systems. So that BMS control for AC system is essential and average 5-10% saving can be achieved with a properly designed BMS system. Strategies involved with AC system BMS control are

- Chiller & Air Side temperature resetting based on ambient conditions
- On line Chiller COP monitoring
- Air side volume control through VAV boxes
- Fresh air demand control
- Scheduling [7]

2.4.2 Demand Driven Fresh Air Systems:

Ventilation has an impact on a building's energy use and air quality, as well as helping to determine how comfortable it is to be in. It is vital, then, for building designers to find an optimum balance between these three components. But this is complicated by the sometimes-conflicting demands of the government, the user and the building managers.

Demand driven Fresh air systems mainly controls volume of fresh air supplied to a building via CO_2 sensor located inside the premises. This can adopt BMS control or local control through stand alone controller. CO_2 level shall be maintained below 800PPM by modulate controlling fresh air damper and system shall be designed in line with ASHRAE 62.1 Indoor Air Quality requirements. Surplus of Fresh air cause loss of energy especially in hot climates like ours. Demand driven fresh air system ensure only the required amount of fresh air will be supplied to the building and sensible & latent loads due to fresh air supply will be optimized.

2.4.3 Use of Heat pipes:

A heat pipe is a simple device that can transfer heat from one point to another without having to use an external power supply. It is a sealed tube that has been partially filled with a working fluid. In HVAC applications, this fluid is called refrigerant.

The sealed refrigerant will boil under low-grade heat and vaporizes inside the tube. The vapor then travels to the high side end of the heat pipe, which is placed in a cold air stream that is produced by the air conditioner. The heat that was absorbed from the warm air at the low end is now transferred from the refrigerant's vapor through the pipe's wall into the cool supply air. This loss of heat causes the vapor inside the tube to condense back into a fluid. The condensed refrigerant the travels by gravity to the low end of the heat pipe where it begins the cycle all over.

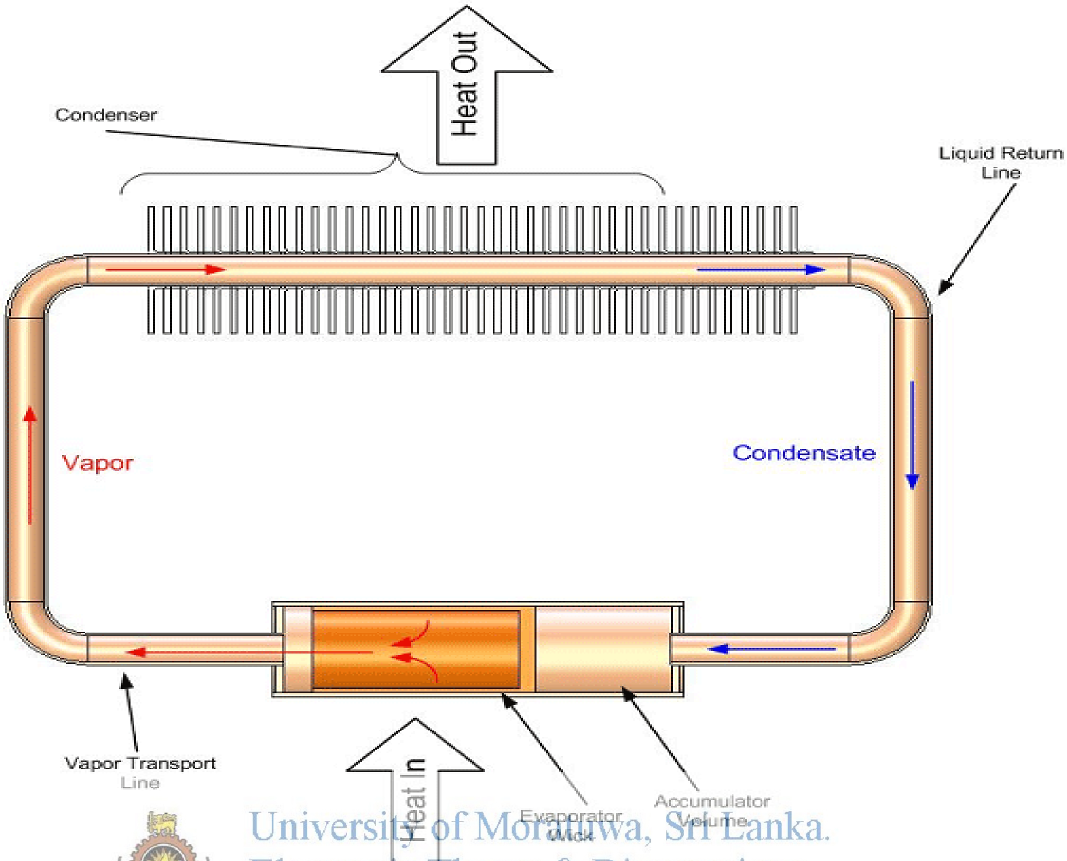


Figure 2.1 : Heat pipe Schematic[8]

Heat Pipe Benefits are as follows.

- Improved Comfort Level
- Moisture Reduced
- Improved Air Quality
- Existing Systems Easily Retrofitted
- No Moving Parts
- No Additional Energy Required To Operate

2.4.3.1. Heat Pipe Technology:

Heat pipes can dramatically improve the moisture removal capabilities of many air-conditioning systems without increasing electricity bills. Air can be pre-cooled by simply transferring heat from the warm incoming air to the cool supply air. This can be achieved by placing the low end of a heat pipe in the return air and the high end in the supply air. Heat is removed from the warm upstream air and directed to the cold downstream air. Therefore heat is absorbed by down stream cold air and thus by pass the cooler. Any way net cooling capacity of the cooling coil and heat pipe is higher than normal AC unit.

2.4.3.2. Applications/Benefits:

The kinds of businesses that can benefit the most from heat-pipe technology include libraries, restaurants, storage facilities, supermarkets and any type of business that needs moisture-controlled air to preserve goods and products kept inside, to prevent the increased wear and tear associated with high humidity, or to increase occupant comfort. Any air-conditioning system that uses reheat, desiccants, or mechanical dehumidification is a good candidate for heat-pipe assistance.

2.4.3.3. Method of operation:

The Cooling coil of an air-conditioner removes moisture from the air in much the same way that a cold glass "sweats". The colder the cooling coil, the more moisture it removes. Old energy-inefficient air-conditioners had very cold cooling coils, which removed sufficient moisture from the air. Today's high efficiency machines have much warmer coils as the coil is generally larger, and less energy is used to cool it, but they save energy at the expense of not removing as much moisture. The problem, up until now, has been how to run a cooling coil cold enough to remove plenty of moisture, while not having to use extra energy to do so.

Dehumidifier heat pipes which "wrap around" the cooling coil acts as a increase dehumidification capacity of unit. One section of the heat pipe is located in the return air and the other section in the supply air. The cool supply air chills one section while the warm return air heats the other. Heat is transferred from the warm return air to the cool supply air. The reheat as it is called, taken from the return air, is free. The effect of pre-cooling the air going to the cooling coil brings it very close to the dew point and moisture begins to condense very early in the cooling coil. Because the coil does not have to perform the pre-cooling function, more of its thickness is used to condense moisture and condensate flow is increased by a factor of 1 ½ to 2. The result is lower relative humidity. Occupants feel equally comfortable even at a higher thermostat setting when the humidity level is low. One degree higher setting represents approximately 8% savings in energy. Typically 20% to 30% energy savings are [8].Indoor air quality is improved, creating a situation of enhanced comfort, greater health, elimination of mold and mildew, and reduction of building deterioration.

2.5. Emerging Technologies:

2.5.1 High efficient chillers for lower tonnage capacities with magnetic bearings and Speed Drives:

Chillers are the highest power consuming equipment in most commercial and institutional facilities. In many cases, they are the single largest user of any form of energy in buildings. For these reasons, Maintenance and Engineering Managers looking for ways to improve the energy efficiency of their buildings start by improving the efficiency of chillers.

Managers/Engineers have two primary options to improving chiller performance, replacement and maintenance. Today's replacement chillers offer managers benefits in both performance and operating efficiency, making any chiller more than 10-15 years old a replacement candidate. But facility managers should not enter into chiller-replacement projects lightly. Chillers are high priced items and their installation often disrupts building occupants. And because most types of chillers have service lives of 15-20 years, managers will have to live with their choices for a very long time. Even the task of selecting the most appropriate chiller for a particular application is not particularly easy. Slight differences between different models can result in rather large differences in the annual energy requirements for cooling a facility. Managers must have enough information to determine if reduced annual energy costs of one model are enough to justify what might seem like a significant difference in first costs.

2.5.1.1. Chiller efficiency indices:

In the past, the most commonly used measure of chiller performance was full-load efficiency rating. Engineers and managers often used the efficiency rating, expressed in kilowatts per ton (kW/RT), to determine the most efficient chiller for a particular application.

While the rating did indicate a chiller's relative efficiency, it had a serious drawback. It was only valid for a chiller operating at full load. As the load on a chiller falls, so does its operating efficiency. For example, a large centrifugal chiller might have an efficiency rating of 0.50 kW/RT when operating at full load under design conditions. But at 50% load, the unit's efficiency might decrease to 0.70kW/RT or lower.

Most chillers operate at full load for about 1 percent of their annual operating hours. That means that for 99 percent of a chiller's operating hours, it operates at less than its full-load efficiency.

This situation creates two problems. First, in making the purchase decision based on chiller full-load operating efficiency, a manager might not have selected the most efficient chiller for the particular application. Second, estimating a chiller's annual energy usage based on the full-load efficiency rating will result in seriously low estimates. Facility managers now have a better estimate of chiller performance that can correct both of these problems. Developed by the Air-conditioning and Refrigeration Institute, the part-load value/application part- load value (IPLV/APLV) is a more realistic value to evaluate chiller efficiency.

The IPLV/APLV rating recognizes that most chiller systems operate below their design ratings for most of the year. As a result, a chiller's kW/ton efficiency rating is calculated using a complex formula that blends chiller performance at four different design loads: 100, 75, 50 and 25 percent.

The breakdown of hours operated at each of those loads represents what one would expect in the real world. The result is a rating that more accurately reflects what managers can expect in the efficiency of a chiller as it would operate in facilities.

By considering the IPLV/APLV ratings, facility managers can make better decisions when considering chiller options for both new-construction and replacement projects. They can make more realistic estimates of annual energy costs, as well as more accurate projections of project payback when comparing chillers with different first costs and efficiency ratings. Managers also should consider the option of equipping existing and replacement chillers with variable-speed drives. Conventional chillers operate at a constant speed. As the load decreases, vanes in the inlet to the compressor close, reducing the chiller's output. This change also reduces the chiller's energy use, but the decrease in energy use does not directly match the decrease in the chiller's output.

A variable-speed drive reduces the output of the chiller by reducing the speed of its compressor. As the chiller speed decreases, so does the compressor's energy use. When evaluated on an annual basis, the average energy savings produced by the variable-speed drive is about 30 percent, providing a rapid return on the investment [9]Major chiller manufacturers came up with high efficient water cooled chillers having low integrated part load values with new technologies. CARRIER achieved IPLV of 0.29 kW/RT with Variable Speed Drive Compressor and DAIKIN developed magnetic bearing VSD screw compressor which can perform 0.32kW/RT. YORK developed magnetic bearing VSD driven Centrifugal chiller with IPLV of 0.31kW/RT. All those chiller capacities are from 200RT to 500RT which chiller manufacturers called Lower tonnage chiller range. There is a break through in chiller plant manufacturing industry with the invention of Centrifugal Type Magnetic oil free compressors. Now there are chillers with this compressor having IPLV around 0.29kW/RT.

2.5.2 Heat recovery Air Handling units with heat wheel:

Re-use of heat arising from any process that would otherwise be lost is called heat recovery. The process might be inherent to a building, such as space heating, ventilation and so on, or could be something carried out as part of business activity, such as the use of ovens, furnaces and the like. Heat recovery can help to reduce the overall energy consumption of the process itself, or provide useful heat for other purposes.

In tropical climates like ours fresh air carries lot of heat energy in to the building and generally cooled air shall be exhausted to outside to based on ASHRAE 62.1 standards. Cold air can be used to pre cool fresh air before it passes through cooling coil. Air handling manufacturers provide units with heat recovery wheels to pre cool fresh air. Heat transfer Efficiency of heat recovery wheel generally around 65% and air leakage /mixing will greatly reduce. This is an important factor for consideration since additional fans and motors are required for heat recovery wheel operation [10].

2.5.3. Liquid desiccant Dehumidifiers for humidity control applications:

There are manufacturers who have introduced desiccant dehumidification and cooling solutions that dramatically improve the energy efficiency of cogeneration systems by utilizing their waste heat to provide cooling and dehumidification. Conventional combustion power generation systems convert only approximately 30% of consumed fuel into electricity. In centralized production systems another 7% on average is lost as the electricity is distributed from the power-station to consumers. Distributed cogeneration systems increase energy efficiency to 80% by utilizing the waste heat released by the generation system for space heating. Since the power is produced locally, there are no transmission losses. However, during a large part of the year, cooling rather than heating is needed so the advantages of cogeneration are lost and efficiency returns to the 30% level. New systems combine desiccant dehumidification with evaporative or geothermal cooling to upgrade co-generation systems to a tri-generation system. New systems provide high efficiency all year round by utilizing waste heat for cooling and dehumidification. This approach eliminates the need for conventional mechanical cooling and reduces the energy required for cooling by up to 90%. The emissions and carbon footprint attributed to the building is reduced by a roughly similar amount. New systems can operate with much lower hot water temperatures than other heat-based cooling equipment such as desiccant wheels and absorption chillers. New unit ability to convert low grade heat into effective cooling and dehumidification is a key advantage.

Compared to absorption chillers, liquid desiccant dehumidification units are more cost effective and require lower hot water temperatures. New unit open-cycle systems operate at atmospheric pressure, as opposed to absorption units which are closed-cycle systems operating at near-vacuum sub-atmospheric pressure conditions. The liquid desiccant systems have a unique process in which during the dehumidification process, air is internally cooled and the air leaves the unit dry and at a comfortable temperature. As a result, much lower temperatures are required for regeneration compared to desiccant wheel dehumidification systems. Cool water for the cooling process can be taken from any convenient source such as a cooling tower, geothermal well, river, etc[11].

2.5.4 Inverter Split Air Conditioners for Domestic/Commercial applications:

Inverter drive is used to control the speed of the compressor motor to allow continuously regulated temperature in inverter type air conditioners. Traditional air conditioners regulate temperature by using a on/off control of compressor that is periodically either working at maximum capacity or switched off entirely. Inverter type air conditioners have a variable-frequency drive that incorporates an adjustable electrical inverter to control the speed of the motor and thus the compressor and cooling output.

The variable-frequency drive uses a rectifier to convert the incoming alternating current (AC) to direct current (DC) and then uses pulse-width modulation in an electrical inverter to produce AC of a desired frequency. The variable frequency AC drives a brushless motor or an induction motor. As the speed of an induction motor is proportional to the frequency of the AC, the compressors runs at different speeds. A microcontroller can then sample the current ambient air temperature and adjust the speed of the compressor appropriately. The additional electronics add to cost of equipment and operation. Conversion from AC to DC, and then back to AC, can cost as much 4 - 6% in energy losses for each conversion step. Eliminating stop-start cycles increases efficiency, extends the life of components, and helps eliminate sharp fluctuations in the load the air conditioner places on the power supply. Ultimately this makes inverter air conditioners less prone to breakdowns, cheaper to run, and the outdoor compressor is generally quieter than a standard air conditioning unit's compressor.

While at the beginning of the 1990s inverter air conditioners had some drawbacks, these have been mostly overcome the conversion losses are lower and filters suppress most of the electromagnetic interference generated in inverters. Since permanent-magnet motors are used, rather than conventional squirrel cage induction motors, motors use less power and no current is required for magnetizing the rotor. Inverter-based air conditioners are therefore more energy efficient. DC inverter compressors are also becoming popular now. For conventional households where each indoor unit is connected to a single dedicated outdoor unit, inverters are the preferred option, as partial loading is the common mode there. The higher initial expense is balanced by lower energy bills. In a typical setting the pay-back time is about two years. For more modern installations where an outdoor unit is connected to multiple indoor units there are better options also available[12].

2.5.5 ITS-Ice Thermal Storages:

Thermal energy storage comprises a number of technologies that store thermal energy in energy storage reservoirs for later use. They can be employed to balance energy demand between day time and night time. The thermal reservoir may be maintained at a temperature below (colder) that of the ambient environment. The applications today include the production of ice, chilled water, or eutectic solution at night which is then used to cool environments during the day.Air conditioning can be provided more efficiently by using cheaper electricity at night to freeze water into ice, then using the cool of the ice in the afternoon to reduce the electricity needed to handle air conditioning demands. Thermal energy storage using ice makes use of the large heat of fusion of water. One metric ton of water(one cubic meter) can store 334 million joules (MJ) or 317,000 BTUs (93kWh or 26.4 ton-hours). In fact, ice was originally transported from mountains to cities for use as a coolant, and the original definition of a "ton" of cooling capacity (heat flow) was the heat to melt one ton of ice every 24 hours. Either way, an agreeably small storage facility can hold enough ice to cool a large building for a day or a week, whether that ice is produced by anhydrous ammonia chillers or hauled in by horse-drawn carts.

As such there are developing and developed applications where ice is produced during off peak periods and used for cooling at later time [13].

2.6 Energy Efficient Alternative Technologies:

2.6.1 Evaporative Cooling system:

Evaporative cooler is a device that cools air through the evaporation of water. Operating principle of Evaporative cooler is different from typical air conditioning systems which use vapor-compression or absorption refrigeration cycles. Evaporative cooling works by employing enthalpy of vaporization of water. The temperature of dry air can be dropped significantly through the phase transition of liquid water to water vapor (evaporation), which can cool air using much less energy than refrigeration. In extremely dry climates, evaporative cooling of air has the added benefit of conditioning the air with more moisture for the comfort of building occupants. Unlike closed-cycle refrigeration, evaporative cooling requires a water source, and must continually consume water to operate. Air washers and wet cooling towers use the same principles as evaporative coolers but are designed for purposes other than directly cooling the air inside a building. For example, an evaporative cooler may be designed to cool the coils of a large air conditioning or refrigeration system to increase its efficiency.

2.6.1.1. Physical principles:

Evaporative cooling is a physical phenomenon in which evaporation of a liquid, typically into surrounding air, cools an object or a liquid in contact with it. Latent heat, the amount of heat that is needed to evaporate the liquid, is drawn from the air. When considering water evaporating into air, the wet-bulb temperature which takes both temperature and humidity into account, as compared to the actual air temperature (dry-bulb temperature), is a measure of the potential for evaporative cooling. The greater the difference between the two temperatures dry bulb and wet bulb temperatures, the greater the evaporative cooling effect is increased. When the temperatures are the same, no net evaporation of water in air occurs, thus there is no cooling effect. The wet-bulb temperature is essentially the lowest temperature which can be attained by evaporative cooling at a given temperature and humidity.

The amount of heat transfer depends on the evaporation rate, however for each kilogram of water vaporized 2,257 kJ of energy (about 890 BTU per pound of pure water, at 95°F) are transferred. The evaporation rate depends on the temperature and humidity of the air, which is why sweat accumulates more on hot, humid days, as it does not evaporate fast enough.

2.6.1.2. Applications:

Evaporative cooling is especially well suited for climates where the air is hot and humidity is low. In dry, arid climates, the installation and operating cost of an evaporative cooler can be much lower than that of refrigerative air conditioning, often by 80% or so. However, evaporative cooling and vapor-compression air conditioning are sometimes used in combination to yield optimal cooling results. Some evaporative coolers may also serve as humidifiers in the heating season.

In locations with moderate humidity there are many cost-effective uses for evaporative cooling, in addition to their widespread use in dry climates. For example, industrial plants, commercial kitchens, laundries, dry cleaners, greenhouses, spot cooling (loading docks, warehouses, factories, construction sites, athletic events, workshops, garages, and kennels) and confinement farming (poultry ranches, hog, and dairy) often employ evaporative cooling. In highly humid climates, evaporative cooling may have little thermal comfort benefit beyond the increased ventilation and air movement it provides.

2.6.1.3. Evaporative cooler designs:

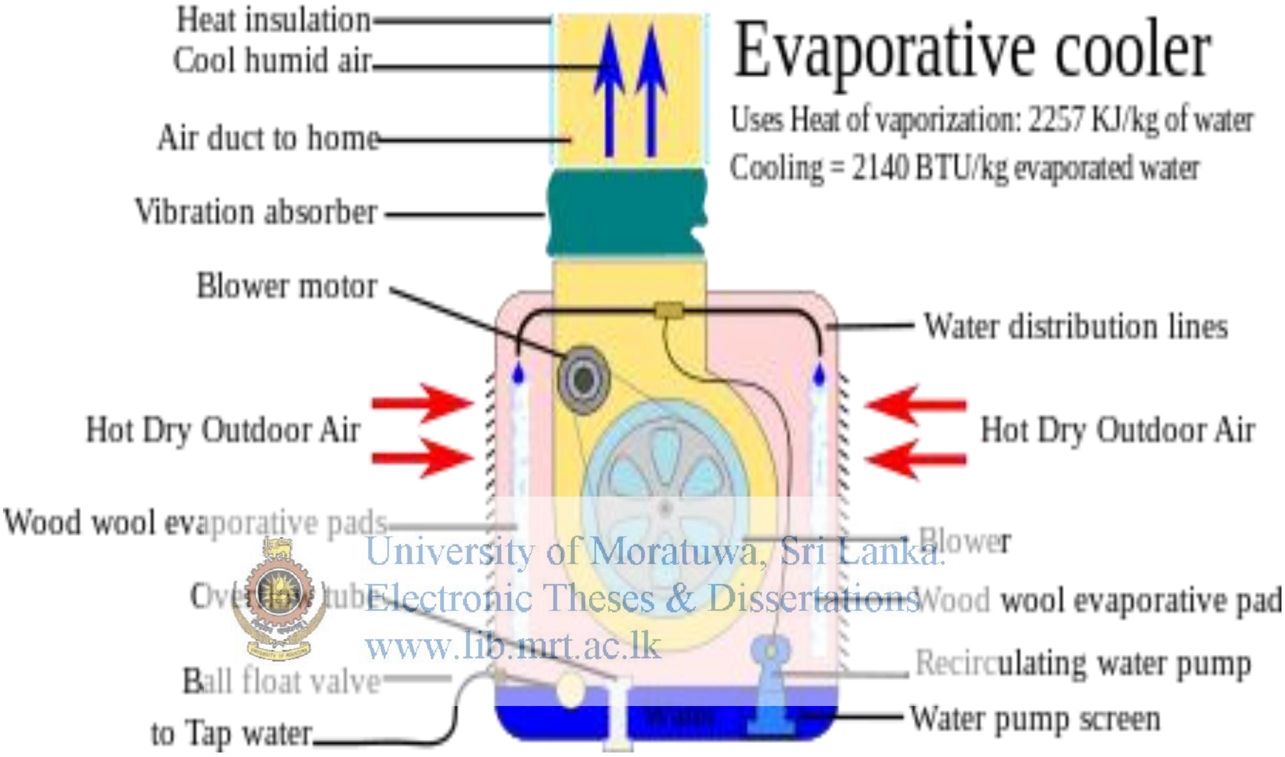


Figure 2.2 : Evaporative Cooler Illustration[14]

Most designs take advantage of the fact that water has one of the highest known enthalpy of vaporization (latent heat of vaporization) values of any common substance. Because of this, evaporative coolers use only a fraction of the energy of vapor-compression or absorption air conditioning systems. Unfortunately, except in very dry climates, the single-stage (direct) cooler can increase relative humidity (RH) to a level that makes occupants uncomfortable. Indirect and Two-stage evaporative coolers keep the RH lower. Direct evaporative cooling (open circuit) is used to lower the temperature of air by using latent heat of evaporation, changing liquid water to water vapor. In this process, the energy in the air does not change. Warm dry air is changed to cool moist air. The heat of the outside air is used to evaporate water. The RH increases to 70 - 90%, which reduces the cooling effect of human perspiration. The moist air has to be continually released to outside or else the air becomes saturated and evaporation stops.

Indirect evaporative cooling (closed circuit) is similar to direct evaporative cooling but uses some type of heat exchanger. The cooled moist air never comes in direct contact with the conditioned air. The moist air stream is released outside or used to cool other external devices such as solar cells which are more efficient if kept cool. One indirect cooler manufacturer uses the so-called Maisotsenko cycle which employs an iterative (multi-step) heat exchanger that can reduce the temperature to below the wet-bulb temperature. While no moisture is added to the incoming air the RH does rise a little according to the Temperature-RH formula. Conditioned air without added moisture increases the evaporation of perspiration improving the cooling effect of Indirect compared to Direct.

In the first stage of a two-stage cooler, warm air is pre-cooled indirectly without adding humidity. In the direct stage, the pre-cooled air passes through a water-soaked pad and picks up humidity as it cools. Since air is pre-cooled in the first stage, less humidity is transferred in the direct stage, to reach the desired cooling temperatures. The result, according to manufacturers, is cooler air with a RH between 50-70%, depending on the climate, compared to a traditional system that produces about 70–80% relative humidity in the conditioned air.

Traditionally, evaporative cooler pads consist of excelsior (aspen wood fiber) inside a containment net, but more modern materials, such as some plastics and melamine paper, are entering use as cooler-pad media [14].

2.6.2 Geo thermal heating/cooling system;

A geothermal heat pump or Ground Source Heat Pump (GSHP) is a central heating and/or cooling system that pumps heat to or from the ground. Ground Source Heat Pumps use the earth as a heat source (in the winter) or a heat sink (in the summer). This design takes advantage of the moderate temperatures in the ground to boost efficiency and reduce the operational costs of heating and cooling systems, and there are instances that GSHP may be combined with solar heating to form a geo solar system with even greater efficiency. Ground source heat pumps are also known as "geothermal heat pumps" although actual heat source of GSHP is sun. Ground source heat pumps harvest heat absorbed at the Earth's surface from solar energy. The temperature in the ground below 6 metres (20 ft) is roughly equal to the mean annual air temperature at that latitude at the surface.

Depending on the location ,earth temperature below 6m of surface is nearly constant temperature between 10C to 16C if area is undisturbed by presence of heat pump. Like a refrigerator or an air conditioner, these systems use a heat pump to force the transfer of heat from the ground. Heat pumps can transfer heat from a cool space to a warm space, against the natural direction of flow, or they can enhance the natural flow of heat from a warm area to a cool one. The core of the heat pump is a loop of refrigerant pumped through a vapor-compression refrigeration cycle that moves heat. A ground source heat pump exchanges heat with the ground. This is much more energy-efficient because underground temperatures are more stable than air temperatures through the year. Seasonal variations drop off with depth and disappear below 7metres (23 ft) due to thermal inertia. Like a cave, the shallow ground temperature is warmer than the air above during the winter and cooler than the air in the summer. A ground source heat pump extracts ground heat in the winter (for heating) and transfers heat back into the ground in the summer (for cooling). Some systems are designed to operate in one mode only, heating or cooling, depending on climate.The geothermal pump systems reach fairly high Coefficient of performance (COP), 3-6, on the coldest of winter nights, compared to 1.75-2.5 for air-source heat pumps on cool days. Ground source heat pumps (GSHPs) are among the most energy efficient technologies for providing HVAC and water heating. Actual COP of a geothermal system which includes the power required to circulate the fluid through the underground tubes can be lower than 2.5. The setup costs are higher than for conventional systems, but the difference is usually returned in energy savings in 3 to 10 years. System life is estimated at 25 years for inside components and 50+ years for the ground loop. As of 2004, there are over a million units installed worldwide providing 12 GW of thermal capacity, with an annual growth rate of 10%. Differing terms and definitions

2.6.2.1. Ground heat exchanger:

Figure 2.3 : Loop field for a 12-ton System [15]

Heat pumps shall be provided winter heating by extracting heat from a source and transferring it into a building. Heat can be extracted from any source, no matter how cold, but a warmer source allows higher efficiency. A ground source heat pump uses the top layer of the earth's crust as a source of heat, thus taking advantage of its seasonally moderated temperature. In the summer, the process can be reversed so the heat pump extracts heat from the building and transfers it to the ground. Transferring heat to a cooler space takes less energy, so the cooling efficiency of the heat pump gains benefits from the lower ground temperature.

2.6.2.2. Open loop:

In an open loop system the secondary loop pumps natural water from a well or body of water into a heat exchanger inside the heat pump. ASHRAE calls open loop systems groundwater heat pumps or surface water heat pumps, depending on the source. Heat is either extracted or added by the primary refrigerant loop, and the water is returned to a separate injection well, irrigation trench, tile field or body of water. The supply and return lines must be placed far enough apart to ensure thermal recharge of the source. Since the water chemistry is not controlled, the appliance may need to be protected from corrosion by using different metals in the heat exchanger and pump. Lime scale may foul the system over time and require periodic acid cleaning. This is much more of a problem with cooling systems than heating systems. Also, as fouling decreases the flow of natural water, it becomes difficult for the heat pump to exchange building heat with the groundwater. If the water contains high levels of salt, minerals, iron bacteria or hydrogen sulfide, a closed loop system is usually preferable.

Deep lake water cooling uses a similar process with an open loop for air conditioning and cooling. Open loop systems using ground water are usually more efficient than closed systems because they are better coupled with ground temperatures. Closed loop systems, in comparison, have to transfer heat across extra layers of pipe wall and dirt [15].

2.6.3. Co-generation & Tri generation with Absorption chillers:

Co-generation is the use of a heat engine or a power station to simultaneously generate both electricity and useful heat. All thermal power plants discharge fair amount of heat during electricity generation. Normally this is released into the natural environment through cooling towers, flue gas, or by other means. By contrast, Combined Heat and Power Plant captures some or all of the by-product heat for heating purposes, either very close to the plant or as hot water for district heating with temperatures ranging from approximately 80 to 130 °C. This is also called Combined Heat and Power District Heating(CHPDH).

Before central stations distributed power, industries generating their own power used exhaust steam for process heating. Large office and apartment buildings, hotels and stores commonly generated their own power and used waste steam for building heat. Because of the economies and high cost of early purchased power, these combined heat and power operations continued for many years after utility electricity became available. Co generation is still common in pulp and paper mills, refineries and chemical plants. By-product heat at moderate temperatures (212-356°F/100-180°C) can also be used in absorption chillers for cooling. A plant producing electricity, heat and cold is sometimes called tri generation or more generally poly generation plant. Cogeneration is a thermodynamically efficient use of fuel. In separate production of electricity, some energy must be rejected as waste heat, but in cogeneration this thermal energy is put to good use.

Tri generation or combined cooling, heat and power refers to the simultaneous generation of electricity and useful heating and cooling from the combustion of a fuel or a solar heat collector. The supply of high-temperature heat first drives a gas or steam turbine powered generator and the resulting low-temperature waste heat is then used for water or space heating as described in cogeneration. Tri generation differs from cogeneration in that the waste heat is used for both heating and cooling, typically in an absorption chiller. CCHP systems can attain higher overall efficiencies than cogeneration or traditional power plants.

Every heat engine is subject to the theoretical efficiency limits of the Carnot cycle. When the fuel is natural gas, a gas turbine following the Rankine cycle is typically used. Mechanical energy from the turbine drives an electric generator. The low-grade (i.e. low temperature) waste heat rejected by the turbine is then applied to space heating or cooling or to industrial processes. Cooling is achieved by passing the waste heat to an absorption chiller [16].

2.6.3.1. Thermal efficiency of tri generation plant:

Thermal efficiency in a tri generation system is defined as follows.

$$\text{Thermal Efficiency} = \frac{\text{Total Work output by all Systems}}{\text{Total Heat input into the System}}$$

$$= \frac{\text{Electrical power output+ Heat output+ Cooling output}}{\text{Total Heat input into the System}}$$

The energy distribution of a Tri Generation Plant is as follows.

Electricity = 45%

Heat + Cooling = 40%

Heat Losses = 13%

Line Losses = 2%

Conventional central coal- or nuclear-powered power stations convert only about 33% of their input heat to electricity. The remaining 67% emerges from the turbines as low-grade waste heat with no significant local uses so it is usually rejected to the environment. These low conversion efficiencies strongly suggest that productive uses be found for this waste heat, and in some countries these plants do produce byproduct steam that can be sold to customers. But if no practical uses can be found for the waste heat from a central power station. Even though the efficiency of a small distributed electrical generator may be lower than a large central power plant, the use of its waste heat for local heating and cooling can result in an overall use of the primary fuel supply as great as 80%. This provides substantial financial and environmental benefits [16].

2.7 Internationally Accepted Energy Efficiency Standards & Guidelines:

2.7.1 ANSI/ASHRAE/IESNA Standard 90.1-2004:

This standard provides minimum requirements for the energy efficient design of buildings except low rise residential buildings.

The standard provides

(a) Minimum energy efficient requirements for the design and construction of new buildings and their systems, new portions of buildings and their systems, new systems and equipments in existing buildings.

(b) Criteria for determining compliance with these requirements.

The provisions of this standard apply to the envelope of buildings, provided that that the enclosed spaces are heated by a heating system whose output capacity is greater than or equal to 10W/m^2 or cooled by a cooling system whose sensible output capacity is greater than or equal to 15W/m^2.

The following systems and equipment used in conjunction with buildings.

- Heating, ventilating & air conditioning
- Service water heating
- Electric power distribution and metering provisions
- Electric motors and belt drives
- Lighting

Standard also specifies building envelope requirements which we will discuss in detail in chapter 5.

Mechanical equipment and systems serving the heating, cooling, or ventilating needs of new buildings shall comply with the requirement of this standard. Mechanical equipment and systems serving the heating, cooling or ventilation needs of additions to existing buildings shall comply with the requirements of this standard. Similarly when new HVAC equipment install as a direct replacement to existing equipment new equipment shall comply with the requirements specified here.

2.7.1.1. Mandatory Provisions:

- Minimum performance requirements of equipment listed in the standard shall be complied.
- HVAC system construction and insulation also covers by the standard. Insulation required by this section shall be installed in accordance with industry accepted standards. All supply and return ducts and plenums installed as a part of an air distribution system shall be thermally insulated in accordance with requirements specified in the standard. Minimum duct seal levels are also specified in the standard.
- Lighting section applies to interior spaces of buildings, exterior building features, including facades, illuminated roofs, architectural features, entrances, exits, loading docks, exterior building ground lights. Lighting power densities were specified and must be complied with the standard [17].

2.7.2. Green Building guide lines:

Green building refers to a structure and using process that is environmentally responsible and resource-efficient throughout a building's life-cycle. Close cooperation of the design team, the architects, the engineers, and the client at all project stages is essential for successful completion of given sustainable building project. The Green Building practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. The common objective is that green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by Efficiently using energy, water, and other resources, Protecting occupant health and improving employee productivity and Reducing waste, pollution and environmental degradation

A similar concept is natural building, which is usually on a smaller scale and tends to focus on the use of natural materials that are available locally. Other related topics include sustainable design and green architecture. Sustainability may be defined as meeting the needs of present generations without compromising the ability of future generations to meet their needs. Although some green building programs don't address the issue of the retrofitting existing homes, others do. Green construction principles can easily be applied to retrofit work as well as new construction.

2.7.2.1. Goals of green building:

The concept of sustainable development can be traced to the energy (especially fossil oil) crisis and the environment pollution concern in the 1970s. The green building movement in the U.S. initiated from the need and desire for more energy efficient and environmentally friendly construction practices. There are a number of motives for building green, including environmental, economic, and social benefits. However, modern sustainability initiatives call for an integrated and synergistic design to both new construction and in the retrofitting of existing structures. Also known as sustainable design, this approach integrates the building life-cycle with each green practice employed with a design-purpose to create a synergy among the practices used. Green building brings together a vast array of practices, techniques, and skills to reduce and ultimately eliminate the impacts of buildings on the environment and human health. It often emphasizes taking advantage of renewable resources like using sunlight through passive solar, active solar, and photovoltaic techniques and using plants and trees through green roofs, rain gardens, and reduction of rainwater run-off.

While the practices, or technologies, employed in green building are constantly evolving and differ from region to region the following fundamental principles persist from which the method is derived, Site and Structure Design Efficiency, Energy Efficiency, Water Efficiency, Materials Efficiency, Indoor Environmental Quality Enhancement, Operations and Maintenance Optimization, and Waste and Toxics Reduction. The objective of green building is an optimization of one or more of these principles. Also, with the proper synergistic design, individual green building technologies may work together to produce a greater cumulative effect. On the aesthetic side of green architecture or sustainable design is the philosophy of designing a building that is in harmony with the natural features and resources surrounding the site. There are several key steps in designing sustainable buildings such as specify 'green' building materials from local sources, reduce loads, optimize systems, and generate on-site renewable energy etc.

2.7.2.2. Life cycle assessment (LCA):

A life cycle assessment (LCA) can help avoid a narrow outlook on environmental, social and economic concerns by assessing a full range of impacts associated with all cradle-to-grave stages of a process. In terms of green building, the last few years have seen a shift away from a prescriptive approach, which assumes that certain prescribed practices are better for the environment, toward the scientific evaluation of actual performance through LCA.

Although LCA is widely recognized as the best way to evaluate the environmental impacts of buildings (ISO 14040 provides a recognized LCA methodology), it is not yet a consistent requirement of green building rating systems and codes, despite the fact that embodied energy and other life cycle impacts are critical to the design of environmentally responsible buildings.

2.7.2.2. Energy efficiency:

Green buildings often include measures to reduce energy consumption, both the embodied energy required to extract, process, transport and install building materials and operating energy to provide services such as heating and power for equipment. As high-performance buildings use less operating energy, embodied energy has assumed much greater importance and may make up as much as 30% of the overall life cycle energy consumption. To reduce operating energy usage, designers use details that reduce air leakage through the building envelope. They also specify high-performance windows and extra insulation in walls, ceilings, and floors. Another strategy, passive solar building design, is often implemented in low-energy homes. Designers orient windows and walls and place awnings, porches, and trees to shade windows and roofs during the summer while maximizing solar gain in the winter. In addition, effective window placement (day lighting) can provide more natural light and lessen the need for electric lighting during the day. Solar water heating further reduces energy costs.

Onsite generation of renewable energy through solar power, wind power, hydro power, or biomass can significantly reduce the environmental impact of the building. Power generation is generally the most expensive feature to add to a building.

2.7.2.3. Indoor environmental quality enhancement:

The Indoor Environmental Quality (IEQ) category in LEED standards, one of the five environmental categories, was created to provide comfort, well-being, and productivity of occupants. The LEED IEQ category addresses design and construction guidelines especially: indoor air quality (IAQ), thermal quality, and lighting quality.

Indoor Air Quality seeks to reduce volatile organic compounds, or VOCs, and other air impurities such as microbial contaminants. Buildings rely on a properly designed ventilation system (passively/naturally or mechanically powered) to provide adequate ventilation of cleaner air from outdoors or re-circulated, filtered air as well as isolated operations (kitchens, dry cleaners, etc.) from other occupancies. During the design and construction process choosing construction materials and interior finish products with zero or low VOC emissions will improve IAQ. Most building materials and cleaning/maintenance products emit gases, some of them toxic, such as many VOCs including formaldehyde. These gases can have a negative impact on occupants' health, comfort, and productivity. Avoiding these products will increase a building's IEQ. LEED, HQE and Green Star contain specifications on use of low-emitting interior. Draft LEED 2012 is about to expand the scope of the involved products. BREEAM limits formaldehyde emissions, no other VOCs.

Also important to indoor air quality is the control of moisture accumulation (dampness) leading to mold growth and the presence of bacteria and viruses as well as dust mites and other organisms and microbiological concerns. Water intrusion through a building's envelope or water condensing on cold surfaces on the building's interior can enhance and sustain microbial growth. A well-insulated and tightly sealed envelope will reduce moisture problems but adequate ventilation is also necessary to eliminate moisture from sources indoors including human metabolic processes, cooking, bathing, cleaning, and other activities. Personal temperature and airflow control over the HVAC system coupled with a properly designed building envelope will also aid in increasing a building's thermal quality. Creating a high performance luminous environment through the careful integration of daylight and electrical light sources will improve on the lighting quality and energy performance of a structure.

2.7.2.4. Operations and maintenance optimization:

Although at the construction stage emphasized on sustainability, actual benefit of green construction can be utilized only if building is operated and maintained responsibly. Ensuring operations and maintenance (O&M) personnel are part of the project's planning and development process will help retain the green criteria designed at the onset of the project. Every aspect of green building is integrated into the O&M phase of a building's life. The addition of new green technologies also falls on the O&M staff. Although the goal of waste reduction may be applied during the design, construction and demolition phases of a building's life-cycle, it is in the O&M phase that green practices such as recycling and air quality enhancement take place.

2.7.2.5. Regulation and operation:

Due to increased interest in green building concepts and practices, a number of organizations have developed standards, codes and rating systems that let government regulators, building professionals and consumers embrace green building with confidence. In some cases, codes are written so local governments can adopt them as bylaws to reduce the local environmental impact of buildings. Green building rating systems such as BREAM (United Kingdom), LEED (United States and Canada), DGNB (Germany) and CASBEE (Japan) help consumers determine a structure’s level of environmental performance. They award credits for optional building features that support green design in categories such as location and maintenance of building site, conservation of water, energy, and building materials, and occupant comfort and health. The number of credits generally determines the level of achievement.

Green building codes and standards, such as the International Code Council’s draft International Green Construction Code, are sets of rules created by standards development organizations that establish minimum requirements for elements of green building such as materials or heating and cooling[18].

Table:2.1. Points Schedule for LEED – NC 2.2

Item No	Category	Max: points
1	Sustainable Sites	14
2	Water Efficiency	5
3	Energy & atmosphere	17
4	Material & resources	13
5	Indoor air quality	15
6	Innovation & design process	5
	Total possible points	69

Table:2.2. Points required for LEED –NC 2.2 Ratings

LEED-NC 2.2 Rating	Points Required
Platinum	52-69
Gold	39-51
Silver	33-38
Certified	26-32
No rating	25 or less

2.7.3. Sri Lankan Code of practice for energy efficient buildings:

The code of practice for energy efficient building in Sri Lanka was compiled by the Sri Lanka Sustainable Energy Authority upon reviewing and amending the energy efficient building code. Purpose of this is to introduce energy efficient designs and/or retrofits to commercial buildings, industrial facilities and large scale housing schemes, to enable design, construction and maintenance to be carried out under minimal energy consumption without compromising the building function, and/or the comfort and health of occupants.

2.7.3.1. Mandatory requirements specified under Ventilation & Air Conditioning:

2.7.3.1.1. Load calculation procedures:

Cooling system design loads for the for the purpose of sizing systems and equipment shall be determined in accordance with the procedures described in the latest edition of the ASHRAE handbook or other publications conforming to equal standards.

2.7.3.1.2. Indoor design conditions:

The indoor condition of an air conditioned space shall be designed for a dry bulb temperature of 25C+ 1.5C and relative humidity of 55% + 5%.The combination of suitable high temperatures and humidity may be used within comfort zone for energy saving purposes ,provided that the conditions maintained herein are agreeable to the occupants.

2.7.3.13. Outdoor air requirements:

Outdoor air ventilation rates shall comply with ASHRAE standard 62.1 2007.Also encouraged to use CO_2 monitors and controls for installations with high and variable occupancy.

2.7.3.1.4. System and Equipment Sizing:

Equipment shall be sized to provide no more than the space and system loads calculated in accordance with item 1.It is recommended that when selecting equipment pressure drops across chiller cooler, condenser, cooling coils shall be maintained below 6m.

2.7.3.1.5. Constant volume fan systems:

For fan systems that provide a constant air volume where the fans are operating there shall be a requirement of 590l/s of supply air volume per 1kw of total input power for the motor to provide the combined fan system at design condition.

2.7.3.1.6. Variable air Volume System:

For fan system which can vary air volume based on load, where the fans are operating there shall be a requirement of 420l/s of supply air volume per 1kw of total input power for the motor to provide the combined fan system at design condition.

2.7.3.1.7. Pumping system design criteria:

Piping system shall be designed at friction pressure loss of 100 -400Pa per equivalent pipe length subject to velocity in the in the pipe length not exceed 2.5m/s.

2.7.3.1.8. Pump Efficiency:

Pump shall be selected for maximum efficiency and shall not be less than 70%.

2.7.3.1.9. Thermostats:

Zone controls shall have an inbuilt feature to prevent setting of the individual zone temperature lower than 24C[4]

2.8 Different Building Envelopes for Energy Optimization:

Building envelope load of an occupied building facility is significant and it contributes substantial share of the cooling or heating load. HVAC system of the facility has to cater to this load in order to maintain indoor conditions at design conditions. Therefore the building envelope load is closely linked to energy consumed and operating cost during entire life time of the facility.

Thus thorough consideration should be given at construction phase to minimize envelope load. Due consideration must be given in finalization of building orientation, Construction materials etc to minimize building envelope load component because this can't be corrected later. Complete details of the material of construction for all building components must be obtained. This should apply not only to the external building components but also to the internal components such as partitions, ceilings etc. In case of all external elements, the color too is very important. The complete details of each component must be carefully listed. As an example for the external wall, the following information must be obtained.

- Material of construction
- Thickness of the wall
- Finishes Internal & External
- Color of the external surface

After obtaining the above data, the weight per unit area must be worked out as accurately as possible.

In the case of external glass surfaces, the Type of Glass, Colour of Glass, Thickness, Any shading films used, Any internal shading devices installed, the availability of a frame and the material of same too must be listed. Under type of glass, Ordinary Glass, Regular Plate Glass, Heat Absorbing Glass etc. must be noted. The number of glass panes used, (01, 02 or 03 etc.) and the space in between must also be noted. Regarding the roof the complete details of the construction including any reflective film used and or any insulation used must be listed. It is important to note the complete details of exactly how the insulating material is installed. If there is any Air-gap provided between the roof and the insulation that too must be noted. In short complete details of the total construction must be listed. If any special materials such as heat Absorbing Glass, composite Double Pane Glass with vacuum in between is used, thermal properties must be obtained from the supplier or the manufacturer.

Another important aspect with respect to buildings with a roof will be the space in between the false ceiling and the roof. If the construction of the building is such that if the 'attic space' has the facility for un-restricted air flow across (ventilated either mechanically or naturally) that too should be noted.

In short this is an extremely important step in the calculation of the Heat Load. If this initial data is not obtained as accurately as possible then it will be necessary to make many assumptions. That obviously will make the Heat Load calculation less accurate. It will be a very good practice to list out as much information as far as practically possible, however trivial and irrelevant it may appear, regarding the construction materials used in the building.

2.8.1 Energy Efficient Building Envelope Design:

2.8.1.1 Pre Considerations:

Minimizing the solar gain through the building envelope happens to be a primary consideration especially in tropical climates like ours. Therefore orientation of the building with its long side is in line with east west line avoiding openings facing east west sides especially west. Use of light colored walls and roof ,appropriate internal & external shading for fenestrations, moderate window to wall ratios, minimum air infiltration to the building ,economic utilization of building envelope, insulations are recommended pre considerations at the design stages.

2.8.1.2. Climatic Zones and Building typology:

- Warm-humid
- Warm-dry
- Uplands

2.8.1.3. Two types of building are in consideration based on duration of operation:

- Day time operation-Offices
- Extended operation-Hotels, Hospitals, Condominium

Overall objective is to meet specified OTTV value subjected to prescriptive criteria of each building envelopes.

2.8.1.4. Mandatory Requirements:

- U values for roofs, fenestrations, facades shall be determined.
- Envelope Sealing:

The following areas of the building envelope shall be sealed to minimize air leakages for buildings whose occupancy area are treated other than by natural or any mechanical means of ventilation.

- Joints around fenestration and doors
- Joints between walls and foundation, between walls and building corners, between walls and structural floors, roofs and between roof or wall panels.
- Openings at penetrations of utility services through roof, walls and floors.
- Site built fenestrations and doors
- Building assemblies used as ducts or plenums
- Joints, seams and penetrations of vapor retarders
- All other openings in the building envelope

2.8.1.5. Air Leakage

Fenestrations and doors shall be designed shall be designed to limit air leakage such that the air infiltration does not exceed 5 l/sm2 for glass swinging entrance doors and revolving doors and 2 l/sm2 for all other fenestration and doors.

2.8.1.6. National Building Legislations

Any existing national building regulations for minimum natural ventilation and daylight harnessing shall be complied with Prescriptive Requirements, The mean visual light transmittance for all fenestration shall be greater than 0.15 and OTTV for each of the distinct facades of the building shall be calculated.

Table:2.3.Maximum U values for facades:

Climate	Day time operation(w/m^{2}k)	Extended operation(w/m^{2}k)
Warm-Humid	0.45	0.40
Warm-Dry	0.45	0.40
Upland	0.38	0.35

2.8.1.7. Roofs:

Exterior roof surfaces solar absorptive for non tiled roof surfaces shall be less than 0.4.

Table:2.4.Maximum U value for roofs:

Climate	Daytime operation tiled(w/m^{2}k)	Daytime operation Non tiled(w/m^{2}k)	Extended operation Tiled(w/m^{2}k)	Extended operation Non tiled(w/m^{2}K)
Warm-Humid	0.30	0.40	0.30	0.28
Warm Dry	0.25	0.40	0.25	0.25
Upland	0.20	0.35	0.20	0.25

2.8.1.8. Windows:

Heat gain through window could be controlled and reduced in many ways.

- Control of window area, expressed as window to wall ratio (WWR)
- Glass type expressed as the shading coefficient (SCg)
- Use of Internal shading devices (SCint) and external shading devices (SCext)[4]

2.8.1.9. Case study:

Refer Annex:2 for detailed study on selection of roof material for Building envelope optimization in a hotel building.

2.9 Building Load and Energy Simulation Techniques:

To predict the performance buildings it is necessary to establish energy consumption, CO_2 emissions, operating costs, and occupant comfort critical to the success of projects ranging from the small and simple to the very large and highly complex. Therefore architects, MEP and building services engineers, and energy assessors need the powerful tools to effective and productive design, analyze, and simulate building energy systems. Now a day there are software which can generate accurate ,fast simulation and analysis for building load, plant energy, passive design, and dynamic thermal simulations. Those simulation tools are supporting ISO, CIBSE, ASHRAE standards and those tools can be used all over the world to provide required compliance.

2.9.1. Available modeling software:

2.9.1.1. Equest:

eQUEST is a sophisticated, yet easy to use building energy use analysis tool which provides professional-level results with an affordable level of effort.

This free down loaded software and enable to perform detailed analysis of today's state-of-the-art building design technologies using today's most sophisticated building energy use simulation techniques and does not require extensive experience in building performance modeling. This is achieved by combining a building creation wizard, an energy efficiency measure (EEM) wizard and a graphical results display module with an enhanced DOE-2-derived building energy use simulation program.

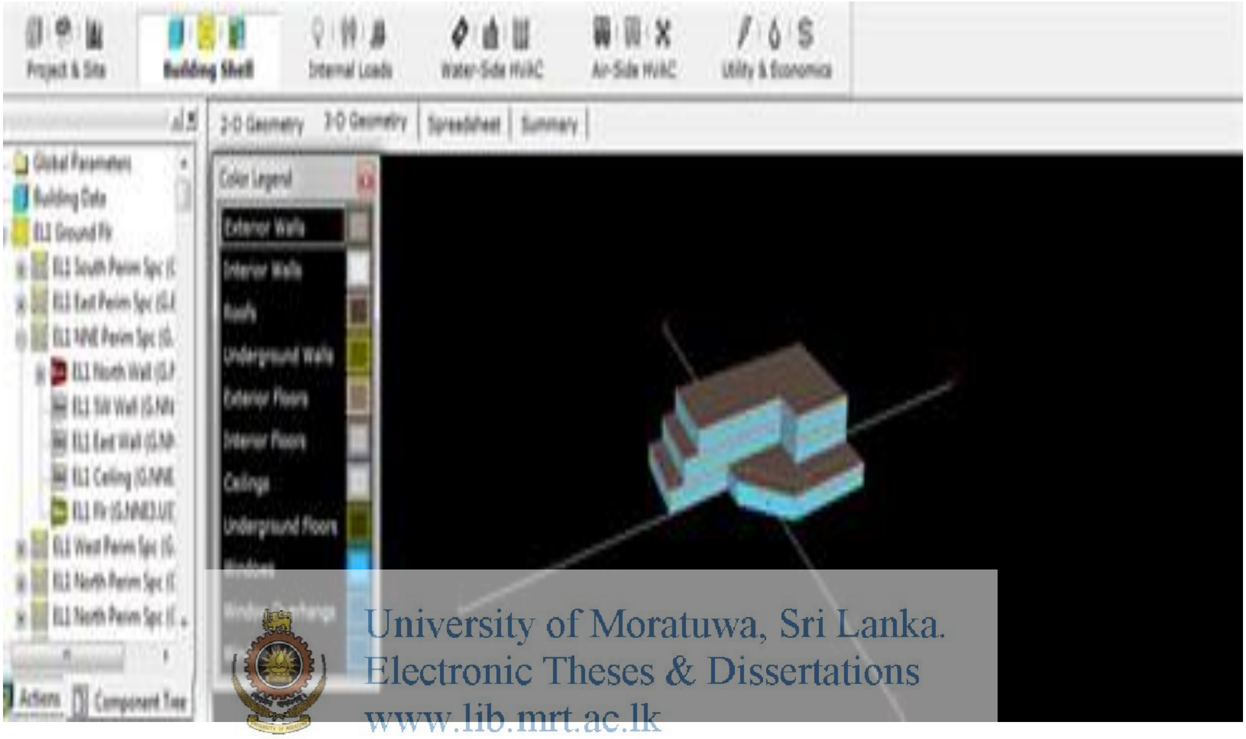


Figure 2.4: 3D Modeling[19]

eQUEST is well named because it provides something the you've been looking for, but have been unable to find a sophisticated, yet easy-to-use building energy analysis tool. eQUEST, shall be able to provide professional-level results in an affordable level of effort.

eQUEST allows to perform detailed analysis of state-of-the-art building design technologies using today's most sophisticated building energy use simulation techniques but without requiring extensive experience in the "art" of building performance modeling. This is accomplished by combining a building creation wizard, an energy efficiency measure (EEM) wizard, and graphical reporting with a simulation "engine" derived from the latest version of DOE-2.

eQUEST features a building creation "wizard" that walks you through the process of creating an effective building energy model. Following series of steps that help you describe the features of your design that would impact energy use, such as

- architectural design
- HVAC equipment
- building type and size
- floor plan layout
- construction materials

- area usage and occupancy
- lighting system

2.9.1.2. Building Creation (Modeling):

The eQUEST building creation wizard first requests the most general information about your building design, and then moves into progressively deeper detail. In all, the building description process comprises 23 data-entry steps, each represented by a "wizard" screen. At each step of describing your building design, the wizard provides easy-to-understand choices of component and system options. It also offers advice in the form of "intelligent defaults" for each choice. In addition, eQUEST automatically skips steps that do not apply to your design.

Although the building description process can get quite detailed, it isn't necessary to complete every single step in the wizard. After compiling a building description, eQUEST produces a detailed simulation of your building, as well as an estimate of how much energy it would use. Although these results are generated quickly, they are quite accurate because this software utilizes the full capabilities of DOE-2 (the latest version of a well-respected and popular building energy simulation program developed over the last 20 years by the U.S. DOE).

eQUEST, DOE-2 performs an hourly simulation of your building design for a one-year period. It calculates heating or cooling loads for each hour of the year, based on the factors such as walls, windows, glass, people, plug loads and ventilation.

DOE-2 also simulates the performance of fans, pumps, chillers, boilers and other energy consuming devices. During the simulation, DOE-2 also tabulates your building's projected energy use for various end uses such as lighting, plug loads (computers, appliances, copiers, etc.), heating, cooling, ventilation and pumping.

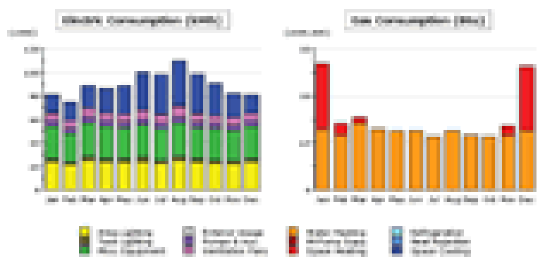
2.9.1.3. eQUEST Results:

eQUEST offers several graphical formats for viewing simulation results. For instance, it can display graphs of estimated overall building energy on an annual or monthly basis. (See Figure 2.4.) and also can compare the performance of alternative building designs. (See Figure 2.5.)

In addition, eQUEST allows to perform multiple simulations and view the alternative results in side-by-side graphics. It offers,

- Energy cost estimating
- Day lighting and lighting system control
- Automatic implementation of common energy efficiency measures (by selecting preferred measures from a list).

The current version of eQUEST provides even more comprehensive analysis capability. It allows the advanced user to input additional building details to analyze complex buildings. A three-dimensional view of the building geometry is available in this version, as well as HVAC system diagrams[19].



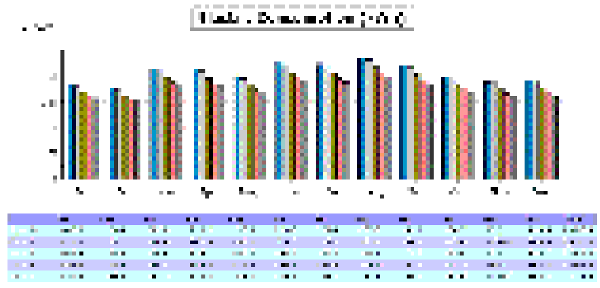


Figure 2.6 :

Comparison of monthly energy use for base building design and four alternatives which incorporate Energy Efficiency Measures (EEMs)[19]

Figure 2.5 :

A building's projected monthly energy consumption, with consumption attributed to various end-use categories.

2.10 Chapter Conclusion:

Chapter two fulfill requirements to meet specific objectives listed in the research study and points discussed here shall be applied in development of research methodology in chapter three.

Literature review is very important part of the study and knowledge on emerging technologies, guidelines would help immensely to develop optimized AC solutions for new commercial buildings and retrofits of existing systems. It is an essential requirement to understand factors such as client requirements, architectural limitations, building operation in selection of most appropriate AC system and much thought shall be given on emerging technologies especially considering energy efficiency perspective.

CHAPTER 3:RESARCH METHODOLOGY:

3.1 Chapter Introduction:

This chapter discuss about development of designs, Testing & Commissioning, Operation & maintenance of commercial building air conditioning system, which is the main objective of the study. Points discussed in the chapter two, under literature survey shall be applied here to develop especially design methodology. Design approach includes establishing comfort levels and indoor air quality, evaluation of stake holder requirements, functional requirements, system sizing, system selection and finally finalization of design.

Procedures for development of Testing & commissioning, operation & maintenance have been also discussed under this chapter.

3.2 Description of Design Approach to Achieve Main and Specific Objectives:

Object of air conditioning is to control environment of the area such as temperature, humidity, air flow, air distribution, suspended particles, germs, smell and toxic gases to meet desired conditions for humans, material or equipment in the area. In order to achieve the object of air conditioning, air conditioning plan is made to enable the air conditioning equipment function and perform efficiently. In the planning process, checking related laws and regulations, selection of air conditioning method and selection of equipment, layout of ducting and piping, determination of automatic control system are to be done considering energy saving , noise and ventilation analysis, space efficiency of building and equipment, initial and maintenance cost.

Technical factors associated with selection of an appropriate ac system was discussed detail in literature review (chapter 2) and points such as environmental conditions, client requirements, architectural limitations, load profile and operation pattern are the key factors for consideration.

Fig:3-1 shows objects and factor of air conditioning.

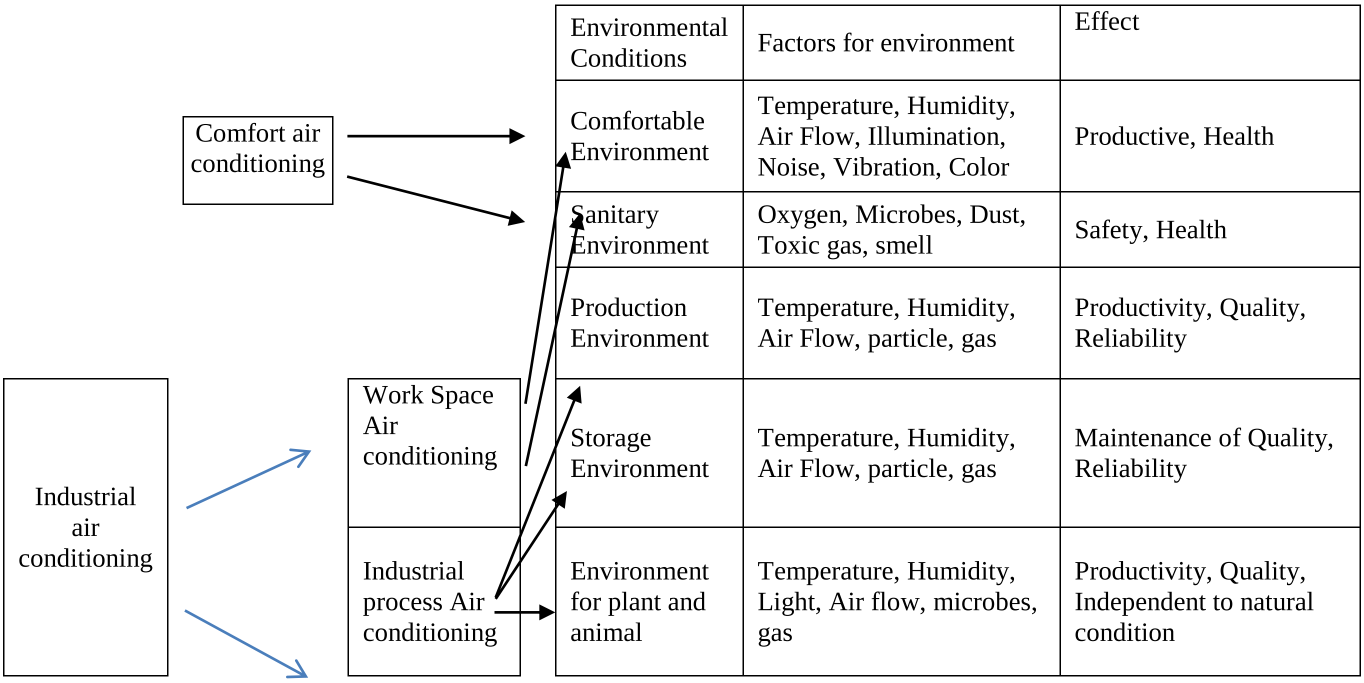


Figure 3-1:Objects and factors of Air Conditioning

3.2.1. Establish Comfort levels and Indoor air Quality:

Standards and guidelines related with thermal comfort levels was deeply discussed in the literature review(Chapter 2)and here we will establish conditions for various type of buildings based on ASHRAE standard 55, ASHRAE 62.1 and other guidelines mentioned in chapter 2.

3.2.1.1. Indoor Temperature and Humidity:

Air conditioning is classified in comfort air conditioning and industrial air conditioning according to the object. Comfort air conditioning is aimed to make human life and working environment comfortable while the object of industrial air conditioning is to improve productivity and maintain product quality in industrial field. Condition of room temperature and humidity differs depend on the usage and object of the room or the area. Table 3-1 shows typical room in comfort air conditioning and industrial air conditioning.

Table 3-1: Typical temperature and humidity condition for comfort air conditioning
(Source: ASHRAE Application Hand Book:1982)

Type of building	Room Name	Dry Bulb Temperature (C)	Relative Humidity (%)
Office	Office	26-27	50-60
	Meeting room	26-27	50-55-60
	Dining	26-27	50-55-60
Theater	Seat	26-27	50-60
	Lobby	26-27	50-60
Department Store	Shopping area	26-27	50-60
Supermarket	Shopping area	26-27	50-60
Hotel	Guest Room	24-25	50-60
	General area	26-27	50-60
	Ball Room	24-26	50-60
	Kitchen	27-29	
	Cold kitchen	24-26	
Museum	Exhibition room	22-26	40-50
	Storage room	22-24	40-50
Hospital	Bio clean operation room	21+1	45-60
	Bio clean sick room	24-26	40-60
	Recovery	24-26	50-60
	Premature baby room	25-27	50-60
	General area of operation room	23-25	50-60
	ICU	24-26	50-60
	New born baby room	25-27	50-60

Further indoor temperature and humidity levels must be in accordance with ASHRAE STANDARD ANSI/ASHRAE 55-2004, Thermal Environmental Conditions for Human Occupancy.

3.2.1.2. Noise Level:

In the air conditioning system noises are generated not only by equipment but also by air flow in duct, water flow in piping. These noises are transmitted to the room through structure or air conditioning duct. If the noises are over the allowable level, countermeasure shall be taken based on the noise calculation. Table 10 shows allowable noise levels for various types of buildings.

Table 3-2:Noise level in side different buildings(Source: ASHRAE Application Hand Book:1982)

dB(A)	20	25	30	35	40	45	50	55	60
NC	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55
Loudness	No sound		very silent		silent		feel noise		noisy
Influence to conversation and telephone	WHISPERING CAN BE HEARD WITHIN 5m			CONVERSATION IS POSSIBLE WITHIN 10m,NO INTERFERENCE FOR TELEPHONE			NORMAL CONVERSATION WITHIN 3M,TELEPHONE POSSIBLE		CONVERSATION IN LOUD VOICE, NO TELEPHONE
Studio	Anchoic room	Anchoic studio	Radio studio	TV studio	Main Control room	General office			
Hall		Concert hall	Theatre		Movie Theatre	Planeta rium	Hall lobby		

dB(A)	20	25	30	35	40	45	50	55	60
NC	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55
Loudness	No sound		very silent		Silent		feel noise		noisy
Influence to conversation and telephone	WHISPERING CAN BE HEARD WITHIN 5m			CONVERSATION IS POSSIBLE WITHIN 10m,NO INTERFERENCE FOR TELEPHONE			NORMAL CONVERSATION WITHIN 3M,TELEPHONE POSSIBLE		CONVERSATION IN LOUD VOICE, NO TELEPHONE
Hospital		Audio inspection room	Special sick room	Operation room, sick room	Consultation room	Inspection room	Waiting room		
Hotel, residence				study	Bed room, guest room	ball room	lobby		
Office building				office	meeting room	meeting room	general office		typing

3.2.1.3. Assessment to indoor environment:

Formation of atmospheric air varies by means of activity of the resident, material used and in the activity and material generated from equipment and building. Generally formation of the atmospheric air mixed with vapor and suspended particles are considered as normal air. If the formation of normal air is changed or mixed with other material, the air is called contaminated air. Contaminated air may cause stress to human. Contaminants of indoor air are Co_2, CO, Nox, Sox, Formaldehyde, O_3 etc. Energy crisis occurred in the late 70's accelerated various energy saving measures. In the air conditioning area, it was affected reduction of ventilation volume and higher air tightness in building. In 1980's, respiratory organ problems was increased among residents of such buildings. This was so called sick building syndrome. The cause was the reduced ventilation air volume and increased contaminated material generation. Recently it was become clear that asbestos will damage human health and use of asbestos is controlled. Also legionella pneumophilia increased in cooling towers caused legionnaires disease in 1976.Thus the air contamination influence to human health seemed to be increased recently.

ANSI/ASHRAE Standard 62.1.2007 ,Ventilation for Acceptable Indoor air Quality is the guideline used to determine ventilation requirements for any building based on application. Below table specifies minimum distance for air intakes from contaminated exhausts.

Table:3-3:Air intake Minimum separation distance(Source: ASHRAE 62.1-2007)

Objects	Minimum distance(m)
Significantly contaminated exhaust	5
Dangerous exhaust	10
Vents, chimineys and flues from combustion appliances and equipment	5
Garage entry, automobile loading area or drive in queue	5
Truck loading area or dock, bus parking/idling area	7.5
Driveway, street or parking place	1.5
High traffic volume	7.5
Garbage storage/pick up area	5
Cooling tower intake or basin	5
Cooling tower exhaust	7.5

ANSI/ASHRAE Standard 62.1.2007, guideline for Ventilation rates for buildings based on application is as follows.

Table:3-4: Minimum ventilation rates in Breathing Zone(ASHRAE 62.1-2007)

Occupancy Category	People outdoor air rate	Area outdoor air rate	Occupancy Density
	cfm per person	cfm per ft2	#/1000ft2
Correctional facilities Cell	5	0.12	25
day room	5	0.06	30
guard station	5	0.06	15
booking/waiting	7.5	0.06	50
Educational facilities day care	10	0.18	25
day care sick room	10	0.18	25
class rooms(ages 5-8)	10	0.12	25
class rooms(age 9+)	10	0.12	35
lecture class room	7.5	0.06	65
lecture hall	7.5	0.06	150
art class room	10	0.18	20
science laboratory	10	0.18	25
university /college laboratory	10	0.18	25
wood/metal shop	10	0.18	20
computer lab	10	0.12	25
media centre	10	0.12	25
music/theatre/dance	10	0.06	35
multi assembly	7.5	0.06	100
Food & Beverage Service restaurant dining rooms	7.5	0.18	70
cafeteria/fast food dinning	7.5	0.18	100
bars, cocktails lounges	7.5	0.18	100
General break rooms	5	0.06	25
coffee stations	5	0.06	20
conference/meeting	5	0.06	50
Hotels, Motels, Resorts, Dormitories bed room/living room	5	0.06	10
barracks sleeping areas	5	0.06	20
laundry rooms, central	5	0.12	10
laundry rooms within dwelling units lobbies/pre function	5 7.5	0.12 0.06	10 30
multipurpose assembly	5	0.06	120

3.2.2. Evaluate Cooling load requirements:

Establishing building cooling load correctly is very critical for proper AC system design and peaceful operation. Without stringent cooling load calculation procedure, we are getting fairly oversized AC systems and this is resulting in efficient system operation and high investment costs. We have discussed about building load and energy simulation techniques used presently and the advantages of using such simulation techniques in the literature review (chapter 2) and here we will discuss applicability of same in detail to develop methodology.

Using a reputed software/simulation tool, calculate the cooling loads and daily load profiles for the facility. In reality the preliminary data required to do the load calculation has to be obtained by the designer. Some-times it may not be possible to obtain all the data. Designer will then use his experience and judgment in making the necessary assumptions.

3.2.2.1. Preliminary Data:

3.2.2.1.1. Location and orientation:

The location of the building is important. The latitude of the location is also required as the solar heat gain is affected by the latitude. Sri Lanka lies between 6N and 8N latitude. The correct latitude for most places can be obtained from the internet quite easily.Also longitude and elevation of the location is also critical. Orientation of the building can be obtained from the site map.

3.2.2.1.2. Environmental factors and services availability:

These are also very important factors that need to be obtained regarding the building. The environmental factors basically should look at the environmental condition. If the site is close to the sea and is possibly exposed to corrosive atmospheric condition which is associated with it must be clearly noted. The availability of good clean water is another factor that needs to be looked at. In the case of large installations, it is not only important to check on the quantitative aspects but the qualitative aspects too should be checked. If necessary a sample should be chemically analyzed. It is important to establish if harmful chemicals such as silica is present. This information is used in deciding the type of equipment to be used.

3.2.2.1.3. Building construction material:

Chapter 2.8 discussed on different building envelopes for energy optimization and this is a routine practice with architects and engineers now a day. Critical factors such as U values of facades, Roofs and building overall thermal transmittance value (OTTV) must be evaluated in new building design and design input were given in chapter 2 under literature review.

Complete details of the material of construction for all building components must be obtained. This should apply not only to the external building components but also to the internal components such as partitions, ceilings etc. In the case of all external elements color too is very important. The complete details of each component must be carefully listed as below.

- Material of construction: Clay bricks, solid cement bricks, Hollow cement blocks
- Thickness of the wall
- Internal finish
- External finish
- Color of the external surface
- After obtaining the above data, the weight per unit area must be worked out as accurately as possible.

In the case of external glass surface, the type of glass, color of glass, thickness, any internal shading devices installed, the availability of a frame and the material of the same must be listed. Under type of glass, ordinary glass, regular plate glass, heat absorbing glass etc must be noted. The number of glass used and the space in between must also be noted.Regarding the roof complete details of the construction including any reflective film used and or any insulation used must be listed. It is important to note the complete details of exactly how the insulating material is installed.

Another important aspect with respect to buildings with a roof will be the space in between the false ceiling and the roof. If the construction of the building is such that if the attic space has the facility for unrestricted air flow across that too should be considered.All above points are related with building envelope load and building internal loads must be considered similarly.

3.2.2.1.4. Occupancy:

This is another very important aspect. It is very important to know the total number of persons occupying the building at any given time. It is also required to know type and the level of activity of the occupants. In the case of a large building, the occupancy levels for each sub area must be obtained. If the occupancy levels are not available, it will be the responsibility of the designer to make an assessment. At least the proposed use of the building must be established and thereafter the possible occupancy levels can be established using standard “area per person “for such applications. If the occupancy of the building is changing on regular pattern, that too must be noted.

3.2.2.1.5. Ventilation:

This is another very important aspect that needs careful assessment. Often it will be up to the designer to decide on the level of ventilation required. Most of the time ventilation refers to the amount of fresh air required to be supplied to the conditioned space. This is determined by the number of people occupying the space based on ASHRAE 62.1 IAQ requirements. In special cases such as operating theaters, kitchen etc, the amount of fresh air to be supplied may depend on the process requirements.

3.2.2.1.6. Lighting:

Lighting is often a significant contributor to the heat load. If the lighting design has been done and the lighting layout is available, complete information on the type and the number of fittings, method of installations and the rated wattage and the type of lamps used must be listed. The details of control gear such as ballasts too must be listed.

In the case of new buildings, complete information on the lighting to be used may not be available. In such situations, it will be once again the responsibility of the designer to establish the amount of lighting to be allowed for. This is done by using guideline figures of power consumptions for lighting per unit floor area.

3.2.2.1.7. Equipment:

This refers to all different types of equipment used within the conditioned space. A comprehensive list of all equipment must be made. The equipment will also include computers, office equipment as well. As much information regarding the equipment must be gathered. This will include the rated power of the equipment. Type of equipment and the location of the drive motor must be required. In the case of cooking appliances, the size and the type must be listed together with the fuel used or if it is electrically operated.

3.2.3. Evaluate client and other stake holder requirements:

Having completed a heat load calculation for a building the next most important step is the selection of the correct equipment. Selection of the equipment will depend on a multitude of factors. The factors cover a wide range and are not necessarily confined to matters of a technical nature. It is extremely important to have a very good understanding of the available options before a final decision is taken regarding the selection of equipment. Factors to be considered in selecting the system are listed below.

3.2.3.1. Budget:

The selection of the system and the equipment will primarily be controlled by the budget. Any system to be installed has to meet the budgetary cost allocations. Very often the type of system to be used and the equipment to be used are determined purely according to the budget. This certainly is not the correct way of making decisions. It is therefore very necessary that all other options available are looked at. Cost of such system found out. The advantages shall be listed out and client must be educated to take the correct decision and not the decision based purely on the price.

3.2.3.2. Client requirements:

The client requirement is essentially the starting point for any system design. However it may be necessary for the designer to educate the client especially on the available options. It is the duty and responsibility of the designer to discuss, in detail all possible options. Discuss the advantages and disadvantages of the possible systems that could be used. Also give an indication of the cost implications for each system. The designer must very clearly understand the client's requirements. An agreement must be reached with client on one or two systems that could be considered. It is also important to understand the price range and the quality range of the equipment the client has in mind. If the client is not looking at relevant factors such as Energy efficiency, life time etc. It will be the duty of the designer to specifically bring such matters to the notice of the client before any decision is taken.

3.2.3.4. Evaluate functional and space requirements:

This is an extremely important aspect in the selection of systems and equipment. The ideal situation is for the AC system design engineer to be involved with the building design from the conceptual design stage. If this is done, it will be possible to make available the necessary spaces, heights and paths for the most suitable system to be installed. That gives a lot of flexibility to the Ac system design where he will be able to design the most appropriate type of system for the building.

Unfortunately this situation does not exist most of the time. Often air conditioning is thought about at the last moment. The building designs have all being finalized, space and heights allocations already fixed and possibly the building is under construction when air conditioning is thought about. This will limit the AC system designer in the number of options that could be considered. Very often it is observed that the required spaces are not available even to consider installing the most suitable system. Under these circumstances compromised solutions have to be found. As to be expected compromised solutions are not the best and often are the worst possible choice.

In selecting the most suitable system, it is important to consider the geographic distribution of the spaces to be air conditioned. If a ducted air distribution system is to be considered, then the availability of space to locate supply ducts and the possibilities for the return air to be directed back to the AC plant needs to be considered. In such centralized systems ,space will also have to be found to house the AC unit which very often has to be either within the conditioned space or adjacent to the conditioned space. In the case of geographically remote and detached spaces to be considered to be considered to be included in one system with ducted air distribution, the space availability to locate both supply and return air ducting is an absolute necessity. The possibility to use the ceiling plenum as the return air path is another aspect that needs to be looked at.

The acceptability of a common temperature for the entire area or the need for individual temperature control for separate areas such as cubicles will play an important part in deciding the type of system. A conventional ducted system will work well where a common temperature is acceptable for the entire area. When individual control is needed then the use of VAV boxes with the ducted air distribution needs to be considered. In this system VAV boxes are used to control the air flow in to each separate section. Due to the possibility of reduction of air flow at a number of outlets at the same time, a variable speed drive is required for the fan motor to avoid excessive air flow being pushed through the outlets that remain opened.

If the separate locations requiring air conditioning is too far spread out and does not have any clear path for locating ducts, then the use of ducted air distribution system will not be possible. This problem will further be compounded if the different areas are used at different times and require individual temperature controls (i.e. Hotel, Large Offices, complex with many full height cubicles). In such situations, one has to consider the use of a chilled water system. The primary requirement for using a chilled water system will be the availability of a space to locate the central equipment and clear paths for routing the chilled water distribution pipes.

In smaller installations having many different segregated rooms requiring air conditioning, especially where the load is shifted from one place to another during the day, the use of VRV (Variable Refrigerant Volume) systems can be considered.

Location of the building to be air conditioned to plays an important part in the type of equipment that is most suited to be used. One very important factor is the proximity to the sea thereby making the environment corrosive. Such locations will generally not be suitable for the use of air cooled systems. This is due to the fact that the aluminum film of the condenser coil perish rather fast due to corrosion and oxidation due to the salt laden atmosphere. Many options of additional treatment are available to minimize the damage due to corrosion. But these have a cost and in some cases still has a limitation of the lifetime.

In situations where the environment is highly corrosive, water cooled units will be the obvious answer provided the required volume of water of acceptable quality is available. On the other hand there could be situations where water cooled units cannot be used due to the very bad quality of the water or non availability of the required volume of water. In such situations air cooled units have to be considered provided corrosion is not a major factor. In certain instances where the building is located in a very remote area, the maintainability of the equipment will also be a factor to be considered as the availability of technicians with the required skills may be a problem and also the time involved in sending technicians from Colombo may be far too long. In such situations we may be compelled to use a very simple system like multiple split units by making a compromise.

Availability of water of acceptable quality and in the required quantity is the major consideration in selecting Water cooled systems. Water is required as the cooling media for the water cooled condenser. There is always a loss of water at the cooling tower which will be due to evaporation as well as drift loss. In addition, a certain volume of water is allowed to drain out from the cooling tower pan to control the total dissolved solids. This can be a substantial volume of water depending on the capacity of the plant. It is therefore extremely important to establish the situation with respect to the availability of water of acceptable quality before taking a decision on the type of equipment. If the water is found to be either scale forming or corrosive then water cooled equipment should be used only if water treatment system and a program is put in place from day one. If this is not done the system may start to malfunction in a very short time and expensive repairs may then be required. Special attention must be given to the presence of harmful dissolved chemicals such as silica. If such chemicals are present the use of water cooled equipment under normal circumstances is not recommended.

Operational pattern of the building area is another very important aspect that needs to be looked at before selecting a system. Very often, in a building where different areas need to be air conditioned and they have different operation patterns. On the other there will be a situation where a multi storey commercial building is occupied by many clients, operating in office, where each floor is occupied by one client. In this situation the operating pattern of all offices are pretty much the same.

When equipment is to be selected for a system with varying operating patterns, systems such as split units, VRV Systems and chillers may have to be considered. When selecting equipment for a building with fairly uniform operating pattern, a system with multiple package units, with separate units feeding separate floors can be considered. If the system is water cooled then a common cooling tower will have to be provided with the necessary circulating pumps also being common.

If the building is occupied by number of clients, issue is how to pay AC system operating costs. If the entire building is occupied by one client, then the possibility of selecting a system considering the total capacity can be considered. One biggest advantage is that when the system can be designed for the total capacity, a very efficient system such as chilled water system with an efficient chiller can be designed. It will be easy if no individual billing and costing on an area basis is required. But nowadays individual billing is also possible for such system through energy meters interfaced with building management system.When the building is occupied by many different clients, then the system selected will have the key equipment only feeding the particular floor or area(i.e. water cooled packages with a central cooling tower). This will permit the major portion of the cost of energy used for air conditioning being directly billed to each client or area.

3.2.4 Define Energy performance:

Energy efficiency is one of the most important aspect that need to be considered in selecting equipment and systems. This unfortunately is not considered very often in selecting equipment. In the literature review (Chapter 2), we have highlighted presently available energy efficient guidelines such as ASHRAE standard 90.1-2004, Green building guidelines and Sri Lanka building code. These standards specified baselines for equipment efficiencies and branded products always complied with those energy guidelines. So that thorough consideration must be given in equipment selection and specifications must call for such energy efficient equipment.

There are proven technologies which enhance building energy efficiency. Chapter 2 discussed about proven technologies and consideration must be given to incorporate building management system, demand driven fresh air system, chiller plant room management system etc at the design phase, so that energy optimization is fairly simple.

Also consideration must be given to emerging technologies available now in selection of equipment for an air conditioning system. High efficient oil free centrifugal type chillers with magnetic bearings and variable speed drives, Tri rotor variable speed drive screw type chillers, Improvements in heat recovery technologies in air handling units, Liquid desiccant dehumidifiers for humidity control applications, DC Inverter split air conditioners, Ice thermal storages are the emerging technologies which we have discussed in detail in the chapter 2.Energy performances of these listed technologies are very much improved compared to existing conventional air conditioning equipment and also they are complied with strict environment regulations.

Energy efficiency needs to be considered at two different stages. The first is in the selection of the system or the type of equipment. That is at initial design stage. This has to be finalized before the details are worked out and specifications are drawn up for the equipment for the purpose of calling quotation.

The next stage is the establishment of the energy efficiency of the equipment for which quotation has been received for the specific system decided upon. This essentially is the comparison of the energy efficiency between different models and different makes.

As the cost of equipment with better energy efficiency is normally higher than the cost of equipment with lower energy efficiency, a cost benefit analysis with a simple payback period at least must be carried out.

Equipment should never be selected based simply on the initial cost.

Presently there are very high efficient chillers with variable speed drives, magnetic bearings, falling film technology flooded type coolers, etc. Each chiller type shows different performance characteristics and task is to select best matching unit for building load profiles. For an example best efficient chiller must be selected for 24X 7 hrs. operating factories and where annual energy consumptions shall be significantly low with such high efficient chillers.

3.2.5. System Sizing methodology:

Initial step is performing cooling load calculation and establish load profiles throughout the year with a reputed software using as a tool. Based on above load profiles, maximum and minimum cooling loads can be found and basic equipment sizing/selection can be done with this information. This has been discussed detail in literature review under chapter 2.But there are simulation tools which enable us to evaluate best equipment mix and equipment loading conditions per year. For easy reference, here we consider real time case analysis to understand facilities provided by simulation tools, now a day.

Below graphs and tables are based on Equest simulation output data for a real case study. Finalized system is having 3Nos each 275RT capacity water cooled chillers and similarly can generate loading condition with respective operating hours for different capacity chiller mix.

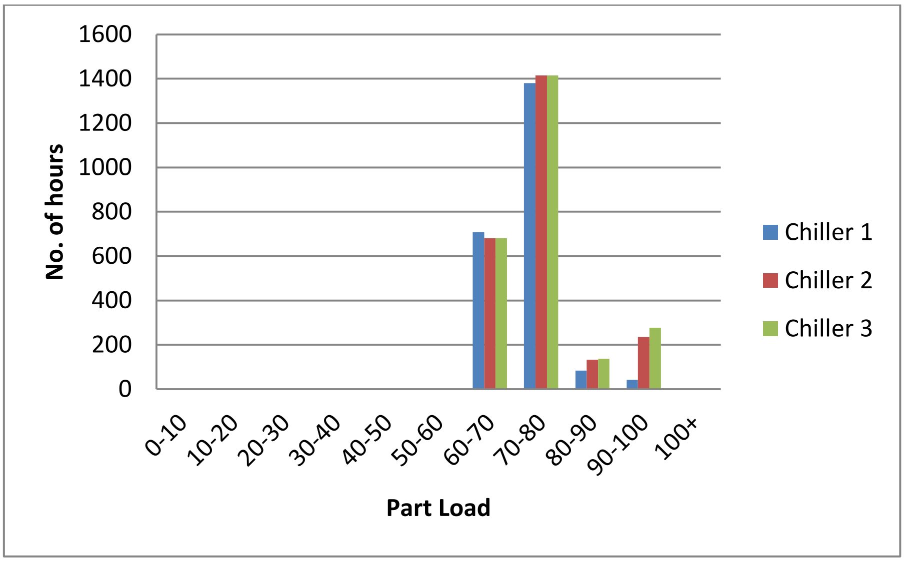


Figure: 3-2 : Part load hours for chillers

Table:3-5: Monthly Part load hours for chiller 1

Chiller size	275 TR											
No. of hours each part load	Chiller 1											
Month	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100+	Total run hrs
January	0	0	0	0	0	0	73	73	4	12	0	162
February	0	0	0	0	0	0	64	78	0	2	0	144
March	0	0	0	0	0	0	57	141	0	4	0	202
April	0	0	0	0	0	0	46	152	18	0	0	216
May	0	0	0	0	0	0	21	143	56	0	0	220
June	0	0	0	0	0	0	43	141	5	2	0	191
July	0	0	0	0	0	0	61	130	0	2	0	193
August	0	0	0	0	0	0	53	131	0	1	0	185
September	0	0	0	0	0	0	45	138	0	5	0	188
October	0	0	0	0	0	0	75	117	0	4	0	196
November	0	0	0	0	0	0	83	59	0	4	0	146
December	0	0	0	0	0	0	87	77	0	6	0	170
Total	**0**	**0**	**0**	**0**	**0**	**0**	**708**	**1380**	**83**	**42**	**0**	**2213**

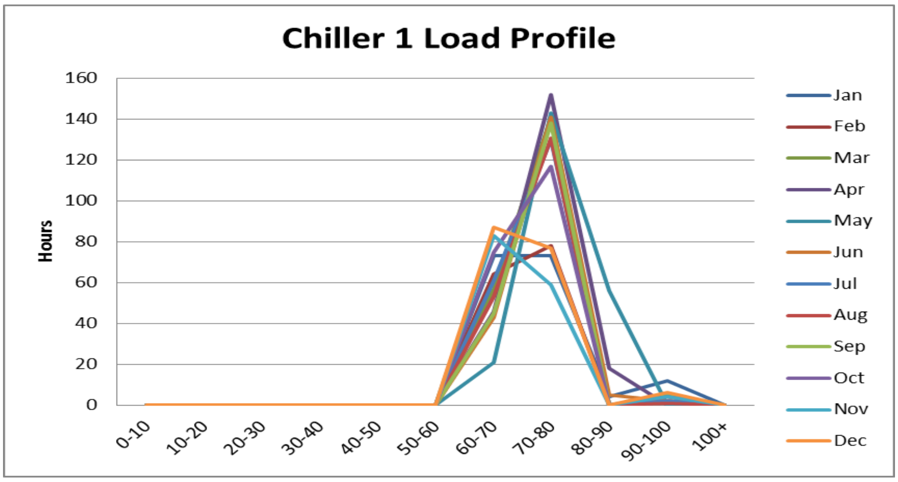


Figure:3-3: Monthly part load hours for chiller 1

Table:3-6: Monthly Part load hours for chiller 2

Chiller size	275 TR											
No. of hours each part load	Chiller 2											
Month	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100+	Total run hrs
January	0	0	0	0	0	0	66	80	9	39	0	194
February	0	0	0	0	0	0	62	82	18	26	0	188
March	0	0	0	0	0	0	56	142	0	8	0	206
April	0	0	0	0	0	0	45	153	18	4	0	220
May	0	0	0	0	0	0	21	143	56	0	0	220
June	0	0	0	0	0	0	42	142	6	8	0	198
July	0	0	0	0	0	0	57	134	0	27	0	218
August	0	0	0	0	0	0	53	137	2	27	0	219
September	0	0	0	0	0	0	43	140	0	12	0	195
October	0	0	0	0	0	0	72	120	6	18	0	216
November	0	0	0	0	0	0	83	59	11	33	0	186
December	0	0	0	0	0	0	81	83	7	33	0	204
Total	**0**	**0**	**0**	**0**	**0**	**0**	**681**	**1415**	**133**	**235**	**0**	**2464**

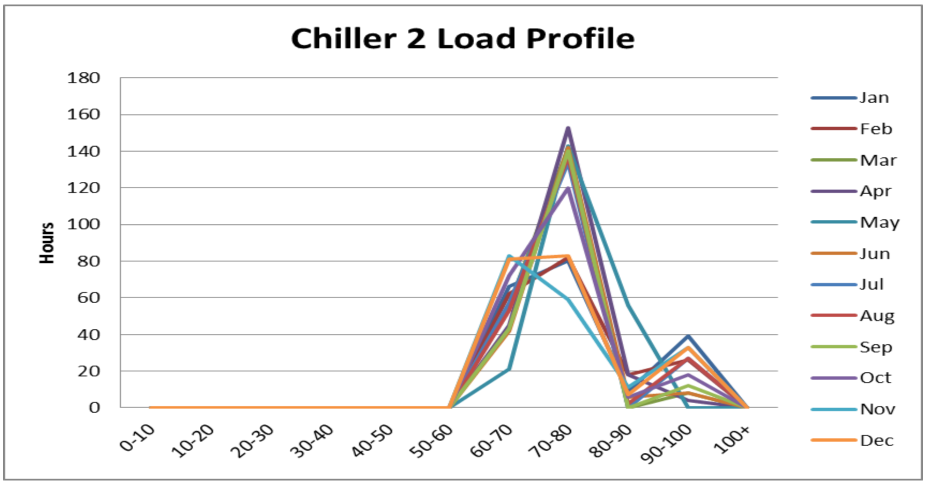


Figure:3-4: Monthly Part load hours for chiller 2

Table: 3-7: Monthly Part load hours for chiller 3

Chiller size	275 TR											
No. of hours each part load	Chiller 3											
Month	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100+	Total run hrs
January	0	0	0	0	0	0	66	80	13	51	0	210
February	0	0	0	0	0	0	62	82	18	28	0	190
March	0	0	0	0	0	0	56	142	0	12	0	210
April	0	0	0	0	0	0	45	153	18	4	0	220
May	0	0	0	0	0	0	21	143	56	0	0	220
June	0	0	0	0	0	0	42	142	6	10	0	200
July	0	0	0	0	0	0	57	134	0	29	0	220
August	0	0	0	0	0	0	53	137	2	28	0	220
September	0	0	0	0	0	0	43	140	0	17	0	200
October	0	0	0	0	0	0	72	120	6	22	0	220
November	0	0	0	0	0	0	83	59	11	37	0	190
December	0	0	0	0	0	0	81	83	7	39	0	210
Total	**0**	**0**	**0**	**0**	**0**	**0**	**681**	**1415**	**137**	**277**	**0**	**2510**

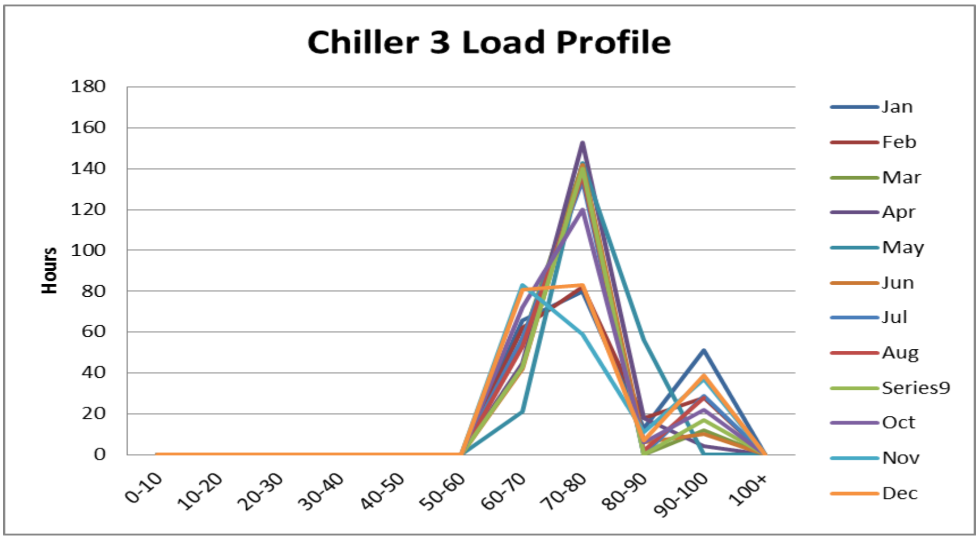


Figure :3-5: Monthly Part load hours for chiller 3

A. Hourly Load Profiles

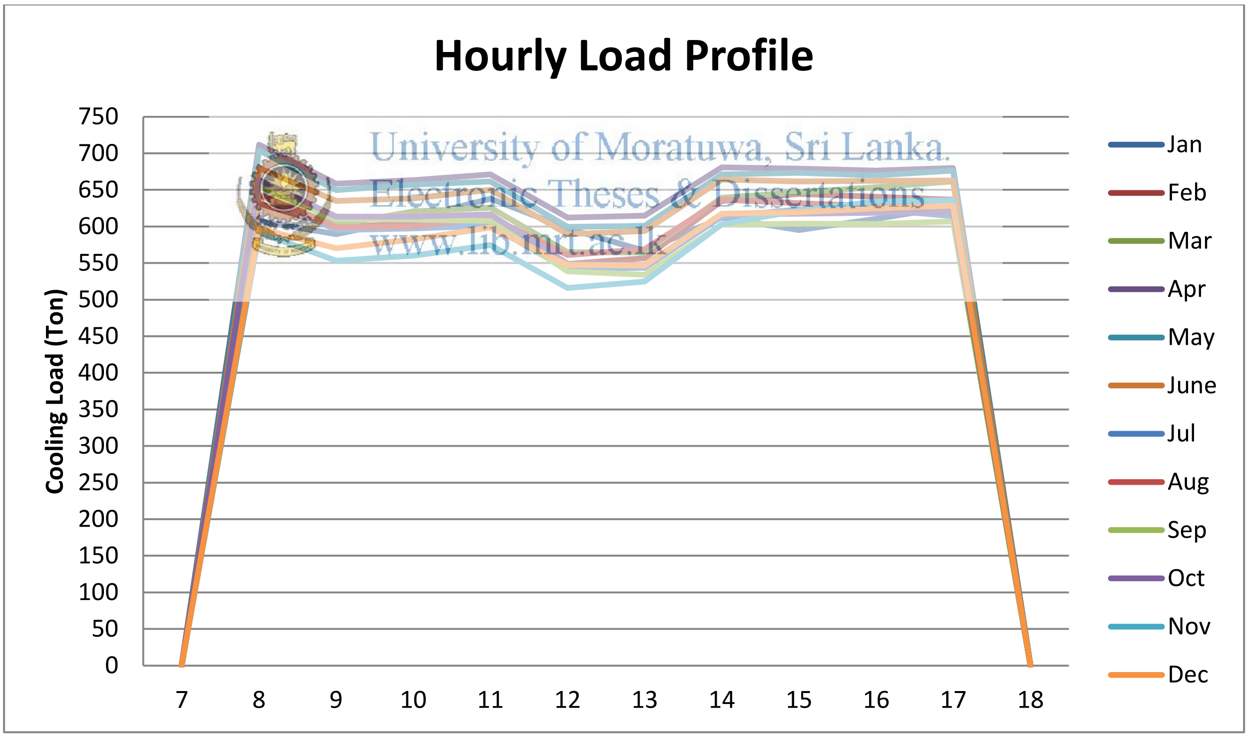


Figure:3-6: Hourly Load Profile

Source: Co-Energy AC system design report-MAS Unichela - Panadura (2013)

3.2.6. System selection procedure:

Here we will discuss about approach for system selection.

Procedure:

Here we define priority levels based on criticalness of each activity for the design process.

Priority Level 0:

Motive power is the most critical factor in finalization of appropriate AC system for the facility.

If Waste heat source is available then Absorption Chiller is suitable.

Otherwise Adequate Electrical power shall be available at facility to use Electric Chillers/DX units for AC System.

If adequate Electrical power supply is not available AC system is not feasible and decide on alternative cooling systems.

Priority Level 1:

Environmental conditions is the next critical factor. Especially corrosion is an important factor in coastal areas where air cooled chiller systems are not feasible due to excessive corrosion of air cooled chiller metal ware.

If Corrosion is critical water cooled chiller/Package system is the feasible Option.

Priority Level 2:

Water quality is bad in some part of the country and AC system selection must consider this fact also. If priority level 1 allows for Air Cooled system then choice is Air Cooled system in cases where water quality is bad.

Priority Level 3:

Application of AC system is important in finalizing best AC system for the facility. There are two applications, Comfort cooling & process Cooling in industrial facilities. For comfort cooling selection can be done from conventional AC machines such as Chillers, DX units etc. But for process cooling it requires process cooling it requires Brine chillers to achieve low temperatures.

Priority Level 4:

Operating pattern is another critical factor under consideration in finalizing best suited AC System for a facility. In cases where facility operates 24X 7 AC equipment operating cost is significant. 80% of life cycle cost is operational costs. Therefore decision must be taken whether operation cost is critical or not before selection of AC system for the facility. Where operational costs are significant efficient equipment must select.

Priority Level 5:

Another fact in deciding type of AC system suited for a building is AC area.

If AC area is less than 1000sqft Individual AC units are preferable because of simplicity and low investment.

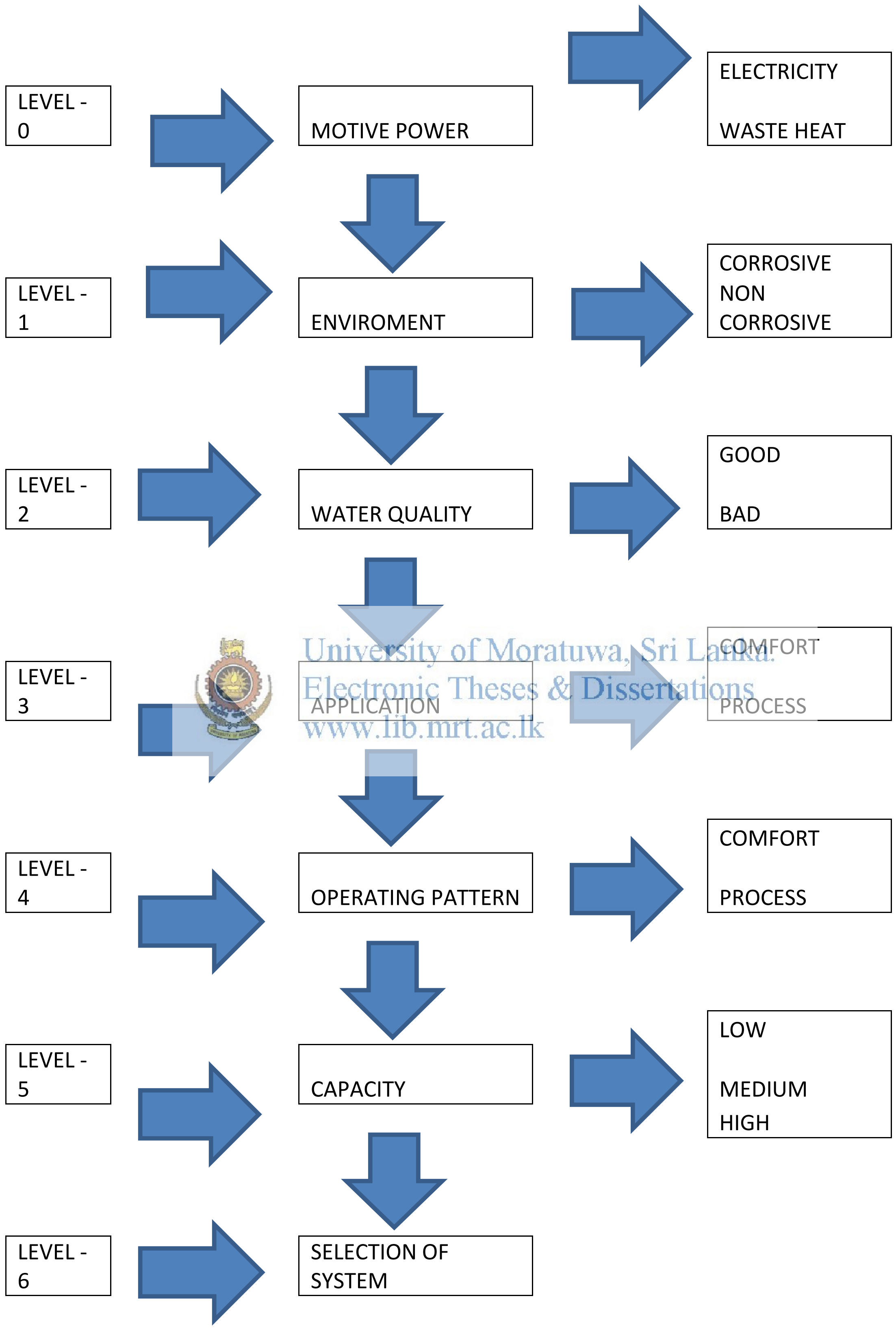
If 1000sqft< AC Area >10,000sqft Small tonnage VRV, Water Cooled packages and Air Cooled packages are preferred.

If AC Area > 10000Sqft chilled water system is preferred.

Once above five levels analyzed we can have an idea, which AC system is suited for facility. AC system sizing & optimization is the next step for selection of equipment based on cooling loads.

Cooling load calculation shall be done with reputed thermal simulation tool or cooling load calculation software as discussed earlier.

3.2.6.1. Flow chart for System selection procedure:



3.3 Description of Testing & Commissioning:

ASHRAE Guideline 1 “The HVAC Commissioning Process” defines commissioning as “the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained to perform in conformity with the design intent.” That’s a fairly broad statement. Another way to define commissioning is it is a quality control/verification process to ensure that everything will work the way intended.

Terms Commissioning, Re Commissioning, Retro Commissioning have been widely used in Air Conditioning projects and definitions of same are as follows.

Commissioning:

Verification of systems installation and operation during and after initial construction. This can be for a new building, or a retrofit project. The key is that the commissioning happens during the project.

Re Commissioning:

Verification systems are still functioning as originally intended and/or reviewing building operations and adjust systems to fit current requirements. This can happen a year, 2 years, or 10 years after construction.

Retro Commissioning:

Commissioning of a building and its systems that was never completed at initial construction.

Building HVAC systems comprise a variety of systems that have to work together to heat, cool and ventilate the various spaces. HVAC commissioning tasks typically include: design reviews, construction installation reviews, pre-start inspection reviews, startup checklists, air and water balancing, full-scale operational testing and finally occupancy with system monitoring and fine tuning. Each project’s commissioning plan is tailored for the specific needs of the work and owner. Instances where HVAC systems were never commissioned typically exhibit one or more of the following symptoms.

- Difficult to control space temperatures.
- Unexpected noises from equipment.
- Equipment fault sensor tripping resulting in operation lockouts.
- Equipment breakdown and failure.
- Higher than expected utility bills. Unsatisfied customers.

Correcting the symptoms will vary from the cheap to expensive solutions listed as follows.

- Review of the heating capacity.
- Review the location of the thermostat so it's not above a heat producing lamp.
- Ensure the circuit breaker is properly rated so it doesn't trip every time the radiator turns on.

While the above is a fairly simple example, you can see that if anyone of those items was not completed properly, the radiator might never work or not heat the space properly. Many buildings are more complicated and can contain a myriad of equipment including: chillers, boilers, heat recovery pumps, air handlers, variable flow pumps/fans, control valves, and temperature sensors, all exposed to fluctuating weather and occupancy schedules. All will not be well if installation, startup and operation verification of the various equipment and systems is not completed properly.

Managing the commissioning process is depending on size of the project. Simple one-to-one equipment change out may be completely handled by the contractor, depending on the amount of changes to piping, ducting and controls. Larger projects will often require a Commissioning Agent. The Commissioning Agent's role will often be handled by the person now most familiar with the work, namely the Mechanical Engineer that surveyed the original equipment, designed the HVAC system/retrofit and saw the project through the construction stage; this is entirely appropriate and in many cases offers quality service.

Even larger and more complicated projects may require the services of a Dedicated Commissioning Agent who is also familiar with the building and most importantly, the HVAC systems being built and/or retrofit. The Dedicated Commissioning Agent will often have several years or more of experience in the field across the many disciplines involved, including but not limited to: Building HVAC loads, sizing methods, construction procedures, air and water balancing, controls, and occupant requirements and behaviour. The appointment of a Dedicated Commissioning Agent will often come at the request of the Owner, and in some cases, to ensure impartiality, will be from a company outside of that involved in the design work. Several of the LEED ratings systems include mandatory requirements for a minimum level of commissioning of building services, such as the HVAC systems. Energy efficient HVAC designs may not deliver their benefits if they are not built, inspected, started and turned over properly. Additional LEED points and correspondingly higher performance buildings are attainable with greater levels of commissioning related tasks.

3.3.1. Develop T & C procedure:

When an HVAC system is installed, the final steps prior to completion are startup, test & balance, and possibly commissioning. Each step is important to ensure that the system performs per the intent and design of the engineer and provide a comfortable environment for the occupants. Startup is a necessary part of completing an HVAC systems, test & balance is a needed but often neglected step, and commissioning is not usually performed unless the project is attempting to obtain a LEED award or is part of a sensitive building system (ie. laboratory, hospital, manufacturing).

3.3.1.1. Startup:

When HVAC equipment is installed and electrical power wiring has been completed, the equipment must be “started up.” The startup process is usually performed by a technician with the HVAC subcontractor, but may also be performed by technicians from the equipment manufacture itself working for the HVAC sub. Each piece of HVAC equipment has a startup checklist provided by the manufacturer in the paperwork that comes with the item. It is very important that the startup technician follow these startup steps as noted by the manufacturer. Failure to properly startup equipment may void the manufactures warranty. The startup process may simply be verification that a fan is spinning in the proper direction and greasing motor bearings up to checking refrigerant charge in chillers and verifying correct amp draw from pumps. Startup reports should be included in the HVAC project documentation (Operation &Maintenance manual). It is important to note the date of equipment startup as the 1 year warranty may begin on the date or startup. A unit isn’t running until it is “started up.”

3.3.1.2. Test & Balance:

When HVAC equipment is started up, it will not blow the air or move the water as engineer intended. The system must be “balanced” so that the correct air and water flows are present during normal system operation. From the airside, the balancing technician will speed up or down equipment fans and may even need to change belts or pulleys to achieve the desire flow out of the equipment. The air coming out the ceiling diffusers is usually controlled by a damper off the rectangular duct above the ceiling. Do not recommend having a volume damper in the face of the grille itself because, although it is easier to adjust the airflow at the ceiling, volume dampers in the face of the diffusers are notorious for whistling and rattling over time. The water side of an HVAC system must also be balanced whether from a chiller, cooling tower, or boiler. The water flow is typically adjusted at a pump and may be as simple as speeding up or slowing the pump or a complicated as replacing the internal components to the pump itself. Test and balance is an absolutely critical step in HVAC system installation. A system designed by the world’s best engineers and installed by the industry’s leading craftsman will be rendered useless if it is not balanced properly.

Every new HVAC system should be tested and balanced by a Certified Test and Balance technician and if you are leaving the Test & Balance up to the HVAC contractor to perform with their own techs and not a certified balance contractor, at least 50% of those systems are not being balanced at all.
The only way to ensure that a system is balanced properly so that the occupants will be comfortable is to have the system balanced by a technician following the guidelines of the two national balancing agencies NEBB or AABC. A certified balance contractor spends years in training in the classroom and the field. A certified balance contractor will balance the HVAC system in accordance with the NEBB or AABC and provide a report that is stamped and sealed verifying proper balance. The Test & Balance contractor may be hired by the HVAC contractor or client.

Usually Testing & Commissioning is left up to the HVAC contractor to have one of their startup technician to perform the T & B and note that many of those systems will never be balanced. This practice is more common that I would care to admit. A certified contractor will lose his customer, reputation, job, and license to perform future work so the likelihood of falsehood is greatly reduced.

3.3.1.3. Commissioning:

Proper HVAC system commissioning is use a third party to verify that the HVAC design satisfies the owners requirements, the system is installed as per the contract documents and manufacturer's instructions, that the equipment is running properly, and the system performs per intent of design. A Commissioning Agent performs HVAC system commissioning. Commissioning is a step beyond startup and air balance and can be used as a final verification of the HVAC system. The extent of the commissioning and by whom the commissioning is performed is dependent on several things including design document requirement, owner preference, budget, and desire for satisfying the LEED Commissioning Prerequisites.

3.3.1.3.1. Pre Functional:

- Installation:

Verify correct material and equipment installation, Verify that the installation meets construction details and manufacturer's installations, Document condition of equipment.

- Start Up:

Document pre-operation requirements, Verify that manufacturer's startup procedures are performed, Document performance, Verify calibration of devices.

- Test Adjust and Balance (TAB):

Review finalized TAB report, Direct quality assurance demonstration, Identify inconsistencies

- Controls:

Review installation of sensors, Document calibration of sensors and devices, Document remote control of equipment.

- Functional Automatic Equipment Operation:

Witness automatic startup and shutdown, Verify that equipment sequence of operations is correct.

- Automatic System Operation:

Witness automatic startup and shutdown of integrated systems, Verify that system sequence operation is correct

- Alarms and Safeties:

Verify that systems alarms are active, Verify sequence of operation under alarm, Verify equipment safeties are active

- Training and Documentation:

Verify that adequate training is provided to building maintenance personnel, Witness portions of the training, Identify additional resources for use after training ends

- Report of Commissioning:

Document commissioning activities, Document issues resolved during the commissioning process, Identify a plan to resolve any issues remaining after construction.

- Systems Manual:

Document operations and maintenance manuals for equipment included in the commissioning process, Create a useable sequence of operations of systems, Document the design intent for use during renovation or retro Commissioning.

In additional to problems found by air balance, a Commissioning agent is capable of finding design and installation issues which owners are not known. Other than buildings desiring a LEED certification, those with critical systems such as laboratories, hospital or specialized manufacturing are prime candidates for HVAC commissioning to ensure proper installation and operation of the HVAC system.

3.3.1.4. Testing & Commissioning procedure for HVAC system:

Related Documents are

- Drawings and general provisions of the Contract, including General Conditions and Specifications
- The purpose of this Section is to define responsibilities in the Commissioning process. Additional system testing is required within individual Specification Sections.
- Ensure that all systems are operating in a manner consistent with the Contract Documents. General Commissioning requirements and co-ordinations. Execute all Commissioning responsibilities assigned.
- HVAC systems to be commissioned include the following

    1. Chilled Water Systems
    2. Cooling Tower
    3. Pumps
    4. Heat Exchangers
    5. Air Handling Units
    6. Fans
    7. Piping Systems
    8. Ductwork Systems
    9. Chemical Treatment
    10. Roof Top Packaged DX Units
    11. Split Systems

12. Fan Coil Units

13. Terminal Units

14. Unit Heaters

15. Building Automation System

3.3.1.5. Submittals:

- (a)Contractor shall prepare Pre functional Checklists and Functional Performance Test (FPT) procedures and execute and document results. All Pre functional Checklists and tests must be documented using specific, procedural forms in Microsoft Word or Excel software developed for that purpose. Prior to testing, Contractor shall submit those forms to the Owner for review and approval.

- (b) Contractor shall provide Owner with documentation required for Commissioning Work. At minimum, documentation shall include: Detailed Start-up procedures, full sequences of operation, Operating and Maintenance data, performance data, Functional Performance Test Procedures, control drawings, and details of Owner-contracted tests.

- (c)Contractor shall submit to Owner installation and checkout materials actually shipped inside equipment and actual field checkout sheet forms used by factory or field technicians.

- (d) Contractor shall review and approve other relative documentation for impact on FPT's of the systems. Those relative documents are

  - Shop drawings and product submittal data related to systems or equipment to be commissioned. The Subcontractor responsible for the FPT shall review and incorporate comments from the Owner and A/E via the Contractor.

  - Incorporate manufacturer's Start-up procedures with Pre functional checklists.

  - Draft Test, Adjust and Balance (TAB) Reports: Review and provide comments to Owner.

  - Factory Performance Test Reports: Review and compile all factory performance data to assure that the data is complete prior to executing the FPT's.

  - Completed equipment Start-up certification forms along with the manufacturer's field or factory performance and Start-up test documentation: Subcontractor performing the test will review the documentation prior to commencing with the scheduled FPT's. Owner may require that system one-line diagrams and applicable Specification Section(s) be attached to the FPT documentation.

- Final TAB Reports: Subcontractor performing the test will review the documentation prior to commencing with the scheduled FPT's.

- Operating and Maintenance (O&M) information per requirements of the Technical Specifications: To validate adequacy and completeness of the FPT, the Contractor shall ensure that the O&M manual content, marked-up record Drawings and Specifications, component submittal drawings, and other pertinent documents are available at the Project Site for review.

3.3.1.6. Products:

- All materials shall meet or exceed all applicable referenced standards, federal, state and local requirements, and conform to codes and ordinances of authorities having jurisdiction.

3.3.1.7. Test Equipment:

- Provide all specialized tools, test equipment and instruments required to execute Start-up, checkout, and testing of equipment.

3.3.1.8. Execution:

- 3.3.1.8.1.Construction Phase:

1 In each purchase order or subcontract that is written for changes in scope, include the following requirements for submittal data, Commissioning documentation, testing assistance, Operating and Maintenance (O&M) data, and training, as a minimum.

2. Attend Pre-Commissioning Meeting(s), Pre-Installation Meeting(s), and other Project meetings scheduled by the Contractor to facilitate the Commissioning process.

3. Provide manufacturer's data sheets and shop drawing submittals of equipment.

   Provide additional requested documentation to the Contractor, prior to O&M manual submittals, for development of Pre functional Checklist and Functional Performance Tests procedures. This information and data request may be made prior to normal submittals.

   - With input from the BAS Provider and Automation Engineer, Clarify the operation and control of commissioned equipment in areas where the Specifications, BAS control drawings, or equipment documentation are not sufficient for writing detailed test procedures.

   - Prepare the specific Functional Performance Test procedures. Ensure that Functional Performance Test procedures address feasibility, safety, and equipment protection and provide necessary written alarm limits to be used during the tests.

- Develop the Commissioning Plan using manufacturer's Start-up procedures and the Pre functional Checklists. Submit manufacturer's detailed Start-up procedures and the Commissioning Plan and procedures and other requested equipment documentation to Owner for review.

- During the Start-up and initial checkout process, execute and document related portions of the Pre functional Checklists for all commissioned equipment.

- Perform and clearly document all completed Pre functional Checklists and Start-up procedures. Provide a copy to the Owner prior to the Functional Performance Test.

- Address current Automation Engineer and Owner punch list items before Functional Performance Tests. Air and water test, adjust and balance shall be completed with discrepancies and problems remedied before Functional Performance Tests of the respective air or water related systems are executed.

- Provide skilled technicians to execute starting of equipment and to assist in execution of Functional Performance Tests. Ensure that they are available and present during the agreed-upon schedules and for a sufficient duration to complete the necessary tests, adjustments, and problem solving.

- Correct deficiencies (differences between specified and observed performance) as interpreted by the Owner's Project Manager and A/E and retest the system and equipment.

- Compile all Commissioning records and documentation to be included in a Commissioning and Closeout Manual.

- Prepare O&M manuals according to the Contract Documents, including clarifying and updating the original sequences of operation to as-built conditions.

- During construction, maintain as-built marked-up Drawings and Specifications of all Contract Documents and Contractor-generated coordination Drawings. Update after completion of Commissioning activities (include deferred tests). The as-built drawings and specifications shall be delivered to the Owner both in electronic format and hard copies as required by the Owner.

- Provide training of the Owner's operating personnel as specified.

- Coordinate with equipment manufacturers to determine specific requirements to maintain the validity of the warranty.

- 3.3.1.9. Warranty Phase:

    1) Complete deferred tests as part of this Contract during the Warranty Period. Schedule this activity with Owner. Perform tests and document and correct deficiencies. Owner may observe the tests and review and approve test documentation and deficiency corrections.

    2) If any check or test cannot be completed prior to Substantial Completion due to the building structure, required occupancy condition, or other condition, execution of such test may be delayed to later in the Warranty Period, upon approval of the Owner. Contractor shall reschedule and conduct these unforeseen deferred tests in the same manner as deferred tests.

    3) Correct deficiencies and make necessary adjustments to O&M manuals, Commissioning documentation, and as-built drawings for applicable issues identified in any seasonal testing.

3.3.1.10. Testing:

- Pre functional Checklists and Start-up:

  Follow the Start-up and initial checkout procedures, Start-up and complete systems and sub-systems so they are fully functional, meeting the requirements of the Contract Documents.

  Pre functional Checklists shall be complete prior to commencement of a Functional Performance test.

-

- Functional Performance Tests:

  Functional Performance Tests are conducted after system Start-up and checkout is satisfactorily completed. Air balancing and water balancing shall be completed before Functional Performance Tests.

-

- Coordination Between Testing Parties:

3.3.1.11. Factory Start-ups:

Factory Start-ups are specified for certain equipment. Factory Start-ups generally are Start-up related activities that will be reviewed and checked prior to Functional Performance Tests. All costs associated with factory Start-ups shall be included with the contract price unless otherwise noted. Notify the Commissioning Team of the factory Start-up schedule and coordinate these factory Start-ups with witnessing parties. The Commissioning Team members may witness these Start-ups at their discretion.

3.3.1.12. Independent Testing Agencies:

For systems that specify testing by an independent testing agency, the cost of the test shall be included in the Contract price unless otherwise noted. Testing performed by independent agencies may cover aspects required in the Pre functional Checklists, Start-ups, and Functional Performance Tests. Coordinate with the independent testing agency so that Owner and/or Automation Engineer can witness the test to ensure that applicable aspects of the test meet requirements[21].

3.3.1.13. Training:

- Factory visits and training

  This includes critical equipment factory run and performance tests

3.3.2 Standards employed:

a) Procedural standards for Testing, Adjusting, Balancing of Environmental Systems, National Environmental Balancing Bureau

b) ASHRAE –Guidelines 1-200X

c) BSRIA

d) ASHRAE Standard 202

3.3.3. Advantages to Stakeholders:

HVAC commissioning promotes a quality assurance approach resulting in significant value for the owner. The specific benefits of the HVAC commissioning process include following.

1. Reduction of change orders and additional claims

2. Fewer deficiencies at substantial completion

3. Fewer project delays

4. Managed start up procedure

5. Shorter building turn over transition period

6. Less post occupancy corrective works

7. Minimum impact from design changes

8. Improved indoor air quality and occupant productivity

9. Better operation maintenance and reliability.

10. Lower energy and operational cost.

11. Value added construction quality.

12. Complete and useful documentation.

13. More knowledgeable O & M staff.

14. Improved future designs.

15. Owner advocacy for designed construction decisions.

3.4. Description of Operation and Maintenance:

HVAC system operations and maintenance ("O&M") is the practice that keep mechanical systems working at peak performance during the life of the building. Top quality operations and maintenance practices such as continuous commissioning can improve energy performance 20% and improve occupant comfort at the same time. Efficient HVAC Operation & Maintenance is measured by system performance. The system should continue providing thermal comfort maintaining energy efficiency as specified in the HVAC design for the building. Commissioning agents usually perform these audits. As technology improves, the performance may even be improved to exceed design specs.

3.4.1. Develop operational procedure:

Key element for successful Air Conditioning system operation is the establishment of system operation procedure which includes operation manual covering all the equipment of the air conditioning system. Operational procedure must include following points.

3.4.1.1. Schedule of operation:

This must be in line with building operational pattern and building cooling demand. Nowadays this can be automated with introduction of building management systems. There should be a management approval process to change operational schedule if required. Operational schedule shall be prepared considering manufacturer recommendations and maintenance requirements of equipment. Some air conditioning equipment specifies operating range for safe operation. So that we emphasis must be given for such equipment in preparation of operational procedure. As an example, most of the variable refrigerant volume units are not recommended to operate below 10% of its capacity. So in operation scheduling this is an important factor for consideration. It is advisable to display “Schedule of operation” in an easily visible place, so that engineering staff can maintain a close track on all equipment operations.

3.4.1.2. Operations Manuals:

Good design process can help ensure good operations and maintenance routines. The HVAC designer should create a manual for operations staff that makes the HVAC design intent clear, lists maintenance and replacement schedules, and makes it clear what parameters should be measured during commissioning, as well as how often such measurements should be done.

Green buildings often do not perform as well as predicted during the design. Without a manual, operations personnel are left to troubleshoot systems through piecemeal guesswork. This is never as effective as the whole-systems approach that can be laid out by an operations manual.

Operational manual shall consist of following points:

- Schedule of equipment covering all the equipment of Air Conditioning system.
- Exploded views of main equipment and list of spare parts.
- Manufacturer recommended maintenance schedule for each equipment.
- Trouble shoot guideline
- As built drawings of ACMV system
- IOM of all the equipment

3.4.2. Develop maintenance procedure:

An important part of the O&M manual is schedules for cleaning ducts, filters, and other components, replacing filters, and measuring energy use and comfort. Performance measurements should be done monthly or at least quarterly, to provide operators with enough data to tell when systems are beginning to perform poorly. Many building automation systems can provide hourly data on temperature, humidity, and energy use.

3.4.2.1. Flexibility and Occupant Behaviour:

When building occupants bring in their own space heaters or desk fans, it may be an indication that the HVAC system is not working as designed, or was not designed to meet the current users' needs. Have the flexibility to work with users to meet their needs while ensuring energy efficiency. This may mean changes to the original design, or helping occupants choose efficient products for their personal use.

3.4.2.2. Filter Cleaning & Replacement:

Keeping filters clean is an important factor in keeping their energy performance and indoor air quality high. This is the most frequently neglected aspect of HVAC operations, because HVAC machines do not break down often but filters do require regular attention. Some filters are designed to be cleaned by spraying with water or vacuuming. Others should simply be replaced. These include not only filters in ducts, but filters in furnaces, heat pumps, and other devices.

3.4.2.3. Cleaning Components:

Other components require periodic cleaning as well. Ducts must be kept clean of dust, mold, and other contaminants for good indoor air quality. They should also be periodically inspected for leaks, as this can cause surprisingly large energy losses. Dirt and dust those settle on coils acts as an insulator. Crooked or crushed fins restrict air flow, reducing the effectiveness of convective cooling. As a result, air conditioners and heat pumps periodically require their coils cleaned and fins straightened so that they can continue conducting heat to and from the air efficiently. Dehumidifiers and air conditioners that dehumidify should have their condensate drains checked. Blocked drains will cause condensed water to pool up and possibly leak into the building envelope or occupied areas, causing mold and mildew.

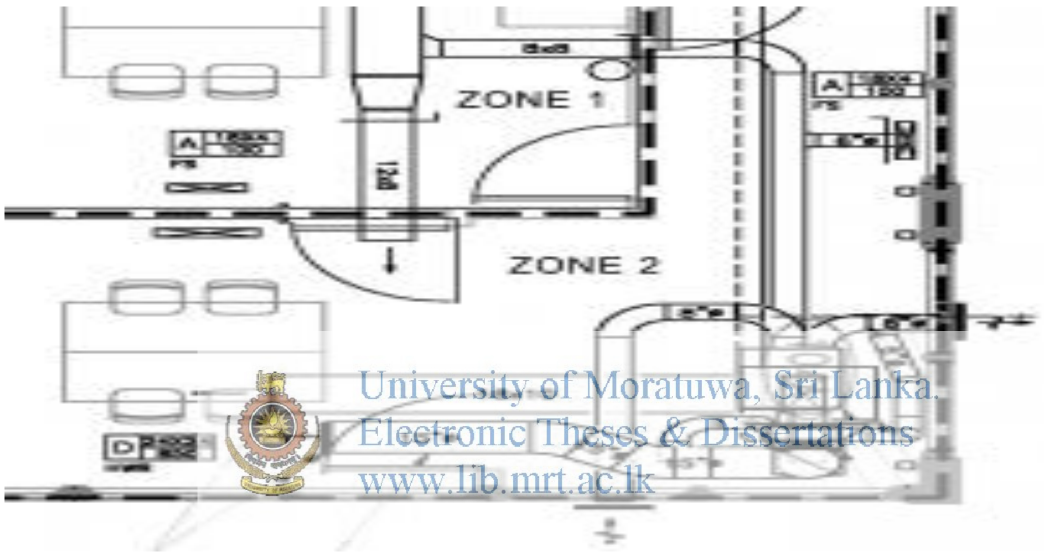
3.4.2.4. Operation of Control Systems:

HVAC control systems are often run by programmable thermostats that schedule heating and cooling for different times of day and days of the week. Such schedules should be set to match the occupancy and activity schedules of different spaces. These schedules change over the years as building use changes, and controls schedules should change to match.Sensors for HVAC controls, such as temperature and humidity sensors, or occupancy sensors, should be regularly checked for proper operation. Sensors that start shutting off or turning on heating or cooling at the wrong times make people too hot or too cold, and can waste energy. Control systems that function but are not tuned according to occupant preferences may get manually disabled by them. Such systems are obviously no longer able to do their jobs, and the result is wasted energy.

3.4.2.5. As Built Drawings:

HVAC duct routing and control diagrams should be created and kept updated, to ensure control systems are easy to understand. This not only makes it easy to troubleshoot problems, but also helps plan replacement schedules and can aid in system upgrades.

These diagrams should include the HVAC units, sensors, ducts and other air handling components, controllers, and how all these components connect to each other, as well as boundaries of different control zones. Often the sensor and control diagrams are separate from air handler layout diagrams, for readability; if so, they should be checked against each other for accuracy.



Figure;3-7:HVAC System Diagrams Assist Operations & Troubleshooting

3.4.3. Advantages:

Air conditioning system cools the air inside and providing fresh filtered air. It is an important part of daily life. We often take the benefits of air conditioning for granted, until it stops working. Air conditioning units need better operational and preventive maintenance program to keep them operating efficiently and smoothly. There are other important benefits of maintaining your air conditioning unit regularly.

3.4.3.1. Lower Energy Bills:

A poorly maintained air conditioner must work harder to provide the same air quality and temperature as a well-maintained unit. This means higher energy costs. Something as simple as a dirty air filter will hinder the air-conditioning unit's ability to circulate cool clean air. This results in wasted energy and money. Dirty condenser coils cause the air compressor to work harder. This problem consumes more energy, as well, resulting in higher energy bills. So with a simple, regular A/C cleaning schedule, you will save energy and money.

3.4.3.2. Lower Repair Costs:

Preventative maintenance may save you a lot of grief, time, and money in repair costs by preventing and catching small problems before they become bigger and more expensive problems. As I mentioned, dirty condenser coils can make the air conditioner work harder for the same results. This extra work can also cause the compressor to fail. The costs of repairs for replacing the compressor is typically much more than the costs of having the coils cleaned and maintained. Preventive maintenance may catch other issues with the system such as a water leak, which could cause damage to your home and air conditioning unit.

3.4.3.3. Extended Equipment Life:

Taking care of your air conditioning unit will extend its life and help it operate more efficiently. The air conditioning unit, as a whole, needs regular service and cleaning. When one part is under strain or fails, it causes the other parts of you air conditioning system to work harder and possibly fail. Maintaining and keeping the parts in working order results in less strain and stress on the entire system. In the long term, a well-maintained air conditioning system operates more efficiently, saving energy and money, and lasts longer, saving repair and replacement costs.

3.4.3.4. Keep a Log:

Keeping track of your preventive maintenance schedule in a notebook or pad is an excellent idea that will save you time and money. You can keep track of filter replacement, equipment cleaning, and outside repairs. Keeping a log helps you to see the overall picture of helping to maintain the integrity of one of your home's most valuable assets. You will also be an informed customer when repairs are needed for you air conditioning system [22].

3.5. Conclusion

Chapter three discussed in detail, the best methodology that shall be adopted for air conditioning system development from project inception to operation. Even client who does not understand subject of air conditioning in detail, will be able to identify salient points involved in AC system design development process. All the aspects in design, testing & commissioning, operation and maintenance related with AC system have been discussed in the chapter and strategic guidelines shall be formulated in line with proposed methodology in the next chapter.

CHAPTER 4: PRESENTATION OF GUIDELINES:

4.1 Chapter Introduction:

This presents the guidelines with respect to design stage, equipment sizing & selection stage, testing & commissioning stage, operation & maintenance stage. Specific guidelines shall be proposed based on methodology discussed for each activity listed below in the design, Testing & Commissioning, Operation and maintenance phases separately. Note that guidelines are based on actual work carried out with supporting evidence and simulation output.

Design Phase activities are

1. Establish requirements on comfort level and indoor air quality
2. Finalize stakeholders requirements and functional requirements
3. Complete Design Phase check lists (Refer Annex: 1)
4. System sizing and selection considering energy performance and other operational key factors.
5. Finalize design stage

Testing & Commissioning Phase activities are;

1. Development of testing & commissioning procedure based on installation specific requirements

Operation & maintenance Phase activities are

1. Development of operational procedure in line with installed system requirements and nature of the operation.
2. Similarly need to develop maintenance program in line with installed system and equipment requirements.

4.2 Design Stage Guidelines:

4.2.1 Establish requirement on comfort level and indoor air quality:

For general applications we can refer below listed standards to establish above levels.

- ASHRAE STANDARD 62.1-2007-Ventilation for Acceptable Indoor Air Quality

- ASHRAE STANDARD 55-2004-Thermal environmental conditions for human occupancy
- ASHRAE Application Hand Book
- ASHRAE Standard 52.5 for filter minimum efficiency reporting value

But there are cases where we need to obtain client advice on internal design conditions for manufacturing plants. As an example printing, dairy, pharmaceutical, food processing, knitting industries specify temperature and humidity levels based on their process requirements. Sometimes they are demanding closed control systems where humidity level deviations are not allowed (i.e. tablet compression in pharmaceutical industry, humidity level must be less than 55%RH).

Indoor air quality shall be strictly controlled in Hospital environment. Pharmaceutical factories and HEPA grade filters are needed for such applications. MERV rating charts have been developed to select appropriate filter media for different applications. Applications and limitations, filter type, typical controlled contaminants, arrestance were listed in the MERV rating chart.

Noise level for each category of buildings are given in the ASHRAE Application hand book.

4.2.2. Finalize stakeholders requirements and functional requirements:

Based on approximate capacity of the new system, the client has to be instructed on investment cost for such a system. Then client will consider same in the project cost estimation and will inform if changes are required. Normally efficient chillers, pumps and cooling towers are fairly expensive compared with standard equipment and operating cost with same is fairly low. In life cycle analysis normally high initial investment cost can be recovered due to low operating costs. Note that investment cost is around 20% of the total life cycle cost and therefore 80% of the cost involved with operation. Therefore it is advantageous to select efficient equipment, especially for fairly high capacity (>200RT) installations.

4.2.3. Design Phase Checklist:

Once item 4.2.1 and 4.2.2 completed, Design phase check lists must be filled and this will be the basis for design development hereafter. Those check lists have been included in the report as an Annex(Refer Annex:1).

4.2.4. System sizing and selection considering energy performance and other operational key factors:

System sizing and selection stages are as follows.

- Collect building envelope data and optimize same where necessary (Chapter 2.8.1.Energy efficient building envelope design).

- Collect building cooling load data: Lighting, Equipment, occupancy-Lighting densities shall be in line with ASHRAE 90.1 Standard 2007.This information would be used for simulation and refer chapter 5.2 Table 01 (people, machine &equipment loads), Table 02 (lighting loads), Table 03 (ASHRAE 62.1 ventilation rate procedure).

- Model building with Thermal simulation tool, eQUEST or any other acceptable thermal simulation tool . Chapter 5 presents a case analysis for a simulation performed for an air conditioning system retrofit project.

- Generate thermal simulation output files such as Air side summary, Load Profiles, power consumption data for a typical year. Refer chapter 5 Table: 5-4:(AHU And FCU summary), Figure:5-3:(Hourly load profiles), Table:5-6:(Total electricity consumption).

- Selection of equipment shall be based on above load profiles and selection shall be targeting least power consumption option and other operational key factors like redundancy, operation pattern etc. Chapter 3 described how to use eQuest to establish chiller capacity based on cooling load profiles. Objective was to select best chiller mix to keep chillers loading between 60-80% of the capacity. Around 60-80% load, screw chiller performance is optimum. Refer chapter 3, Figure:3-2 - Part load hours for chillers where all chillers are running around 60-80% load throughout the year.

4.2.5. Finalize design stage:

Once air conditioning system requirements were established for the building, we need to check and verify on below points for successful operation of the system.

- Availability of adequate motive power. For electric chillers we need grid power and generally power consumption of water cooled chilled water system is around 0.9kW/RT. Since we have already calculated the capacity, electrical requirement can be found out easily. For an air cooled chilled water system electrical power requirement is 1.1kW/RT.

- Environment conditions must be accessed in finalization of air conditioning system. Corrosion is a severe problem especially in western and south coastal belt, so that air cooled systems are not recommended for such locations. Also another important factor to be accessed is water quality of the area. Water test report must be obtained to check water hardness, TDS, Electrical Conductivity, Silica content before selection of the system.

- In selection of appropriate AC system for building system capacity is important. In chapter 3, we have discussed about guideline for appropriate system based on building floor area. For low capacities, individual AC units (Less than 1000sqft) are preferred and for medium scale (less than 10,000sqft) installations water/air cooled packages, VRV systems are widely used. Chilled water systems are mostly used for large installations where building floor area exceeds 10,000sqft.This industry norms have been established based on economic life cycle analysis for different systems.

4.3. Testing & Commissioning Phase Guidelines:

Testing & commissioning procedure is different from one AC system to another. Chapter 3 discussed in detail, the importance of Testing & Commissioning for successful operation of the new installation. We can specify following guidelines for Testing & Commissioning.

- Establish commissioning plan based on drawings, specifications of the system. This must cover every important equipment of the system, total air and water balancing, manufacturer guidelines for start up and testing. Necessary check lists and formats must be prepared in accordance with manufacturer instructions and shall cover all areas.

- Identify suitable certified Testing & Balancing technician for the process. This can’t be assigned to contractor to perform since there will be lot of cover up their mistakes etc.

- Identify training needs and formulate strategies to train client engineering staff. This must be a part of T & C process.

- List out tools and equipment required for Testing & Commissioning. Make sure that all the tools are recently calibrated.

- Documentation of testing and commissioning data is very important. This information shall be filed and kept for future reference.

- Testing and commissioning process must start from design stage and shall continue up to system life time. Nowadays re commissioning of systems is also encouraged since it will ensure that system performance remain same even after considerable time of system operation.

- Identify processes which require commissioning at the time of installation. This is so critical since if missed at the time of installation, there would be difficulties at final T&C.

- Defects and short falls identified at the time of commissioning must corrected immediately and re commissioned.

4.3.1. Check Lists for Testing & Commissioning Phase:

Check lists have been developed for T & C phase and included in the report as an Annex in the report(Refer annex:1).

4.4. Operation & Maintenance phase guidelines:

Operation and maintenance is key aspect of system efficiency and reliability. Better operation and maintenance program will ensure that all the system major equipment and controls function properly as expected. We can specify following guidelines for operation and maintenance.

- Contractor must provide operation and maintenance manual (O & M) covering all the major equipment and T & C data. O & M must complete with all spare parts manual, exploded views of machinery, maintenance schedules, trouble shooting guide etc.

- Complete set of as built drawings must be available covering full AC system.

- Establish schedule of operation in line with facility operational behavior.

- Develop maintenance program meeting manufacturer recommendations.

- Maintain critical spare parts stock for major equipment.

- Since Ac system efficient performance is closely related with control system, sensors must be tested and calibrated every six months.

- Maintain operation and maintenance logs for all the major equipment.

- On completion of defect liability period, recommend to sign a service & maintenance agreement with equipment supplier (for complex and high value items).

- Continuous training of maintenance staff is also very important since it will improve their capabilities immensely.

4.5 Chapter Conclusion:

Here we have specifically focused on to develop "Strategic Guidelines for Selection of an Energy Efficient Air Conditioning System/Equipment for Commercial Buildings in Sri Lanka" from project inception stage to completion of proposed AC system life cycle. Proposed process involves lot of mathematical analysis, expert judgments, standard references and finally which leads to an energy efficient, good AC system for the facility. In the next chapter we will discuss applicability of proposed methodology, guidelines through a real time case analysis.

CHAPTER 5: APPLICATION OF PROPOSED METHODOLOGY:

5.1 Chapter Introduction:

Here we discuss about a real time AC system retrofit project implemented in Sri Lanka where design procedure is very similar to process which we have discussed. Name of the client undisclosed and below project design report explains clearly methodology adopted. Client wanted to retrofit existing air conditioning system in the apparel factory which was installed twenty years ago with a new energy efficient cooling system since company pays a lot for electricity to run old AC system. We were asked to explore different technologies available and finally a detailed analysis was performed for steam source absorption chillers and water cooled electric chillers.

Design development basically followed the methodology already we discussed above and will highlight use and applicability of specified guidelines in the design, T & C and O & M.

5.2 Analysis on design phase:

Since project objective was to upgrade and expand existing AC system with an energy efficient air conditioning system study of existing system and limitations if any is very important. As discussed in chapter 3, we need to establish factors like environmental conditions, comfort level, process requirements very clearly.

5.2.1.About the Facility:

This is to understand site location, building orientation, details about operation/process, existing AC system etc, which is an important aspect of design approach. This is an apparel factory located in Central province, Kandy. It has one main production building Office block covering more than 60000 ft^2.

Figure:5-1: Google Image of Facility

Facility is initially air conditioned with 15nos of 14RT Water Cooled Packages (WPUs). Most of the office spaces have split air conditioning units. But the current issue is all the WPUs are nearly 15 years old and significantly inefficient. Presence of the old units makes high energy consumption and they are not enough for the future machine loads and plant has been under an expansion project, now. Production section is operated under two shifts, first is from6 a.m. to 2 p.m. and second is from 2 p.m. to 10 p.m. There are two breaks; one is from 8.30 a.m to 10.00 a.m and other is from 6.00 p.m to 7.30 p.m.Offices workers are working from 7.30 a.m to 5.30 p.m. with 9 a.m -10 a.m tea break and 2.00 p.m – to 3.00 p.m lunch break. Factory is operating from Monday to Saturday.

Chapter 3.2.2 discussed about evaluating cooling load calculation requirements such as occupancy, activity level, ventilation rates, lighting and equipment loads. Therefore below tables are prepared to establish people, equipment, ventilation rate and lighting loads to be used as input data for Thermal simulation.

5.2.2. Machine and people loads:

All the equipment and machine loads which were given by client considering the future loads were used in the simulations. For the areas which is supposed to change in the future but not finalized, equipment loads are considered as per the worst case basis. Machine loads for the cutting and the production sections are considered as same (used the max value i.e. $8W/ft^2$) for keeping the consistency of the production floor if in case the layout changes will happen.

Table:5-1:People, Machine and Equipment Loads

Building Area	Number of occupants	ft^2/person	Type of Equipment	Power Consumption of Equipment (W)	Number of Equipment	Diversity Factor	Equipment Load (W)	Area (ft^2)	W/ft^2
GM Room	**1**	**280**	**Printers**	**450**	**1**	**0.7**	**315**	**280**	**1.13**
IT room	1	169	Servers	780	7	1.0	5460		
			PC	450	1	0.7	315		
		169					**5775**	**169**	**34.2**
Medical Centre	**5**	**44.6**	**PC**	**450**	**1**	**0.7**	**315**	**223**	**1.41**
Needle Recorder Room	2		PC	450	1	0.7	315		
PCU Room	16		PC	450	16	0.7	5040		
			Ploter	800	1	0.8	640		
			Photocophy machine	750	1	0.5	375		
AQL Room	6		PC	450	3	0.7	945		
MOS Room	3		PC	450	2	0.7	630		
			Printers	450	2	0.7	630		
Training Room	50	0	Projector	1250	1	0.2	250		
	77	29					**8825**	**2237**	**3.95**
HR department	12		PC	450	6	0.7	1890		
			Printers	450	2	0.7	630		
			Laminating machine	1350	1	0.2	270		
		232.5					**2790**	**1026**	**2.72**
Board Room	25		Projector	1250	1	0.2	250	**620**	**0.40**
Interview room	20		Fridge	600	1	1.0	600		
Machine Training room	10		TV	120	1	0.5	60		
			Sewing machine	600	24	0.25	3600		
							3660	**763**	**5**
Laser Room	25		Laser Cutting machines	2500	14	0.8	28000		
			Iron	750	6	0.8	3600		
			Fan	60	1	0.8	48		
			Heat seal machine	1800	1	1.0	1800		
		55.3					**33448**	**1382**	**24**
Pad Printing Section			**Pad printing machines**	**1700**	**6**	**0.8**	**8160**	**367**	**22**
Prodution Floor	**581**	**55.9**	**Sewing machine**	**600**	**550**	**0.25**	**82500**	**17467**	**5**
Cutting			Heat seal machine	1800	58	1.0	104400		
			spreader	1250	2	0.5	1250		
			Fushing Maching	2500	1	0.5	1250		
			Endcutter	750	12	0.5	4500		
			Band Knife	2800	2	0.5	2800		
			Hand Cutters	750	15	0.5	5625		
		55.9					**119825**	**15035**	**8.0**

5.2.3. Lighting Loads:

Lighting loads were considered as following table. Most of the production spaces have T5 lights. Since there is a concern of installing skylights for the expansion area in future, simulation was done with 24 nos. of 4’x4’ skylights (Covering 2.5% of the roof area of the expansion area) with on/off controlling for the artificial lights to obtain 600lux at 3.5 feet height.

Table:5-2:Lighting loads

Building Area	Type of Fixture & No of Fixtures										
	T8(35W)	Wattage (W)	T5 (25W)	Wattage (W)	CFL (12W)	Wattage (W)	LED	Wattage (W)	Total Lighting Load (W)	Area (ft2)	W/ft2
GM Room	4	35	1	25					165	**280**	**0.59**
IT room			4	25					100		
			4	25					100		
									200	**169**	**1.18**
Medical Centre	**4**	**35**							**140**	**223**	**0.63**
Needle Recorder Room											
PCU Room			18	25					450		
AQL Room	18	35	12	25					930		
MOS Room							6	5	30		
Training Room							12	5	60		
									1470	**2237**	**0.66**
HR department	**12**	**35**	**28**	**25**	**3**	**12**	**11**	**5**	**1211**	**1026**	**1.18**
Board Room	**18**	**35**			**8**	**12**			**726**	**620**	**1.17**
Interview room	2	35	2	25					120		
Machine Training room			**36**	**25**					**900**	**763**	**1.18**
Laser Room			**50**	**25**					**1250**	**1382**	**0.90**
Pad Printing Section	**6**	**35**			**4**	**12**			**258**	**367**	**0.70**
Prodution Floor	**30**	**35**	**932**	**25**			**20**	**70**	**25750**	**17467**	**1.47**
Cutting			**260**	**25**					**6500**	**15035**	**0.43**

5.2.4. Building Modeling:

Chapter 3. discussed about Initial steps in performing cooling load calculation and establish load profiles throughout the year with a reputed software using as a tool. Based on above, load profiles, maximum and minimum cooling loads can be found and basic equipment sizing/selection can be done with this information. So that here we used eQUEST thermal simulation software to establish cooling load profiles for a typical meteorological year (TMY) based on the proximity climate file for Nugadeniya.

Based on the drawings provided by the client, 3D computer model for main buildings were modeled in eQuest with actual dimensions and material properties of the buildings and windows. Most appropriate values for roofs and walls were used. We can optimize building envelope to reduce heat inflow to the building with better selection of construction materials such as glass, roofing insulation, color etc. This was discussed in detail in chapters 2.8 (Different building envelopes for energy optimization) and chapter 3.2.2(Building construction material).Since this is a retrofit project, there were limitations in optimizing building envelope. Zoning were separated based on the existing ducting system and Water cooled Pacakage(WPU) locations.

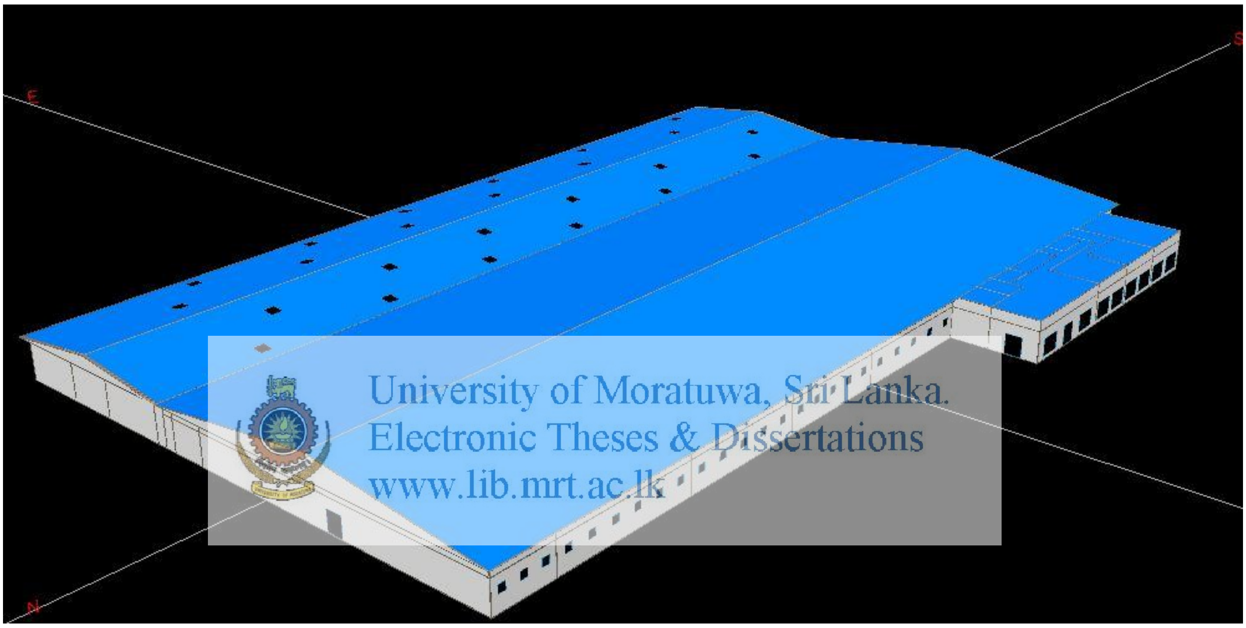


Figure:5-2:3D Model of The Facility

5.2.5. Simulation:

Climate data for a typical meteorological year (TMY) was used for the simulation. Based on the proximity climate file for Nugadeniya was used for the simulation. The temperature set points for the production floors were kept at 26 °C while the office spaces were set at 24 °C. Air Side System Design:

In finalization air distribution, chilled water distribution and AC unit locations, we had to fit into layouts given by client, which was basically prepared considering optimum production plan. This point was discussed detail in chapter 3.2.3 (Evaluate client and other stake holders requirements) and chapter 3.2.4 (Evaluate functional and space requirements).

Chilled water cooling system with Air handling Units (AHUs) and Fan Coil Units (FCUs) are selected for this facility based on system load profile and energy efficiency savings/life cycle costing. Demand control ventilation is considered in the main production and cutting areas.

5.2.6.Standards and Compliance:

The system as specified in the BOQ meets ASHRAE 90.1:2007 and 55.1:2007 standards for energy efficiency and thermal comfort. The system is also designed to meet ASHRAE standards.

Description	Zone	Occupancy Category	Design air volume (cfm)	People	Area (sq ft)	outdoor air rate (cfm/person)	Table 6-1 Area Outdoor Air Rate (cfm/ft2)	occupant Density (#/1000 sq ft)	Zone Outdoor airflow Vbz (cfm)	Zone air distribution effectiven	outdoor airflow Voz (cfm)	System Ventilation Efficiency	Air Intake flow Vot (cfm)	Outdoor air intake flow (cfm)	Zone primary airflow Vpz (cfm)	outdoor air fraction Zp=Voz/	% Increase over standard
Zone Identification						**Standard Case: ASHRAE Std 62.1-2004 Verification Rate Procedure**								**Design Case**			
Production	P1	Production	6151	57.4	3,210	6	0.12	18	730	1	730	1	730	730	6151	0.12	100%
	P2	Production	5732	50.7	2,833	6	0.12	18	644	1	644	1	644	644	5732	0.11	100%
	P3	Production	5148	45.4	2,538	6	0.12	18	577	1	577	1	577	577	5148	0.11	100%
	P4	Production	5990	53.3	2,980	6	0.12	18	677	1	677	1	677	677	5990	0.11	100%
	P5	Production	6327	58.3	3,259	6	0.12	18	741	1	741	1	741	741	6327	0.12	100%
	P6	Production	5122	47.4	2,647	6	0.12	18	602	1	602	1	602	602	5122	0.12	100%
Cutting	C1	Production	5201	50.0	2,793	6	0.12	18	635	1	635	1	635	635	5201	0.12	100%
	C2	Production	4784	44.1	2,465	6	0.12	18	560	1	560	1	560	560	4784	0.12	100%
	C3	Production	4286	39.5	2,209	6	0.12	18	502	1	502	1	502	502	4286	0.12	100%
	C4	Production	5033	46.4	2,594	6	0.12	18	590	1	590	1	590	590	5033	0.12	100%
	C5	Production	5476	50.5	2,822	6	0.12	18	642	1	642	1	642	642	5476	0.12	100%
	C6	Production	4176	38.5	2,152	6	0.12	18	489	1	489	1	489	489	4176	0.12	100%
Expansion Production	Exp1	Production	6694	57.2	3,197	6	0.12	18	727	1	727	1	727	727	6694	0.11	100%
	Exp2	Production	6004	50.5	2,822	6	0.12	18	642	1	642	1	642	642	6004	0.11	100%
	Exp3	Production	5278	45.2	2,528	6	0.12	18	575	1	575	1	575	575	5278	0.11	100%
	Exp4	Production	6297	53.1	2,969	6	0.12	18	675	1	675	1	675	675	6297	0.11	100%
	Exp5	Production	6841	58.1	3,246	6	0.12	18	738	1	738	1	738	738	6841	0.11	100%
	Exp6	Production	5229	44.1	2,463	6	0.12	18	560	1	560	1	560	560	5229	0.11	100%
Lazer Printing	Lazer1	Production	6300	25.0	1,382	6	0.12	18	316	1	316	1	316	1462	6300	0.05	463%
	Lazer2	Production	3305	4	708	6	0.12	6	109	1	109	1	109	388	3305	0.03	356%

Air distribution is overhead; hence Ez=1

Ventilation Efficiency Ev=1; This is calculated as per Appendix A of ASHRAE Std 62.1-2004

3:ASHRAE 62.1 Ventilation Rate Procedure

62.1:2007, the compliance chart based on ventilation rate procedure is given above.

5.2.7. Air Handling Units and Duct Layout:

Critical points for consideration in duct layout finalization and air handling units was space limitations and use of existing ducts as much as possible to control project budget. Air Handling units were selected with vertical draw through horizontal discharge arrangement considering space limitation for plant installation within the factory area. There were no plant rooms and only we were allowed to use side of the path way.

Ducting cost is considerable portion of AC project cost and therefore existing duct usage saved fair amount of money to the client and was able to work on tight budget. Also note that air distribution system was a constant air volume system and industrial drum louvers, four way air diffusers were used for air diffusion.

There were twelve air handlers in the sewing and cutting floor, one in the Lazer room and one AHU for office area.AHU and FCU summary table (Table No: 19) shows eQUEST simulation output for air side with all relevant technical details required for air side equipment selection. Also note that last column shows operating hours outside throttling range (set points).

Table: 5-4: AHU and FCU Summary

Zone	Type	General				Design Flow			Design Ventilation				Design Capacity					Hrs Outside
		No. of Occupants	Cooling Temperature (F)	Sensible Heat Ratio	Area	Supply cfm	Supply cfm/sqft	Min flow	OSA cfm	OSA %	OSA cfm/sqft	OSA cfm/per	Cool tons	Cool BTU/h	Cool sqft/ton	Cool cfm/ton	Cool BTUh/sqft	Cool Hrs
AHU P1	Production	57	78.8	0.792	3,210	6,151	1.92	100%	730	12%	0.227	13	15	180600	213	409	56.3	0
AHU P2	Production	51	78.8	0.795	2,833	5,732	2.02	100%	644	11%	0.227	13	14	167640	203	410	59.2	0
AHU P3	Production	45	78.8	0.795	2,538	5,148	2.03	100%	577	11%	0.227	13	13	150000	203	412	59.1	0
AHU P4	Production	53	78.8	0.794	2,980	5,990	2.01	100%	677	11%	0.227	13	15	174600	205	412	58.6	0
AHU P5	Production	58	78.8	0.792	3,259	6,327	1.94	100%	741	12%	0.227	13	15	185280	211	410	56.9	0
AHU P6	Production	47	78.8	0.792	2,647	5,122	1.94	100%	602	12%	0.227	13	13	150000	212	410	56.7	0
AHU C1	Production	107	78.8	0.793	5,990	11,895	1.99	100%	1362	11%	0.227	13	29	348000	207	410	58.1	0
AHU C2	Production	94	78.8	0.795	5,287	10,788	2.04	100%	1202	11%	0.227	13	26	312000	203	415	59.0	0
AHU C3	Production	85	78.8	0.794	4,737	9,564	2.02	100%	1077	11%	0.227	13	23	279600	203	410	59.0	0
AHU C4	Production	99	78.8	0.794	5,562	11,330	2.04	100%	1265	11%	0.227	13	28	331200	202	411	59.5	0
AHU C5	Production	108	78.8	0.794	6,068	12,316	2.03	100%	1380	11%	0.227	13	30	358680	203	412	59.1	0
AHU C6	Production	82	78.8	0.794	4,615	9,405	2.04	100%	1049	11%	0.227	13	23	274080	202	412	59.4	0
AHU Lazer	Production	45	78.8	0.788	2,457	11,203	4.56	100%	2599	23%	1.058	58	28	330000	89	407	134.3	0
AHU Office	Office	20	75.2	0.845	2,632	5,698	2.16	100%	560	10%	0.213	28	12	147480	214	464	56.0	0

5.2.8. Hourly Load Profiles:

Hourly load profiles are useful in equipment optimization such as chillers, pumps and cooling towers. Based on hourly load profiles per a typical year, chiller selection can be optimized. We can select best suited chiller from a chiller mix, if part load performance data are available by performing multiple runs of thermal simulation with eQUEST. We have discussed in detail this aspect in chapter 3 under Define energy performance section and under system sizing methodology.

Therefore Maximum building thermal load was plotted for each month as follows.

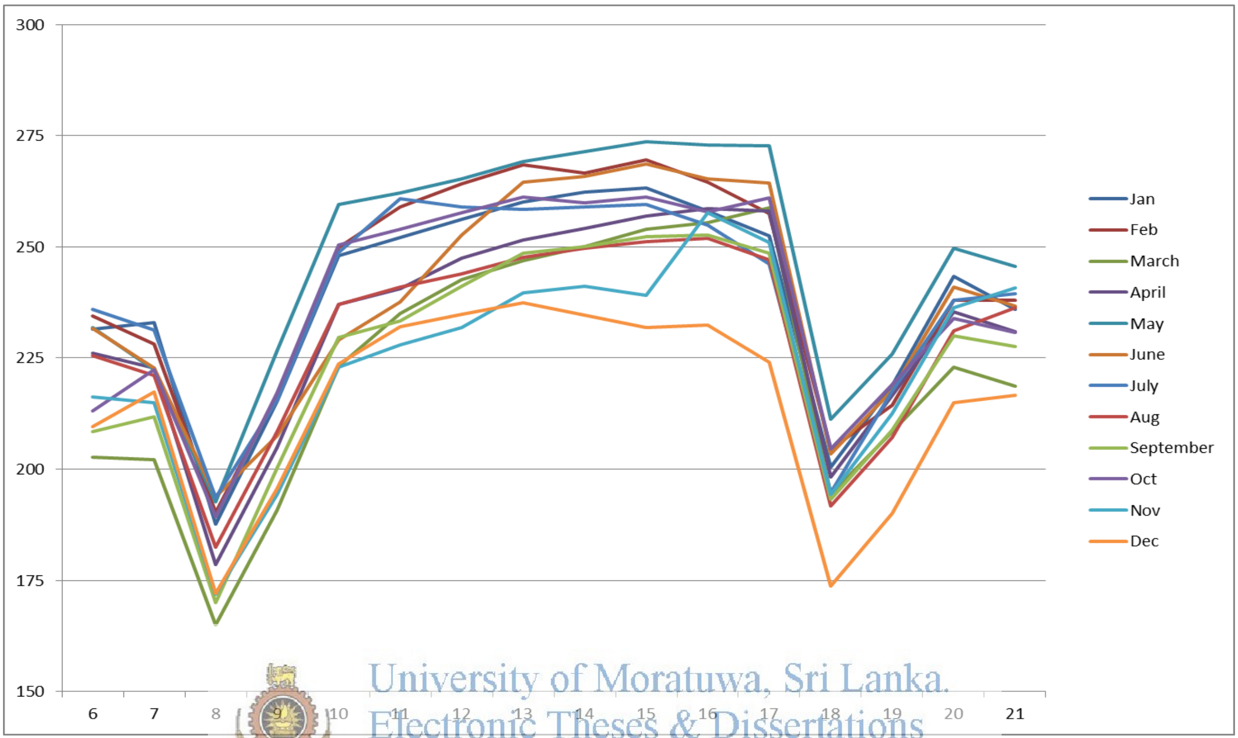


Figure:5-3:Hourly Load Profiles

5.2.9. Water side system Design:

Further on equipment optimization, we have considered two options for the analysis.

1. Electric chiller solution
2. Absorption Chiller solution with steam boiler as the heat source.

Option 1 - Electric Chiller solution:

Chiller Sizing:

Chiller capacity for the complete facility is sized at 300 TR. Based on load profiles generated and considering criticalness of operation, we have selected two electrical screw chillers with capacities of 150TR each for option 1.

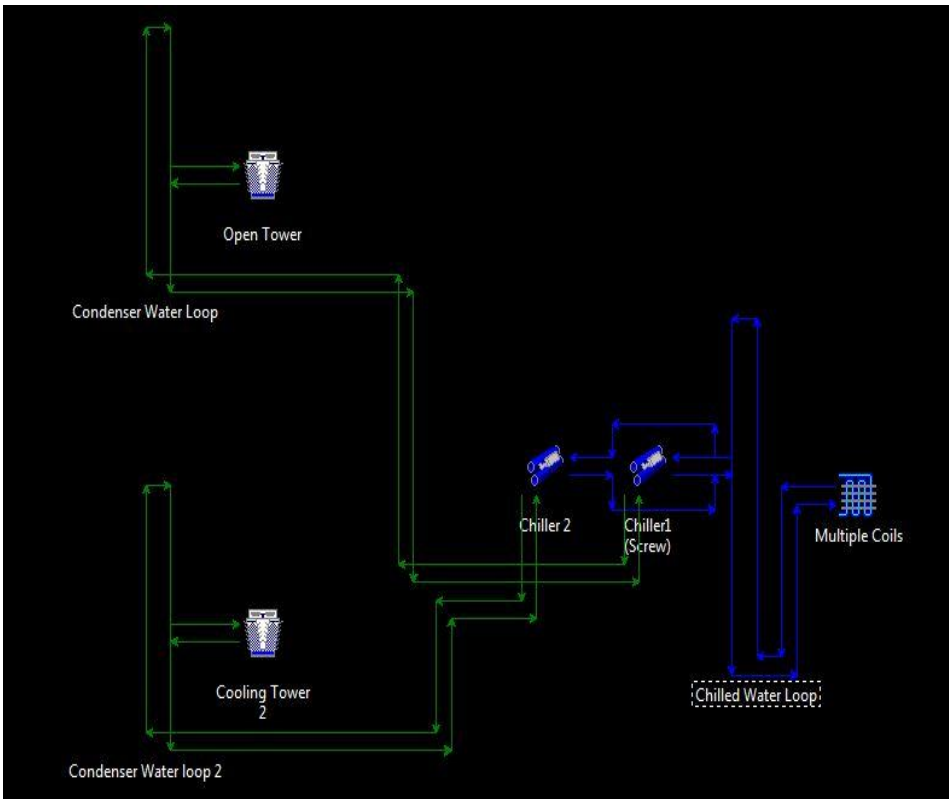


Figure:5-4:Cooling Towers and Chiller Configuration – Option 1

Chillers, Pumps and cooling Towers:

The selected chillers are screw type chillers. COP of one chiller is taken as 5.86 (0.6 kW/ton) in the simulation.

Chill water pumps have variable speed motors while the Cooling towers have two speed fans in order to have energy savings than with the constant speed motors. Condenser water pumps are two speed controllability.

5.2.10. System Specifications:

System specifications are as follows for option 1, based on eQUEST thermal simulation output file.

Table:5-5:System Specifications – Option 1

Circulation loop			
	Cooling Capacity (MBTU/hr)	Loop flow (Gal/min)	Total head (ft)
Chill water loop	3.765	745.9	51.6
Condenser water loop1	2.227	441.2	56.6
Condenser water loop2	2.227	441.2	56.6

Pumps						
	Flow (Gal/min)	Head (ft)	power (kW)	Mech efficiency	Motor efficiency	Capacity control
Condenser water pump 1	441.2	56	6.573	0.8	0.85	Two speed
Condenser water pump 2	441.2	56	6.573	0.8	0.85	Two speed
Chill water pump 1	745.9	110	21.231	0.8	0.85	VSD

Chillers					
	Equipment type	Attached to	Equipment capacity (MBTU/hr	Flow rate (Gal/min)	Rated EIR
Chiller 01	ELEC - Screw	Chill water loop 1	1.891	376.2	0.171
		Condenser water loop 1	2.208	441.2	
Chiller 02	ELEC - Screw	Chill water loop 2	1.891	376.2	0.171
		Condenser water loop 2	2.208	441.2	

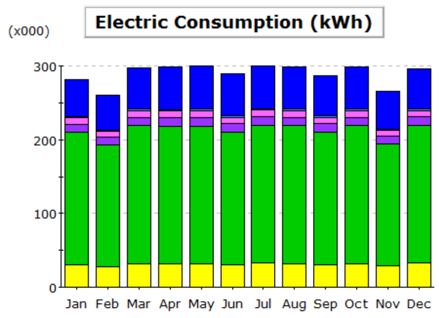
Cooling Towers			
	Equipment Capacity (MBTU/hr)	Fan Power (kW)	Fan control
Open tower 1	2.227	8.074	Two-speed
Open tower 2	2.227	8.074	Two-speed

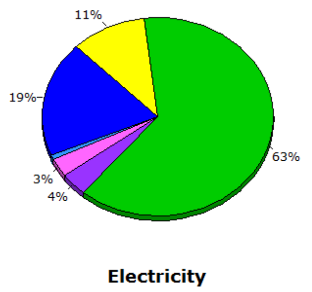
5.2.11.Energy Consumption:

For option 1, The system Energy performance is listed below as specified in chapter 3.2.5.

Table:5-6:Total Electricity consumption – Option 1

Electricity Consumption (kWh x1000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Chiller	50	48.4	56.7	57.6	58.6	56.9	57.5	57.3	55.2	57.1	50.9	54.2	660.5
Cooling Tower	1.5	1.5	2.1	2.1	2.4	2.4	2.2	2.1	2	2.1	1.9	1.7	23.9
AHU blowers	8.8	8.1	9.1	9.1	9.1	8.8	9.1	9.1	8.8	9.1	8.1	9.1	106.3
Pumps	9.2	8.7	10.1	10	10.2	9.9	10.1	10.1	9.8	10.1	9.4	9.7	117.2
AC total	**69.5**	**66.7**	**78**	**78.8**	**80.3**	**78**	**78.9**	**78.6**	**75.8**	**78.4**	**70.3**	**74.7**	**907.9**
Euipment	180	165.6	187.2	187.2	187.2	180	187.2	187.2	180	187.2	165.6	187.2	2,181.40
Lighting	30.8	27.8	31.7	31.2	31.4	30.6	32.4	31.8	30.4	31.7	28.4	32.5	370.6
Total	**280.3**	**260.1**	**296.9**	**297.2**	**298.9**	**288.6**	**298.5**	**297.6**	**286.2**	**297.3**	**264.3**	**294.4**	**3459.9**





Total Consumption **Peak Demand**

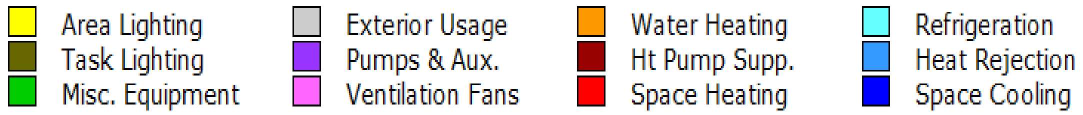


Figure: 5-5: Electric Power Consumption Chart – Option 1

Table:5-7:Annual Peak Demand – Option 1

Load Category	Electricity kW
Chillers	165.31
Cooling Towers	10.79
AHU blowers	21.83
Pumps	21.44
AC Total	**219.37**
Equipment	481.50
Lighting	82.14
Total	**783.01**

Option 2 - Absorption Chiller Solution:

5.2.12. Chiller Sizing:

Similarly we have obtained system specifications for option 2, based on simulation output.

Chiller capacity for the facility is 300RT and single double stage absorption chiller is used for the system.

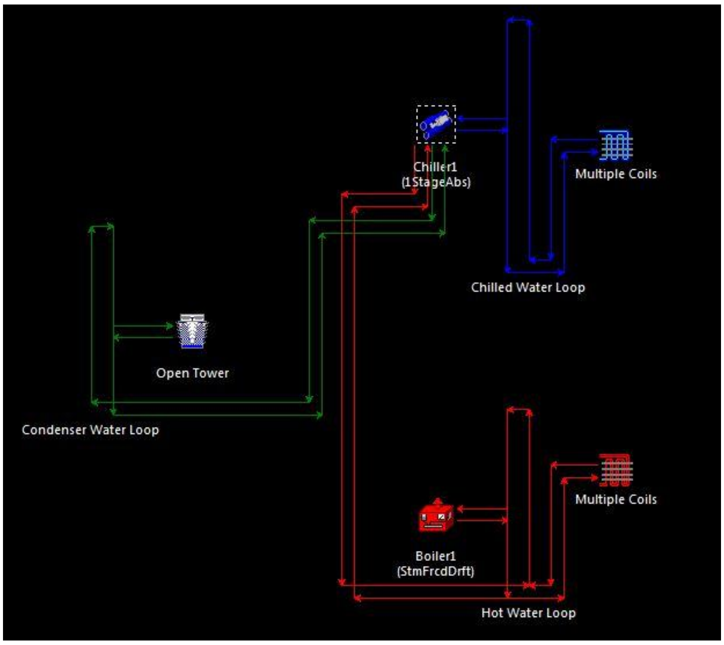


Figure:5-6: Cooling Towers and Chiller Configuration – Option 2

5.2.12. Chillers, Boiler, Pumps and cooling Towers:

The selected chiller is a two stage absorption chiller. COP of one chiller is taken as 1.3 in the simulation. Steam boiler with 65% efficiency is used as the heat source.

Chill water pumps have variable speed motors while the Cooling tower has two speed fans in order to have energy savings than with the constant speed motors. Condenser water pumps are two speed controllability.

5.2.13. System Specifications:

Table:5-8: System Specifications – Option 2

Circulation loop			
	Cooling Capacity (MBTU/hr)	Loop flow (Gal/min)	Total head (ft)
Chill water loop	3.794	744.9	56.6
Condenser water loop	6.947	852.2	61.6
Hot Water Loop	4.920	246.3	36.6

Pumps						
	Flow (Gal/min)	Head (ft)	power (kW)	Mech efficiency	Motor efficiency	Capacity control
Chilled water pump	744.9	110	20.748	0.8	0.93	VSD
Condenser water pump	852.2	56	12.35	0.8	0.875	Two speed
Hot water pump	246.3	56	3.713	0.8	0.91	Two speed

Chiller and Boiler					
	Equipment type	Attached to	Equipment capacity (MBTU/hr	Flow rate (Gal/min)	Rated HIR
Chiller	Two-stage absption	Chill water loop	4.405	758.1	0.769
		Condenser water loop	6.851	852.2	
		Hot water loop	3.072	154.8	
Boiler	Steam	Hot water loop	4.920	246.3	1.538

Cooling Towers			
	Equipment Capacity (MBTU/hr)	Fan Power (kW)	Fan control
Open tower 1	6.947	21.889	Two-speed

Energy Consumption:

For option 2, the system Energy performance is listed below. This is the most critical factor in finalizing the most appropriate system for the project.

Table:5-9: Total Electricity consumption – Option 2

	Electricity Consumption (kWh x1000)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Chiller	4.9	4.5	5	4.8	5	4.8	5	5	4.8	5	4.7	5	58.3
Cooling Tower	1.8	1.8	2.5	2.6	2.9	3	2.6	2.5	2.5	2.5	2.3	2	28.9
AHU blowers	8.8	8.1	9.1	9.1	9.1	8.8	9.1	9.1	8.8	9.1	8.1	9.1	106.3
Pumps	13.9	12.7	14.2	13.9	14.3	13.8	14.2	14.2	13.7	14.2	13.6	14	166.8
AC total	**29.4**	**27.1**	**30.8**	**30.4**	**31.3**	**30.4**	**30.9**	**30.8**	**29.8**	**30.8**	**28.7**	**30.1**	**360.3**
Euipment	180	165.6	187.2	187.2	187.2	180	187.2	187.2	180	187.2	165.6	187.2	2,181.40
Lighting	30.8	27.8	31.7	31.2	31.4	30.6	32.4	31.8	30.4	31.7	28.4	32.5	370.6
Total	**240.2**	**220.5**	**249.7**	**248.8**	**249.9**	**241**	**250.5**	**249.8**	**240.2**	**249.7**	**222.7**	**249.8**	**2912.3**

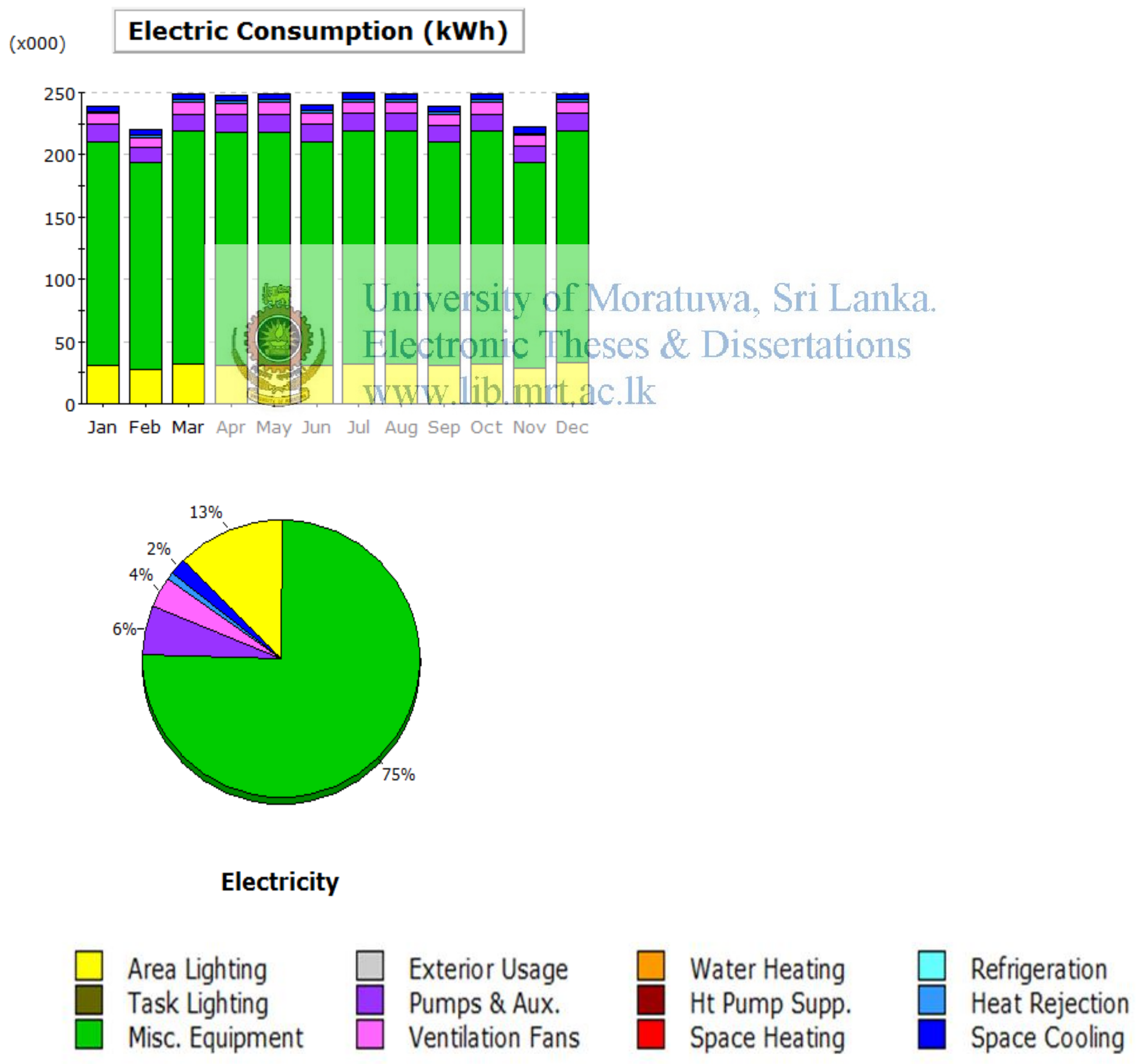


Figure:5-7: Electric Power Consumption Chart – Option 2

Apart from electricity absorption chiller system consumes energy for steam boiler. Natural gas energy consumption for generating the required steam is 16720MBtu per annum.

Table: 5-10: Annual Peak Demand – Option 2

Load Category	Option 1	Option 2	Savings of Absorption system	Savings %
Chiller	660.5	58.3	602.2	91%
Cooling Tower	23.9	28.9	-5	-21%
AHU blowers	106.3	106.3	0	0%
Pumps	117.2	166.8	-49.6	-42%
AC total	**907.9**	**360.3**	**547.6**	**60%**
Equipment	2,181.40	2,181.40	0	0%
Lighting	370.6	370.6	0	0%
Total	**3459.9**	**2912.3**	**547.6**	**16%**

Load Category	Electricity kW	Natural Gas (kBTU/hr)
Chiller	7.52	3,918.70
Cooling Tower	12.6	
AHU blowers	21.82	
Pumps	23.23	
AC Total	**65.17**	
Equipment	481.50	
Lighting	82.14	
Total	628.81	3918.7

Table: 5-11: Electricity Consumption Comparison

I. Energy Comparison:

Energy savings comparison for option 1 & 2 ,was prepared as follows which will be a critical factor in finalization the most suited system for this case.

II. Life Cycle Cost Analysis:

Life Cycle Assessment (LCA) can help avoid a narrow outlook on environmental, social and economic concerns by assessing a full range of impacts associated with all cradle-to-grave stages of a process: from extraction of raw materials through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. Impacts taken into account include (among others) embodied energy, global warming potential, resource use, air pollution, water pollution, and waste.

So we have decided to perform life cycle cost analysis to select best suited technology for this case as follows.

Life Cycle cost is done based on the following details and assumptions

1. Cost for the 275 RT absorption chiller is taken from the quotation provided by Supplier X.

2. Electricity unit cost is considered as Rs.13.4/= and it has increment annually.

3. Maintenance cost and spare parts cost for absorption chiller system are considered as, 5% rate from the same for electric chillers.

4. Maintenance costs have 10% incremental annually.

5. Spare parts costs have 5% incremental annually.

6. Rate of return is taken as 10%.

Table: 5-12:Life Cycle Cost Analysis

Option		Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total Cost
Electric Chiller system	Capital Cost	22,000,000											22,000,000
	Electricity Cost		12,311,920	13,789,350	15,444,072	17,297,361	19,373,044	21,697,810	24,301,547	27,217,733	30,483,861	34,141,924	216,058,622
	Maintenance Cost		-	900,000	990,000	1,089,000	1,197,900	1,317,690	1,449,459	1,594,405	1,753,845	1,929,230	12,221,529
	Spare Parts			600,000	630,000	661,500	694,575	729,304	765,769	804,057	844,260	886,473	6,615,939
	Total	22,000,000	12,311,920	15,289,350	17,064,072	19,047,861	21,265,519	23,744,804	26,516,775	29,616,195	33,081,966	36,957,627	256,896,090
	NPV @ 10%	153,968,674											
Absorption Chiller system	Capital Cost	19,777,940											19,777,940
	Electricity Cost		4,700,720	5,264,806	5,896,583	6,604,173	7,396,674	8,284,275	9,278,388	10,391,794	11,638,810	13,035,467	82,491,690
	Maintenance Cost		-	45,000	49,500	54,450	59,895	65,885	72,473	79,720	87,692	96,461	611,076
	Spare Parts			30,000	31,500	33,075	34,729	36,465	38,288	40,203	42,213	44,324	330,797
	Boiler Capital Cost	6,000,000											
	Boiler Operating Cost		12,711,840	13,983,024	15,381,326	16,919,459	18,611,405	20,472,545	22,519,800	24,771,780	27,248,958	29,973,854	202,593,992
	Total	25,777,940	17,412,560	19,322,830	21,358,910	23,611,157	26,102,703	28,859,170	31,908,949	35,283,497	39,017,673	43,150,106	305,805,495
	NPV @ 10%	188,266,682											

III. Sensitivity Analysis:

Variation of the NPV value is analyzed w.r.t. to the variation of COP of the absorption chiller and calorific value incorporated with moisture content variation.

Table:5-13:NPV vs. COP

Sensitivity of the NPV w.r.t. to COP of the absorption chiller						
COP	HIR (Heat Input ratio)	Steam (kg/hr)	Saving of Biomass Cost	NPV of electric chiller system	NPV of absorption chiller system	% change of NPV
1.2	0.8333	1419	0%	153,968,674	192985147	25%
1.3	0.7692	1316	7%	153,968,674	186070288.8	21%
1.4	0.7143	1227	14%	153,968,674	180095314.3	17%
1.5	0.6667	1149	19%	153,968,674	174858819.8	14%

Table:5-14:NPV vs. Moisture content

Sensitivity of the NPV w.r.t. to moisture content of the firewood and the calorafic value						
Moisture Content	Firewood Cost per annum	Change of moisture content	Change of biomass Cost	NPV of electric chiller system	NPV of absorption chiller system	% change of NPV
0%	6063372	-5%	-9%	153,968,674	152,842,787	-1%
5%	6644442	0%	0%	153,968,674	158,125,244	3%
10%	7257342	5%	9%	153,968,674	163,697,065	6%
15%	7900091	10%	19%	153,968,674	169,540,238	10%
20%	8569565	15%	29%	153,968,674	175,626,365	14%
25%	9261326	20%	39%	153,968,674	181,915,097	18%
30%	9969480	25%	50%	153,968,674	188,352,863	22%
35%	10686597	30%	61%	153,968,674	194,872,112	27%
40%	11403711	35%	72%	153,968,674	201,391,323	31%

5.2.14. Summary:

According to the energy comparison there is 16% electricity saving from the absorption chiller system. Apart from that absorption chiller system needs 1350 kg/hr steam flow rate dedicated only to the chiller and Biomass boiler partial load performance is not efficient compared to fuel fired boilers. But building cooling load profiles show significant variations throughout the year and Biomass boiler is not the best fit for this application. Therefore investment cost and the operational cost of the boiler is affected to the monetary savings.

Based on the sensitivity analysis COP of the absorption chiller should be greater than 1.5 even for close to the electric chiller cost. Moisture content of the firewood should be less than 5 % (which is practically unachievable) in order to have the same NPV of the electric chiller system. It concludes that electric chiller system is more beneficial than the absorption chiller system for this facility.

5.3 Analysis on Testing & Commissioning Phase:

We have not discussed on testing & commissioning aspect in this report and it is one of the salient weakness of it. We should have established T & C procedure for selected technology and cost associated with such a process must be built in to the project cost. As discussed in chapter 3.3, we have to document complete T & C procedure with this design document, so that we can ensure that systems are designed, installed, functionally tested, and capable of being operated and maintained to perform in conformity with the design intent.

5.4 Analysis on operation & maintenance Phase:

This is also not deeply discussed in this report. Costs involved with operation and maintenance were considered in the life cycle costing, but detailed plan was not presented. Importance of such a plan was deeply discussed in chapter 3.4 under design phase for O & M.

5.5 Chapter Conclusion:

Chapter 5 discussion clearly shows that research methodology and guidelines developed for development of air conditioning systems for commercial buildings are very beneficial from client's perspective to make correct decisions based on scientific analysis as shown.

CHAPTER 6:CONCLUSION AND RECOMMENDATIONS:

6.1. Conclusion:

- Design process must follow clear procedure as discussed in the study and it is mandatory to complete design, testing & commissioning and Operation & maintenance check lists.

- Must be assured that design is in line with International standards especially in energy performance, indoor air quality and thermal comfort.

- Load calculation must be performed with reputed Thermal simulation tools and must optimized the results with expert involvement.

6.2. Recommendation:

- Must perform life cycle cost analysis in finalization of the design and equipment.
- Case study is for apparel factory and recommend to expand this study to other commercial building categories like office building, hospital, universities, show rooms, shopping mall etc. Once this is performed we can establish bench mark for each building category.

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CHECK LIST NO:1

AIR CONDITIONING SYSTEM DESIGN:CHECK LIST FOR OBJECTS & FACTORS-COMFORT AIR CONDITIONING

DESCRIPTION	CHECK LIST/ANSWERS			REMARKS
(A) Environmental conditions	1.Corrosive	2.Non corrosive		
(B) Water Quality	1.Good	2.Bad	3.Worst	If (A) & (B) are negatively answered,critical analysis is needed to finalize appropriate AC system.
(C) Availability of motive power	1.Grid Electricity	2.Steam	3.Waste heat	
(D) Comfortable Environment	1.Temperature/Humidity:			Refer ASHRAE Application Hand book 1982
	2.Air Flow rate:			Refer ASHRAE Application Hand book 1983
	3.Expected noise level:			Refer ASHRAE Application Hand book 1984
(E)	**Hospital**	**Residential**	**Commercial**	
Sanitary Environment (Filteration)	General surgery-HEPA/Bag Filter(MERV16)	Superior Residential -Bag filter (MERV 12)	Better Commercial - Bag filter (MERV 11)	
	Inpatient Care-Bag filter (MERV 15)	Better Residential-Cartrige Filter(MERV 7)	Commercial Building-Pleated Filters (MERV 8)	
		Residential-Washable Filter(MERV 3)		

CHECK LIST NO:2

AIR CONDITIONING SYSTEM DESIGN:CHECK LIST FOR OBJECTS & FACTORS-INDUSTRIAL AIR CONDITIONING

DESCRIPTION	CHECK LIST/ANSWERS			REMARKS
(A) Type of industrial air conditioning	1.Work space AC	2.Industrial process AC		
(B) Environmental conditions	1.Corrosive	2.Non corrosive		
(C) Water Quality	1.Good	2.Bad	3.Worst	If (A) & (B) are negatively answered,critical analysis is needed to finalize appropriate AC system.
(D) Availability of motive power	1.Grid Electricity	2.Steam	3.Waste heat	
(D) Environment for work place AC	1.Temperature/Humidity:			Refer ASHRAE Application Hand book 1982
	2.Air Flow rate:			Refer ASHRAE Application Hand book 1983
	3.Expected noise level:			Refer ASHRAE Application Hand book 1984
(E) Sanitary Environment(Filteration) for work place AC	Cartridge filters/Synthetic panel filters(MERV6)			
(F) Industrial process Air Conditioning storage Environment	1.Temperature/Humidity:			Specific on actual requirement
	2.Air Flow rate:			Specific on actual requirement
(G) Sanitary Environment(Filteration) for storage	Clean room environment HEPA/ULPA filters (MERV 20)			Must check wether this is required or not with client?
(H) Industrial process air conditioning Environment for plants & animal	1.Temperature/Humidity:			Specific on actual requirement
	2.Air Flow rate:			Specific on actual requirement

CHECK LIST NO:3
AIR CONDITIONING SYSTEM DESIGN:CHECK LIST FOR ASSESMENT ON INDOOR ENVIRONMENT

DESCRIPTION	CHECKLIST/ANSWERS			REMARKS
(A) Provision for fresh air supply	Provided	Not Provided	Not Relevant	
(B) Conditioned space is under positive pressure?	Positive	Negative	Not Relevant	Kitchen,Pantry,Restaurant and similar area must be provided with negative pressure.
(C) Air intakes are located 10m away from dangerous exhaust,chimineys,road ways with heavy traffic,garage exhaust and similar exhausts	Yes	No		
(D) Demand control ventilation system	Provided	Not Provided	Not Relevant	For high occupany areas, this is very impportant

CHECK LIST NO:4
AIR CONDITIONING SYSTEM DESIGN:CHECK LIST FOR COOLING LOAD CALCULATION

DESCRIPTION		CHECKLIST/ANSWERS			REMARKS
(A)	Reputed software shall be used for cooling load calculation	Yes	No	Not Relevant	
(B)	Comprehensive Architectural layouts are available	Yes	No	Not Relevant	
(C)	Site Location				
	Country				
	District				
	Latitude				
	Logitude				
(D)	Building Orientation	Provided	Not Provided	Not Relevant	
(E)	Building orientation is optimized.	Yes	No	Not Relevant	
(F)	Availability of Local climatic data for TMY.	Available	Not Avialable	Not Relevant	Cases where data not avilable use available climatic data of closest location to the site.
(G)	Building construction details of each zone	Thickness(mm)	Area(sq.m)	Thermal Conductivity (w/mk) & SC	
	Wall				
	Roof				
	Glass/Façade				
(H)	Whether slab roofs are provided with Thermal insulation material	Yes	No	Not Relevant	Where applicable, Thermal conductivity of insulation material?
(I)	Where zinc alum roofs are used,50mm thick$X16m^3$/kg density glasswool insulation must be provided.	Yes	No	Not Relevant	Where applicable, Thermal conductivity of insulation material?
(J)	Floor details	Slab on grade	Slab above unconditioned space	Not Relevant	Specify floor thickness?
(K)	Each zone occupancy level	Zone-1	Zone-2	Zone-3	No of people per zone
(L)	Activity level	Heavy work	Light work	Seated at rest	This must be considered for each zone.
(M)	Building operating pattern	Continuous	6 week days each 8hrs	6 week days each 16hrs	Use actual client data
(N)	Fresh air requirement must be calculated for each zone based on actual occupants and floor area of each zone.	Complied	Not Complied	Not Relevant	
(O)	Establish actual lighting loads for each zone(w/m^2)	Zone-1	Zone-2	Zone-3	
(P)	Ballast factor for lighting				
(Q)	Establish actual equipment loads for each zone(w/m2)				

CHECK LIST NO:5
AIR CONDITIONING SYSTEM DESIGN:CHECK LIST FOR CLIENT, FUNCTIONAL AND SPACE REQUIREMENTS:

DESCRIPTION		CHECKLIST/ANSWERS			REMARKS
(A)	Budget limitations if any	No constraint	Limited	Not relevant	If budget is limited, cost pf alternatives must be evaluated to select best match.
(B)	Client Specific requirements				
	Redundancy	Required	Not required	Not relevant	
	Premium efficiency	Required	Not required	Not relevant	
	Restriction on Harmonics level	Must Comply	Not required	Not relevant	
	Continuous cooling required	Must Comply	Not required	Not relevant	
(c)	Space availability for proposed system	Available	Not available	Not relevant	If no check on feasible alternatives
(D)	Plant rooms are adequately provided with space	Yes	No	Not relevant	If no check on feasible alternatives
(E)	Whether proposed AC system considered zoning restrictions within the building	Yes	No	Not relevant	If no redesign the system
(F)	Operational pattern of the building must be considered in main AC equipment sizing	Considered	Not Considered	Not relevant	If not considered resize the main equipment
(G)	What is the billing startegy in case of condominum/apartments	Individual	Shared	BTU metering	

CHECK LIST NO:6
AIR CONDITIONING SYSTEM DESIGN:CHECK LIST FOR ENERGY PERFORMANCE

DESCRIPTION		CHECKLIST/ANSWERS			REMARKS
(A)	whether equipment specified in the design meets ASHRAE 90.1-2010 efficiency baseline	YES	No		
(B)	Does AC system operate continuously or intermittent	Continuous	Intermittent		If continuous , all the equipment must be selected with premium efficiency
(C)	Whather design called for submission of selection data sheet for all the critical equipment	YES	No		This is very critical for selection of matching equipment for the project.
(D)	System equipment sizing methodology	Optimized selection based on computer simulation performed with reputed software.	Basic selection based on maximum loading conditions		This is very important to justify equipment selection.
(E)	System selection based on loading ,Industry norms and experience				
	Domestic use (< 1000 sqft)	Individual Split AC units			
	Residential apartments	Multi split AC units/VRV			
	Offices,Commercial buildings	VRV,Water/Air cooled package			
	Large installations	Chiller system is preferred.			
(F)	Whether AHUs,Chillers,water pumps,cooling towers are provided with VFDs & automatic controls	YES	No		
(G)	Whather VAV boxes are incorporated to the system where applicable	YES	No	Not Relevant	

CHECK LIST NO:7
AIR CONDITIONING SYSTEM DESIGN:CHECK LIST FOR TESTING & COMMISSIONING

DESCRIPTION		CHECKLIST/ANSWERS			REMARKS
(A)	Whether commissioning agent is required or not	Required	Not Required	Not Relevant	All complicated and large installation would reqire competent commissioning authority for T & C
(B)	T & C procedure is developed	Yes	No	Not Relevant	
(C)	Design review performed	Yes	No	Not Relevant	
(D)	Installation review performed	Yes	No	Not Relevant	
(E)	Start up check list prepared for all the major equipment	Yes	No	Not Relevant	This must be prepared by each equipment manufacturer.
(F)	Start up test perform for all the major equipment	Yes	No	Not Relevant	
(G)	System air balancing has been performed and results recorded with recommendations for corrections	Yes	No	Not Relevant	
(H)	System hydronic balancing and results recorded with recommendations for improvement	Yes	No	Not Relevant	
(I)	Certified Test & Balance technician participated for commissioning process.	Yes	No	Not Relevant	
(J)	Pre functional-Installation commissioning performed	Yes	No	Not Relevant	Verify correct material and equipment used for installation
(K)	Start up-Tests have been carried out	Yes	No	Not Relevant	Document pre operational requirements,Verify that manufacturer recommended start up procedure followed.
(L)	AC system Test/Adjust/Balance	Yes	No	Not Relevant	Review finalized TAB reports
(M)	Control system T & C performed	Yes	No	Not Relevant	Review installation of sensors,document calibration of sensors and devices.
(N)	Performed check on functional automatic controls and operation	Yes	No	Not Relevant	
		Yes	No	Not Relevant	
(O)	Check and verify functionality of alarm,safeties.	Yes	No	Not Relevant	Alarms msut be active ,verify sequence of operstion under alarm condition.
(P)	Adequate training provided	Yes	No	Not Relevant	
(Q)	Submission of T & C repors	Yes	No	Not Relevant	Document must include corrective actions where necesssary
(R)	Submission of operation & maintenance manual	Yes	No	Not Relevant	
(S)	Shall provide all specialized calibrated tools,test equipment and instruments required to start up,test and commission	Yes	No	Not Relevant	

CHECK LIST NO:8
AIR CONDITIONING SYSTEM DESIGN:CHECK LIST FOR TESTING & COMMISSIONING

DESCRIPTION		CHECKLIST/ANSWERS			REMARKS
(A)	Schedule of operation must be introduced for AC equipment	Yes	No	Not Relevant	This must be inline with building operation pattern and building cooling demand.
(B)	Display schedule of operation in a visible place.	Yes	No	Not Relevant	This is for engineering staff to maintain a close track on it.
(C)	Availability of As built drawings	Available	Not Available		This is important to unerstand construction and troble shoot
(D)	Availability of Operation & Maintenance manual	Available	Not Available		This must include schedule of equipment,troble shoot guidelines,IOM of all equipment
(E)	Availability of maintenance program	Available	Not Available		This must cover all the equipment of AC system
(F)	Maintain operation log sheets for imporatnt equipment	Available	Not Available		This is useful for trobleshooting

Appendix:2:Case study – Roof slab design to reduce solar load- Hotel at North East:

Case study:

Roof slab design to reduce slab solar load:

Introduction:

Site is located in East part of the country close to coastal belt. Weather conditions are quite dry and dry bulb temperatures are around 37-40C. Humidity levels are relatively low compared to Colombo. Hotel consist of individual bungalows. Reception and Admin Office located in same building and our study is to propose economical roof for this building.

At the moment Architects proposed 150mm reinforced concrete with pebbles layer for roof and study will look for improvements of same and alternative roof construction methods.

Critical operational factors in deciding type of roof are listed below.

1. High ambient and direct sun light prevailing in the area
2. Corrosive environment
3. Operational cost of AC
4. Acoustics
5. Sustainability/Maintenance

Main Objectives Of Analysis:

Investigate on various Roofing solutions and technology, study technical pros & cons of each design and Select best roof structure based on quantitative techniques i.e cooling load calculation and also qualitative aspects.

Methodology:

Study available options for this case

Perform cooling load calculation

Calculate operational costs

Analyze acoustic characteristics

Study Qualitative aspects of options

Tools:

CARRIER HOURLY ANALYSIS PROGRAM VERSION 4.41 for performing load analysis.

Options Available:

There are a few options which we can discuss.

As already proposed RCC slab can be used provided that measures are being taken to reduce heat transfer rate of concrete. This is of prime importance since conductivity coefficient of concrete is very much favorable for high heat transfer rates. How can we resolve this issue? There are different techniques used to reduce heat transfer from slab roofs as listed below.

Pebble Layer on top of the Slab:

30-50mm thick pebble layer over the roof slab will reduce heat transmitted through solar. White color pebbles act as a very good heat reflectance and study shows that maximum roof surface temperature can be dropped to 40-45C from 70C.

Cool Roof:

Application of single ply membrane having high solar reflectance can used to reduce heat transfer rate due to direct solar. This is called COOL ROOFS and a drop of 20C can be expected on roof thus reducing energy on AC 10-15%.For further information refer Annex 2.One of key point we have to consider is that effect of glare is a concern in cool roofs. This will not be significant because in our case roof slab is horizontal and thus solar irradiance will be directed upwards.

Application of Insulation Layer:

Another method of improving heat resistance is application of insulation layer over the slab and application of screed over it. 25mm thick Rigidfoam sheets or appropriate insulation (i.e STYROFOAM) can be used for this. Reasonable reduction of heat transfer rate can be achieved and also Rigid foam layer acts as an acoustic barrier also. Detail calculation showing reduction of AC load with above is annexed. By having GEOTEXTILE layer we can protect insulation layer from water penetration.

Green Roofs:

A green roof, or rooftop garden, is a vegetative layer grown on a rooftop. Green roofs provide shade and remove heat from the air through evapo-transpiration , reducing temperatures of the roof surface and the surrounding air. On hot summer days, the surface temperature of a green roof can be cooler than the air temperature, whereas the surface of a conventional rooftop can be up to 70°C warmer.

Green roofs can be installed on a wide range of buildings, from industrial facilities to private residences. They can be as simple as a 2-inch covering of hardy groundcover or as complex as a fully accessible park complete with trees. Green roofs are becoming popular now and there is a big green roof in Havelock City Condominium, Colombo. Plants selection shall be based on parameters like climatic conditions and wind pattern etc.

Green Roof, Insulation layers on roof slabs will act as sound insulation and also sound reduction index can be improved further by having a small air gap between slab and insulation.

Zinc alum Roofs with a Insulation layer and ceiling:

This is an alternative solution to slab roofs and now a day becoming popular due to below points.

Ease of Installation

Availability of Aesthetically beautiful profiles.

Solar reflective colors

Durability

A good quality zinc alum roof with adequate insulation shows good heat resistance characteristics and therefore this is a good choice as an alternative to above mentioned slab roofs.

Metal roofs protect homes from extreme weather events with durable, attractive solutions that reduce the homeowner’s carbon footprint. With a minimum recycled content of 28 percent and demonstrated ability to lower energy consumption, metal roofs are in great demand. New manufacturing and coating technologies have allowed metal roofs to expand into the residential roofing market.

Advantages:

Metal Roofs are Attractive and Versatile

Residential metal roofs are available in a wide variety of designs, textures, styles and colors.

Metal roofing is available in traditional vertical seam profiles or can be manufactured to resemble wood shake, slate, shingles or clay tiles.

They can complement any type of architecture.

Metal Roofs are Durable.

Resistant to cracking, shrinking and eroding.

Metal roofing systems can withstand extreme weather conditions.

Many metal roofing systems feature interlocking panels, which resist and eliminate damage from high winds.

Residential metal roofs have long-term warranties, often up to 50 years.

Metal Roofs are Energy and Cost Efficient

Metal roofs can save home owners annual energy costs depending on geographical region.

Metal Roofs are environmentally friendly

Many residential metal roofs now utilize reflective pigment technology, which results in overall home energy efficiency.

Residential metal roofs are made from 28-60% recycled material.

Disadvantages:

There is a myth that metal roofs are louder than other types of roofs during a rainstorm. As long as the roof is properly installed with correct under laying material, it won't be any louder than an asphalt roof. Still, this myth makes some people reject metal roofs.

Applications:

The material used in metal roofing is versatile and durable. It can be used on residential, commercial, industrial or agricultural buildings. The same material used for metal roofs can be used for siding. There are many different profiles and styles available to fit most every building situation.

One may combine shapes for aesthetic impact. Using the same material and same color with different shapes can have an impact on "curb appeal" and building value. Alternatively, different metals can be used to create interesting colour combinations.

Metal roofing in new construction:

Metal roofing is usually easily applied over an existing roof. In situations where reducing the cost of labor is essential, it can be helpful to have this option.

Material types:

Corrugated galvanized steel:

This describes the original product that was wrought iron–steel sheet coated with zinc and then roll formed into corrugated sheets. This product is still used today in most areas. The newer push of modern architecture and "green" products has brought these products back to the foreground.

Metal tile sheets:

These are usually painted or stone-coated steel.

Stainless steel:

Available for harsh conditions and/or as a distinctive design element. Usually roll-formed into standing seam profiles; however, shingles are available.

Aluminum:

One of the longest-lasting metals, but somewhat expensive compared to steel products. Aluminum roofs are very lightweight, corrosion-resistant, have high natural reflectivity and even higher natural emissivity, increasing a building's energy efficiency. Aluminum products with Kynar paints easily last over 50 years. The newest innovation is anodizing of the aluminium coil stock for use in architectural details and standing seam panels. The anodized layer is intimately bonded the metal and is not normally subject to weathering and wear.

Stone coated steel. Panels made from zinc/aluminium-coated steel with acrylic gel coating. The stones are usually a natural product with a colored ceramic coating.

Coating:

Many different types of coatings are used on metal panels: anti-rust, waterproofing, heat reflective. They are made of various materials such as epoxy, ceramic and, more recently, materials developed through nanotechnology.

Nanotechnology solar reflective coatings are efficient heat-reflective coatings that can be applied on roofing materials. They are radiant barriers which increase in performance exponentially with the surface's heat, making them perfect for application on metal sheet roofs. Heat load on buildings with metal sheet roofs is typically reduced by 30%, which instantly improves the building's energy-efficiency and caps heat build-up. Developers can take advantage of the affordability and wide availability of metal roofs while transforming them into a high performance heat shield. Traditional under-roof insulation such as PU foam or PE foam can provide additional insulation.

Maintenance

A metal roof graded "AG" or "Utility" will need recoating once the factory finish wears off, or corrosion will occur. These paints are commonly acrylic or polyester based. Roof coatings are the preferred material since they are able to stay elastic and withstand the thermal cycling that occurs in metal roofs.

Roofing materials made from stainless steel, zinc or copper will rarely require maintenance over their lifetime. Any required maintenance is usually due to design or installation mistakes. Otherwise, these materials commonly last over a century.

Metal roofing with long life polymer coatings like Kynar should not normally require maintenance until the coating fails. These products have been used for over half a century now in the U.S. and few installations have failed. They should be considered lifetime products.

Analysis:

Assumptions:

1. Operating hours & Days: 8.00AM – 6.00PM & 365Days
2. Split AC System average power consumption/RT: 1.30KW
3. Design Temperature/Humidity: 24C , 60%RH
4. Rate of electricity:Rs.21.00 per Kwh.
5. Thermal resistance values are from load calculation package.

Pros & Cons matrix is prepared as follow for options A,B & C.

Option A =Slab roof (150mm) with insulation(25mm)

Option B =Slab roof(150mm) with pebbles layer(75mm)

Option C =Zinc Alum Roof + Insulation(25mm) +Durra Ceiling (50mm)

MBH: 1000BTU/Hr

OPTIONS

Description	A	B	C	Best Rank Option
Average MBH	64.69	75.08	65.23	A
Power Consumption for AC(KW)	7.00	8.14	7.07	A
Annual AC operating Cost(SLRs)	590,957	685,785	595,884	A
Investment Cost	High+	High	Low	C
Durability	Best	Better	Good	A
Sound Insulation Property	Best	Better	Average	A
Maintenance	Low	Average	Average	A

Table 5 : MATRIX 1

Qualitative analysis is carried out for Green Roofs and Cool roof comparing with option A which is having more A ranks in the matrix analysis.

OPTIONS

Description	A	OPTION D-GREEN ROOF	OPTION E-COOL ROOF	Best Rank OPTION
Average MBH	64.69	>64.69	<64.69	D
Power Consumption for AC(KW)	7.00	>7.00	<7.00	D
Annual AC operating Cost(SLRs)	590,957	>590,957	<590,957	D
Investment Cost	High+	High+++	AVERAGE	C
Durability	Best	Good	Better	A
Sound Insulation Property	Better	Best	Average	D
Maintenance	Low	High	Average	A

Table 6 : MATRIX 2

Conclusion:

Based on above matrix analysis , Option A & D have advantages over other options. Option D investment cost will be high since structure shall be capable of holding weight of Green roof. Since operating cost of AC is around half a million per annum investment cost will be significant in life cycle costing.

Also note that similarly this study can be extended to Bungalows as well.

Ref: Product Catalogues of each categories

Limitations:

1. Operating cost Analysis was limited to only three options due to unavailability of data for Cool roof and Green roofs.

2. Construction cost to be finalized.