Specifying Air Conditioning Requirements for Commercial Buildings of Ethiopia

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(*With Specialization in Thermal Engineering*)

By:

Jemal Worku

Advisor:

Dr. -Ing. Demiss Alemu

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Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

Thermal Engineering Stream

“Specifying Air Conditioning Requirements for Commercial Buildings of Ethiopia”

By:

Jemal Worku

Approved by Board of Examiners

Dr. -Ing. Demiss Alemu ______________
Advisor and Thermal Engineering Chair Signature

Dr. Tesfaye Dama ______________
Internal Examiner Signature

Dr.-Ing. Abebayehu Assefa ______________
External Examiner Signature

Dr.Daniel Tilahun ______________
Chairman of SMIE Signature

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Abstract

Having Conditioned air is a non questionable comfort issue for both commercial and residential buildings. To do so there should be a specified air condition requirements for air conditioning design so that the required comfort will effectively be attained. Specifying the local or national air conditioning requirements is the only way to effectively attain the human comfort while constructing any building.

The main intension of this paper is to specify the air conditioning requirements based on local or national data. Mainly the cooling load in w/m^2 which is the main parameter for AC design is determined for representative areas of Ethiopia using the HAP software. These selected representative areas are at different temperature zones. These are Addis Ababa for moderate temperature, Bahir-Dar for warm temperature, Dire-Dawa for hot temperature, and Semera for very hot temperature.

While doing this paper first the weather data for the selected areas of Ethiopia are collected from the National Metrology Agency. Also the architectural data or floor plans are gathered for each representative room types. Then all the data are entered in to the soft ware and analyzed by keeping some parameters like relative humidity as a checking point for comfort conditions. Finally the main AC design parameters are specified. Mainly the cooling load in w/m^2 for all representative areas of the country is specified for rooms of various applications.

The results show that the air conditioning design for commercial buildings depend on many factors. These are geographical locations, orientation of the building, types of applications to which the building is used for, number of population, the floor to which the room is located and the material to which the building is made. In general it is observed that north oriented buildings have lower cooling load in relative to other orientations. And the cooling load is specified for based on north orientation. And also other parameters have their own effect on the effective design of the room from AC perspective. Hence it is recommended for the air conditioning designers of the commercial building to use these local or national standards in which the above factors are considered and to have an effective air conditioning system.

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List of Abbreviations

NME	National Metrology Agency
OA	outdoor air
ADP	apparatus dew point
CAV	constant air volume
VAV	variable air volume
A	area
HVAC	heating ventilation and air condition
ASHRAE	American society of heating refrigeration and air conditioning
HAP	hourly analysis program
DB	dry bulb
WB	wet bulb
DP	dew point
EBCS	Ethiopian building code standards
CAD	computer aided design
AC	air conditioning
R	refrigeration
AA	Addis Ababa
AHU	air handling unit
DX	direct expansion
CLF	cooling load factor
U	overall heat transfer coefficient
LPS	litter per second
FPM	feet per minute
MIN	Minimum
MAX	Maximum
RH	relative humidity
CFM	cubic feet per minute
SHGC	maximum solar heat gain factor
SC	shading coefficient

CLTD	corrected cooling load temperature factor
BF	ballast factor
CWB	coincident wet bulb
GPM	Gallon per minute
MDR	Mean daily range
HW	high weight
LW	low weight

Chapter One: Introduction

1.1. Background

The basic concept behind air conditioning is known to have been applied in ancient Egypt where reeds hung in windows had water trickling down. The evaporation of water cooled the air blowing through the window, though this process also made the air more humid. In ancient Rome, water from aqueducts was circulated through the walls of certain houses to cool them down. Other techniques in medieval Persia involved the use of cisterns and wind towers to cool buildings during the hot season. Modern air conditioning emerged from advances in chemistry during the 19th century, and the first large-scale electrical air conditioning was invented and used on 1911 by Willis Havil and Carrier. The introduction of residential air conditioning in the 1920s helped start the great migration to the Sunbelt **[2]**. In construction, a complete system of heating, ventilation and air conditioning is referred to as "HVAC ".

Air conditioning is the process of altering the properties of air (primarily temperature and humidity) to more favorable conditions. More generally, air conditioning can refer to any form of technological cooling, heating, ventilation, or disinfection, which modifies the condition of air to a more favorable one. It is a process that simultaneously conditions air; distributes it combined with the outdoor air to the conditioned space; and at the same time controls and maintains the required space's temperature, humidity, air movement, air cleanliness, sound level, and pressure differential within predetermined limits for the health and comfort of the occupants, for product processing, or both. An air conditioner (often referred to as AC) is a major or home appliance, system, or mechanism designed to change the air temperature and humidity within an area (used for cooling and sometimes heating depending on the air properties at a given time.

Now a day our country Ethiopia is developing rapidly in various aspects. And the living standard and seeking for comfort condition of the population in both working and residential area is also increasing rapidly from time to time. And in fact there are modern buildings with air conditioned such as; Hotels in Addis Ababa like, Capital Hotel, Radison blue, Harmony, Kenenisa, lexsus and the like are. Not only in Addis but also in other parts like Semera in

almost all governmental office buildings using split AC, in Mekele example Yirdaw Hotel, and some hotels and conference halls in bahir dar have a nice designed Air conditioneds.
Having a conditioned, comfort and world wise computable buildings of various purposes is one of the development or change. This is attained by having specified requirements for air condition and considering the comfort from the AC aspect during the design and the construction of the building so that the building will have better aesthetic value and comfort.

It is difficult for engineers to design or calculate air conditioning design parameters for each and every building or to use non local standards while designing or constructing buildings of various applications such as institutional buildings, commercial buildings, residential buildings or buildings for manufacturing purpose. But if there are "*locally or nationally specified requirements*" the design of AC will be easier and sustainable. Even if the designer is out of the standards for convincing reasons these standards helps to be within the acceptable range and avoids errors and simplifies the design. This creates the conditioned room that is comfortable and healthy for the people staying inside the room. In air conditioning the main parameters to be controlled are temperature, humidity, cleanness of the air and air motion.

Temperature: air temperature is controlled by either heating or cooling the air

Humidity**:** air humidity or the water vapor content of the air is controlled by adding or removing water vapor from the air.

Cleanness**:** Air cleanness or air quality is controlled by either filtration, the removal of undesirable contaminants using filters or other devices or ventilation

Motion**:** Air motion refers to air velocity and to where the air is distributed. It is controlled by appropriate air distribution equipment.

Need for specifying the requirements for building air conditioning

Most air conditioning system is used for either human comfort or for process control. The design of air distribution equipment in today's buildings presents challenges for the mechanical engineer. Equipment selection must combine properly engineered products, which efficiently provide conditioned air to the occupied space while blending in with the architectural features of the interior. Considerable time and money can be spent developing and purchasing the appropriate mechanical components, system controls, ductwork and piping. If components are selected improperly, the HVAC system will operate inefficiently, not meet requirements and create cost overruns to correct the situation. Since one aspect of the system affects another, proper selection of every component, regardless of apparent significance, is imperative.

In fact, without HVAC systems, many manufactured products produced by industry that is literally taken for granted would not be available today.

In general having specified air conditioning requirements at national level have the following advantages

- To properly select the equipments for HVAC in building at national level or local
- To have a consistency in air conditioning design
- Highly reduces the effort on air conditioning engineers, controller of AC works
- Designer, contractor as well as the client can easily communicate
- To get the exact range of air temperature, humidity, cleanness, and motion, for both human comfort and process control etc…

1.2. Statement of the Problem

In Ethiopia the construction of buildings is increasing from time to time including buildings with the height of more than 20 floors together with the increasing of temperature from time to time. This is mainly due to the increasing demand for house and living standard of population. And the major material for most of the buildings is glass which highly transmits solar radiation. But most of the buildings are not constructed with a standard air conditioning and ventilation systems. This is may be due to the reason that many people of Ethiopia have less awareness of the air conditioning systems, even if the issue is critical. For example there are places like Afar, Somali, Dire Dawa, Gode and Gambela, and even in most areas of Addis Ababa and second city of Ethiopia like; Dahr-Dar, Mekele and Awasa during some seasons, the population is highly affected by high temperature inside the room and they feel discomfort in either their resident or working place. In fact currently there are some practices of building air conditioning in some of modern buildings such as, in modern hotels, banks, conference halls, hospitals, airport terminal and other organizations even if there are no specified standards for the design.

Now a day the demand of people for air conditioned systems is increasing rapidly from time to time due to the increasing in living standards of the society. Therefore the building engineer should take these systems in to considerations for upgrading the living standards of the people of Ethiopia one step and satisfying the customers' interest as well as to be competitive with world wise by constructing standardized AC systems.

Specifying AC requirements for building nationally for our country play a major role in answering the above issue, by simplifying the duty of the AC engineers, designers, constructors and controllers of such engineering works. And it helps to have uniform AC parameters in buildings of different purpose. It also helps to controls and maintains the temperature, humidity, air movement, air cleanliness, sound level, and pressure differential in a space within predetermined limits for the comfort and health of the occupants of the conditioned space or for the purpose of product processing. But yet there are no specified local AC parameters. Mostly the current trend is to use ASHRAE (American Society of Heating, Refrigeration and Air conditioning Engineers) standards. Having the locally specified AC requirements will have a great role to make the design more accurate and sustainable, and also simplifies the work of AC engineers. This paper is aimed to solve this problem.

1.3. Objectives

General objective

The main objective of this project is to specify the air conditioning requirements for commercial buildings of Ethiopia.

Specific objectives

The specific objectives of this paper are:

- Use HAP(Hourly Analysis Program) Software to calculate the cooling load
- Calculate the cooling load for different geographical locations which represent the moderate, worm, hot, ant very hot parts of the country
- Calculating the cooling load for different building types or applications

- Checking the designed dry-bulb temperature, relative humidity or system psychometry of the designed room for comfort conditions.

1.4. Organization

This paper contains six chapters. It starts with introductory part which deals with the background about Air Conditioning, statement of the problem and objectives of the thesis. The second chapter is a literature review. In this chapter recommended Air Conditioning standards, as well as building materials and exposures from Air Conditioning point of view are discussed. The third chapter deals with Air Conditioning design soft-wares in which their significance on AC design is discussed. The next chapter which is the main chapter deals with determining the AC requirements for Ethiopia using HAP (Hourly Analysis Program) by considering buildings from representative areas of the country. The weather data for the considered areas are included. The fifth chapter is about the discussion and result of the paper, which summarizes the result obtained. Last but not list chapter concludes the paper by putting feature works to be done in relation to the topic. And also there are references and appendices included.

1.5. Delimitation

This paper specifies the air conditioning requirements for commercial buildings in Ethiopia by considering the existing buildings for various applications like, hotel bedroom, conference hall, bank lobby, office and shop. The main issue related to AC in Ethiopia is to protect high room temperature. Hence this paper mainly focuses on determining the cooling load for representative areas. The standard is done for the representative areas of Ethiopia which are Addis Ababa, Bahir Dar, Dire Dawa and Semera. These areas represent the moderate, warm, hot and very hot area of the country. Various factors are considered while calculating the cooling load, which are the main parameters in air conditioning design. These are the effect of orientation, floor location, and the geographical location. By specifying the cooling load in w/m^2 for each location one can select the HVAC equipments. The result is checked via comfort standards like relative humidity, dry bulb temperature or on system psychrometry.

Chapter Two: Review of Related Literature

2.1. Air Conditioning for Commercial Buildings

As described earlier air conditioning is the process of altering the properties of air (primarily temperature and humidity) to more favorable conditions. It is also used to provide conditions that some processes require. For example Textile, Printing, Photo graphic processing facilities, as well as computer rooms and medical facilities, require certain air temperatures and humidity for successful operation. Or air conditioning is the supply of conditioned air that is intentionally cooled, heated, humidified or dehumidified air in to the room. Air conditioning mostly required in building which have a high internal temperature. If inside temperature of a space rises to above 25^{o}c then air conditioning will probably be necessary comfort levels.

Air conditioning may be required in buildings which have a high heat gain and as a result a high internal temperature. The heat gain may be from solar radiation and/or internal gains such as people, lights and business machines. These all are attain in the desired manner if there are air conditioning standards.

Most air conditioning systems perform the following functions: it may be required to provide the cooling and heating energy required, for conditioning the supply air, that is, heat or cool, humidify or dehumidify, clean and purify, and attenuate any objectionable noise produced by the HVAC&R equipment, to distribute the conditioned air containing sufficient outdoor air to the conditioned space, or to control and maintain the indoor environmental parameters such as temperature, humidity, cleanliness, air movement, sound level, and pressure differential between the conditioned space and surroundings within predetermined limits

2.1.1. Types and Components of Air Conditioning

Air conditioning systems can be classified according to their applications as comfort air conditioning systems and process air conditioning systems.

Comfort Air Conditioning Systems

Comfort air conditioning systems provide occupants with a comfortable and healthy indoor environment in which to carry out their activities. The various sectors to which comfort air conditioning systems applied are as follows:

a) The commercial sector includes office buildings, supermarkets, department stores, shopping centers, restaurants, and others. It is common in our country that many high-rise buildings such as office buildings, hotels, assembly halls and the like use air conditioning systems to satisfy multiple purposes. In light commercial buildings, the air conditioning system serves the conditioned space of only a single-zone or comparatively smaller area.

b) The institutional sector includes such applications as schools, colleges, universities, libraries, museums, indoor stadiums, cinemas, theaters, concert halls, and recreation centers.

c) The residential and lodging sector consists of hotels, motels, apartment houses, and private homes. Many systems serving the lodging industry and apartment houses are operated continuously, on a 24-hour, 7-day-a-week schedule, since they can be occupied at any time.

d) The health care sector encompasses hospitals, nursing homes, and convalescent care facilities. Special air filters are generally used in hospitals to remove bacteria and particulates of sub micrometer size from areas such as operating rooms, nurseries, and intensive care units. The relative humidity in a general clinical area is often maintained at a minimum of 30 percent in winter.

e) The transportation sector includes aircraft, automobiles, railroad cars, buses, and cruising ships. Passengers increasingly demand ease and environmental comfort, especially for long distance travel. Modern airplanes flying at high altitudes may require a pressure differential of about 5 psi between the cabin and the outside atmosphere.

Process Air Conditioning Systems

Process air conditioning systems provide needed indoor environmental control for manufacturing, product storage, or other research and development processes. The following areas are examples of process air conditioning systems:

a) In textile mills, natural fibers and manufactured fibers are hygroscopic. Proper control of humidity increases the strength of the yarn and fabric during processing. For man textile manufacturing processes, too high a value for the space relative humidity can cause problems in the spinning process. On the other hand, a lower relative humidity may induce static electricity that is harmful for the production processes.

b) Many electronic products require clean rooms for manufacturing such things as integrated circuits, since their quality is adversely affected by airborne particles. Relative-humidity control is also needed to prevent corrosion and condensation and to eliminate static electricity. Temperature control maintains materials and instruments at stable condition and is also required for workers who wear dust-free garments. For example, a class 100 clean room in an electronic factory requires a temperature of (22.2-1.1°C), a relative humidity at 45 - 55 percent, and a count of dust particles of 0.5m diameter or larger not to exceed 3531 particles/ m^3**[27].**

c) Precision manufacturers always need precise temperature control during production of precision instruments, tools, and equipment. Bausch and Lomb successfully constructed a constant temperature control room of 20 - 0.56°C to produce light grating products in the 1950s.

d) Pharmaceutical products require temperature, humidity, and air cleanliness control. For instance, liver extracts require a temperature of 23.9°C and a relative humidity of 35 percent. If the temperature exceeds 26.7°C, the extracts tend to deteriorate. High-efficiency air filters must be installed for most of the areas in pharmaceutical factories to prevent contamination.

e) Modern refrigerated warehouses not only store commodities in coolers at temperatures of 2.8 to 0°C and frozen foods at 23 to 29°C, but also provide relative-humidity control for perishable foods between 90 and 100 percent. Refrigerated storage is used to prevent deterioration. Temperature control can be performed by refrigeration systems only, but the simultaneous control of both temperature and relative humidity in the space can only be performed by process air conditioning systems **[27]**.

Air conditioning systems can also be classified into three categories according to *their related equipment* as follows:

a) ***Individual Systems****:* - use a self-contained, factory-made air conditioner to serve one or two rooms (e.g. room/ window air conditioner and split-type units).

Split air conditioners have two main parts, the outdoor unit which is the section which generates the cold refrigerant gas and the indoor unit uses this cold refrigerant to cool the air in a space.

The outdoor unit uses a compressor and air cooled condenser to provide cold refrigerant to a cooling coil in the indoor unit. A fan then blows air across the cooling coil and into the room. The indoor unit can either be ceiling mounted (cassette unit), floor mounted or duct type.

Window or wall units are more compact than split units since all the plant items are contained in one box. Window units are installed into an appropriate hole in the window and supported from a metal frame**.** Wall units are built into an external wall and contain all the necessary items of equipment to provide cool air in summer and some may even provide heating in winter.

b) ***Unitary Packaged Systems***: **-** similar in nature to individual systems but serve more rooms or even more than one floor, have an air system consisting of fans, coils, filters, ductwork and outlets (e.g. in small restaurants, small shops and small cold storage rooms). A packaged system always has a refrigeration system that uses a DX (direct expansion) coil to cool air directly.

c) ***Central (Hydronic) Systems***: - it consists of conditioned air supply by air handling unit using chilled water from a chillier or hot water or electrical heating. It basically consists of three major parts:

Air system: **–** air handling units (AHU), air distribution (air duct) system and terminals.

Water system: **–** chilled water system, hot water system, condenser water system.

Central plant: **–** refrigeration (chiller) plant, boiler plant.

Air handling units (*A.H.U.):* **–**are widely used as a package unit which incorporates all or some of the following. These are Pre-filter, Filter, Cooling Coil, Heating Coil, Dehumidifier /Humidifiers. AHU is the basic piece of equipment used in an air system. It can be either a field-assembled built-up system or a factory-made unit. Because a central system always has a chilled water system, the type of coil installed in an AHU is a water cooling coil, which is different from an air handler in a packaged system, which uses a DX (direct expansion) coil.

Chiller: - For large installations the Condenser, Evaporator, Compressor and Expansion device can be purchased as a package unit, known as a Chiller. In a chilled-water system, the entire air conditioner is situated on the roof or behind the building. It cools water to between 4.0^{o}C and 8.0^{o}C. This chilled water is then piped throughout the building and connected to the cooling coils in air handlers as needed.

2.1.2. Heating and Cooling Loads

Heating and cooling loads are the measure of energy needed to be added or removed from a space by the Heating Ventilation and Air Conditioning (HVAC) system to provide the desired level of comfort within a space. Right-sizing the HVAC system begins with an accurate understanding of the heating and cooling loads on a space. Right-sizing is selecting HVAC equipment and designing the air distribution system to meet the accurate predicted heating and cooling loads of the house. The values determined by the heating and cooling load calculation process will dictate the equipment selection and duct design to deliver conditioned air to the rooms of the house, right-sizing the HVAC system. The heating and cooling load calculation results will have a direct impact on first construction costs along with the operating energy efficiency, occupant comfort, indoor air quality, and building durability **[15].**

The heat gain or heat loss through a building depends on: the temperature difference between outside temperature and our desired temperature, the type of construction and the amount of insulation in ceiling and walls, how much shade is on the building's windows, walls, and roof, the area of the room, including wall, window, roof and door, the amount of air that leaks into indoor space from the outside, the amount of heat generated by the appliances and occupants, activities and other equipment within a building, amount of lighting in the room.
Fig 2.1 below shows the sources of cooling load in a particular room of the building.

Heat always travels from a warmer to a cooler area. Most heating and cooling systems have at a minimum the following basic components. First there should be a heating source that adds heat to a fluid (air, water, or steam) and a Cooling source that removes heat from a fluid (air or water). Then there should be a distribution system (a network of dust or piping) to the rooms to be heated or cooled. Equipment (fans or pumps) for moving the air or water and devices (e.g. radiation) for transferring the heat between the fluid and the room are also needed.

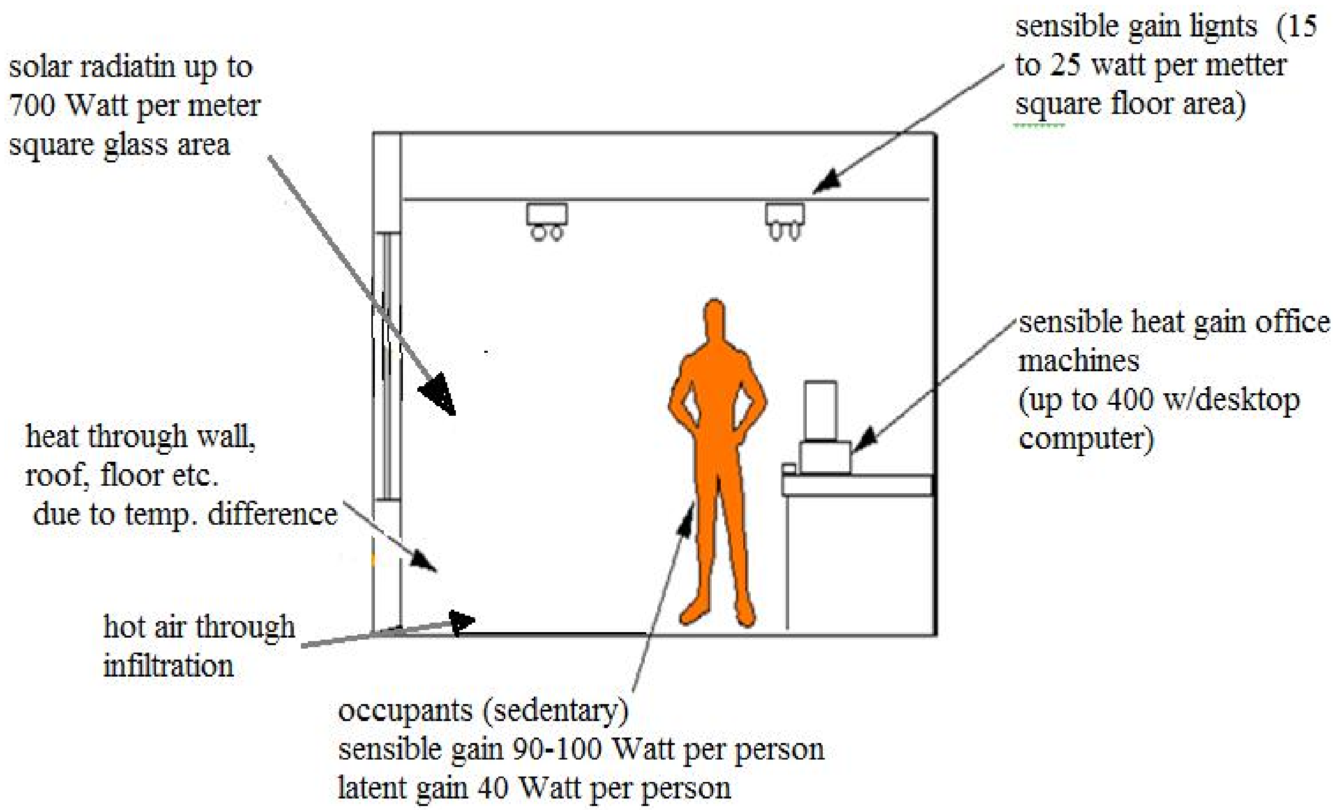

Figure 2.1: Sources of Cooling Loads Building

Generally there are two types of heat gains, these are:

Sensible Heat Gain (related with increase of Temperature). It may be external or internal.

a) External Loads:

- Solar Heat gain From: Roof; Wall; Window; door etc.
- Ambient Temperature: Roof; Wall; Window; door etc
- Hot air infiltration.

b) Internal Loads:

- Electric Lamp; Occupants; Electric apparatus etc

Latent Heat Gain (related with moisture content and relative Humidity). It may also be external or internal

a) External Loads:

- Humid air infiltration.

b) Internal Loads:

- Occupants; Boiler; Hot food etc

The load calculation is the first step of the HVAC design procedure, as a full HVAC design involves much more than just the load calculation. The loads modeled by the heating and cooling load calculation process will dictate the equipment selection and duct design to deliver conditioned air to the rooms of the house. This load can be calculated by analytically or by using AC software like HAP (Hourly Analysis Program).

Analytically the cooling loads are calculated as follows.

a) Conduction Through Exterior Walls, Roof, and Glass

Cooling Load through Roof,

$$Q \qquad U \times A \times CLTD \qquad (2.1)$$

Cooling Load through Wall,

$$Q \quad = U \times A \times CLTD \qquad (2.2)$$

Cooling Load through Window ’ Conduction Gain,

$$Q \quad = U \times A \times CLTD \qquad (2.3)$$

b) Solar Radiation Through Glass

The amount of solar radiation through the glass is given by

$$Q \quad = SHGF \times A \times SC \times CLF \qquad (2.4)$$

Where, U= Overall heat transfer coefficient, A = area of roof, wall, window or glass, CLTD= corrected cooling load temperature difference, SHGF= Maximum solar heat gain factor, SC= shading coefficient, CLF = Cooling load factor for glass, Q= Cooling load for roof wall, window, wall or glass.

c) Lighting Cooling Load

By observing the number of lights and their wattage the load from lighting can be calculated by using.

$$Q \qquad W \times BF \times CLF \qquad 2.5$$

Where Q= Cooling load from lighting, W=Lighting capacity, watts =160watts, CLF= Cooling load factor for lighting, Bf= Ballast factor.

d) People

The heat gain from people is composed of two parts. These are sensible heat and latent heat resulting from perspiration. Some of the sensible heat may be absorbed by the heat storage effect, but not the latent heat.

The sensible heat loads from pe is ven by:

$$Q \quad q \quad n \times CLF \tag{2.6}$$

And for latent heat we use the f wi

$$Q \quad q \quad n \times CLF \tag{2.7}$$

Where, q_s & q_l =sensible and latent heat gains per person respectively, n= number of people. Total Heat Gain of Building is t e sun ati n of a the al ove l his implies

$$Q \;= Q \quad Q \;+ Q \;+ Q \;+ Q \tag{2.8}$$

In general the load on an air-conditioning system consists of:

- Sensible Transmission through glass
- Solar Gain through glass
- Heat gain through walls
- Heat gain through roof
- Ventilation and/ or infiltration gains
- Internal heat gain from persons
- Internal heat gain from lightening
- Internal heat gain from equipment

There are ways to reduce these heat gains where ever possible. These are:

- Solar radiation can be reduced by having heat reflecting glass
- Sensible heat gain from lights can be reduced by having higher ceiling heights and by using lights having lower level of over head illuminance.
- To reduce infiltration loads increase insulation in fabric
- Heat from working machines can be removed by a purpose made extract ventilation system.

The occupancy or the number of people per area in m^2 can have a vital in the cooling load. If the number of people in a certain area is high the cooling load will also be high. Because there is a latent and sensible heat losses from each individual. So the is a certain limit for this and the following table shows the ASHRAE standard cooling load check list for various building types **[25]**.

Table 2.1: Cooling Load Check Figures for Occupancy

Building type	**Occupancy (m^2/person)**		
	Low	Average	High
Assembly area	4.6	3.3	2.3
Beds, motels, Dormitories	18.6	13.9	9.3
Office building (general)	12.1	10.2	7.4
Private office	13.9	11.6	9.3
Restaurant	1.6	1.4	1.2
Stores specialty shop Beauty and barber shop	4.2	3.7	2.3
Dress shop	4.6	3.7	2.8

2.1.3. Infiltration

Infiltration is the flow of outdoor air into a building through cracks and other unintentional openings and through the normal use of exterior doors for entrance and egress. Infiltration is also known as air leakage into a building **[18]**. Infiltration may be caused by wind, negative pressurization of the building, and by air buoyancy commonly known as the stack effect. It is the volumetric flow rate of outside air into a building, typically in cubic feet per minute (CFM) or liters per second (LPS). It is the product of the wind speed with the area of the openings to which infiltration occurs.

Minimizing infiltration gives many advantages. These are minimizing dust, increasing thermal comfort, decreases energy consumption. For all buildings, infiltration can be reduced by sealing cracks in a building's envelope, and for new construction or major renovations, by installing continuous air retarders. In buildings where forced ventilation is provided, their HVAC designers typically choose to slightly pressurize the buildings by admitting more outside air than exhausting so that infiltration is dramatically reduced.

2.1.4. Air Conditioning Requirements for Human Comfort

The general definition for thermal comfort is that, “Thermal Comfort is that condition of mind that expresses satisfaction with the thermal environment” (ASHRAE Standard 55). ASHRAE Standard 55 recommends temperature range guidelines perceived as “comfortable” to be 74 to 82^{o}F (23 to 28^{o}C) during the summer and 68 to 78^{o}F (20 to 25.5^{o}C) during winter as shown in the figure below.

Figure 2.2: ASHREA Comfort Zones for Winter and Summer

Most individuals generally consider an indoor relative humidity level maintained between 30 and 65 percent to be comfortable. A flow of air is created when a differential pressure condition exists between spaces, and a sensation of draft is perceived when this difference is high enough.

Drafts below 0.20m/s are generally not noticed by occupants and, therefore, maintaining levels near this is recommended. Too little draft may create a sensation of stuffiness or stale air. The comfort zones also varied depending on the type of applications.

The following table shows the comfort dry bulb temperature and relative humidity ranges for different commercial applications **[13].**

Table 2.2: DB Temperature and RH for Comfort Air Conditioning

Typical applications	**Recommended ranges for Commercial practice**	
	Dry bulb (^{o}c)	Rel. Humid (%)
General comfort: air port, house, hotel, office, hospital, school, etc.	25-26	55-45
Retail shops (short term occupancy): bank, barber, or beauty salon, dept. store, supermarket, etc.	26-27	55-45
Low sensible heat factor applications (high latent load): auditorium, church, bar, restaurant, kitchen, etc.	26-27	60-50
Factory comfort: Assembly areas, machine rooms, etc.	26-30	60-50

2.2. Factors Affecting Building Air Conditioning Loads

As the intensity of solar heat gain is the major factor for the cooling or heating load in a particular building there are also many factors that influence on the AC load. This includes building materials, building envelopes, orientations, geographical location of the building, the purpose of the building or building type, even the floor level to which the room is located within same building, population size of the room, infiltration and ventilation, room size and etc.

2.2.1. Building Materials

As the heat transfer between the inside and the outside of the room is through the building envelopes, the properties of these components will have a critical role on heat transfer. In addition to this both indoor and outdoor materials must be durable, resistant to vandalism, easy to maintain, and affordable. They must be strong enough to meet structural and seismic codes, yet appear aesthetically pleasing.

Building construction, proper details, and materials are critical components of the heating and cooling load calculations. The R-value of the building wall, roof, and foundation construction components can be accurately calculated using the insulation levels specified combined with the remainder of the components that make up the construction assembly (i.e. drywall, sheathing, exterior siding materials, structural framing system, roofing materials, etc). The window performance, described by the U-value and SHGC, must be known and accurately represented by the data input.

Wall Materials

Stone, concrete, and burnt clay are the most common materials used for buildings walls. Other types of wall materials like wood, steel and structural insulated panels are also sometimes used.

The wall may be composed of either a single wall material or a combination of different layers. The layers include the wall finishing material as well. Their properties like thickness, density, specific heat, R-value and weight are inbuilt in the software. The outside surface color highly affects the absorptivity and the relative humidity of the wall. If the outside surface is light RH will be high. If it is dark, then RH will be low. Factors mainly affect the design are orientation, design supply temperature, roof and wall outside color. For example as the HAP inbuilt data indicates, if the outside wall is dark then the absorpitivity of the wall is 0.9, if it is medium the absorpitivity will be 0.675, and if the outside color is light, then the absorptivity is 0.45. For this paper the considered building is composed of gypsum plaster, low weight concrete block and common breaks layers accordingly from inside to outside. The materials used for the construction of the building wall are as shown below. (*Source HAP software*)

Table 2.3: Wall Materials and Their Properties

Layer/wall material	**Thickness (mm)**	**Density (kg/m^3)**	**Specific heat (KJ/Kg/k)**	**R-value (m^2-k/w)**	**Weight (Kg/m^2)**
102mm face brick	102	2002.3	0.92	0.07624	203.4
102mm common brick	102	1922.2	0.84	0.13977	195.3
203mm common brick	203	1922.2	0.84	0.27954	309.6
102mm LW concrete block	102	608.7	0.84	0.26683	61.8
203mm LW concrete block	203	608.7	0.84	0.35578	123.7
102mm HW concrete block	102	101.6	0.84	0.1249	99.3
203mm HW concrete block	203	977.1	0.84	0.19568	198.6
102mm LW concrete	102	640.7	0.84	0.58703	65.1
203mm LW concrete	203	977.1	0.84	0.19568	198.6

102mm HW concrete	102	2242.6	0.84	0.0587	227.8
203mm HW concrete	203	2242.6	0.84	0.11741	455.7
10mm plywood	9.525	544.6	1.21	0.08214	5.2
13mm plywood	12.7	54.6	1.21	0.10952	6.9
16mm plywood	15.875	544.6	1.21	0.1369	8.6
19mm plywood	19.05	544.6	1.21	0.16428	10.4
Asphalt sheathing	12.7	1121.3	1.47	0.25303	14.2
13mm vegetable board	12.7	288.3	1.3	0.22931	3.7
13mm gypsum board	12.7	800.9	1.09	0.0789	10.2
16mm gypsum board	15.875	800.9	1.09	0.0986	12.7
13mm gypsum plaster	12.7	720.8	1.34	0.05645	9.2
RSI-1.2 board insulation	25.4	32	0.92	1.22299	0.8
RSI-2.5 board insulation	50.8	32	0.92	2.44598	1.6
RSI-1.9 batt insulation	88.9	8	0.84	1.9756	0.7
RSI-2.3 batt insulation	101.6	8	0.84	2.25782	0.8
RSI-3.3 batt insulation	152.4	8	0.84	3.38673	1.2
RSI-3.9 batt insulation	171.45	8	0.84	3.8102	1.4
RSI-4.4 batt insulation	203.2	8	0.84	4.51565	1.6
RSI-5.3 batt insulation	241.3	8	0.84	5.36233	1.9
RSI-6.7 batt insulation	304.8	8	0.84	6.77347	2.4
25mm stucco	25.4	1858.1	0.84	0.03519	47.2
Asphalt shingles	3.175	1121.3	1.26	0.07644	3.6
Asphalt roll	1.588	1121.3	1.51	0.02698	1.8
Wood singles	12.7	400.5	1.3	0.16677	5.1
	12.7	4325	1.26	0.00881	54.9

U-value of Wall Materials

U-value for some wall materials is given in the following table **[16]**. The wall is composed of different layers.

Table 2.4: Overall Heat Transfer Coefficient for Wall Materials

External wall	U-value (w/m^2k)	External wall	U-value (w/m^2k)
Solid brick wall, dense plaster		**Solid concrete wall, dense plaster**	
Brick 102mm, plaster	2.97	Concrete 152mm, plaster	3.12
Brick 228mm, plaster	2.11	Concrete 204mm, plaster	2.8
Brick 343mm, plaster	1.64	Concrete 254mm, plaster	2.54
Solid stone wall, un plastered		**Internal wall**	
Stone 305mm	2.78	Plasterboard 12.5mm, studding 75mm, plasterboard12.5mm	1.72
Stone 457mm	2.23	Plaster 13mm, block 10mm, cavity, block 100mm, plaster 13mm	1.02
Stone 610mm	1.68	Plaster 13mm, brick 102.5mm, plaster 13mm	1.76
		Plaster 13mm, brick 215mm, plaster 13mm	1.33
		Plaster, breeze block 100mm, plaster	1.58

Roof and Ceiling

The materials for the roof are also various. It is depending on the floor to which the room is located. If the room located in the intermediate floor, it will be low weight concrete roof and if it is in the last floor or only one floor case, the layers for the roof may contain ply wood, air space, and steel deck. The roof can have different layers. The HAP software contains the inbuilt roofing materials as in the case of wall material. Some of these materials include: air space, ply wood of different sizes, Built-up roofing, Wood siding, 22 gage steel deck, Slate, plasterboard.

Window and Door

Most of the heat transfer in the room through building envelops is through door and window. Almost all windows and doors are made up of glasses which have high U-value. So the designer should take care to the position of window and door so as not to direct in direction of maximum solar hat gain. The selection of window and door material is mostly depends on the overall heat transfer coefficien*t*. The overall heat transfer coefficient for some of window and door is given below **[16].**

Table 2.5: U-value for Window and Glass Materials

Windows with wood or PVC-U frames	**U-value W/m^{2}k**	**windows with metal frames**	**U-value W/m^{2}k**
Single	4.8	Single	5.7
Double	2.8	Double	3.4
Double, low-E glass	2.3	Double, low-E glass	2.8
Double, low-E glass, argon filled	2.1	Double, low-E glass, argon filled	2.6
Triple	2.1	Triple	2.6
Triple, low-E glass	1.7	Triple, low-E glass	2.1
Triple, low-E glass, argon filled	1.6	Triple, low-E glass, argon filled	2.0
Single glazed window with secondary Glazing doors		**U-value W/m^{2}k**	
Solid wood door to outside		3.0	
Solid wood door to unheated corridor		1.4	
Triple, low-E glass, argon filled		2.0	

2.2.2. Building Orientation

Building orientation is the sun's path about the buildings. It is one of the main factors in calculating the cooling load calculation. This highly determines solar gain characteristics of the building. The solar heat gains changes at various times of the day and the impact of those gains affect highly the load calculation. North, Northeast, East, Southeast, South, Southwest, West, Northwest or North are typically the orientations used for undertaking load calculations as shown below.

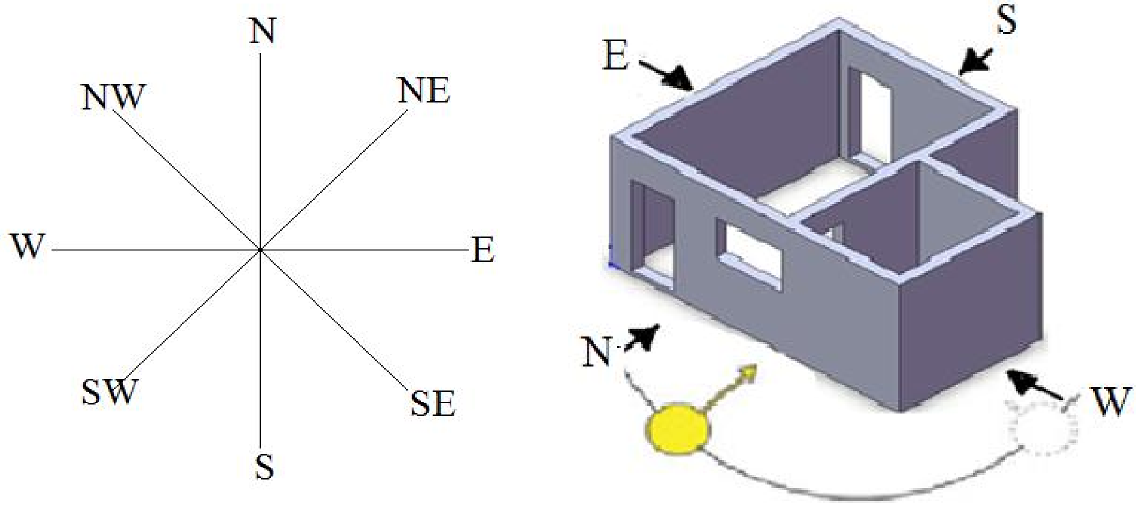

Figure 2.3: Orientations in Building AC Design for a Particular Room

On the figure first one is the compass or direction for orientation and the latter is the exposure. For example N shows the exposure for north orientation. Similarly all exposures for each and every orientation shown are in their opposite direction.

While designing a building from AC perspective, all orientations for given house must be considered. Often times, the peak cooling load for the worst case orientation is acceptable for system sizing; however, if there is a significant difference between loads at various orientations, system sizing may vary for the same house. The following figure shows the effect of orientation in a particular location **[3].**

Figure 2.4: Effects of Orientations in Cooling Load of Building AC Design for a Particular Room

From the figure it is clear that East orientation is best option for the cooling load design, this is due to is lower cooling load. Hence we will incur less cost for our HVAC equipments.

2.2.3. Building Location

The building location is described by its latitude and elevation. This location describes the values for the outdoor design conditions such as the elevation of the location, latitude, winter heating dry bulb temperatures, summer cooling dry bulb temperatures and relative humidity (RH) information.

2.2.4. Building Type

The type or purpose of the building also affects the air conditioning design. And also the type of the room has a vital effect. It may be of residential or commercial type. And the rooms may be for bed room, conference hall, office, shop, barber shop, medical applications etc. The standards in this paper are used for commercial purposes, such as office bed, room, conference hall, shop.

2.2.5. Internal Conditions Internal Loads

These include the number of occupants, area of the room, types and number of electrical equipments in the room, infiltration and ventilation, floor to which the room is located **[21].**

Table 2.6: Estimated Wattage for Common Appliances

Common Appliances			
Appliance	**Heating load (W)**	**Appliance**	**Heating load (W)**
Coffee pot (10 cup)	1200	VCR	40-60
Coffee pot (4 cup)	650	CD or DVD Player	35
Toaster	800-1500	Stereo	30-100
Cappuccino Maker	1250	Clock Radio	50
Coffee Grinder	100	AM/FM car cassette	8+
Blender	300	Satellite dish	30+
Microwave (600 to 1000 W cooking power)	1100-2000W (elec. consumption)	Vacuum cleaner	300-1100
Waffle iron	1200	Mini Christmas lights (50)	25
Hot plate	1200	Space Heater	1000-1500
Frying pan	1200	Iron	1000
Toaster Oven	1200	Washing machine	920
Blow dryer	900-1500	12" 3 speed table fan	230
Computer - laptop - pc & monitor - printer-inkjet	 50-75 200-400 60-75	TV - 25" color - 19" color TV or monitor - 12" b&w 13" color TV/VCR Combo	300 160 30 230

Refrigerator/Freezer	600	Game Console (X-Box)	100
Freezer	500-800	Furnace Fan (1/3hp)	1200
Tool		**Tools**	
Jig Saw	300	1/4" drill	250
Band Saw	1200	3/8" drill	500
Table Saw	1800	1/2" drill	750
6 1/2" circ. saw	1000	Shop Vac 5 hp	1000
7 1/4" circ. saw	1200+	Sabre Saw	500
8 1/4" circ. saw	1800	Portable Grinder	1380
Disc Sander	1200	Electric Chain Saw 14"	1200
Makita Chop Saw	1550	Airless Sprayer 1/2 hp	600
Makita Cut Off Saw	1000	Air Compressor 1 hp	2000

Chapter Three: AC Design and Simulation Software

Nowadays, there are lots of commercial softwares that used to calculate the heating and cooling loads easily and accurately. These softwares are used for various purposes such as, HVAC (Heating Ventilation and Air Conditioning) load calculations, building energy analysis, HVAC duct and pipe sizing, plumbing & lighting design, fault current calculations, voltage drops, fuse and breaker coordination, and much more. There are over 30 programs offered for such applications, some of these are the following.

3.1. Elite Software

It was founded in 1979; Elite Software has offered HVAC, electrical, plumbing, and fire protection design software longer than anyone else in the industry. (It is not free $295-$1495**).** It is the HVAC software that sets the standard for excellence and ease-of-use in the industry. Elite Software is a HVAC software development company almost as old as the computer industry itself. Its features include **[13]**:

Rhvac*:* - it is an easy and powerful load calculations and duct sizing software with $495. It calculates peak heating and cooling loads for residential and small commercial buildings. Besides calculating peak heating and cooling loads, Rhvac can also calculate the length of tubing needed for hydronic radiant floors. It also calculates duct sizes, as well as the static pressure loss of the duct system, showing the static pressure requirement of the system fan. Duct sizing options include all types of duct materials, height and width restrictions, velocity limits, and more. Additionally, Rhvac creates sales proposals and selects HVAC equipment. For equipment selection, Rhvac is provided thousands of equipment models from over 250 HVAC manufacturers. Standard air conditioners, heat pumps, furnaces, boilers, and ground source heat pumps are among the types of equipment Rhvac can select. The sales proposal feature of Rhvac prints key features of the proposed equipment and work to be performed. Also included are standard terms and conditions of the proposal. Rhvac shares data with Elite Software's Energy Audit operating cost analysis program, Ductsize, Quick Quote, and Drawing Board program. Rhvac can be used stand alone or in conjunction with any of these programs.

Chvac: - used to calculate ASHRAE based heating and cooling loads for commercial buildings. Chvac quickly and accurately calculates the maximum heating and cooling loads for commercial buildings. The program allows an unlimited number of rooms which can be grouped into as many as 100 air handling systems. Chvac automatically looks up all cooling load and correction factors necessary for computing loads. In addition, it can look up outdoor design weather data for over 2000 cities located around the world. There is also provision for editing the weather data as well as adding data for other cities. Comprehensive reports list the general project data, detailed room loads, air handler summary loads, outside air loads, total building loads, building envelope analysis, tonnage requirements, CFM air quantities, chilled water flow rates (if applicable), and complete psychrometric data with entering and leaving coil conditions. Other outstanding features include ASHRAE Standard 62 analysis, automatic building rotation, 360 degree wall orientations, tilted glass, exterior shading, internal operating load profiles, variable indoor design temperatures, people diversity, pretreated outside air, seasonal infiltration and ventilation rates, reheat loads, duct gains and losses, and return air plenums. It is best but not free soft ware.

Electrical Tools: - it is a very essential program for Electrical Engineers or designers that Performs common electrical calculation and data look-up tasks. These tasks include wire sizing, conduit sizing, motor equipment sizing, panel sizing, lighting requirements (in metric or English units), current to power conversion, Ohm's Law calculator, capacitor sizing, voltage drop, short circuit, and the quick look-up of many electrical formulas and conversion factors. Results are instantly displayed on the screen as data is entered.

Light: - The Elite Software Light Program quickly calculates the number of luminaries required for a desired average level of lighting in a room. Projects with as many as 10,000 rooms can be computed.

Fire: - Elite's Fire Program quickly performs all necessary hydraulic calculations as required by the National Fire Protection Association (NFPA 13). Fire also estimates sprinkler head requirements, calculates optimal pipe sizes, and automatically performs a peaking analysis. Fire can handle all types of sprinkler systems (trees, grids, and hybrids) with up to 1,000 or more sprinklers and pipes. Meters and standpipes can also be analyzed. Fire calculates the gpm (gallon per minute) water flow and velocity through all pipe sections, the gpm flow and residual pressure at each sprinkler head, the pressure losses incurred in each pipe section due to both friction and elevation changes, the maximum system demand pressure, and the total water gpm demanded by the system. The report format is designed to aid both the designer and the plan reviewer.

S-Pipe: - It has lots of built-in pipe and fitting data, plus the flexibility that let to enter one's own data, plus direct links with 32-bit Autodesk Building Systems and 32-bit AutoCAD MEP (Mechanical Electrical Plumbing). S-Pipe computes optimal pipe sizes for hot and cold water domestic water supply systems in both residential and commercial buildings. It can handle systems with virtually unlimited numbers of pipes. Besides computing pipe sizes, S-Pipe can also perform a system analysis complete with a bill of materials and labor estimate. Reports list the GPM water flow, velocity, and pressure losses through all pipe sections, the maximum system demand pressure, and the total water GPM demanded by the system.

3.2. Mechanical, Electrical & Plumbing (MEP) Engineering

This is also common in our country. It is Autodesk's comprehensive and used to design, simulate, and document complex building systems more accurately and efficiently even if it is not free **[19].**

Comfort Air: Comfort Air is a very useful program, which helps professionals working and dealing with cooling and heating systems. The program assists its users a great deal by providing useful heating and cooling information in easily understandable format. It is an important for such professionals as architects, interior designers and contractors because it provides reports in both summarized and in detailed form. It is free software [**10].**

3.3. HAP (Hourly Analysis Program)

Currently it is the commonly used commercial software throughout the world due to its many interesting features like being free application, international, hourly based analysis. It is also common package in our country and I have preferred to use it for my work on this paper. The details for this software will be discussed in the next chapter.

Chapter Four: Estimating the AC Requirements for Commercial Buildings in Ethiopia by Using HAP

4.1. Hourly Analysis Program (HAP) Software

As it was explained earlier when one talks about air conditioning, cooling load for the room is the main factor for design followed by dry –bulb temperature, relative humidity, air flow speed and the like. These factors vary from place to place according to the environmental temperature. Unless the room is designed to put these factors in the desired range they may not be comfortable for human activity. Hence in this chapter mainly the cooling load for representative locations of Ethiopia and different purpose buildings will be estimated with the help of HAP software.

HAP is a computer tool which assists engineers in designing HVAC systems for commercial buildings. HAP is two tools in one. First it is a tool for estimating loads and designing systems. Second, it is a tool for simulating energy use and calculating energy costs. This design software uses the ASHRAE-endorsed transfer function method for load calculations and detailed 8,760 hour-by-hour energy simulation techniques for the energy analysis. This program is released as two similar, but separate products**.** The "*HAP System Design Load*" program provides the system design and load estimating features. The full "*HAP*" program provides the same system design capabilities plus energy analysis features.

4.1.1. HAP Energy Analysis Features

HAP estimates annual energy use and energy costs for HVAC and non-HVAC energy consuming systems in a building by simulating building operation for each of the 8,760 hours in a year. Results of the energy analysis are used to compare the energy use and energy costs of alternate HVAC system designs so the best design can be chosen. Specifically, HAP performs the following tasks during an energy analysis:

- Simulates hour-by-hour operation of all heating and air conditioning systems in the building.
- Simulates hour-by-hour operation of all plant equipment in the building.

- Simulates hour-by-hour operation of non-HVAC systems including lighting and appliances.
- Uses results of the hour-by-hour simulations to calculate total annual energy use and energy costs. Costs are calculated using actual utility rate features such as stepped, time-of-day and demand charges, if specified
- Generates tabular and graphical reports of hourly, daily, monthly and annual data.

4.1.2. HAP System Design Features

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

- Calculates design cooling and heating loads for spaces, zones, and coils in the HVAC system.
- Determines required airflow rates for spaces, zones and the system.
- Sizes cooling and heating coils.
- Sizes air circulation fans.
- Sizes chillers and boilers.

4.2. Steps in Using HAP to Design Systems and Plants

The following steps show how to use HAP to design systems and plants.

a) Defining the Problem

First define the scope and objectives of the design analysis. For example, what type of building is involved?

b) Data Gathering

Before design calculations can be performed, information about the building, its environment and its HVAC equipment must be gathered. This step involves extracting data from building floor plans, evaluating building usage and studying HVAC system needs. Specific types of information needed include:

- Climate data for the building site.

- Construction material data for walls, roofs, windows, doors, exterior shading devices and floors, and for interior partitions between conditioned and non-conditioned regions.
- Building size and layout data including wall, roof, window, door and floor areas, exposure orientations and external shading features.
- Internal load characteristics determined by levels and schedules for occupancy, lighting systems, office equipment, appliances and machinery within the building.
- Data concerning HVAC equipment, controls and components to be used.

c) Data Entry in to HAP

Once the data is gathered, use HAP to enter climate, building and HVAC equipment data. When using HAP, the base of operation is the main program window. From the main program window, first create a new project or open an existing project. Then define the following types of data which are needed for system design work:

Weather Data

Weather data defines the temperature, humidity and solar radiation conditions the building encounters during the course of a year. These conditions play an important role in influencing loads and system operation. To define weather data, a city can be chosen from the program's weather database, or weather parameters can be directly entered. Weather data is entered using the weather input form.

Space Data

A ***space*** is a region of the building comprised of one or more heat flow elements and served by one or more air distribution terminals. Usually a space in HAP represents a single room. However, the definition of a space is flexible. For some applications, it is more efficient for a space to represent a group of rooms or even an entire building. To define a space, all elements which affect heat flow in the space must be described.

Space Elements include walls, windows, doors, roofs, skylights, floors, occupants, lighting, electrical equipment, miscellaneous heat sources, infiltration, and partitions. While defining a space, information about the construction of walls, roofs, windows, doors and external shading devices is needed, as well as information about the hourly schedules for internal heat gains. This construction and schedule data can be specified directly from the space input form (via links to the construction and schedule forms), or alternately can be defined prior to entering space data. Space information is stored in the project database and is later linked to zones in an air system.

Air System Data

An Air System is the equipment and controls used to provide cooling and heating to a region of the building. An air system serves one or more zones.

Zones are groups of spaces having a single thermostatic control. Examples of systems include central station air handlers, packaged rooftop units, packaged vertical units, split systems, packaged DX fan coils, hydraulic fan coils and water source heat pumps. In all cases, the air system also includes associated ductwork, supply terminals and controls. To define an air system, the components, controls and zones associated with the system must be defined as well as the system sizing criteria. This data is entered on the air system input form.

Plant Data (if necessary)

A plant is the equipment and controls used to provide cooling or heating to coils in one or more air systems. Examples include chiller plants, hot water boiler plants and steam boiler plants. This step is optional; it is only required if you are sizing chiller or boiler plants.

To define a plant for design purposes, the type of plant and the air systems it serves must be defined. This data is entered on the plant input form.

d) Generating Design Reports Using HAP

Once weather, space, air system and plant data has been entered, HAP can be used to generate system and plant design reports. To generate design reports, go to the main program window and select the desired air systems or plants. Next choose the “Print/View Design Data” menu bar option, toolbar button, or pop-up menu option. For systems this displays the System Design Reports form; for plants this displays the Plant Design Reports form. Select the desired report options on this form. If calculations are needed to supply data for these reports, the program will automatically run the calculations before generating the reports. If all the data needed for the reports already exists, reports are generated immediately.

e) Equipment Selection

Finally, using data from the reports generated, one can select the appropriate cooling and heating equipment from product catalogs or electronic catalog software. System and plant design reports provide information necessary to select all the components of the HVAC system including air handlers, packaged equipment, supply terminals, duct systems, piping systems and plant equipment.

4.3. AC Requirements for Commercial Buildings in Ethiopia by Using HAP

The step by step approaches done with this software for this project are summarized as follow.

4.3.1. Defining the Problem

In this project mainly the cooling load in w/m^2 for commercial buildings in representative areas of Ethiopia will be estimated. This cooling load should satisfy human comfort conditions like relative humidity, dry bulb temperature. Not only the cooling loads but also the heating loads will be estimated as a design even if they have no or rear applications in our country. Based on this, equipments like supply fan, space and zone data will be sized and Space required supply airflow rates in L/S will be estimated. The floor plan for different types of commercial buildings is obtained from the architects and some of these are attached at the back. For example the floor plan for Conference hall is shown in the figure below.

The buildings considered have different purposes which are, for hotel bed room, conference hall, bank lobby, shop, and office. The rooms vary, like at the ground floor, middle floor, roof floor and corner floor. The paper is done for representative areas of our country Ethiopia. These are Addis Ababa (moderate), Bahir-Dar (warm), Dire-Dawa (hot) and Semera (very hot). The standard is mainly applied for buildings specified above.

4.3.2. Data Gathering

This involves gathering data for the building, its environment and its air system data. These are as follows.

4.3.2.1. Weather Data

The weather data includes monthly maximum and minimum dry bulb and wet bulb temperatures, design DB temperatures for both summer and winter, summer coincident WB, winter coincident WB, region, location, city, latitude, longitude, elevation, and the sunshine hour, for the area of interests which are Addis Ababa, Bahir-Dar, Dire-Dawa and Semera, which are collected from the National Metrology Agency (NME).

Dry-bulb Temperature

The temperature of the air measured by the ordinary thermometer, when exposed to the atmosphere, is called as the dry bulb temperature of air, commonly referred as DBT. It is nothing but the atmospheric temperature. In this case the sensing bulb of one of the thermometers is always kept dry .The temperature reading of the dry bulb is called the dry-bulb temperature. . It is an important consideration when designing a building for a certain climate.

Wet-bulb Temperature

The wet bulb temperature of air is also measured by the ordinary thermometer, but the only difference is that the bulb of the thermometer is covered by the wet cloth (a piece of cotton wick). Temperature of the ordinary air measured by the thermometer when it is covered by wet cloth or wick is called as the wet bulb temperature, commonly referred to as WBT. When the air comes in contact with the wet cloth it absorbs some moisture and gives up some heat, to which the temperature of the air reduces. It is always less than DBT. The difference between the DBT and WBT is called as wet bulb depression. Unlike the DBT this indicates the amount of moisture in the air. See figure bellow.

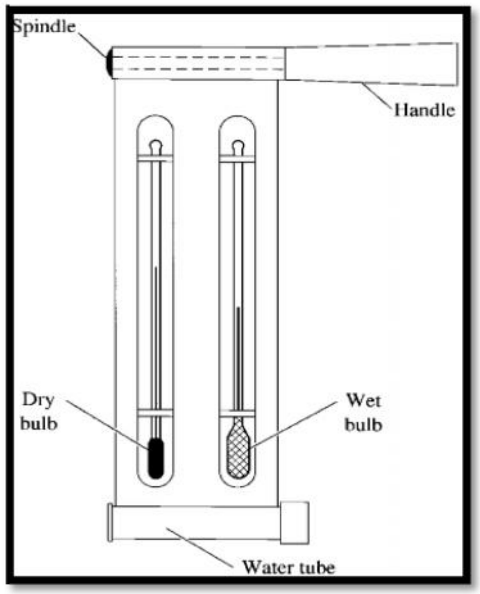

Figure 4.2: Thermometer for Dry-bulb and Wet-bulb

The maximum and minimum dry bulb temperatures as well as maximum and minimum wet bulb temperature are taken from the national metrology agency (NMA). The row data was hourly for each day of the 10 year. Then from that I have get the average values for each month and tabulated as shown in the table 4.1 below. This dry bulb and wet bulb temperature data will be entered in the software under Design Temperature.

Table 4.1: Maximum and Minimum Wet bulb and Dry bulb Temperature for Addis Ababa

Month/ Temp	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
(DB)Max	26.8	28.8	28.8	28.2	28.4	29.2	25.6	23.4	27.2	25.4	25.4	26.2
(DB)Min	10.8	12.6	11.6	12.4	12.4	11.0	10.0	11.2	11.2	12.2	12.6	11.0
(WB)Max	19.0	17.1	24.6	23.6	19.2	24.2	20.2	17.8	19.1	17.6	15.6	19.4
(WB)Min	3.0	6.1	6.8	9.2	9.2	10.4	9.5	9.8	10.6	7.2	6.2	6. 0

Dew Point Temperature of Air (DPT)

The dew point temperature of the air or DPT is the temperature at which the water vapor within the air at some temperature starts condensing. When the dew is formed the air is said to be in saturated condition.

When any object is cooled below the dew point temperature of the air, we can see the formation of sweat on its surface. A glass of water filled with chilled water is an example. The dew point temperature of air depends upon its moisture content. Higher the moisture content of the air, higher is the dew point temperature. For the saturated air, the dry bulb temperature, the wet bulb temperature and dew point temperature are the same.

The Relative Humidity

Humidity is the amount of water vapor in a given space. The humidity ratio or specific humidity is the weight of water vapor per unit weight of dry air; it is given in either grains per pound or pound per pound (kg/kg). The thermal effect of humidity on the comfort of sedentary persons is small, that is, comfort is maintained over a wide range of humidity conditions.

In winter, the body feels no discomfort over a range of RH from 50 percent down to 20 percent. In summer, the tolerance range extends even higher, up to 60 percent RH when the temperature is 24^0c; above that, the skin feels sweaty.

Nevertheless, some types of industrial applications, such as textile manufacturing, optical lens grinding, and food storage, maintain RH above 60 percent because of equipment, manufacturing processes, or product storage requirements. At the other extreme, certain pharmaceutical products, plywood cold pressing, and some other processes require an RH below 20 percent. Hospitals also must carefully control humidity since the level of bacteria propagation is lowest between 50 and 55 percent RH.

In general Human comfort requires the relative humidity to be in the range 25 - 60% RH**.** But it may vary depending on the type of applications to which the buildings are used.

Sun Shine Hour

The sunshine hour for Addis Ababa is obtained from the NMA for 10 consecutive years on hourly basis. Then I have calculated the daily value for each day of the 10 years data. Then I have calculated the average value the sunshine hours for each month as shown below.

Table 4.2: Sunshine Hours for Addis Ababa

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Sunshine Hr	8.82	8.50	8.30	8.00	8.02	7.68	7.22	6.86	6.77	7.01	7.29	7.55

The representation of DBT, WBT, DPT and RH for a certain room at a certain temperature (TDB) and pressure on psychometric chart will be represented as follow.

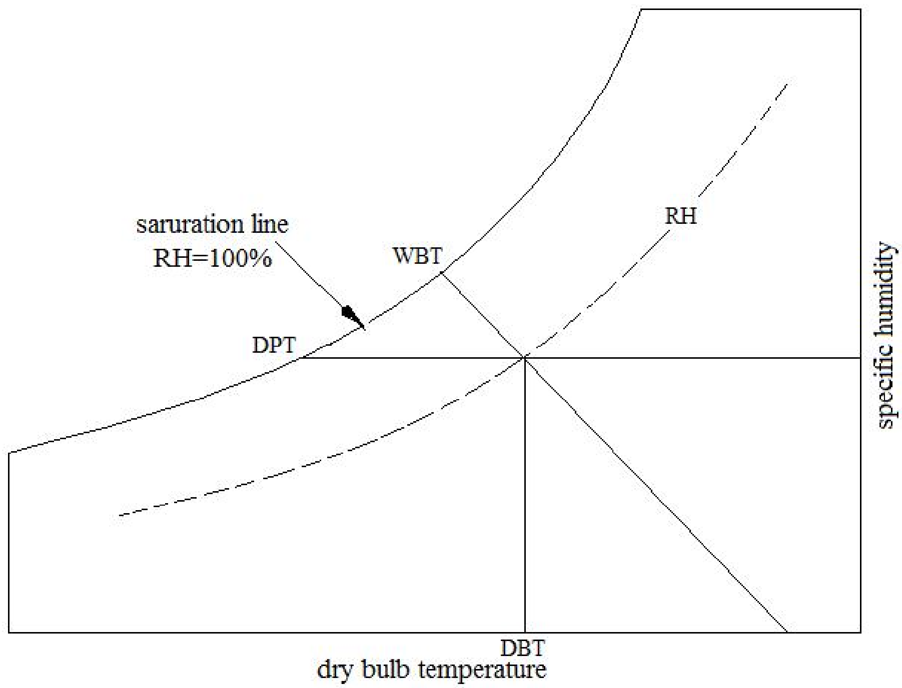

Figure 4.3: the Psychometric Representation of DBT, WBT, BPT and RH for a Certain Room

The design conditions from long term (10 years) hourly observations for different parts of Ethiopia are shown in the following tables. These show the outdoor air conditioning design conditions for different areas of Ethiopia for both cooling and heating load design [11].

So the values with maximum value of occurrence will be taken while designing. For example for cooling loads design the values under a frequency of occurrence of 2.5% will be taken and for heating load design that of 99.6% will be taken for the selected locations or case areas for this paper.

Table 4.3: Outdoor Design for Different Locations of Ethiopia for Cooling Load Design

	Location				Annual cumulative frequency of occurrence (%)											
					0.4				1				2.5			
Region	**City/Town**	**Latitude**	**Longitude**	**Elevation**	**DBT (^{0}C)**	**CWB (^{0}C)**	**DPT (^{0}C)**	**MDR**	**DBT (^{0}C)**	**CWB**	**DPT (^{0}C)**	**MDR**	**DBT (^{0}C)**	**CWB**	**DPT (^{0}C)**	**MDR**
Oromia	Adama	08^{0}55’N	38^{0}55’E	2485m	39.9	28.03	21.25	19.71	33.5	23.43	18.25	19.71	32.6	24.54	20.82	19.71
Addis Ababa	Addis Ababa	09^{0}02’N	39^{0}42’E	2355m	29	23.07	20.35	18.46	28.5	22.59	19.81	18.46	28	21.19	17.73	18.46
Benishangul-Gumuz	Assosa	10^{0}04’N	34^{0}32’E	1570m	35	22.86	14.56	22.84	34.5	21.7	14.16	22.84	34	22.94	17.02	22.84
Amhara	Bahirdar	11^{0}37’N	37^{0}10’E	1800m	33	21.48	14.72	23.59	32.6	19.73	11.3	23.59	32.2	21.09	14.52	23.59
Dire Dawa	Dire Dawa	09^{0}35’N	41^{0}45’E	1200m	38.5	25.88	19.8	20.31	38	27.4	22.75	20.31	37.6	25.99	20.53	20.31
Gambella	Gambella	08^{0}15’N	34^{0}34’E	514m	42.5	29.92	24.92	23.50	42	30.08	25.38	23.50	41.5	29.78	25.11	23.50
Somali	Gode	05^{0}57’N	43^{0}27’E	254m	39.6	34.78	33.13	17.89	39.2	33.94	32.1	17.89	38.7	33.33	31.44	17.89
Somali	Jijiga	09^{0}20’N	42^0 50’E	1609m	32.5	24.12	20.1	26.72	32.2	22.53	17.45	26.72	31.7	23.64	19.72	26.72
Tigray	Mekelle	13^{0}33’N	39^{0}30’E	2084m	30	27.97	27.18	18.95	29.8	27.48	26.57	18.95	29.4	27.28	26.44	18.95
Afar	semera	11^{0}30’N	41^0 12’E	633m	44.5	28.71	21.81	25.85	44	28.62	21.99	25.85	43.8	31.65	27.1	25.85

Note**:** DBT= Dry Bulb Temperature, CWB = Coincident Wet Bulb Temperature, DP= Dew Point Temperature, MDR = Mean Daily Range (K)

Table 4.4: Outdoor Design Conditions for Different Locations of Ethiopia

	Location				Annual cumulative frequency of occurrence (%)					
					99.6		99		97.5	
Region	**City/Town**	**Latitude**	**Longitude**	**Elevation**	**DBT (^{0}C)**	**CWB (^{0}C)**	**DBT (^{0}C)**	**CWB (^{0}C)**	**DBT (^{0}C)**	**CWB (^{0}C)**
Oromia	Adama	08055'N	38055'E	2485m	6	2.52	7.7	5.19	9.4	6.7
Addis Ababa	Addis Ababa	09002'N	39042'E	2355m	4.5	0.66	5	1.57	5.6	2.09
Benishangul-Gumuz	Assosa	10004'N	34032'E	1570m	8.4	4.92	9	5.62	10	5.4
Amhara	Bahirdar	11037'N	37010'E	1800m	3.5	0.54	4.1	1.33	5	2.77
Dire Dawa	Dire Dawa	09035'N	41045'E	1200m	11.1	8.14	12	9.32	12.8	9.9
Gambella	Gambella	08015'N	34034'E	514m	17	14.99	17.5	15.51	18.5	16.3
Somali	Gode	05057'N	43027'E	254m	17.3	14.11	18.5	14.5	19.6	16.29
Somali	Jijiga	09020'N	420 50'E	1609m	1	-0.16	2	0.2	3.5	1.84
Tigray	Mekelle	13033'N	39030'E	2084m	5	2.9	6	3.9	7.3	5.3
Afar	Semera	11030'N	410 12'E	633m	13.5	11.82	14.5	11.16	15.3	13.38

The monthly design maximum and minimum dry-bulb and wet-bulb temperatures for each location is also entered under design temperature column for each location **[11].**

Table 4.5: Monthly Maximum and Minimum Temperature Values for Different Locations

Month	Location										
	DBT	**Adama**	**Addis Ababa**	**Assosa**	**Bahirdar**	**Dire Dawa**	**Gambella**	**Gode**	**Jijiga**	**Mekelle**	**Semera**
January	Max. DBT (^{0}C)	30.1	26.67	33.28	29.53	31.91	40.90	37.70	30.25	26.16	34.62
	Min. DBT (^{0}C)	7.61	4.87	9.60	4.55	11.71	17.50	18.12	2.91	5.44	14.66
	MDR (^{0}C)	22.45	21.8	23.68	24.98	20.20	23.40	19.58	27.34	20.72	19.96
February	Max. DBT (^{0}C)	32.09	28.13	34.07	30.92	34.71	42.20	38.53	31.95	27.91	37.13
	Min. DBT (^{0}C)	10.11	6.27	10.93	6.26	12.17	18.60	19.32	3.85	6.99	15.86
	MDR (^{0}C)	21.98	21.86	23.14	24.66	22.54	23.60	19.21	28.11	20.92	21.27
March	Max. DBT (^{0}C)	32.71	28.62	34.53	32.16	36.65	43.00	39.29	32.44	28.42	40.30
	Min. DBT (^{0}C)	10.92	7.54	11.69	7.66	14.07	19.50	21.40	5.72	8.11	16.73
	MDR (^{0}C)	21.79	21.08	22.84	24.49	22.58	23.50	17.89	26.72	20.31	23.57
April	Max. DBT (^{0}C)	32.5	28.39	33.85	32.39	37.12	42.20	39.34	32.14	28.73	41.90
	Min. DBT (^{0}C)	12.42	9.55	13.17	8.80	16.42	21.20	21.64	8.60	9.65	18.30
	MDR (^{0}C)	20.08	18.84	20.68	23.59	20.70	21.00	17.70	23.54	19.08	23.60
May	Max. DBT (^{0}C)	33.38	28.46	32.29	31.89	38.17	39.50	36.97	31.74	29.66	43.84

	Min. DBT (^{0}C)	13.67	10.00	13.22	11.45	17.86	20.90	21.70	10.03	11.26	23.60
	MDR (^{0}C)	19.71	18.46	19.07	20.44	20.31	18.60	15.27	21.71	18.40	20.24
June	Max. DBT (^{0}C)	32.68	27.11	28.21	29.99	38.05	38.02	36.48	30.93	29.97	45.25
	Min. DBT (^{0}C)	12.99	9.60	14.15	12.06	17.60	19.90	22.67	11.98	11.02	22.35
	MDR (^{0}C)	19.69	17.51	14.06	17.93	20.45	18.12	13.81	18.95	18.95	22.90
July	Max. DBT (^{0}C)	29.54	24.36	26.59	26.67	36.85	36.50	35.56	30.36	27.06	45.55
	Min. DBT (^{0}C)	13.81	9.49	13.80	11.87	16.89	20.10	22.11	13.56	10.96	19.70
	MDR (^{0}C)	15.73	14.87	12.79	14.80	19.96	16.40	13.44	16.80	16.10	25.85
August	Max. DBT (^{0}C)	28.47	23.61	27.25	26.48	35.84	35.43	36.09	30.02	25.52	42.68
	Min. DBT (^{0}C)	13.61	9.54	13.70	12.01	16.92	19.30	22.04	12.78	11.10	18.48
	MDR (^{0}C)	14.86	14.07	13.55	14.46	18.92	16.13	14.04	17.24	14.42	24.20
September	Max. DBT (^{0}C)	29.46	24.244	27.74	26.92	35.69	36.07	37.16	30.58	26.36	42.93
	Min. DBT (^{0}C)	12.29	8.92	13.70	11.07	16.64	20.30	22.46	11.03	9.20	19.80
	MDR (^{0}C)	17.17	15.3222	14.04	15.85	19.04	15.77	14.70	19.55	17.16	23.13
October	Max. DBT (^{0}C)	29.7	25.8	28.77	27.95	35.53	37.67	37.36	30.09	26.19	40.25
	Min.	9.83	6.92	11.80	9.85	14.63	20.30	21.18	5.83	7.02	18.20

	DBT (^{0}C)										
	MDR (^{0}C)	19.87	18.8778	16.97	18.10	20.90	17.37	16.18	24.26	19.17	22.05
November	Max. DBT (^{0}C)	29.22	25.19	30.03	28.53	33.84	38.33	36.51	29.88	25.40	37.65
	Min. DBT (^{0}C)	9.31	4.26	9.98	5.27	12.44	18.17	18.60	3.11	6.99	17.20
	MDR (^{0}C)	19.91	20.93	20.05	23.26	21.40	20.17	17.91	26.76	18.41	20.45
December	Max. DBT (^{0}C)	28.7	25.7	31.25	28.59	31.78	38.73	36.78	30.26	25.23	35.20
	Min. DBT (^{0}C)	8.02	5.37	9.26	4.44	12.21	17.63	18.40	2.84	5.76	17.20
	MDR (^{0}C)	20.68	20.3333	21.99	24.14	19.56	21.10	18.38	27.42	19.46	18.00
Annual	Max. DBT (^{0}C)	33.38	28.5	34.53	32.39	38.17	43.00	39.29	32.44	29.97	45.55
	Min. DBT (^{0}C)	13.67	10.00	11.69	8.80	17.86	19.50	21.40	5.72	11.02	19.70
	MDR (^{0}C)	19.71	18.46	22.84	23.59	20.31	23.50	17.89	26.72	18.95	25.85

The annual temperature varies from location to location. Graphically it can be represent it as follow.

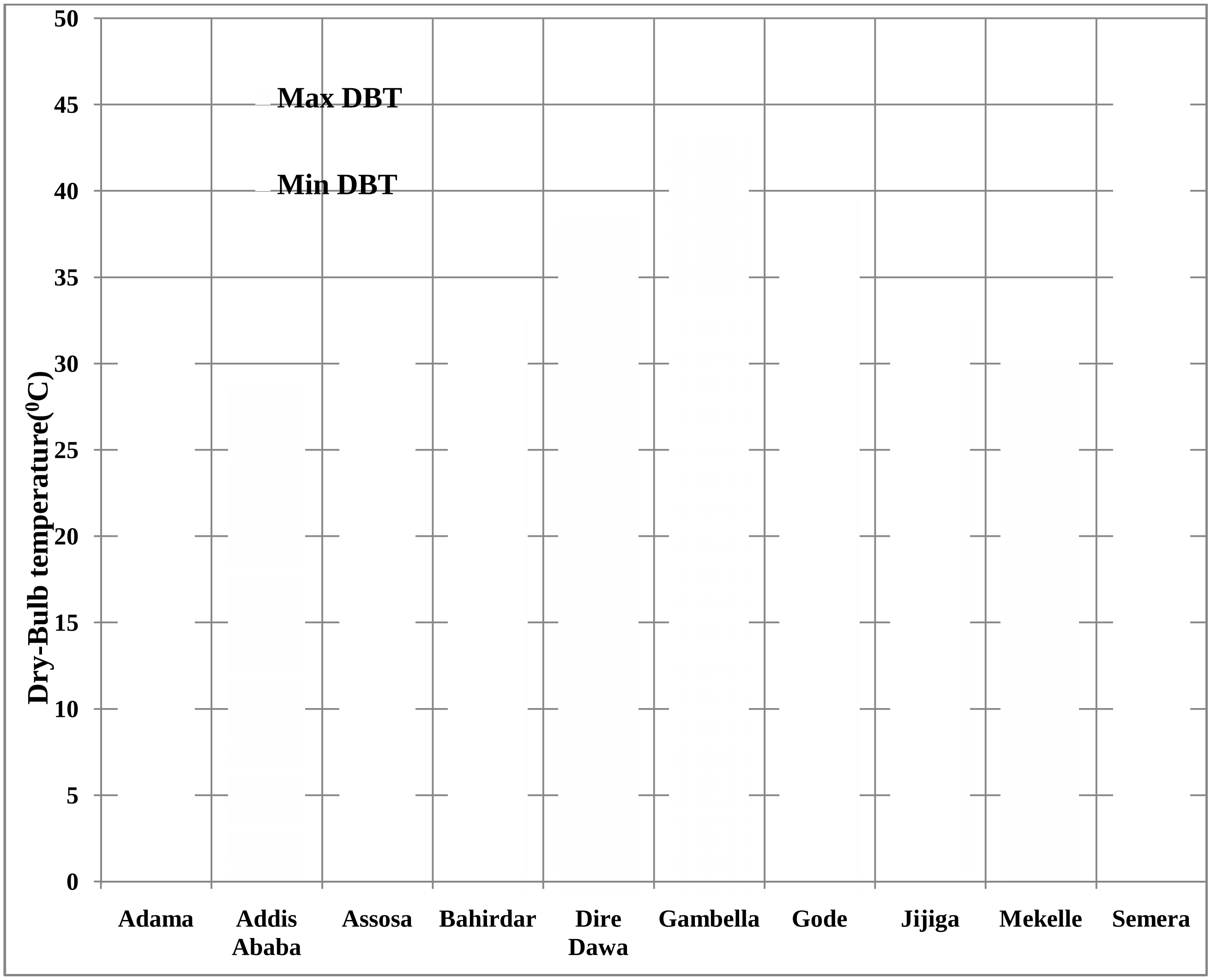

Figure 4.4: the Annual Maximum and Minimum DBT for Representative Locations of Ethiopia

Form these locations Addis Ababa, Bahr-Dar, Dire-Dawa, and Semera are selected for the design. These parts of the country represent the low temperature, warm temperature, hot and very hot regions of the country respectively.

These weather data including the minimum and maximum dry-bulb and wet-bulb temperatures are entered in to the software using the weather column as shown in the figure bellow for each of the five locations.

Figure 4.5: Weather Input Data for Addis Ababa

Then for each month, the weather parameters and the maximum solar heat gains from each orientation will be obtained from the software. The maximum solar heat gain varies from location to location, because it is a function of temperature and the temperature is varied depending on the geographical location.

Also the multiplying factor for the design day maximum solar heat gain depends on the presence of cloudy on the day. It can be taken as 1 for clear sky months and can be 0.75, 0.85 0.9 depending on the strength of the cloud.

The design parameters and the design day maximum solar heat gain for each month for the case of Addis Ababa and Semera are given in following figures.

Figure 4.7: The Design Parameters and Maximum Solar Heat Gain for Semera

Similarly for other locations we can have the weather data and solar heat gains after entering the data.

The following figure shows the design temperature profile for January specifically for Addis Ababa.

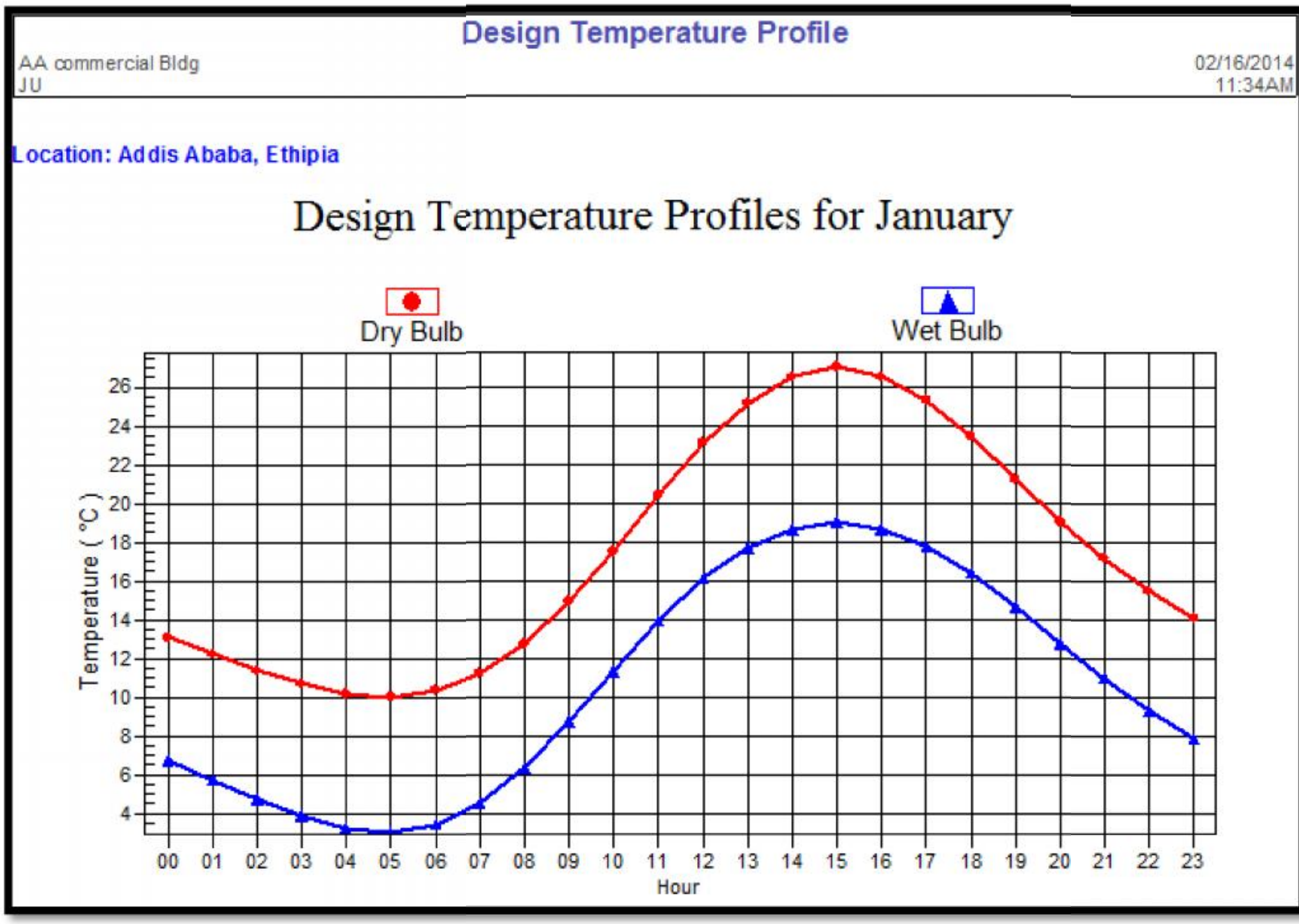

Figure 4.8: Design Temperature Profile Graph for Addis Ababa at January

4.3.2.2. Enter Space Data

There are a variety of spaces considered for this project and their characteristics were derived from architectural floor plans and professionals on that area and some of these informations are described below.

Walls**:** - In present day most parts of the walls are glasses which increase the need for air conditioning. In this project the size of the window in some room is taken to maximum size to consider the maximum heat transfer through the wall that is exposed to sun light. One common wall construction is used for all exterior wall types located in different locations. The construction consists of 13mm gypsum plaster finish, 102mm LW concrete block, and an air space. The exterior surface absorption can be dark, medium or light. But for this case it is taken to be the "Medium" category.

The overall U-value is 1.789W/m^2/k and the overall weight is 80.2kg/ m^2. And the different types of building orientation are considered.

Roofs: **-**There may be different roof types used while constructing different buildings. But I have taken the most commonly used roof types observation and by asking those professionals on that area. The roof type used is horizontal roof construction to enhance the position for air conditioning equipment. Hence the roof construction considered consists of built-up roofing, 22 gage steel deck, Air space, 16mm plywood.

The exterior surface absorption is in the "light" category. The overall U-value is 2.099W/m^2/k. The overall weight is 15.3kg/ m^2. The roof considered above is for the last floor roof, but if the room is at the intermediate floor or ground floor the roof may be concrete. In that case the property of concrete will be taken.

Windows & External Shading: - Windows of different size are used for different room types. The windows units' measures are 2mx1.2m, 1mx1.2m or 1.67mx0.6m and are double glazed with an aluminum frame. No internal Shades are used. These windows have a U-value of 3.685W/m^2/k and a shading coefficient of 0.82.

Doors: - Doors contain a single-glazing in an aluminum frame. The door unit's measures are 2.1mx1.5m, 2mx1.2m. Frame thickness of 3mm. These doors have a U-value of 1.703 W/m^2/k and a shading coefficient of 0.94.

Lighting: - Recessed, unvented lighting fixtures are used for all rooms in this commercial building. A lighting density of 32.29 W/m^2 is used. The fixture ballast multiplier is 1.0. And an electrical equipment of 8.75w/m^2 for bank is used.

Occupants: - The number of occupants varies by space. For example for conference hall it is taken to be 500, 2 people for bed room, 5 people for office, 70 people for bank lobby and 5 people for shop. For hotel bed room and conference hall a "seated at rest" activity level will be used (with sensible heat of 67.4w/m^{2}and latent heat of 35.2w/m^2) and for other applications "office work" activity level will be used (with sensible heat of 71.8w/m^{2}and latent heat of 60.1w/m^2).

Spaces: - Spaces are defined for different application of commercial buildings like; office, bank lobby, conference hall, hotel bed room, and shop are interred on the space column as shown below.

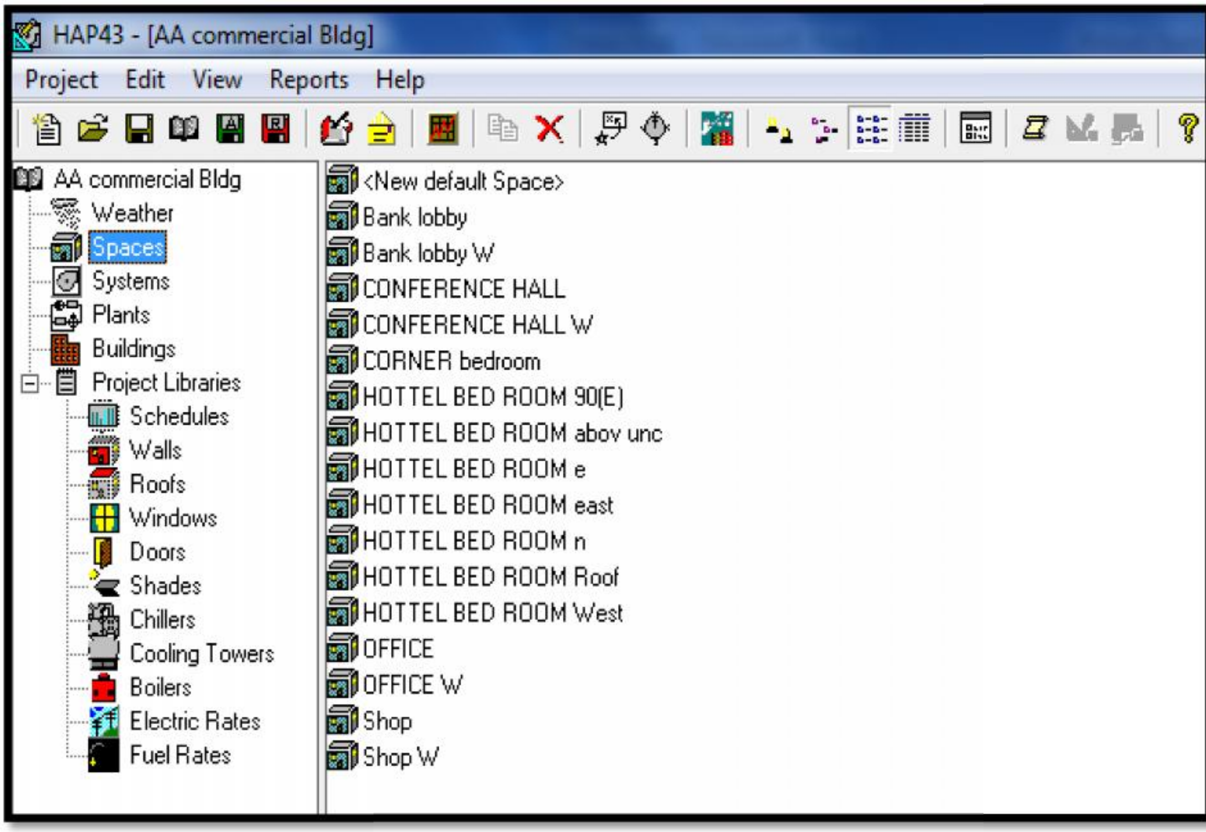

Figure 4.9: Defined Spaces in the HAP for the Case of AA Commercial Buildings

After entering the space data it will looks like the following.

Space Input Data

AA commercial Bldg
JU

02/26/2014
09:51PM

CONFERENCE HALL

1. General Details:
Floor Area .... **1200.0** m²
Avg. Ceiling Height .... **6.0** m
Building Weight .... **341.8** kg/m²

1.1. OA Ventilation Requirements:
Space Usage .... **OFFICE: Conference Rooms**
OA Requirement 1 .... **10.0** L/s/person
OA Requirement 2 .... **0.00** L/(s-m²)
Space Usage Defaults .... **ASHRAE Std 62-2001**

2. Internals:

2.1. Overhead Lighting:
Fixture Type .... **Recessed (Unvented)**
Wattage .... **32.29** W/m²
Ballast Multiplier **1.00**
Schedule .... **lighting schedule**

2.2. Task Lighting:
Wattage .... **0.00** W/m²
Schedule .... **None**

2.3. Electrical Equipment:
Wattage .... **4.17** W/m²
Schedule .... **Electrical**

2.4. People:
Occupancy .... **500.0** People
Activity Level .... **Seated at Rest**
Sensible .... **67.4** W/person
Latent .... **35.2** W/person
Schedule .... **t-stat**

2.5. Miscellaneous Loads:
Sensible .... **0** W
Schedule .... **None**
Latent .... **0** W
Schedule .... **None**

3. Walls, Windows, Doors:

Exp.	Wall Gross Area (m²)	Window 1 Qty.	Window 2 Qty.	Door 1 Qty.
N	150.0	4	2	2
E	60.0	0	0	2
SE	175.0	2	2	2
S	60.0	0	0	2
W	150.0	0	0	0
NW	40.0	2	0	0

3.1. Construction Types for Exposure N
Wall Type .... N wall
1st Window Type W1
2nd Window Type W2
Door Type D1

3.2. Construction Types for Exposure E
Wall Type .... N wall
Door Type D1

3.3. Construction Types for Exposure SE
Wall Type .... N wall
1st Window Type W1
2nd Window Type W2
Door Type D1

3.4. Construction Types for Exposure S
Wall Type .... N wall
Door Type D1

3.5. Construction Types for Exposure W
Wall Type .... N wall

3.6. Construction Types for Exposure NW
Wall Type .... N wall
1st Window Type W-1

4. Roofs, Skylights:

Exp.	Roof Gross Area (m²)	Roof Slope (deg.)	Skylight Qty.
H	1200.0	0	0

5. Infiltration:
Design Cooling .... 10.00 L/s
Design Heating .... 0.00 L/s
Energy Analysis .... 0.00 L/s
Infiltration occurs at all hours.

Figure 4.10: Space Input Data for Conference Hall at Addis Ababa

4.3.2.3. Air System Data

The air handling unit used in this case is chilled water air handling unit, and the air system is constant air volume single zone. The design is done for a single room then it will be applied to many rooms having the same conditions. The design supply temperature is taken to be 14.4 ^{0}c and 12.8 ^{0}c. All the data from A to C will be entered in to the HAP and the next step is to generate the design reports.

Generally there are two types of HVAC air systems. These are CAV (Constant Air Volume) and VAV (Variable Air Volume).

Constant Air Volume (CAV)

In a simple CAV system, the supply air flow rate is constant, but the supply air temperature is varied to meet the thermal loads of a space. Constant-volume, variable-temperature system consumes constant fan energy while providing refrigeration energy savings at part load. However, it can only deliver comfort to spaces with similar loads.

Most CAV systems are small, and serve a single thermal zone. However, variations such as CAV with reheat, CAV multi-zone, and CAV primary-secondary systems can serve multiple zones and larger buildings.

In small buildings and residences, CAV systems are often the system of choice due to simplicity, low cost, and reliability. Such small CAV systems often have on/off control, rather than supply air temperature modulation, to vary their heating or cooling capacities.

Variable Air Volume (VAV)

The simplest VAV system incorporates one supply duct that, when in cooling mode, distributes approximately (13 °C) supply air. Because the supply air temperature, in this simplest of VAV systems, is constant, the air flow rate must vary to meet the rising and falling heat gains or losses within the thermal zone served.

There are two primary advantages to VAV systems over constant-volume systems. The fan capacity control, especially with modern electronic variable-speed drives, reduces the energy consumed by fans, which can be a substantial part of the total cooling energy requirements of a building. Dehumidification is greater with VAV systems than it is with constant-volume systems, which modulate the discharge air temperature to attain part load cooling capacity. And also these systems have low operating cost.

4.3.3. Use HAP to Generate Design Reports

The design reports includes system sizing summary, zone sizing summary, system load summary, zone load summary, space load summary, hourly system and zone loads and system psychometrics for each and every space or room types in each locations. For example the system sizing summary, zone sizing and system psychometric for conference hall at Semera are shown below.

Air System Sizing Summary for CONFERENCE HALL

Project Name: Semera commercial bldg
Prepared by: JU

12/16/2013
05:42PM

Air System Information

Air System Name	CONFERENCE HALL		Number of zones	1	
Equipment Class	CW AHU		Floor Area	1200.0	m²
Air System Type	SZCAV		Location	Semera, Ethiopia	

Sizing Calculation Information

Zone and Space Sizing Method:

Zone L/s	Peak zone sensible load	Calculation Months	Jan to Dec
Space L/s	Individual peak space loads	Sizing Data	Calculated

Central Cooling Coil Sizing Data

Total coil load	563.5	kW	Load occurs at	Jun 1400	
Sensible coil load	315.6	kW	OA DB / WB	42.5 / 31.6	°C
Coil L/s at Jun 1400	18873	L/s	Entering DB / WB	29.3 / 22.2	°C
Max block L/s	18873	L/s	Leaving DB / WB	14.4 / 13.8	°C
Sum of peak zone L/s	19866	L/s	Coil ADP	12.7	°C
Sensible heat ratio	0.560		Bypass Factor	0.100	
m²/kW	2.1		Resulting RH	50	%
W/m²	469.6		Design supply temp.	14.0	°C
Water flow@ 5.6 °K rise	24.28	L/s	Zone T-stat Check	1 of 1	OK
			Max zone temperature deviation	0.0	°K

Central Heating Coil Sizing Data

Max coil load	58.0	kW	Load occurs at	Des Htg	
Coil L/s at Des Htg	18873	L/s	W/m²	48.3	
Max coil L/s	18873	L/s	Ent. DB / Lvg DB	19.1 / 21.8	°C
Water flow@ 11.1 °K drop	1.25	L/s			

Supply Fan Sizing Data

Actual max L/s	18873	L/s	Fan motor BHP	18.08	BHP
Standard L/s	17499	L/s	Fan motor kW	13.48	kW
Actual max L/(s-m²)	15.73	L/(s-m²)	Fan static	500	Pa

Outdoor Ventilation Air Data

Design airflow L/s	5000	L/s	L/s/person	10.00	L/s/person
L/(s-m²)	4.17	L/(s-m²)			

Figure 4.11: System Sizing Summary for Conference Hall at Semera

Thus the all the reports for this project with different cases will be discussed in detail in the next chapter. Here one can try to observe the effect of parameters like building orientation, room type, room location, and the geographical location on air conditioning design.

Zone Sizing Summary for CONFERENCE HALL

Project Name: Semera commercial bldg
Prepared by: JU

12/16/2013
05:45PM

Air System Information

Air System Name .... CONFERENCE HALL
Equipment Class .... CW AHU
Air System Type .... SZCAV

Number of zones 1
Floor Area .... 1200.0 m²
Location .... Semera, Ethiopia

Sizing Calculation Information

Zone and Space Sizing Method:

Zone L/s .... Peak zone sensible load
Space L/s .... Individual peak space loads

Calculation Months .... Jan to Dec
Sizing Data .... Calculated

Zone Sizing Data

Zone Name	Maximum Cooling Sensible (kW)	Design Air Flow (L/s)	Minimum Air Flow (L/s)	Time of Peak Load	Maximum Heating Load (kW)	Zone Floor Area (m²)	Zone L/(s-m²)
Zone 1	208.9	18873	18873	Jun 1400	29.4	1200.0	15.73

Zone Terminal Sizing Data

No Zone Terminal Sizing Data required for this system.

Space Loads and Airflows

Zone Name / Space Name	Mult.	Cooling Sensible (kW)	Time of Load	Air Flow (L/s)	Heating Load (kW)	Floor Area (m²)	Space L/(s-m²)
Zone 1							
CONFERENCE HALL	1	208.9	Jun 1400	18873	29.4	1200.0	15.73

Figure 4.12: System Sizing Summary for Conference Hall at Semera

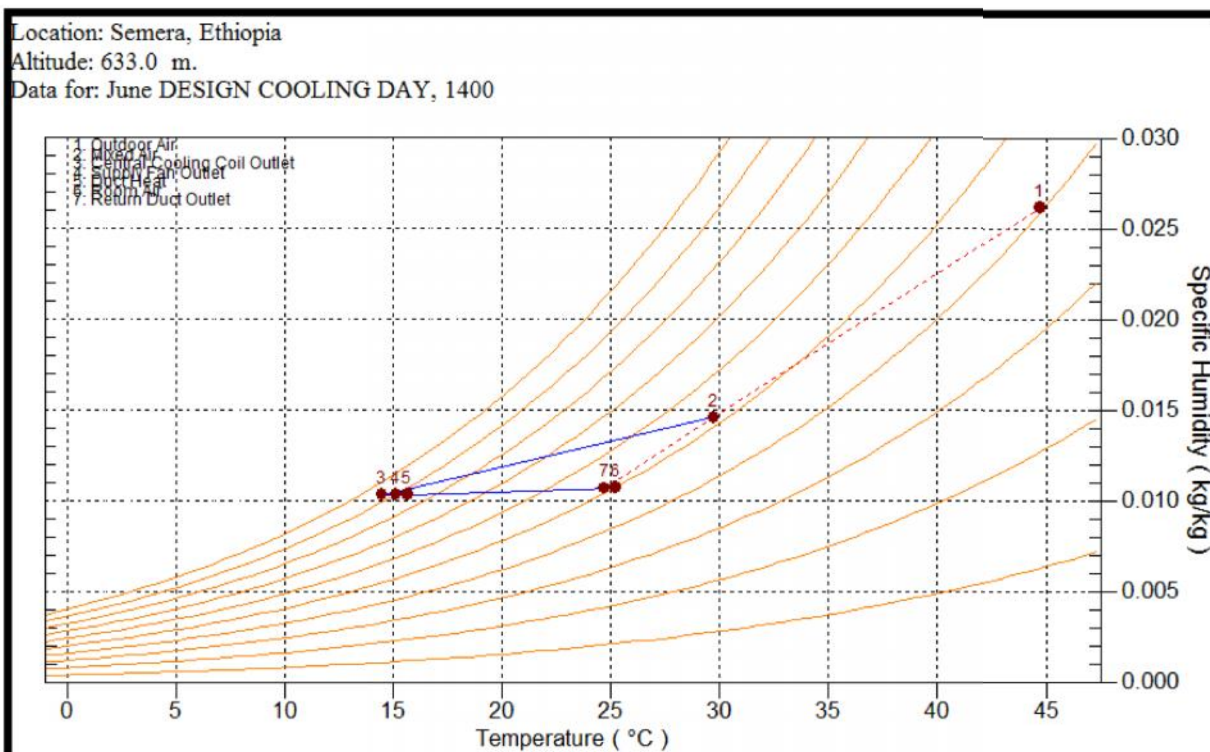

Figure 4.13: System Psychometric Chart for Conference Hall at Semera

4.3.4. Select Equipment

This is the final step in the design process in which the system design reports are used to select HVAC equipment.

From the design report we will get system sizing data and zone sizing data. The System Sizing Summary report contains data used to select the packaged rooftop unit. The Central Cooling Coil Sizing Data table lists the peak coil capacities, coil entering and leaving conditions and a number of useful check figures. The Preheat Coil Sizing Data table lists the peak load for this coil as well as entering and leaving conditions. The Supply Fan Sizing Data table provides the required airflow rates and motor data for the supply fan. Together this data can be used in packaged rooftop unit selection software offered by Carrier and other manufacturers to select a rooftop unit which meets the sizing requirements.

The Zone Sizing Summary report contains data used to select terminal equipment. The Zone Sizing Data table lists the required airflow rate for each zone terminal. It also lists the minimum airflow rate which can be used to set minimum damper positions for the mixing boxes. The Zone Terminal Sizing Data table lists the required sizes for the parallel mixing box fans and the reheat coils. The Space Loads and Airflows table lists the required airflows for each space served by the system. This data can also be used in duct design calculations to size ductwork for the system. But the equipment selection is beyond the scope of this paper.

Chapter Five: Findings and Discussions

5.1. Findings

The air conditioning parameters for commercial buildings can be specified by considering different cases. These parameters are different for different geographical locations of the country.

Addis Ababa, Bahir-Dar, Dire-Dawa and Semera are the selected regions of the country which represent the rest areas as well. Addis Ababa with annual dry bulb temperature of 28^oc represents the moderate temperature areas like Mekele (29.4^oc). Bahir-Dar (32.2^oc) represents the warm temperature areas like Adama ($32.6\ ^oc$), Jigjiga (31.7^oc), Assosa (34^oc), and Hawassa (31^oc). Dire-Dawa (37.6^oc) represents the hot areas like Gode (38.7^oc) and finally Semera represents the very hot areas like Gambela (41.5^oc).

The outputs from the HAP (hourly analysis program) software are illustrated as follow for different cases and for different locations. It is shown the results for different countries or locations and different room applications as well as for rooms at different floor levels of the buildings. And also the design is done at different building orientations to see its effect on cooling load hence the orientation with lower cooling load will be recommended.

5.1.1. North Orientation

The building may be either north, east or west oriented. But most existing buildings are either north or west oriented, even if there are also other oriented buildings. In the north orientation the building is assumed to face to north direction. That is the envelopes with higher heat transfer are faced to north. For example door and window or wall (if some parts of the external wall for the building are composed of glass), are assumed to be faced due north. And the cases for each room type will be discussed individually as follow.

a) Hotel Bed Room

There may be various bedrooms may be in terms of area, orientation, materials for envelope and others. But the room considered represents most of the existing rooms and has the following parameters. The same thing is done for other rooms also.

- Number of people =2

- Room area A =34.3m^2 (area of most existing bed rooms)
- Average ceiling height =2.8m (used for most existing bed rooms)
- Room location is *at* intermediate floor (the floor at the middle floor of the building**)**
- Building orientation North
- Coil bypass=0.1(the property of the air conditioning system)

Then these parameters are used to design the room air conditioning by the help of HAP software. Hence the outputs HAP for air conditioning design parameters are given in the following table for different geographical locations.

Table 5.1 AC Design Parameters for *Bedroom* at Different Locations of Ethiopia

Parameter/Location	**A/A**	**B/DAR**	**DIRE**	**SEMERA**
Air System Information				
Equipment Class	FCUAH	FCUAHU	FCU AHU	FCU AHU
Air System Type	SZCAV	SZCAV	SZCAV	SZCAV
Central Cooling Coil Sizing Data				
Total coil load (kw)	3.3	3.6	5.1	6.9
W/m²	96.2	104.8	149.2	199.8
OA DB / WB (^{0}C)	29.2/24.2	31.9 / 26.2	37.0 / 26.0	44.6 / 31.4
Entering DB / WB (^{0}C)	24.9/17.7	24.9 / 17.5	25.1 / 18.1	25.3/ 17.9
Leaving DB / WB (^{0}C)	15.0/14.3	13.5 / 12.8	15.0 / 14.4	13.7 / 13.0
Coil ADP (^{0}C)	13.2	12.3	13.9	12.8
Resulting RH	50%	48%	51%	49 %
Design supply temp(^{0}C)	12.8	14.4	14.0	12.8
Central Heating Coil Sizing Data				
Max coil load (kw)	2.0	2.0	0.8	0.4
Max coil L/s	279	333	430	408
W/m²	57.2	58.4	21.9	11.9
Supply Fan Sizing Data				
*Actual max L/s	242	319	430	408

Standard L/s	182	256	372	378
Outdoor Ventilation Air Data				
Design airflow L/s	15	15	15	15
L/s/person	7.5	7.5	7.5	7.5
L/(s-m²)	0.44	0.44	0.44	0.44
Zone Sizing Data				
Maximum cooling sensible (KW)	2.8	2.9	4.4	5.4
Maximum heating load (KW)	1.9	2.2	0.7	0.4
Space Loads and Airflows				
Cooling sensible (KW)	2.8	2.9	4.4	5.4
Heating load (KW)	1.9	2.2	0.7	0.4

*actual max L/s=space air flow L/s =zone design air flow L/s= Max block L/s cooling

OA= outdoor air, ADP=apparatus dew point

The system psychrometry can also be obtained for different locations. In the following two figures it is shown for bed rooms in Addis Ababa and Semera. For the case of Addis Ababa it is observed from the figure that the temperature of the air is reduce from 27^0c at outside to 25 ^{0}c inside the room with a relative humidity of 50% which is within the range of human comfort as described in the litrature. To do so the required cooling load is 96.2w/m^2. For the case of Semera air DT temperature is reduced from 45^0c at outside to 25.3^0c inside the room with the relative humidity value of 59%. To get this the design cooling load is 199.8w/m^2.

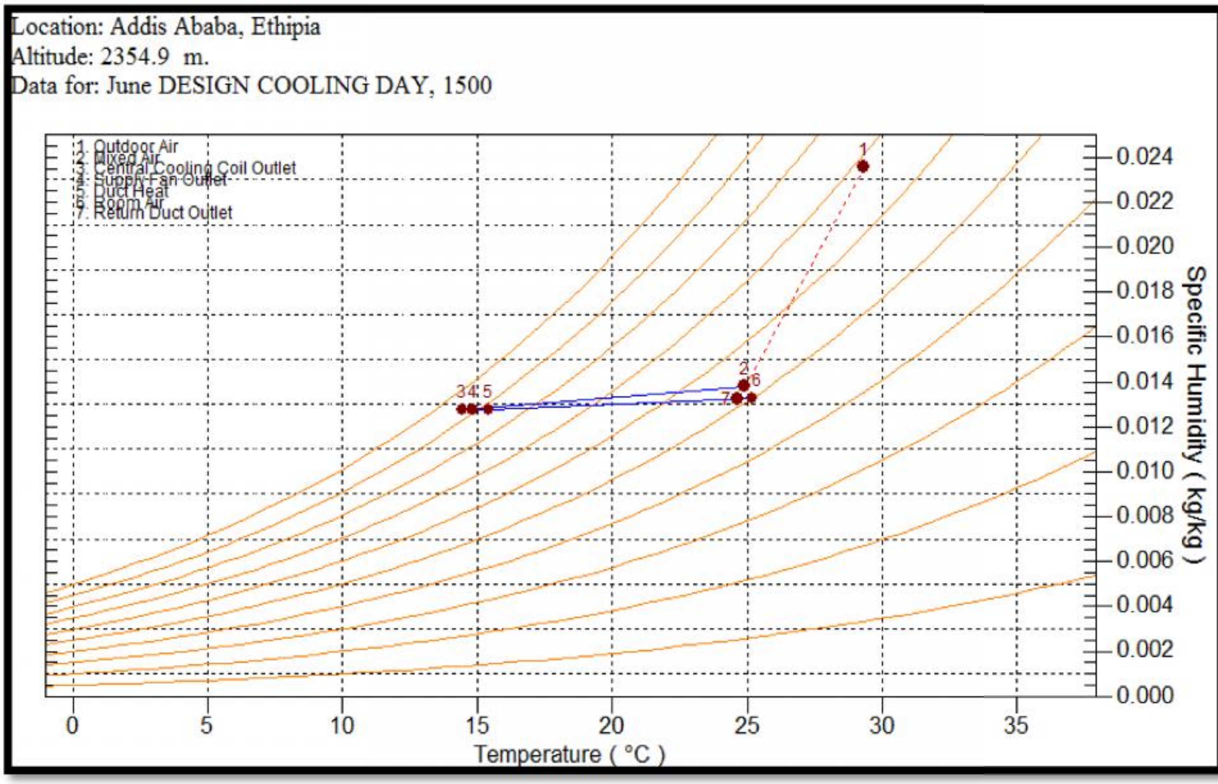

Figure 4.14: System Psychometric Chart for Hotel Bedroom at Addis Ababa

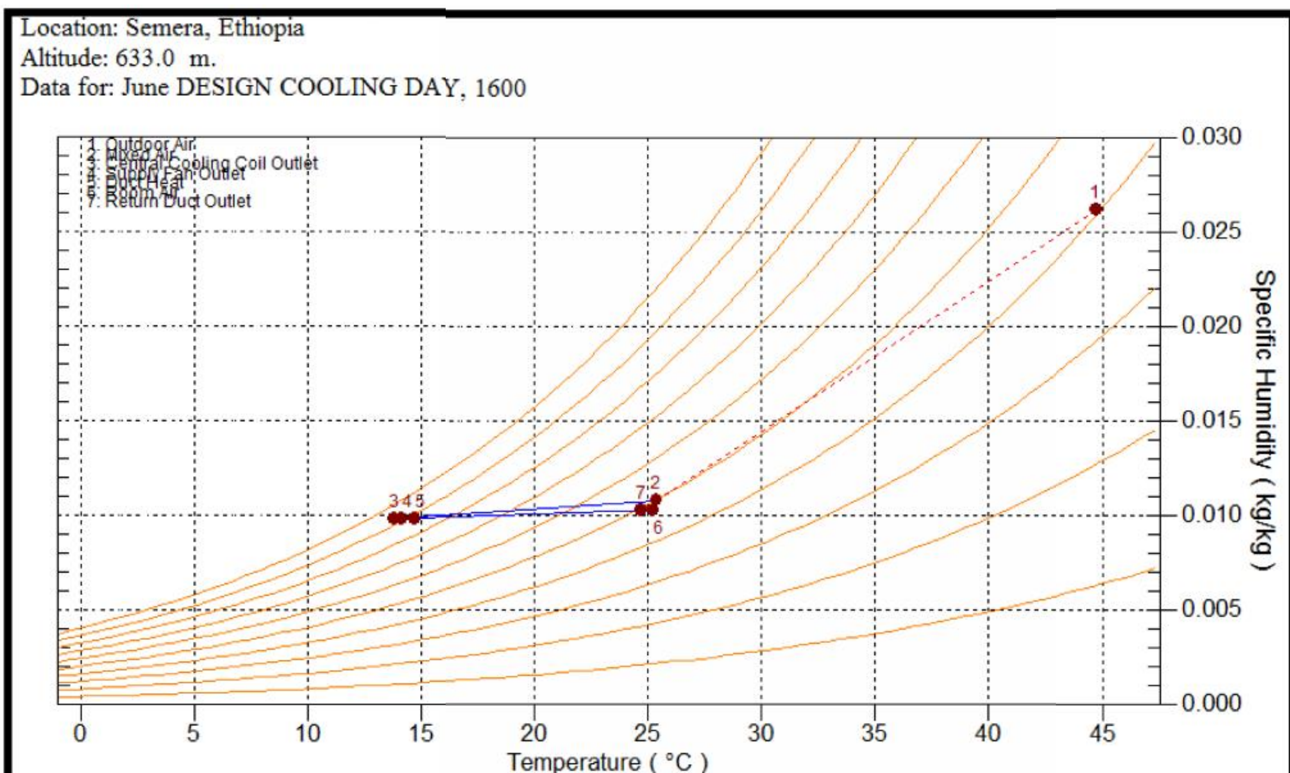

Figure 4.15: System Psychometric Chart for Hotel Bedroom at Semera

Similarly to bedroom the system psychometric chart for all types of rooms can also be plotted for all locations.

b) Conference Hall

Similar to the case of hotel bedroom conference hall can also be varied based on different parameters like number of populations, room area, orientation and the like. The one taken here is the most commonly observed and existing. The floor plan is at the appendix. The effect of number of population and room area will be discussed latter.

- Room area A = 1200m^2
- Average ceiling height =5m
- Number of people=500
- Building **orientation *North***
- Equipment Class FC AHU, Air System Type SZCAV

Table 5.2 AC Design Parameters for Conference Hall at Different Locations

Parameter/Location	**A/A**	**B/DAR**	**DIRE DAWA**	**SEMERA**
Central Cooling Coil Sizing Data				
Total coil load (KW)	318.6	365.0	391.9	563.5
W/m²	265.5	304.2	326.6	469.6
OA DB / WB (^{0}C)	28.3/ 24.2	31.7 / 26.3	36.4 / 25.9	42.5 / 31.6
Entering DB / W (^{0}C)	25.6/ 19.5	26.7 / 20.5	27.7 / 20.0	29.2 / 22.2
Leaving DB / WB (^{0}C)	4.9 / 14.4	15.0 / 14.4	14.4 / 13.7	14.4 / 13.8
Coil ADP (^{0}C)	13.7	13.7	12.9	12.7
Resulting RH	52%	52%	50%	50%
Design supply temp(^{0}C)	14.0	14.0	14.0	14.0
Central Heating Coil Sizing Data				
Max coil load (KW)	128.6	145.7	76.3	58.0
Max coil L/s	19292	18022	18861	18873
W/m²	107.2	121.4	63.6	48.3

Zone Sizing Data				
Maximum cooling sensible (KW)	172.9	173.0	194.9	208.9
Maximum heating load (KW)	66.6	70.7	40.1	29.4
Space Loads and Airflows				
Cooling sensible (KW)	172.9	173.0	194.9	208.9
Heating load (KW)	66.6	70.7	40.1	29.4

The cooling load is increasing as the dry bulb temperature for the area is increasing. The relative humidity is within the comfort range, hence the design is safe. That is the equipment having this capacity will be selected.

c) bank lobby

- Area of bank lobby A = $70m^2$
- Average ceiling height =3.5m
- Number of people=70
- Building **orientation *North***
- Coil bypass=0.1 Equipment Class CW AHU Air System Type SZCAV

Table 5.3 AC Design Parameters for Bank Lobby at Different Locations

Parameter/Location	**A/A**	**B/DAR**	**DIRE DAWA**	**SEMERA**
Central Cooling Coil Sizing Data				
Total coil load (KW)	36.8	44.1	46.5	67.0
W/m^2	525.2	629.8	664.2	956.6
OA DB / WB (^0C)	28.3 / 24.2	32.2 / 26.5	36.4 / 25.9	43.2 / 31.7
Entering DB / WB (^0C)	25.7 / 19.8	26.9 / 20.7	28.0 / 20.1	29.9 / 22.5
Leaving DB / WB (^0C)	14.0 / 13.6	13.8 / 13.3	13.3 / 12.7	13.7 / 13.2
Coil ADP (^0C)	12.8	12.3	11.7	11.9
Resulting RH	52%	52 %	49%	50%
Design supply temp(^0C)	12.8	12.8	12.8	12.8
Central Heating Coil Sizing Data				
Max coil load (KW)	15.3	17.4	9.6	7.4

Max coil L/s	1668	1796	1911	2017
W/m²	216.5	247.9	136.9	105.9
Zone Sizing Data				
Maximum cooling sensible (KW)	18.7	19.3	22.1	25.0
Maximum heating load (KW)	7.8	8.5	4.4	3.2
Space Loads and Airflows				
Cooling sensible (KW)	18.7	19.3	22.1	25.0
Heating load (KW)	7.8	8.5	4.4	3.2

Since the internal loads and the population taken are higher other rooms, the cooling load is also higher. And also the relative humidity for each location is within the comfort range

d) Office

- Room location is at ***intermediate floor***
- Room area A = 51.6m^2
- Average ceiling height =2.8m
- Number of people=5
- Building ***orientation North*** and Air System Name Office

Table 5.4: AC Design Parameters for Office at Different Locations

Parameter/Location	**A/A**	**B/DAR**	**DIRE DAWA**	**SEMERA**
Central Cooling Coil Sizing Data				
Total coil load (KW)	5.5	6.9	8.8	11.8
W/m²	106.6	132.9	171.3	227.9
OA DB / WB (^{0}C)	29.2/24.2	31.9/26.2	37.0 / 26.0	42.5 / 31.6
Entering DB / WB (^{0}C)	25.1/ 18.3	25.4 / 18.5	25.6 / 18.0	26.0 / 18.8
Leaving DB / WB (^{0}C)	14.4/ 3.8	14.3 / 13.7	13.8 / 13.1	13.7 / 13.1
Coil ADP (^{0}C)	13.2	13.1	12.5	12.4
Resulting RH	51 %	51%	48 %	48 %
Design supply temp(^{0}C)	12.8	12.8	12.8	12.8

Central Heating Coil Sizing Data				
Max coil load (KW)	3.6	3.8	1.5	0.9
Max coil L/s	394	446	576	627
W/m²	69.1	74.4	29.7	18.1
Zone Sizing Data				
Maximum cooling sensible (KW)	4.0	4.8	6.7	7.8
Maximum heating load (KW)	3.1	3.3	1.2	0.7
Space Loads and Airflows				
Cooling sensible (KW)	4.0	4.8	6.7	7.8
Heating load (KW)	3.1	3.3	1.2	0.7

These results are specific for the above conditions. To take for the applications other than the above conditions, there is some change. For example if the area is increased the cooling load will decrease, if the number of people inside the room is increase, the cooling load will also increase.

e) Shop

The floor plan for the shop is also at the back of the paper. This room is considered to be super market. The number of people may be higher or lower than this.

- Room location is at ***intermediate floor***
- Area of shop A = 15m^2
- Average ceiling height =3m
- Number of people=5
- Building **orientation *North***

Table 5.5 AC Design Parameters for Shop at Different Locations

Parameter/Location	**A/A**	**B/DAR**	**DIRE DAWA**	**SEMERA**
Central Cooling Coil Sizing Data				
Total coil load (kw)	3.7	4.3	5.3	7.2
W/m²	243.8	289.3	350.8	482.4
OA DB / WB (^{0}C)	27.4/ 21.2	31.9/26.2	37.0 / 26.0	43.2 / 31.7
Entering DB / WB (^{0}C)	25.2/ 18.2	25.9 / 19.5	26.3 / 18.7	27.0/ 20.0
Leaving DB / WB (^{0}C)	14.3/ 13.6	14.2 /13.6	13.8 / 13.1	13.7 / 13.1
Coil ADP (^{0}C)	13.1	12.9	12.4	12.2
Resulting RH	52%	52%	49%	51%
Design supply temp(^{0}C)	12.9	12.8	12.8	12.8
Central Heating Coil Sizing Data				
Max coil load (kw)	1.7	2.0	0.9	0.6
Max coil L/s	221	231	291	311
W/m²	112.7	131.0	59.2	39.0
Zone Sizing Data				
Maximum cooling sensible (KW)	2.0	2.4	3.2	3.7
Maximum heating load (kw)	1.2	1.3	0.6	0.4
Space Loads and Airflows				
Cooling sensible (kw)	2.0	2.4	3.2	3.7
Heating load (kw)	1.2	1.3	0.6	0.4

Similar to the above cases the cooling load is highest for Semera.

5.1.2. West orientation

In the west orientation the building is assumed to face in the west direction. That is the envelopes with higher heat transfer are faced to west. For example doors, windows or wall with glass material are assumed to be faced due west. And the cases for each room type will be discussed individually as follow. The specifications for the room used in the north orientation are also used here to compare the effect.

a) Hotel bedroom

The same room as in the north orientation is considered to see the difference (A =34.3m^2 and for 2 people)

Table 5.6: AC Design Parameters for Bedroom at Different Locations

Parameter/Location	**A/A**	**B/DAR**	**DIRE DAWA**	**SEMERA**
Central Cooling Coil Sizing Data				
Total coil load (kw)	4.2	4.5	5.7	7.1
W/m²	122.4	130.1	165.6	206.0
OA DB / WB (^{0}C)	27.4 / 21.1	31.7 / 26.3	37.0 / 25.9	42.5 / 31.6
Entering DB / WB (^{0}C)	24.7 / 17.1	24.8 / 17.2	25.0 / 18.0	25.2 / 18.0
Leaving DB / WB (^{0}C)	14.3 / 13.6	13.5 / 12.8	15.0 / 14.3	13.8 / 13.1
Coil ADP (^{0}C)	13.1	12.3	13.9	12.6
Resulting RH	49%	47%	51%	48%
Design supply temp(^{0}C)	12.8	14.4	14.0	12.8
Central Heating Coil Sizing Data				
Max coil load (kw)	2.0	2.0	0.8	0.4
Max coil L/s	320	427	486	456
W/m²	56.3	58.2	22.7	11.7
Zone Sizing Data				
Maximum cooling sensible (KW)	3.2	3.9	5.0	5.7
Maximum heating load (kw)	1.9	2.1	0.7	0.4
Space Loads and Airflows				
Cooling sensible (kw)	3.7	3.9	5.0	5.7
Heating load (kw)	1.9	2.1	0.7	0.4

Cleary the cooling load for west orientation is higher than for north orientation. For example for Addis Ababa it was 96.2w/m^2 for north orientation, now it is 122.4w/m^2 for west orientation. This applied for all of the following room types.

b) Conference hall

(Room area, A = 1200m^2, and for 500 people)

Table 5.7 Ac Design Parameters for Conference Hall in Different Locations

Parameter/Location	A/A	B/DAR	D/DAWA	SEMERA
Central Cooling Coil Sizing Data				
Total coil load (kw)	241.0	369.4	392.9	567.2
W/m²	200.9	307.8	327.4	472.6
OA DB / WB (^{0}C)	26.9 / 21.1	31.7 / 26.3	36.4 / 25.9	42.5 / 31.6
Entering DB / WB (^{0}C)	25.3 / 18.5	26.6 / 20.4	27.7 / 19.9	29.3 / 22.1
Leaving DB / WB (^{0}C)	14.7 / 14.1	14.9 / 14.3	14.4 / 13.7	14.3 / 13.8
Coil ADP (^{0}C)	13.5	13.5	13.0	12.6
Resulting RH	51%	52%	50%	50%
Design supply temp(^{0}C)	14.0	14.0	14.0	14.0
Central Heating Coil Sizing Data				
Max coil load (kw)	125.4	142.1	82.5	61.1
Max coil L/s	17345	18198	19041	19011
W/m²	104.5	118.4	68.8	50.9
Zone Sizing Data				
Maximum cooling sensible (KW)	155.4	174.7	196.8	210.4
Maximum heating load (kw)	66.6	70.7	40.1	29.4
Space Loads and Airflows				
Cooling sensible (kw)	155.4	174.7	196.8	210.4
Heating load (kw)	66.6	70.7	40.1	29.4

c) Bank lobby

(Room area of, A = 70m^2, and size for 70 people)

Table 5.8: Ac Design Parameters for Bank Lobby in Different Locations

Parameter/Location	**A/A**	**B/DAR**	**D/DAWA**	**SEMERA**
Air System Name	Bank lobby	Bank lobby	Bank lobby	Bank lobby
Central Cooling Coil Sizing Data				
Total coil load (kw)	29.7	46.3	47.2	68.2
W/m²	424.1	661.4	674.8	973.8
OA DB / WB (^{0}C)	27.4 / 21.2	32.4 / 26.7	37.6 / 26.0	43.8 / 31.7
Entering DB / WB (^{0}C)	25.5 / 18.6	26.9 / 20.6	28.3 / 20.1	29.7 / 22.3
Leaving DB / WB (^{0}C)	13.7 / 13.1	13.8 / 13.3	13.6 / 12.9	13.4 / 12.9
Coil ADP (^{0}C)	12.4	12.3	11.9	11.6
Resulting RH	51%	51%	49%	50%
Central Heating Coil Sizing Data				
Max coil load (kw)	15.4	17.3	9.8	7.4
W/m²	219.6	247.6	139.5	105.7
Zone Sizing Data				
Maximum cooling sensible (KW)	17.6	20.7	23.0	25.7
Maximum heating load (kw)	7.8	8.5	4.4	3.2
Space Loads and Airflows				
Cooling sensible (kw)	17.6	20.7	23.0	25.7
Heating load (kw)	7.8	8.5	4.4	3.2

d) Office

(Area of the office, A = 51.6m^2, and for 7 people)

Table 5.9: Ac Design Parameters for Office in Different Locations

Parameter/Location	**A/A**	**B/DAR**	**D/DAWA**	**SEMERA**
Air System Name	Office	Office	Office	Office
Central Cooling Coil Sizing Data				

Total coil load (kw)	5.0	8.3	9.6	12.7
W/m²	96.7	161.4	186.0	246.0
OA DB / WB (^{0}C)	27.4 / 21.1	31.7 / 26.3	37.0 / 25.9	43.0 / 31.6
Entering DB / WB (^{0}C)	24.9 / 17.6	25.2 / 18.1	25.6 / 17.9	25.9 / 18.6
Leaving DB / WB (^{0}C)	14.4 / 13.7	14.1 / 13.4	14.0 / 13.3	13.7 / 13.1
Coil ADP (^{0}C)	13.2	12.8	12.7	12.4
Resulting RH	50%	49%	48%	48%
Central Heating Coil Sizing Data				
Max coil load (kw)	3.5	3.9	1.6	0.8
W/m²	68.8	75.7	30.9	15.2
Zone Sizing Data				
Maximum cooling sensible (KW)	4.2	6.2	7.6	8.7
Maximum heating load (kw)	3.1	3.3	1.2	0.7
Space Loads and Airflows				
Cooling sensible (kw)	4.2	6.2	7.6	8.7
Heating load (kw)	3.1	3.3	1.2	0.7

e) Shop

(A = 15m^2), 5 people keeping other parameters the same.

Table 5.10: Ac Design Parameters for *Bank lobby* in Different Locations

Parameter/Location	**A/A**	**B/DAR**	**D/DAWA**	**SEMERA**
Air System Name	Shop	Shop	Shop	Shop
Central Cooling Coil Sizing Data				
Total coil load (kw)	3.3	5.5	5.8	7.9
W/m²	221.7	363.5	387.9	524.4
OA DB / WB (^{0}C)	26.9 / 21.1	31.5 / 26.1	37.0 / 25.9	43.0 / 31.6
Entering DB / WB (^{0}C)	25.0 / 18.0	25.5 / 18.6	26.1 / 18.5	26.5 / 19.6

Leaving DB / WB (^{0}C)	14.5 / 13.8	13.8 / 13.2	14.0 / 13.3	13.8 / 13.2
Coil ADP (^{0}C)	13.3	12.6	12.7	12.3
Resulting RH	51%	50%	49%	50%
Central Heating Coil Sizing Data				
Max coil load (kw)	1.7	1.9	0.9	0.6
W/m²	115.3	125.8	59.7	39.9
Zone Sizing Data				
Maximum cooling sensible (KW)	2.5	3.3	3.8	4.3
Maximum heating load (kw)	1.2	1.3	0.6	0.4
Space Loads and Airflows				
Cooling sensible (kw)	2.5	3.3	3.8	4.3
Heating load (kw)	1.2	1.3	0.6	0.4

5.1.3. The effect of room location

In Hotel bedroom of area A =34.3m^2 and for 2 persons.

Table 5.11: Ac Design Parameters at Different Room for Bed Room @N-orientation for AA

Parameter/room type	Room above un-conditioned	Room flip @90	Intermediate floor	Corner room	Roof floor room
Central Cooling Coil					
Total coil load (kw)	2.5	2.6	2.8	3.4	4.4
W/m²	74.0	77.1	81.9	98.5	128.1
OA DB / WB (^{0}C)	27.4 / 21.2	28.0 / 21.2	37.0 / 26.0	27.4 / 21.2	26.9 / 21.1
Entering DB / WB (^{0}C)	24.6 / 17.9	24.8 / 17.4	24.9 / 17.7	24.7 / 17.3	24.7 / 16.9
Leaving DB / WB (^{0}C)	15.4 / 14.8	14.6 / 13.9	15.0 / 14.3	14.5 / 13.8	14.1 / 13.4
Coil ADP (^{0}C)	14.4	13.4	13.9	13.4	12.9
Resulting RH	54%	50%	50%	49%	48%
Design supply temp(^{0}C)	12.8	12.8	12.8	12.8	12.8
Central Heating Coil					
Max coil load (kw)	3.1	2.0	2.0	2.7	1.9
W/m²	91.1	58.5	56.9	78.5	54.9

Zone Sizing Data					
Maximum cooling	2.7	2.5	2.4	3.3	4.2
Maximum heating load	3.3	1.9	1.9	2.7	1.9
Space Loads and					
Cooling sensible (kw)	2.7	2.5	2.4	3.3	4.2
Heating load (kw)	3.3	1.9	1.9	2.7	1.9

5.2. Discussion

5.2.1. Factors Affecting the Cooling Load

From the results shown so far the air conditioning load in W/m^2 is the main air conditioning design parameter for each location. The other parameters like the relative humidity, entering and leaving wet-bulb and dry-bulb temperatures are used as a checking, so that the system will be within the human comfort range. Hence by multiplying these values of the cooling loads for a particular room by the respective room area, one can get the cooling load of that particular room.

Finally the room checked via system psychometric chart so that the system will be at the comfort conditions. If the system is not with in comfort condition by observing RH, DB and the like, then the design will be done again. For example the psychometric chart for one of the room is shown in figure 5.1 bellow. The room air is located by point 6, in which the dry bulb temperature is almost 25 ^{0}c and the relative humidity is approximately 52%. This is within the acceptable limit for human comfort condition.

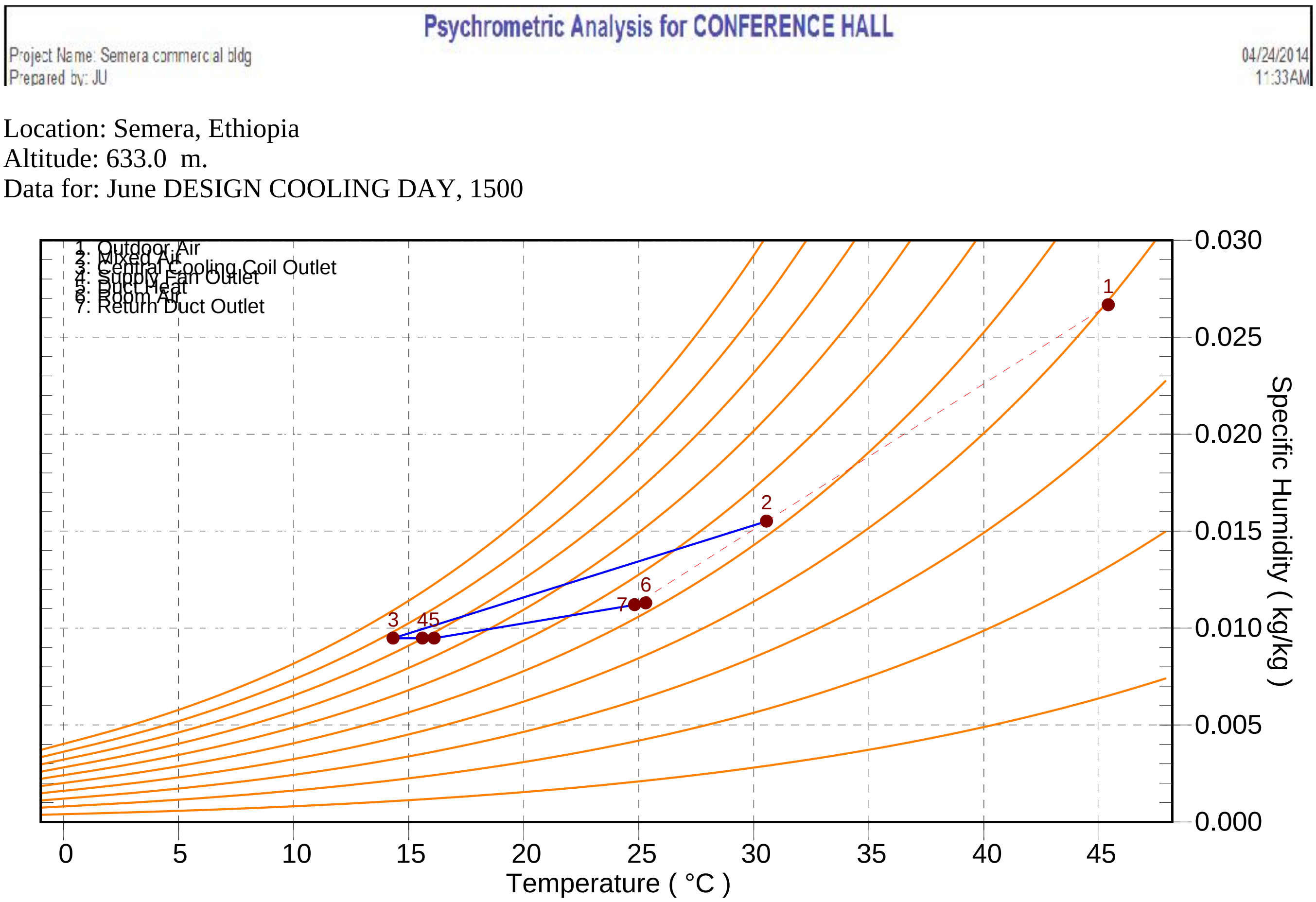

Figure 5.1: Psychometric Chart for the Conference Room in Semera

Where, 1=outdoor air	4=supply fan outlet
2=mixed air	5=Duct heat
3=central cooling coil outlet	7=return duct outlet

It is also shown that the air conditioning loads are affected by many factors. These are building orientation, room area, number of occupants, material to which the room is made up of, the floor to which the room is located, the outside color of the wall and the roof, the coil bypass factor, the internal loads and the presence of partitions inside the room.

a) Orientation

Orientation is the position of the building in relation to its exposure to the sun light. As it is explained so far the building can be north, north east, east, south east, south, south west, west or North West oriented. But from the results it is observed that orientation have a vital effect for the room air conditioning load. Especially for rooms with small area the effect is more. It is dependent on the geographical location of the room. The variation in cooling load for different locations is shown below. Generally when the room is west oriented (or when most doors and windows parts of the building are in the direction of west) there will be high AC load relative to North oriented building. For example the cooling loads in w/m^2 for hotel bedroom and conference hall are shown bellow. For N-orientated bed room in Addis Ababa it is 81.9w/m^2 and 98.9w/m^2 for that of west orientated.

Table 5.12: The Effect of Orientation on Cooling Load for West and North

	Hotel bed room				**Conference hall**			
Locations	(a.a)	(B/Dar	(D/Dawa)	(Semera)	(a.a)	(B/Dar)	(D/Dawa)	(Semera)
Summer design DB(^{o}c)	28	32.2	37.6	43.8	28	32.2	37.6	43.8
w/m^2 (N-orientation)	81.9	100.7	149.2	187.7	198.9	304.2	326.6	469.6
w/m^2 (W-orientation)	98.9	130.1	165.6	206.0	200.9	307.8	327.4	472.6

Graphically the results for the case of Addis Ababa can be shown as bellow.

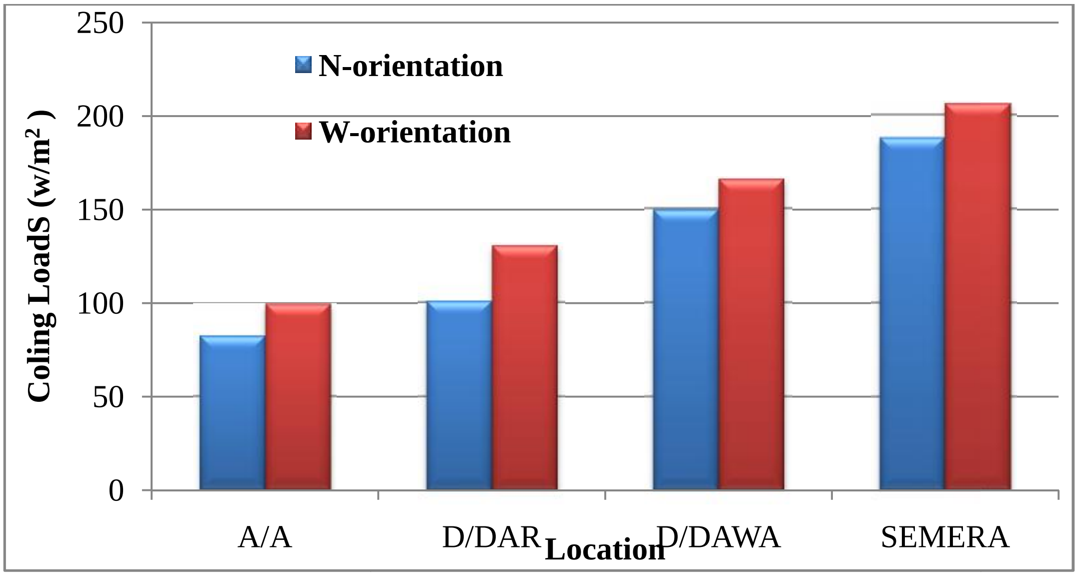

Figure 5.2: The Effect of Orientation on Cooling Load for Bedroom

The cooling load for all the major orientation is shown below for each selected areas.

Table 5.13: Effect of Orientations on Cooling for Bedroom Located in Addis Ababa

Orientation	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
Cooling load (w/m^2)	96.2	94.3	98.2	95.0	98.1	108.6	117.5	110.6
RH%	50	50	50	52	49	53	50	50

For Addis Ababa the NE orientation has the lowest cooling load, followed by SE then N orientation. West has the highest cooling load. Hence for building which are going to be constructed in Addis Ababa these are best orientations.

Table 5.14: Effect of Orientations on Cooling for Bedroom Located in Bahr Dar

Orientation	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
Cooling load (w/m^2)	104.8	108.2	109.4	105.7	114.8	122.7	130.1	125.5
RH (%)	48	48	48	48	47	47	47	47

In this case N orientation has lowest cooling load where as W orientation has the highest cooling load. Bhir-Dar represents Northern parts of Ethiopia. So for those areas North orientation is the best one.

Table 5.15: Effect of Orientations on Cooling for Bedroom Located in Dire-Dawa

Orientation	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
Cooling load (w/m^2)	149.1	145.4	145.4	137.4	148.1	155.7	165.6	167.3
RH (%)	51	52	51	52	51	51	51	51

In this location E orientation has lower cooling load following the SE orientation, then major N orientation. It located in the Eastern part.

Table5.16: Effect of Orientations on Cooling for Bedroom Located in Semera

Orientation	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
Cooling load (w/m^2)	199.8	200.1	199.0	187.9	183.4	195.5	215.2	219.0
RH (%)	48	48	48	48	50	49	48	47

For Semera South orientation has the lowest cooling load. Semera is in the NE part.

For western parts Gambella is selected. As shown below North orientation has lowest cooling load keeping other parameters constant. Hence it is the best option for northern parts.

Table5.17: Effect of Orientations on Cooling for Bedroom Located in Gambella

Orientation	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
Cooling load(w/m^2)	64.1	66.1	65.5	67.1	76	81	77.2	75.9
RH (%)	53	53	52	52	53	53	53	53

b) Room Area

Rooms with different areas will have different cooling loads, keeping other parameters constant. For example the following table shows the variation of cooling load for various areas for bed room at Addis Ababa.

Table 5.17: Effect of Room Area on Cooling load for Bedroom Located in Addis Ababa

Bed room area (m^2)	30	34.3	40	45
Cooling load (w/m^2)	104.2	96.2	88.5	82.4

Form these areas 34.3m^2 used in this paper from the existing buildings. It is observed from the figure that the cooling load decreases as the room are increases. This principle applies for all types of rooms.

c) Number of People

While the number of occupants inside the room is increasing it is clear that the heat inside the room will also increase. And to compensate that the cooling load is also increases. The following table shows this by taking the case for conference hall located in Addis Ababa.

Table 5.18: Effect of Number of People on Cooling for Bedroom

Number of people	100	200	300	400	500	600
Cooling load (w/m^2)	143.7	176.5	207.5	235.2	265.5	295.9

The room having a capacity for 500 people is taken for the analysis.

d) The Floor to Which the Room is Located

The room that requires AC may be located at the ground floor, at the intermediate floor, at the corner floor or at the roof floor.

Table 5.19: Cooling load for Different Room Locations for Bedroom @N-orientation for AA

room type	**Room above un-conditioned**	**Room flip @90**	**Intermediate floor**	**Corner room**	**Roof floor room**
Cooling load(w/m^2)	74.0	77.1	81.9	89.5	128.1

The results show that air conditioning loads at the roof floor are higher than the rooms at other floors. Thus AC engineers should also take this in to consideration.

e) Coil Bypass Factor

This is the property of the cooling machine. The coil bypass factor ranges from 0.02 to 0.1. The machine having a coil bypass factor nearly 0.02 will need lower cooling load for the same other effects. But it may have high capital cost in relative to those with higher coil by pass factor. In this work the coil bypass factor of 0.1 is used.

f) Outside Surface Color

The outside color of the roof and floor may be light, medium or dark. This will highly affect the air conditioning load. If the outside surface is dark the absorptivity will be high enough. It will need high w/m^2. And also it will affect the relative humidity of the room.

g) Internal Loads

The internal loads to the room are varied for according to the function of the room. As the internal loads get higher and higher it is obvious that the cooling load will be higher. For example for rooms located at Addis Ababa, the cooling load for conference hall=265.5 w/m^2, for hotel bed =96.2w/m^2, for shop=231.4 w/m^2, for office=112.6 w/m^2 and for bank room=370 w/m^2.

As far as cooling load is concerned in addition to type of application that the room is used for, the geographical location also has a vital effect. From the result it is observed that for the same room and internal loads and other factors the cooling load in Semera is the highest, followed by Dire-Dawa, then Bahir Dar and finally Addis Ababa. So the need for AC is much higher in hot areas of the country.

5.2.1. Cooling Load for Different Types of Room in the Selected Locations

In the above discussion it is clearly presented that North orientation has the lowest cooling load in most of the areas of Ethiopia, hence the cooling loads obtained for different types of rooms in different parts of the country are taken as a standard accordingly. The following table summarizes the results.

Table 5.20: Cooling Load for Different Room in the Selected Locations

Room type	**Cooling load (w/m^2)**			
	Addis Ababa	Bahr-Dar	Dire-Dawa	Semera
Bedroom	96.2	104.8	149.2	199.8
Bank lobby	525.2	629.8	664.2	956.2
Conference Hall	256.5	304.2	326.6	469.6
Office	106.6	132.9	171.3	227.9
Shop	243.8	289.3	350.8	482.4

These results are based on the parameters discussed so far like room area, number of occupants, and the like. So to use these standards one should take the parameters in to consideration.

Chapter Six: Conclusion and Recommendation

Almost all areas of Ethiopia need cooling. Hence most air conditioning design in Ethiopia are designed for cooling. To design the air conditioner, specifying the cooling load satisfying the comfort condition for that room is the main task. After the cooling load is specified then the equipment satisfying that condition will be selected.

The cooling load is dependent on many factors. Geographical location is the main factor. For example the cooling load for Semera is almost 2.3 times that of for Addias Ababa. The paper covered the all temperature zones of the country. That is Semera for very hot temperature areas, Dire-Dawa for hot temperature areas, Bahir-Dar for warmer areas and Addis Ababa for relatively moderate temperature areas of the country. Therefore the design of the rest areas can be based on these locations. The cooling load for various locations and rooms of different applications is calculated in w/m^2. Hence by multiplying these values with the area of the room one can get the cooling load required by a particular room.

As illustrated so far orientation of the building highly affects the cooling loads. Even if there are areas having lower cooling load in orientations other than north, like eastern parts which have lowest cooling load in east, almost all locations have lowest cooling load in north orientation. Hence north orientation of the building is the best option to minimize the cooling load. West orientation is the one with the highest cooling load. It is observed that the cooling load in the west orientation is almost 1.3 times that of north orientation for those rooms with less population number.

The number of occupants, room area, and internal loads are also the major factors affecting the cooling load. As the number of occupants and internal loads increases, the cooling load also increases. If the room area increases the cooling load will decreases. The parameters also vary depending on the type of room to which the air condition is designed for. Hence the designer should take these in to consideration while taking these parameters, so as to have a standardized AC system and local based air conditioning.

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Appendix A

CAD Drawings for Floor Plans

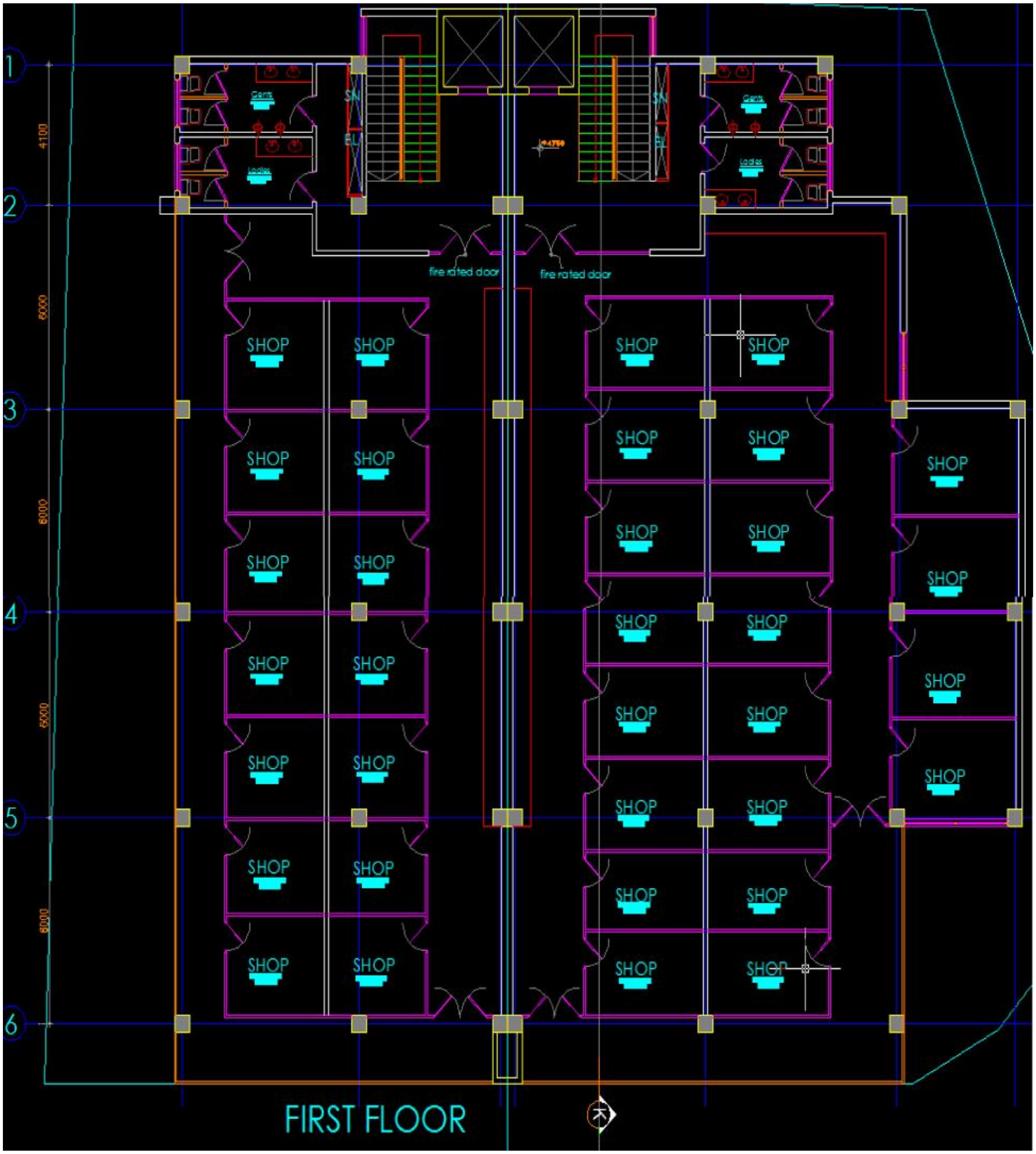

Figure 8.1: Floor Plan for Shop Building Located in Merkato

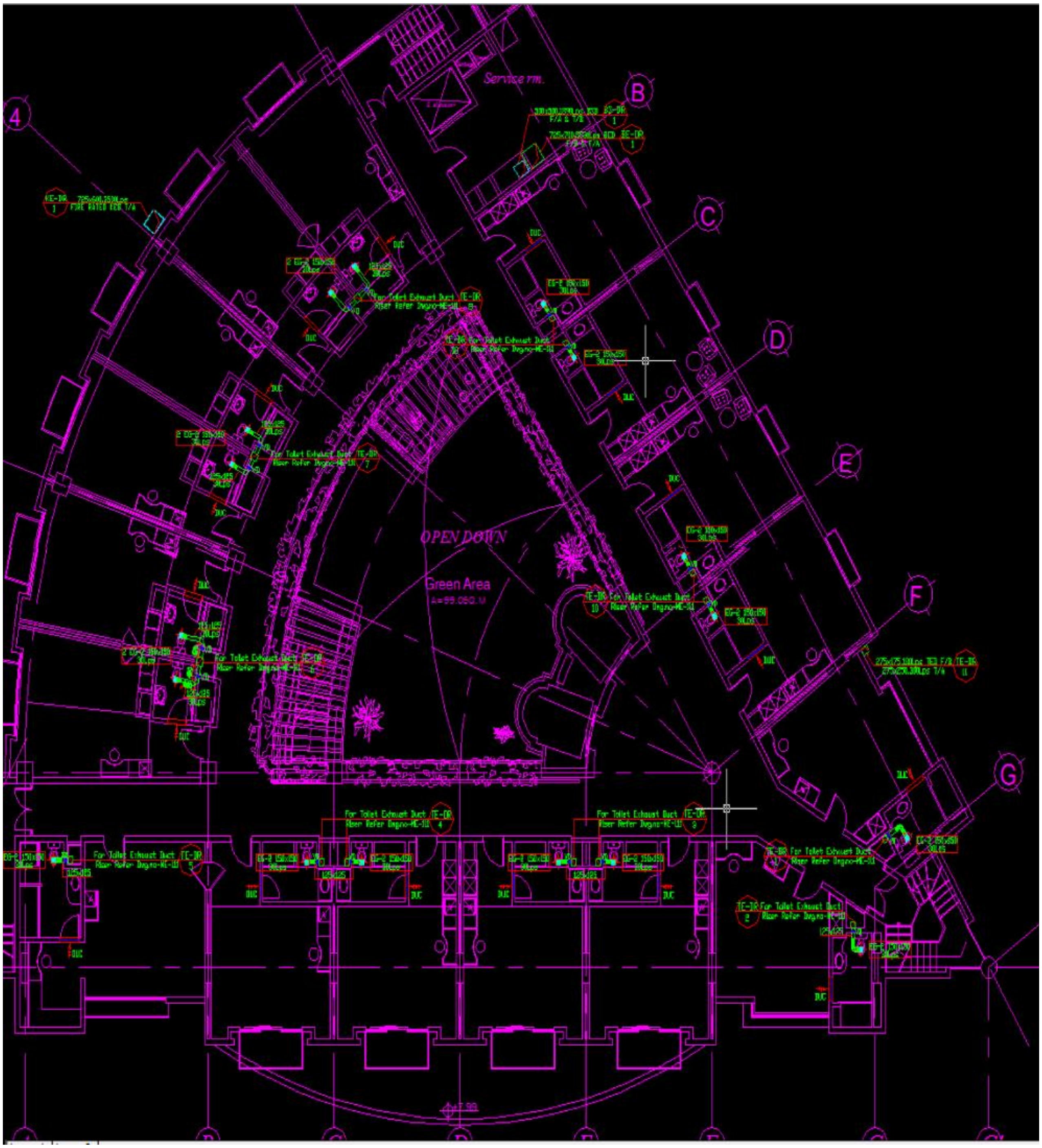

Figure 8.2: Floor Plan for Hotel Bedroom Building

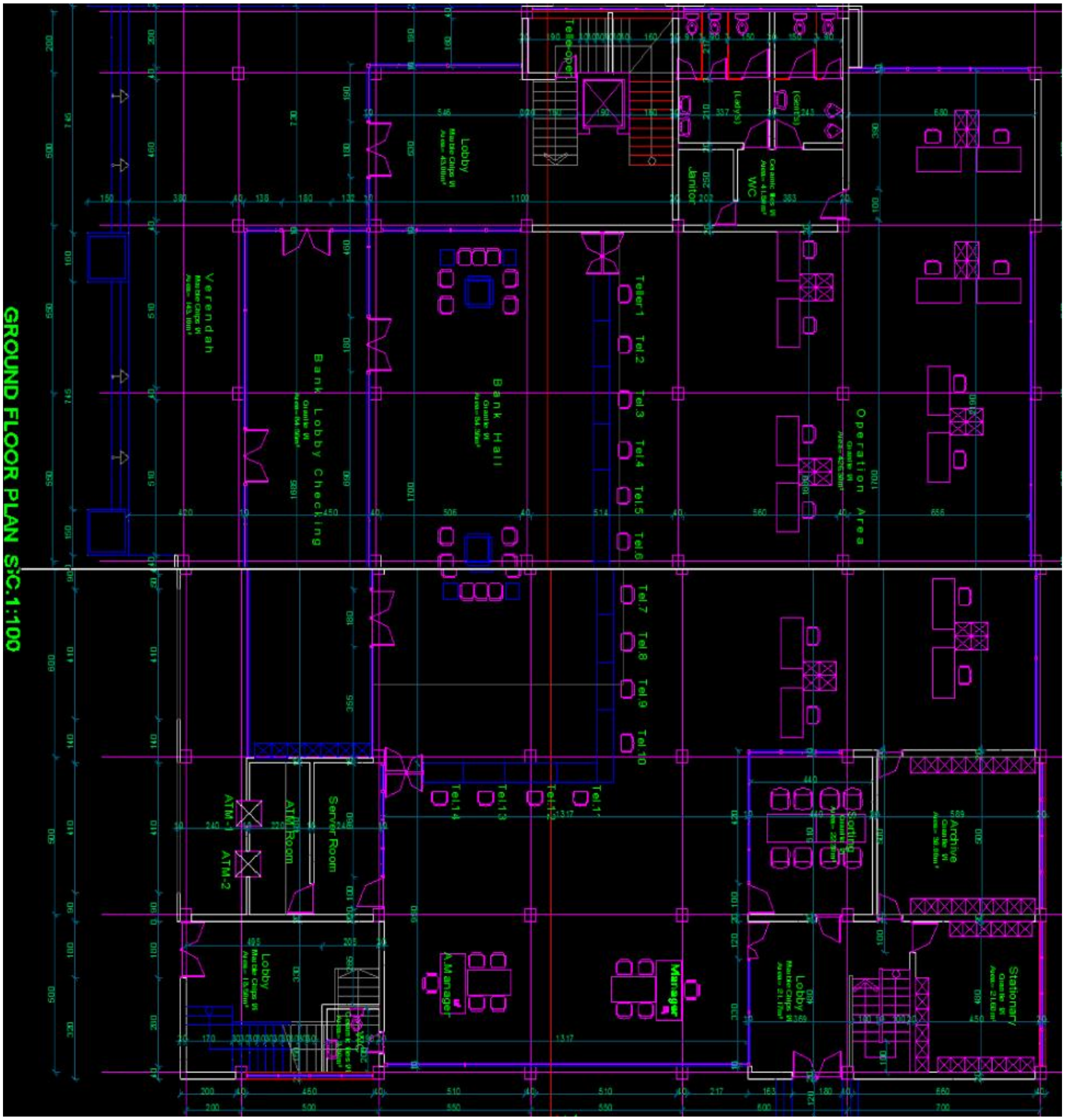

Figure 8.3: Floor Plan for Commercial Bank Building

Appendix B

Space Input Data

Space Input Data

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HOTTEL BED ROOM n

1. General Details:

Floor Area .... **34.3** m²
Avg. Ceiling Height .... **2.8** m
Building Weight .... **351.5** kg/m²

1.1. OA Ventilation Requirements:

Space Usage .... **HOTEL: Bedrooms**
OA Requirement 1 .... **15.0** L/s
OA Requirement 2 .... **0.00** L/(s-m²)
Space Usage Defaults .... **ASHRAE Std 62-2001**

2. Internals:

2.1. Overhead Lighting:

Fixture Type .... **Recessed (Unvented)**
Wattage .... **32.30** W/m²
Ballast Multiplier **1.00**
Schedule .... **lighting schedule**

2.2. Task Lighting:

Wattage .... **0.00** W/m²
Schedule .... **None**

2.3. Electrical Equipment:

Wattage .... **5.80** W/m²
Schedule .... **Electrical**

2.4. People:

Occupancy .... **2.0** People
Activity Level .... **Seated at Rest**
Sensible .... **67.4** W/person
Latent .... **35.2** W/person
Schedule .... **Electrical**

2.5. Miscellaneous Loads:

Sensible .... **0** W
Schedule .... **Electrical**
Latent .... **0** W
Schedule .... **None**

3. Walls, Windows, Doors:

Exp.	Wall Gross Area (m²)	Window 1 Qty.	Window 2 Qty.	Door 1 Qty.
N	12.1	1	0	1

3.1. Construction Types for Exposure N

Wall Type .... **N wall**
1st Window Type **W1**
Door Type **D1**

4. Roofs, Skylights:

(No Roof or Skylight data).

5. Infiltration:

Design Cooling .... **10.00** L/s
Design Heating .... **0.00** L/s
Energy Analysis .... **0.00** L/s
Infiltration occurs at all hours.

6. Floors:
Type .... Floor Above Conditioned Space
(No additional input required for this floor type).

7. Partitions:

7.1. 1st Partition Details:

Partition Type	Ceiling Partition	
Area	34.3	m²
U-Value	3.510	W/(m²-°K)
Uncondit. Space Max Temp	28.0	°C
Ambient at Space Max Temp	29.0	°C
Uncondit. Space Min Temp	10.0	°C
Ambient at Space Min Temp	5.0	°C

7.2. 2nd Partition Details:
(No partition data).

Figure 8.4: Space Input Data for Shop

Space Input Data

AA commercial Bldg
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OFFICE

1. General Details:

Floor Area	51.6	m²
Avg. Ceiling Height	2.8	m
Building Weight	341.8	kg/m²

1.1. OA Ventilation Requirements:

Space Usage	OFFICE: Office Space	
OA Requirement 1	10.0	L/s/person
OA Requirement 2	0.00	L/(s-m²)
Space Usage Defaults	ASHRAE Std 62-2001	

2. Internals:

2.1. Overhead Lighting:

Fixture Type	Recessed (Unvented)	
Wattage	32.30	W/m²
Ballast Multiplier	1.00	
Schedule	OFFICE LIGHT	

2.2. Task Lighting:

Wattage	0.00	W/m²
Schedule	None	

2.3. Electrical Equipment:

Wattage	4.84	W/m²
Schedule	OFFICE	

2.4. People:

Occupancy	5.0	People
Activity Level	Office Work	
Sensible	71.8	W/person
Latent	60.1	W/person
Schedule	PEPL SCHE	

2.5. Miscellaneous Loads:

Sensible	0	W
Schedule	None	
Latent	0	W
Schedule	None	

3. Walls, Windows, Doors:

Exp.	Wall Gross Area (m²)	Window 1 Qty.	Window 2 Qty.	Door 1 Qty.
N	23.7	2	0	1

3.1. Construction Types for Exposure N

Wall Type	N
1st Window Type	W1
Door Type	D1

4. Roofs, Skylights:
(No Roof or Skylight data).

5. Infiltration:

Design Cooling .... 10.00 L/s
Design Heating .... 0.00 L/s
Energy Analysis .... 0.00 L/s
Infiltration occurs at all hours.

6. Floors:

Type .... Floor Above Conditioned Space
(No additional input required for this floor type).

7. Partitions:

7.1. 1st Partition Details:

Partition Type .... Ceiling Partition
Area .... 51.6 m²
U-Value .... 3.685 W/(m²-°K)
Condit. Space Max Temp .... 27.0 °C
Ambient at Space Max Temp .... 29.0 °C
Uncondit. Space Min Temp .... 10.0 °C
Ambient at Space Min Temp .... 5.0 °C

7.2. 2nd Partition Details:

(No partition data).

Figure 8.5: Space Input Data for Shop

Bank lobby

1. General Details:

Floor Area .... 70.0 m²
Avg. Ceiling Height .... 3.5 m
Building Weight .... 341.8 kg/m²

1.1. OA Ventilation Requirements:

Space Usage .... WORKROOMS: Bank Vaults
OA Requirement 1 .... 8.0 L/s/person
OA Requirement 2 .... 0.00 L/(s-m²)
Space Usage Defaults .... ASHRAE Std 62-2001

2. Internals:

2.1. Overhead Lighting:

Fixture Type .... Recessed (Unvented)
Wattage .... 32.29 W/m²
Ballast Multiplier 1.00
Schedule .... lighting schedule

2.2. Task Lighting:

Wattage .... 0.00 W/m²
Schedule .... None

2.3. Electrical Equipment:

Wattage .... 35.71 W/m²
Schedule .... Electrical

2.4. People:

Occupancy .... 70.0 People
Activity Level .... Office Work
Sensible .... 71.8 W/person
Latent .... 60.1 W/person
Schedule .... Electrical

2.5. Miscellaneous Loads:

Sensible .... 0 W
Schedule .... None
Latent .... 0 W
Schedule .... None

3. Walls, Windows, Doors:

Exp.	Wall Gross Area (m²)	Window 1 Qty.	Window 2 Qty.	Door 1 Qty.
N	35.0	2	0	1
E	24.5	0	0	0
S	35.0	2	0	1
W	24.5	2	0	0

3.1. Construction Types for Exposure N

Wall Type .... N wall
1st Window Type W1
Door Type D1

3.2. Construction Types for Exposure E

Wall Type .... N wall

3.3. Construction Types for Exposure S

Wall Type .... N wall
1st Window Type W1
Door Type D1

3.4. Construction Types for Exposure W

Wall Type .... N wall
1st Window Type W-1

4. Roofs, Skylights:

Exp.	Roof Gross Area (m²)	Roof Slope (deg.)	Skylight Qty.
H	70.0	0	0

4.1. Construction Types for Exposure H
Roof Type .... **Roof 1**

5. Infiltration:
Design Cooling .... **10.00** L/s
Design Heating .... **0.00** L/s
Energy Analysis .... **0.00** L/s
Infiltration occurs at all hours.

6. Floors:
Type .... **Floor Above Conditioned Space**
(No additional input required for this floor type).

7. Partitions:
7.1. 1st Partition Details: (No partition data).

7.2. 2nd Partition Details:
Partition Type .... **Wall Partition**
Area .... **22.0** m²
U-Value .... **3.685** W/(m²-°K)
Uncondit. Space Max Temp .... **29.0** °C
Ambient at Space Max Temp .... **28.0** °C
Uncondit. Space Min Temp .... **10.0** °C
Ambient at Space Min Temp .... **5.0** °C

Figure 8.6: space input data for shop

Space Input Data

AA commercial Bldg
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Shop

1. General Details:

Floor Area .... **15.0** m²
Avg. Ceiling Height .... **3.0** m
Building Weight .... **341.8** kg/m²

1.1. OA Ventilation Requirements:

Space Usage ..... **SPECIALTY SHOPS: Supermarkets**
OA Requirement 1 .... **8.0** L/s/person
OA Requirement 2 .... **0.00** L/(s-m²)
Space Usage Defaults .... **ASHRAE Std 62-2001**

2. Internals:

2.1. Overhead Lighting:

Fixture Type .... **Recessed (Unvented)**
Wattage .... **32.30** W/m²
Ballast Multiplier **1.00**
Schedule .... **Electrical**

2.2. Task Lighting:

Wattage .... **0.00** W/m²
Schedule .... **None**

2.3. Electrical Equipment:

Wattage .... **8.89** W/m²
Schedule .... **Electrical**

2.4. People:

Occupancy .... **5.0** People
Activity Level .... **Office Work**
Sensible .... **71.8** W/person
Latent .... **60.1** W/person
Schedule .... **Electrical**

2.5. Miscellaneous Loads:

Sensible .... **0** W
Schedule .... **None**
Latent .... **0** W
Schedule .... **None**

3. Walls, Windows, Doors:

Exp.	Wall Gross Area (m²)	Window 1 Qty.	Window 2 Qty.	Door 1 Qty.
N	15.0	1	0	1

3.1. Construction Types for Exposure N

Wall Type .... **N**
1st Window Type **W1**
Door Type **D1**

4. Roofs, Skylights:

(No Roof or Skylight data).

5. Infiltration:

Design Cooling .... **10.00** L/s
Design Heating .... **0.00** L/s
Energy Analysis .... **0.00** L/s
Infiltration occurs at all hours.

6. Floors:

Type .... **Floor Above Conditioned Space**
(No additional input required for this floor type).

7. Partitions:

7.1. 1st Partition Details:

Partition Type .... **Ceiling Partition**
Area .... **15.0** m²
U-Value .... **3.510** W/(m²-°K)
Uncondit. Space Max Temp .... **28.0** °C
Ambient at Space Max Temp .... **29.0** °C
Uncondit. Space Min Temp .... **10.0** °C
Ambient at Space Min Temp .... **5.0** °C

7.2. 2nd Partition Details:

(No partition data).

Figure 8.7: space input data for shop

CONFERENCE HALL

1. General Details:

Floor Area .... **1200.0** m²
Avg. Ceiling Height .... **6.0** m
Building Weight .... **341.8** kg/m²

1.1. OA Ventilation Requirements:

Space Usage .... **OFFICE: Conference Rooms**
OA Requirement 1 .... **10.0** L/s/person
OA Requirement 2 .... **0.00** L/(s-m²)
Space Usage Defaults .... **ASHRAE Std 62-2001**

2. Internals:

2.1. Overhead Lighting:

Fixture Type .... **Recessed (Unvented)**
Wattage .... **32.29** W/m²
Ballast Multiplier **1.00**
Schedule .... **lighting schedule**

2.2. Task Lighting:

Wattage .... **0.00** W/m²
Schedule .... **None**

2.3. Electrical Equipment:

Wattage .... **4.17** W/m²
Schedule .... **Electrical**

2.4. People:

Occupancy .... **500.0** People
Activity Level .... **Seated at Rest**
Sensible .... **67.4** W/person
Latent .... **35.2** W/person
Schedule .... **t-stat**

2.5. Miscellaneous Loads:

Sensible .... **0** W
Schedule .... **None**
Latent .... **0** W
Schedule .... **None**

3. Walls, Windows, Doors:

Exp.	Wall Gross Area (m²)	Window 1 Qty.	Window 2 Qty.	Door 1 Qty.
N	150.0	4	2	2
E	60.0	0	0	2
SE	175.0	2	2	2
S	60.0	0	0	2
W	150.0	0	0	0
NW	40.0	2	0	0

3.1. Construction Types for Exposure N

Wall Type .... **N wall**
1st Window Type **W1**
2nd Window Type **W2**
Door Type **D1**

3.2. Construction Types for Exposure E
Wall Type .... N wall
Door Type D1

3.3. Construction Types for Exposure SE
Wall Type .... N wall
1st Window Type W1
2nd Window Type W2
Door Type D1

3.4. Construction Types for Exposure S
Wall Type .... N wall
Door Type D1

3.5. Construction Types for Exposure W
Wall Type .... N wall

3.6. Construction Types for Exposure NW
Wall Type .... N wall
1st Window Type W-1

4. Roofs, Skylights:

Exp.	Roof Gross Area (m²)	Roof Slope (deg.)	Skylight Qty.
H	1200.0	0	0

4.1. Construction Types for Exposure H
Roof Type .... Roof 1

5. Infiltration:
Design Cooling .... 10.00 L/s
Design Heating .... 0.00 L/s
Energy Analysis .... 0.00 L/s
Infiltration occurs at all hours.

6. Floors:
Type .... Floor Above Conditioned Space
(No additional input required for this floor type).

7. Partitions:
(No partition data).

Figure 8.8: space input data for shop

Declaration

I hereby declare that the work which is being presented in this thesis entitled "Specifying *Air conditioning Requirements for Commercial Buildings of Ethiopia* " is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

____________________________ ________________________

Jemal Worku Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

____________________________ ________________________

Dr.-Ing. Demiss Alemu (Advisor) Date