Palestine Polytechnic University

College of engineering and technology

Mechanical engineering department

Building Management Systems (BMS)and Building Services Design for the Palestinian Red Crescent society in Hebron

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Submitted to the College of engineering and technology

in partial fulfillment of the requirements of the Bachelor's degree in refrigeration and air conditioning engineering

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Palestine Polytechnic University

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Graduation project evaluation

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Submitted to the College of engineering and technology in partial fulfillment of the requirements for the Bachelor's degree in refrigeration and air conditioning engineering and according to their agreements this project has been submitted.

Supervisor's signature

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Testing Committee signature

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Head of the department signature

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June ,2021

الملخص

يستكشف المشروع أهمية تطبيق أنظمة التدفئة والتهوية وتكييف الهواء ومكافحة الحريق والغازات الطبية في مستشفى جمعية الهلال الأحمر الفلسطيني في مدينة الخليل من أجل توفير ظروف الراحة والأمان. يهدف الباحثان إلى تقديم رؤية لأنظمة البيئة الطبية ومدى أهمية النظام للمرضى ومقدمي الرعاية والزائرين و بالأخص الطاقم الطبي داخل المؤسسة الصحية، كما يهدف المشروع إلى تصميم خدمات المباني مثل أنظمة التدفئة والتهوية وتكييف الهواء ومكافحة الحرائق وأنظمة الغازات الطبية، بالإضافة إلى تصميم مخططات نظام إدارة المباني (BMS) الذي يتحكم ويراقب تلك الأنظمة ويساعد بشكل ملحوظ على الترشيد في استهلاكها للطاقة عن طريق قراءة مدخلات ومخرجات وحاجة المبنى لعمل المعدات والاضاءة في كل الاوقات، واختيار كل ما يلزم من هذه المعدات بشكل صحيح وفعال بحيث يساعد على تحقيق كفاءة لكل ما ذكر من الانظمة مما يخلق في الأساس نظام هندسي أمثل يستطيع نظام إدارة المباني التعامل معه، ومراعاة كل الإرشادات والاقتراحات من الهيئات العالمية المختصة خصوصاً فيما يتعلق بغرف العمليات وغيرها من الغرف ذات الحساسية العالية في البيئة الطبية داخل المشفى.

هذا المشروع عبارة عن مشروع هندسي سيوفر حلولاً للمشاكل الحالية المتعلقة في انتشار العدوى في أنظمة البيئة الطبية و استهلاك الطاقة فيها. والهدف العام للمشروع هو توفير فهم أوسع لتأثير لنظام التكييف والتبريد على صحة المريض والطاقم الطبي، وأهمية وجود نظام يتحكم في معدات المبنى المتعلقة بهذه الأنظمة وكل ما يتعلق بالاضاءة. سيكون هذا البحث بمثابة نقطة انطلاق لمزيد من الأبحاث والمشاريع العلمية الأكبر في المستقبل.

Abstract

The project explores the importance of the implementation of the HVAC, and firefighting systems for comfort and safety. The researcher aims to provide insight into the systems in a medical setting and how important the system is for patients, caretakers, and visitors but most significantly the medical staff within the health establishment. The project aims at designing building services such as HVAC, firefighting, and medical gases systems. Also, designing a Building Management System (BMS) system that controls and monitors those systems and their energy consumption. Finally, decide on a suitable component for the Palestine Red Crescent Society Hospital in Hebron city.

This project is an engineering project that provides solutions to current problems in terms of energy control for the HVAC, firefighting systems through BMS monitoring. The overall objective of the project is to provide a broader understanding of the impact of the HVAC system in a hospital setting and creating the ideal money-saving solution within hospitals using international guideline standards for healthcare facilities like NEPA, FGI, and ASHRAE. This research will act as a stepping stone for further research and bigger scientific projects in the future.

Dedication

To our families and loved ones.

Acknowledgment

We would like to express our deepest gratitude to our supervisor Eng. Kazem Osaily for his support and guidance. We would also like to acknowledge the academic staff of Palestine Polytechnic University for their valuable knowledge, patience, and support.

We would like to thank our families and friends especially for their patience and encouragement throughout the compilation of our studies.

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Abbreviations

HVAC	Heating, Ventilation and Air Conditioning
BMS	Building Management System
HAI	Hospital-Associated Infections
IPC	Infection Prevention Control
MRI	Magnetic Resonance Imaging
CT	Computerized Tomography
SOAP	Subjective, Objective, Assessment and Plan
XML	Extensible Markup Language
BACnet	Building Automation and Control Networking Protocol
BAS	Building Automation System
CCTV	Closed-Circuit Television
GHG	Greenhouse Gas
DHW	Domestic Hot Water
FACP	Fire Alarm Control Panel
HEPA	High Efficiency Particulate Air
VAV	Variable Air Volume
WHO	World Health Organization
ICU	Intensive Care Unit
TFM	Transfer Function Method
HAP	Hourly Analysis Program
TFM	Transfer Function Method
BIM	Building Information Modeling
MEP	Mechanical, Electrical and Plumbing
CFM	Cubic Feet per Minute

Chapter 1
Introduction

1.1 Background

The main objective of implementing the design of HVAC, and firefighting systems is to fulfill human comfort needs and safety. Also, to satisfy the medical needs of patients, caretakers, and medical staff within the hospital structure. However, it is becoming increasingly important not only to provide a comfortable and hygienic environment for patients, staff, and visitors but also to reduce energy usage. Subsequently, one of the best controls and monitoring systems suitable for HVAC is Building Management Systems (BMS).

HVAC is a sub-discipline of mechanical engineering which is based on the principles of thermodynamics, fluid mechanics, and heat transfer. It refers to multiple systems like Heating, Ventilation, and Air Conditioning. Essentially these systems are used to provide thermal comfort and acceptable indoor air quality.

The HVAC system works through exchanging or replacing air in any space to provide high indoor air quality. It involves temperature control, oxygen replenishment, removal or adding moisture (humidity control), odors, smoke, heat, dust, airborne bacteria, carbon dioxide, and other gases. Also, the system allows the removal of unpleasant odors and adjusting the heating and cooling systems in both residential and commercial buildings.

But unlike other facilities, the HVAC system for medical facilities is typically quite a sensitive project to approach. Thermal comfort is essential, but it is imperative for hospitals to protect both patients and personnel occupying the building from hospital-associated infections (HAI). A modern Infection Prevention Control (IPC) is achieved through clean air, negative-positive pressure isolation, operation rooms, the cooling of equipment such as MRI machines and lasers, mortuary, and blood bank storages.

A fire-Fighting system is a set of equipment used to prevent, extinguish, localize, and block fires in enclosed spaces. One of the most complicated types of facilities that a firefighter will ever respond to is a healthcare facility. The reasons may vary, but usually, because occupants are mostly incapable of self-preservation due to age, physical or mental disability, or because of the security measures which are not under the control of the occupants. In addition to the problems posed by inpatient areas that cannot evacuate on their own, there are surgical procedures that cannot halt because of fires. Other hospital challenges may include helipads, laboratories with significant quantities of flammable and potentially hazardous chemicals, equipment that requires specialized response including, MRI and CT scan machines. Also, linear accelerators, full-service commercial kitchens, large complex central energy plants, and hazardous materials storage, among others.

A Building Management System (BMS) is a computer-based control system installed in buildings that control and monitor buildings' mechanical and electrical equipment such as, ventilation, lighting, power systems, fire systems, and security systems. A BMS consists of software and hardware programs. The software program, usually configured in a hierarchical manner, can be proprietary, using such protocols as C-bus, and Profibus. However, recently there have been new vendors that are producing BMSs that integrate using Internet protocols and open standards such as DeviceNet, SOAP, XML, BACnet, LonWorks, and Modbus.

1.2 Problem Statement

Hospitals are unique environments with a set of challenges that can be distinctive. Usually, hospitals face challenges due to many viral and bacterial diseases. In particular, in 2020, Due to COVID-19, hospitals around the world face a new set of challenges. These infections are dangerous, especially to the elderly, infants, or vulnerable individuals who suffer from a compromised immune system. In light of the fact that there is no current treatment of COVID-19. Since most diseases are transmitted through contact with an infected patient, hospitals are working on reducing the risk by improving their HVAC systems.

The diverse nature of activities within a hospital, ranging from activities in the medical wards to catering and housekeeping to chemicals waste, means that a precise design must be used to achieve a hygienic and safe environment for both patients and staff.

Significantly, hospitals suffer from high financial operational costs. The powering of HVAC equipment consumes a significant percentage of energy at 35% to 60%. Also, lighting systems consume more than 15% of the overall power consumption [1]. Consequently, every hospital must have an energy monitoring and control system, such as BMS.

Some of the previously mentioned challenges are solved by the original hospital (Palestinian Red Crescent Hospital) by the project MEP engineers team. However, the energy consumption problem has not been solved yet. Hence, the main objective of this project is to lessen energy consumption through the BMS system.

1.3 Research Aim

This project aims at designing building services such as HVAC, firefighting, and medical gases systems. Also, design a BMS system that controls and monitors those systems and their energy consumption. Finally, decide on a suitable component for the Palestine Red Crescent Society Hospital in Hebron city.

1.4 Literature Review

Building Management System (BMS) is also known as Building Automation System (BAS), is a system that is a computer operated system which is installed in buildings for the purpose of controlling and monitoring buildings’ mechanical and electrical fixers like “ventilation, power systems, fire and security systems”. In more basic words, the BMS system allows the control of “temperature, humidity and carbon dioxide inside the building" [2]. Aslo, in their article, the authors also emphasize that minimizing carbon dioxide and increasing oxygen is also an important feature of the BMS system. The BMS system consists of software and hardware applications by designing the control. The software system uses protocols such as "C-Bus, and Profitbus". The BMS system is usually manufactured in a way that is easier to facilitate the internet and "open standards like DeviceNet, SOAP, XML, BACnet, LonWorks and Modbus". The BMS is designed to meet the specific needs of buildings in order to save energy. Also, any external devices and equipment installed can be controlled through a specific set of instructions. The system is based on the pre-collection of information which can be controlled through monitors to encourage the system to abide by the orders given to achieve the predetermined tasks. There are numerous benefits to installing a Building Management System which can be varied from, minimizing energy used and thus being cost effective [3].

The concept of BMS is not a new one; the prospect has been present in the late 20st century and evolved since the beginning of the 20st century. In the past, each system in buildings usually operated on its own IT structure. Consequently, subsystems used to be operated separately from one another. Due to the complexity of new additions like energy saving, a new need for a management system has risen for the reduction of the increased costs. The current BMS system authorizes "for historical trend analysis to be paired with real-time data collection to optimize subsystems such as lighting and HVAC" [3]. Since data is growing constantly in an accelerated way, the way and the capacity to be able to analyze them enhance, which means that "the greater the application of intelligence and optimization in terms of energy utilization" [3].

The BMS system has many benefits for buildings. For example, the BMS system can control and manage the air quality through creating "an indoor environment that boosts employee health and productivity". Also, through the monitoring the BMS does of medical machines, it can keep a set schedule of all maintenance planned and needed. Thus, decreasing any costs resulting from the machines downtime, and prolonging the production capability performance [3].

In addition, the system allows remote monitoring. This can give better flexibility for the supervisors of the building but it also increases security for both the occupants and the equipment and assets inside. Additionally, this promptness provides a quick response to any possible emergency. According to Eseosa and Temitope (2019), this is possible because of the "Internet of Things (IoT) in smart buildings" in the past years. The initial cost of the BMS system might make investors hesitant to acquire the system. However, the long-lasting benefits overrides any cost doubts especially for the owners of industrial buildings, governmental buildings, hospitals and the like. They also state that the take-off of the BMS system has always been inevitable since the future of buildings is "unequivocally data and connectivity" [3].

Despite the initial cost of the BMS system, the owners of the buildings are expected to save tremendous amounts on the outrange. As seen in "Review of Smart Based Building Management System" [3], the system helps saving money through applying different monitoring and evaluation strategies and protocols for the electromechanical equipment within the building. Also, the BMS system allows the control of many activities such as electrical distribution panels, lighting control, fire alarm systems, public address CCTV monitoring, any intrusion detection and water consumption which would be costly on their own [2].

The BMS system has different monitoring and control protocols and strategies in place for the electromechanical equipment. The Building Automation System (BAS) also known as the BMS can predict the temperature's needs based on data collected. Therefore, saving money on heating and cooling bills through saving energy. According to Iwuagwu (2014) as seen in Eseosa and Temitope (2019), the system can save energy usage by 10-30%. Also, the BMS system can coincide with the outside environment in terms of using the outside light during the summer and spring to save on artificial lighting inside the building. The system is also time efficient in ways that notifies of any errors or failures immediately [2].

Additionally, the BMS system improves the comfort and productivity of the work. This is achieved through the improvement of the "building's indoor environment". Thus, increasing the comfort of the occupants inside the building and their productivity levels. This is due to the easy control over the heating and cooling systems and consequently the ventilation inside the building [3].

Importantly, the BMS system conserves energy in a way that reduces greenhouse gas emissions (GHG). This makes the system eco-friendly which has a long-lasting effect in fighting climate change. Since lighting, DHW (Domestic Hot Water), auxiliary energy and heating require considerable energy, the system should be a standard requirement in all buildings and to treat energy reduction as a top priority. Luckily, in the past few years, energy consumption has been a part of "estate management, facilities management, and operations strategy" [3].

Wireless communication is vital within the BMS system. There are "less cables, wires and conduits". This is particularly important in terms of facilitating all infrastructure challenges. The wireless aspect within the BMS has many benefits. First, "increased use of sensors", in large buildings like hospitals it is imperative to have an easier technological connection since the building is spread over a large geographical space. Second, it promotes "flexibility and adaptivity". According to Swarnalatha (2011) as seen in Eseosa and Temitope (2019), the wireless aspect has reduced the "capital expenditure of installing BMS in new and existing buildings by 34% and 55% respectively". Third, the wireless system in BMS allows remote usage and control. All electronic devices like tablets and phones can be easily linked with the BMS system. Consequently, giving relevant people access, monitor, and control the system regardless of the time and location in any emergency setting [3].

A report by the International Finance Corporation has done an extensive study about the hazards of fires in a hospital setting. Fires can be hazardous and disastrous at any rate. However, a fire in a health care structure can lead to destructive effects. Patients are one of the most vulnerable people in case of fire in the hospitals. Patients are unable to move freely in case of evacuation. They may not be able to leave the building due to many reasons like age, or mental or physical disabilities [4].

The importance of preventing fires before they happen is very important. However, in case they occur hospitals have set in place a set of protocols and procedures to follow for the safety of the patients. A “defend-in-place” method is one of the main strategies put in place. This method stands on the grounds of doing all possible to stop the fire without moving the patients outside the hospital. It is important to note that the report indicated that patients are indeed moved to a safe “refuge” area on the same floor for their protection. Different mitigation measures are set up within this system such as, sprinklers, alarm, control of contents and furnishings, the infrastructure and detection systems. Also, it is vital to have trained staff in case of emergencies. The staff are in charge of protecting the vulnerable patients and their ability to have good “availability, actions, and management” can save lives [4].

A BMS system can help prevent and control fire inside buildings. For example, elevator shafts can be like chimneys in their design. They permit smoke and air to move from floor to another, which is facilitated by the move of elevators themselves. The BMS system can control this problem through an existing fire alarm control panel (FACP). Also, alarms connected directly through sensors through the BMS can alert the building supervisor fast to avoid the spread of the fire [5].

This research aims at designing a hospital system that will control aspects that would benefit the patients and help the health takers to provide the best medical assistant they can offer. Isolation rooms are very important in hospitals. They are prominent in Infection Prevention Control (IPC) policies and protocols in any hospital to reduce risks of contamination. They allow the control of the airflow in the room to prevent “airborne infectious particles” through various methods. First, through controlling the quality and quantity of air. Second, maintaining different air pressure between areas that are closed. Third, designing airflow for certain clinical procedures. Fourth, air filtrations using air filters. Finally, diluting the” infectious particles with large air volumes” [6].

There are different types of isolation rooms. First, “neutral or standard room air pressure”, which can reference normal air conditioning. Second, “positive room air pressure”, this room allows protections for patients with compromised immune systems and as such, the patient is protected from airborne transmissions. Third, “Negative room air pressure”, in this type of rooms the visitors are protected from any airborne transmissions that might be in the air. Fourth, “Negative room air pressure with additional barriers including an Anteroom”. They are known as class S, Class P, Class N, Class Q respectively [6].

Ventilation is an important pillar within isolation rooms. A good ventilation can reduce the risk of airborne transmissions. This is done through two ways: dilution and removal. Dilution reduces the risk of people breathing in air that is contaminated; it means that it dilutes the “concentration” of the contaminations in the room. The removal method is applied when air is either removed completely to another safe place, or recycled through “HEPA filters” where droplets are “trapped” before they are circulated [7].

When heating, ventilating, and air-conditioning (HVAC) is designed in a building, usually comfort concerns are what the designs are based on. However, any standards requirements should be a priority. In addition, there are different systems when mechanical engineers design variable air volume systems (VAV). Sometimes those systems do not always provide “constant airflow rate”. The

VAV systems are designed to “vary” the amount of heating and cooling air delivered to the required amount. Usually, the VAV systems are not included in hospitals but they do exist in buildings with clinics. That mentioned, the air volume that is supplied in isolation rooms should not vary. Therefore, airflow provided should be constant and the designing mechanical engineer will usually address every comfort level separately.

In a report called “Analytical Determination of Medical Gases Consumption and Their Impact on Hospital Sustainability” (2018), the authors state how important medical gasses are in health structures as they are used for anesthesia, therapy, or diagnosis purposes. Medical gasses are important as they have many “anesthetic, analgesic and respiratory properties in the ambit of disease diagnosis, treatment, prevention or relief”. Medical gasses are also referred to as “special medicines” (Hurlé 2005, as seen in Gómez-Chaparro, García-Sanz-Calcedo and Armenta Márquez 2018). The most used gasses in medical facilities are N^2, CO^2 and N_2O, H_2O. Therefore, the safe and efficient transfer of these gasses is guaranteed by a certain system. Oxygen is considered one of the most used medical gasses for its therapeutic effects, especially respiratory ones which makes the structure and the way it is designed to reach the patient important [8].

The installation of the medical gas equipment needs different sorting and distribution systems. For example, “portable gas cylinders, single cylinders batteries, cryogenic tanks and specific devices for self-production of medical air”. The authors of “Analytical Determination of Medical Gases Consumption and Their Impact on Hospital Sustainability” (2018) have reviewed different literature in their report where different researcher has either forgot to count for “individual gas consumption rates”, or not accounting for the “mean consumption rates for standard operating rates” (Zelaya 2013, and Lara 2010 respectively) [8].

Producing medical gasses has severe environmental consequences. The World Health Organization (WHO) and many other UN environmental organizations are concerned with the risks produced by medical gas production and the insufficient management especially generating “NOx compounds”. Therefore, the authors are suggesting that efforts need to be put in place to have better monitoring and management of the facilities that produce medical gas. Also, it is important to be more cost efficient as well as producing less “atmospheric emissions”. The authors state that so far there are no adequate monitoring systems for the consumption rates of the medical gasses has been set in place yet, nor the existence of studies regarding the saving in costs when better monitoring systems were set in place [8].

In a recent report by INSPITAL, they present a comprehensive system about managing, monitoring and controlling medical gasses in hospital settings. The report “Medical Gas Stations & Control Units” offers a thorough look into the system and what it entails. The INSPITAL consists of “medical gas generators, manifolds, pipeline systems, area control units, alarm systems, monitoring screens and the final gas outlets in Operating Theatres, ICU and patient rooms” [9].

This is especially relevant due to the COVID-19 pandemic and the disparate need for a comprehensive system for medical gasses within hospitals especially in COVID ICU’s. The system offers “continuous” medical gasses through hospital pipelines to the cylinders. Also, the electronically controlled multifarious system decreases the “cylinder pressure to required level”. In addition, each station has specific and main cylinder racks and a backup, additional one which the system transitions between the two without disconnecting the continuous flow [9].

The system is designed to “provide isolation of individual floors of medical gases in the hospital”, which is important for installation, maintenance or in case of emergencies. In addition, vacuum is a pivotal part for the supply system in hospitals. This system offers a stable vacuum station which is used to “aspirate airways in the operating theatres, on ICU and on regular patient rooms”. All data notes and any errors are controlled by a digital controlling panel. There is an emergency “reserve manifold” which has two regulation systems which offers continuous flow in case of emergencies [9].

1.5 Research Methodology

The manual design of the sample room HVAC systems is done by referring to the Transfer Function Method (TFM) based on ASHRAE instructions found in their Fundamentals handbook and their HVAC Design Manual for Hospitals and Clinics. And by using the Carrier’s Hourly Analysis Program (HAP).

HAP is a computer software 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 building energy use and calculating energy costs. HAP uses the ASHRAE transfer function method (TFM) for load calculations and detailed 8,760 hour-by-hour simulation techniques for the energy analysis. The 8760-energy model is an hour-by-hour analysis that simulates a building’s performance for all 8,760 hours in a given 12-month period. This method uses the actual sequence of days and weather data, instead of averages. An 8760 analysis produces the most accurate energy model and operating cost estimates. The maximum total cooling load difference between hand calculation and HAP program is 23.1 % [10]. Based on this HAP was used as the main load software in this project alongside MEP, which will be used for heating and cooling load estimation.

Autodesk Revit MEP is a building information modeling (BIM) software created by Autodesk for professionals who work in MEP engineering. MEP stands for mechanical and electrical, which are the three engineering disciplines that are addressed by Revit MEP. The software is powerful enough to leverage dynamic information in intelligent models. The software is used to streamline the engineering design process making product design and development more efficient.

1.6 Chapters Overview

Chapter One Introduction: Include an overview about the project, and the importance of the HVAC systems in health care facilities.

Chapter Two HVAC System Design: Include the thermal loads estimations, cooling equipment selection, duct system calculations and hospital sensitive rooms design.

Chapter Four Firefighting System: Will include the firefighting systems design in hospitals with the hydraulic calculations and selection for the components.

Chapter Three Medical Gases System: Will include the hospital needed capacity for the different types of medical gases, with their pipeline system design

Chapter Five BMS for HVAC Systems: Will present a practical emerging between BMS and HVAC, firefighting, lighting system in the Red Crescent Society in Hebron city.

Chapter 2

HVAC System Design

2.1 Introduction

HVAC systems in hospitals provide a broad range of services in support of populations who are uniquely vulnerable to an elevated risk of health. These heavily regulated, high-stakes facilities undergo continuous maintenance, verification, inspection, and recertification; typically operate 24 hours/day, 7 days/ week; and are owner-occupied for long life cycles. Health care HVAC systems must be installed, operated, and maintained in spatial and functional conjunction with a host of other essential building services, including emergency and normal power, plumbing and medical-gas systems, automatic transport, fire protection, and myriad IT systems, all within a constrained building envelope. Health care facilities are characterized by high rates of modification because of the continuously evolving science and economics of health care, and consume large quantities of energy and potable water. The often-unique environmental conditions associated with these facilities, and the critical performance, reliability, and maintainability of the HVAC systems necessary to their success, demand a specialized set of engineering practices and design criteria established by model codes and standards and enforced by authorities having jurisdiction. And the starting point in designing such systems is to estimate the cooling and heating loads, and this will be done using HAP for the whole project, but firstly a by hand calculations will be applied on a sample room using CLTD method.

2.2 Temperature Design Conditions and Weather Data

When designing an HVAC system, it is of high importance to use the correct outdoor design conditions for the locality in which the building located. This data is used when calculating the building component heating load and component cooling load, which in turn are used to determine the required cubic feet per minute (CFM) for each room, design the appropriate duct work, and select the optimal equipment for the application. As is evident, not using the relevant outdoor design conditions can cause errors that will propagate throughout the system design process. The results are an uncomfortable indoor environment, energy inefficiency, and avoidable expenses.

2.2.1 Inside Design Conditions

There are four parameters that directly affect occupant comfort and must be considered when designing: temperature, humidity, air velocity and temperature. These effects can vary dramatically between winter and summer.

As shown in Figure 2.1 [11], the ASHRAE Comfort Zone is defined as the range of temperature and humidity conditions where 80% of people engaged in light office work are satisfied with the thermal condition. In heating situations for cold climates, the introduction of cold dry outside air into the space can result in low space humidity, that will cause occupant discomfort due to scratchy throats, nosebleeds and static electricity. Humidification of the air may be required for these situations. In air-conditioning situations, most traditional cooling systems have targeted the upper right corner of the summer comfort zone, with typical conditions being 78°F (25.5 ℃) at 50% relative humidity. Moving air increases the rate of convective heat transfer from people's skin and provides evaporative cooling if they are sweating. A blast of cool air, and air movement in general, might be very welcome during the cooling season in many industrial applications. However, during the heating season, high velocities from the air distribution system, or air cascading down large glass windows, can cause annoying drafts. The goal of the air distribution system is usually to deliver the required air flow without being sensed by the occupant. To accomplish this, most air-conditioning designs call for relatively low air velocity (less than 100 fpm or 0.5 m/s) within the controlled space [12].

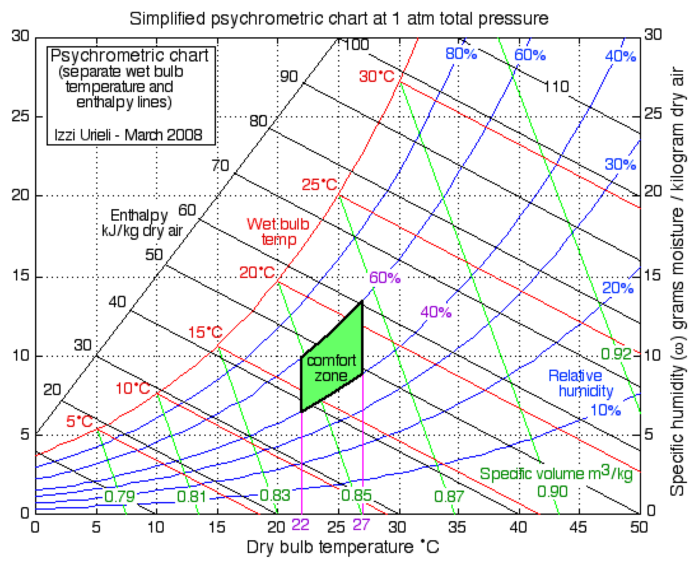

Figure 2. 1: ASHRAE Comfort Zone Chart

According to ASHRAE HVAC Design Manual for Hospitals and Clinics [13], the inside design conditions recommended are as shown in Appendix A1.

2.2.2 Outside Design Conditions

When calculating the thermal loads for a building, it is very important that the heating and cooling equipment system be capable of maintaining adequate comfort under all reasonable conditions. But sizing a heating system for the coldest temperature ever recorded will result in an oversized furnace that will be more expensive than necessary to buy and often less efficient to operate. So, winter and summer design conditions have been developed that provide adequate and acceptable capacity and save the building owner both construction dollars as well as operating costs.

We will consider the conditions that are provided by ASHARE website [14], but the problem with it is that ASHARE have only one weather station in Palestine and it’s located in Jerusalem, but since the weather data are very similar with Hebron, the given results are in the acceptable range and thus will be used for the whole project. Figure 2.2 includes all the weather data and other data that will be discussed in the following sections.

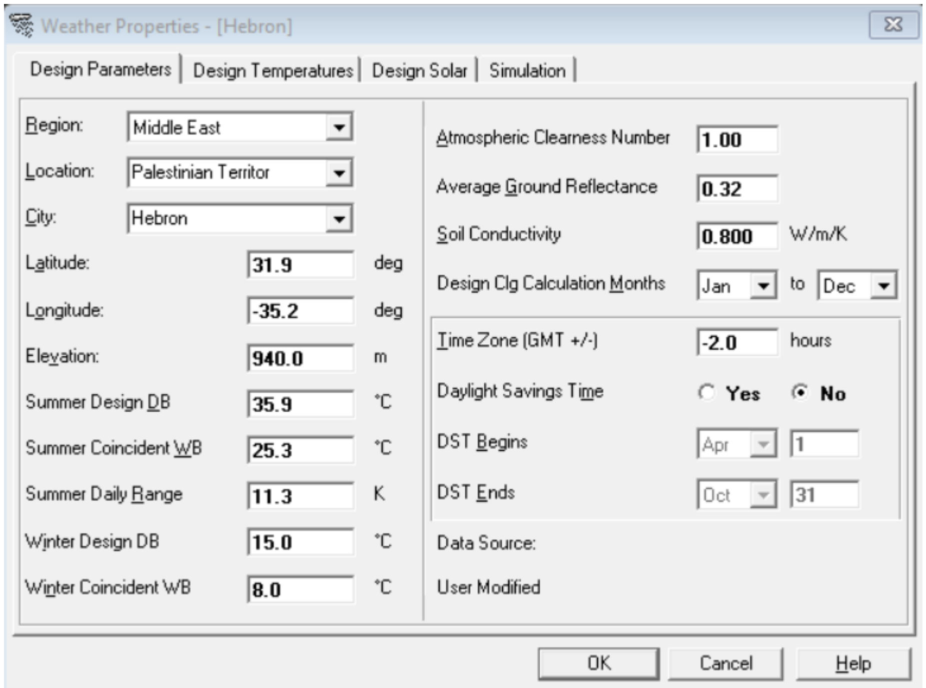

Figure 2. 2: Weather Data from ASHRAE

1) Summer Design DB (Dry Bulb): The outside design dry-bulb temperature.
2) Summer Coincident WB (Wet-Bulb): The outside design wet-bulb temperature.
3) Summer Daily Range: The difference between the highest and minimum temperature in summer.
4) Atmospheric Clearness Number: is a dimensionless number indicating the fraction of the solar radiation striking the top of the atmosphere that makes it through the atmosphere to strike the Earth's surface. It will be chosen as 1 as a default number since there is no data about the atmospheric clearness for West Bank in ASHRAE or any other reference.
5) Average Ground Reflectance: also known as albedo is defined as the average fraction of incident radiation reflected by the ground. The respective values should be in a percentage form (e.g., 0% stands for total absorption and 100% for total reflection). It's selected as an average value of 0.32 from the Table 2.1 [15].

Table 2. 1 :Solar Reflectance of Foreground Surfaces

	Incident Angle					
Foreground Surface	**20°**	**30°**	**40°**	**50°**	**60°**	**70°**
New concrete	0.31	0.31	0.32	0.32	0.33	0.34
Old concrete	0.22	0.22	0.22	0.23	0.23	0.25
Bright green grass	0.21	0.22	0.23	0.25	0.28	0.31
Crushed rock	0.20	0.20	0.20	0.20	0.20	0.20
Bitumen and gravel roof	0.14	0.14	0.14	0.14	0.14	0.14
Bituminous parking lot	0.09	0.09	0.10	0.10	0.11	0.12

Adapted from Threlkeld (1962).

6) Soil Conductivity: is the thermal conductivity for the ground which surround the walls of the basement and its floor. It’s chosen as sand of 0.8

Table 2. 2: Thermal Conductivity Values for Soils

Table 8 Typical Apparent Thermal Conductivity Values for Soils, W/(m·K)

		Recommended Values for Design[a]	
	Normal Range	Low[b]	High[c]
Sands	0.6 to 2.5	0.78	2.25
Silts	0.9 to 2.5	1.64	2.25
Clays	0.9 to 1.6	1.12	1.56
Loams	0.9 to 2.5	0.95	2.25

[a]Reasonable values for use when no site- or soil-specific data are available.
[b]Moderately conservative values for minimum heat loss through soil (e.g., use in soil heat exchanger or earth-contact cooling calculations). Values are from Salomone and Marlowe (1989).
[c]Moderately conservative values for maximum heat loss through soil (e.g., use in peak winter heat loss calculations). Values are from Salomone and Marlowe (1989).

2.3 Thermal Properties of Materials

The thermal characteristics of the hospital building materials used to construct it is structure have a major impact on the load estimation and thus its energy cost of it is operation. In this section we will examine both the thermal properties of construction materials and calculate the composite U-factor for different cross-sections of the walls, floors, ceiling, etc.

2.3.1 Construction Material

1) Inside Walls

The following Figure 2.3 shows the section of the inside wall construction materials.

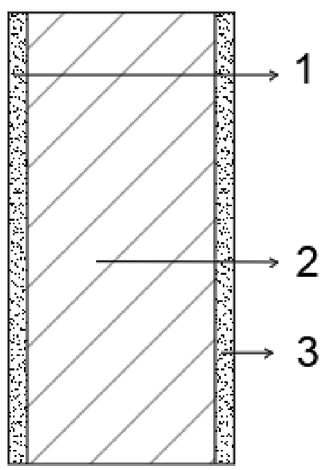

Figure 2. 3: Inside Wall Section

The thermal properties (conductivity, thermal resistance) are shown in Table 2.3 and were taken from ASHRAE Fundamentals 1997 [14] and the Palestinian Energy Efficient Building Code [16].

Table 2. 3: Materials Type and Thermal Properties for Inside Walls

Number	Material	**Conductivity** [W/ (m.K)]	**Thickness** [m]	**Resistance** $[K.m^2/\text{W}]$	**Specific Heat** [kJ/(kg·K)]
1, 3	Cement Plaster	0.72	0.01	0.014	0.84
2	Concrete Block	0.89	0.1	0.112	0.97

2) External Walls

The following Figure 2.4 shows the section of the inside wall construction materials.

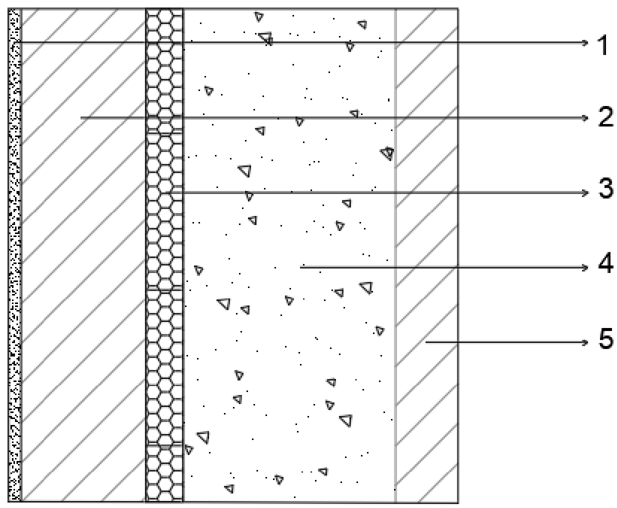

Figure 2. 4: External Wall Section

The thermal properties (conductivity, thermal resistance) for the external walls are shown in the below Table 2.4.

Table 2. 4: Materials Type and Thermal Properties for External Walls

Number	Material	**Conductivity** [W/ (m.K)]	**Thickness** [m]	**Resistance** $[K.m^2/\text{W}]$	**Specific Heat** [kJ/(kg·K)]
1	Cement Plaster	0.72	0.01	0.014	0.84
2	Concrete Block	0.89	0.1	0.112	0.97
3	Polystyrene (extruded)	0.022	0.03	1.36	1.47
4	Concrete	1.40	0.17	0.121	0.8
5	Stone (Taffuh)	1.40	0.05	0.035	0.85

3) Basement External Walls

The following Figure 2.5 shows the section of the inside wall construction materials.

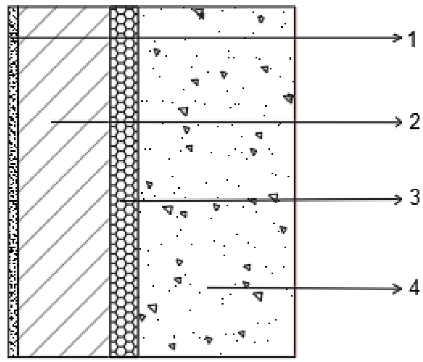

Figure 2. 5: Basement Wall Section

The thermal properties (conductivity, thermal resistance) for the external walls are shown in the below Table 2.5.

Table 2. 5: Materials Type and Thermal Properties for Basement Walls

Number	**Material**	**Conductivity** [W/ (m.K)]	**Thickness** [m]	**Resistance** [$K.m^2$/W]	**Specific Heat** [kJ/ (kg·K)]
1	Cement Plaster	0.72	0.01	0.014	0.84
2	Concrete Block	0.89	0.1	0.112	0.97
3	Polystyrene (extruded)	0.022	0.03	1.36	1.47
4	Concrete	1.40	0.17	0.121	0.8

4) Basement Floor

The following Figure 2.6 shows the section of the inside wall construction materials.

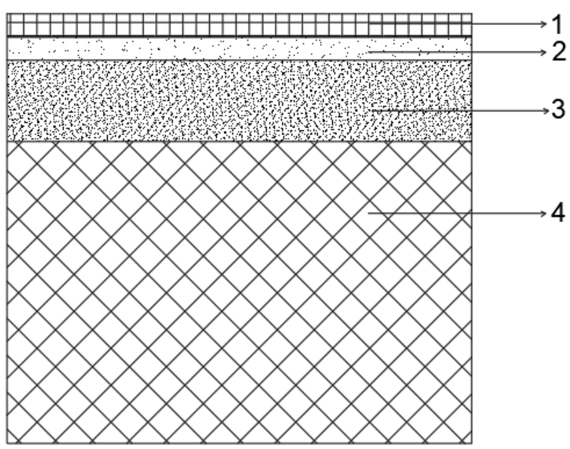

Figure 2. 6: Basement Floor Section

The thermal properties (conductivity, thermal resistance) for the external walls are shown in the below Table 2.6.

Table 2. 6: Materials Type and Thermal Properties for Basement Floor

Number	Material	Conductivity [W/ (m.K)]	Thickness [m]	Resistance $[K.m^2/W]$	Specific Heat [kJ/ (kg. K)]
1	Ceramic Tiles	1.2	0.02	0.0167	0.85
2	Cement Mortar	1.4	0.02	0.014	0.96
3	Sand	0.3	0.07	0.23	0.8
4	Reinforced Concrete [17]	1.55	0.26	0.167	0.9

5) Floor

The following Figure 2.7 shows the section of the inside wall construction materials.

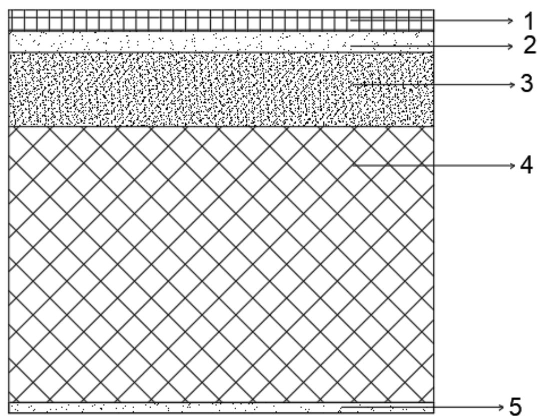

Figure 2. 7: Floors Section

The thermal properties (conductivity, thermal resistance) for the external walls are shown in the below Table 2.7.

Table 2. 7: Materials Type and Thermal Properties for Floor

Number	Material	Conductivity [W/ (m.K)]	Thickness [m]	Resistance $[K.m^2/W]$	Specific Heat [kJ/ (kg·K)]
1	Ceramic Tiles	1.2	0.02	0.0167	0.85
2	Cement Mortar	1.4	0.02	0.014	0.96
3	Sand	0.3	0.07	0.23	0.8
4	Reinforced Concrete	1.55	0.26	0.167	0.9
5	Cement Plaster	0.72	0.01	0.014	0.84

6) Ceiling

The following Figure 2.8 shows the section of the inside wall construction materials.

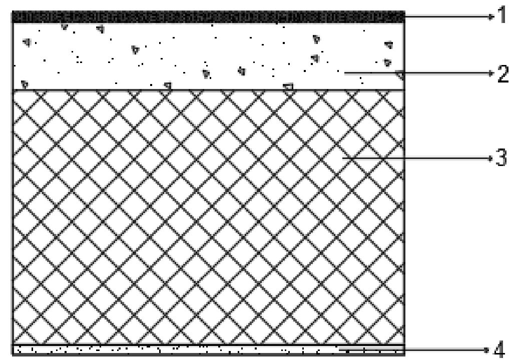

Figure 2. 8: Ceiling Section

The thermal properties (conductivity, thermal resistance) for the external walls are shown in the below Table 2.8.

Table 2. 8: Materials Type and Thermal Properties for Ceiling

Number	**Material**	**Conductivity** [W/ (m.K)]	**Thickness** [m]	**Resistance** $[K.m^2/\text{W}]$	**Specific Heat** [kJ/ (kg·K)]
1	Asphalt Roll Roofing	0.37	0.01	0.027	1.51
2	Concrete	1.40	0.07	0.05	0.8
3	Reinforced Concrete	1.55	0.26	0.167	0.9
4	Cement Plaster	0.72	0.01	0.014	0.84

7) Window

The following Figure 2.9 shows the section of the used windows (Double Glass with Aluminum-Frame)

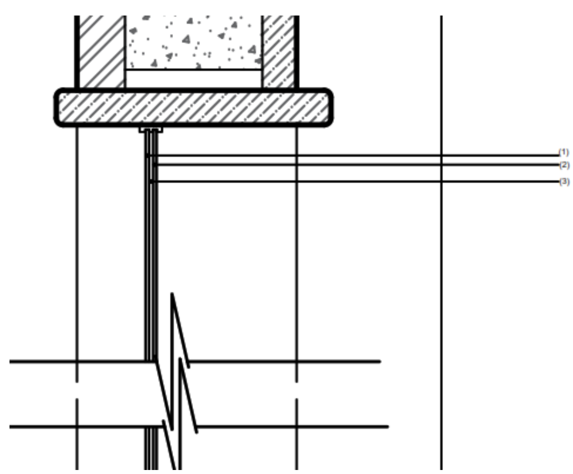

Figure 2. 9: Window Section

The thermal properties (conductivity, thermal resistance) for the windows are shown in the below Table 2.9.

Table 2. 9: Materials Type and Thermal Properties for Windows

Number	**Material**	**Conductivity** [W/ (m.K)]	**Thickness** [m]	**Resistance** [$K.m^2$/W]	**Specific Heat** [kJ/ (kg·K)]
1, 2	Glass	0.96	0.005	0.00625	0.84
3	Air Gap	0.023	0.006	0.231	1.005

8) Doors

a) Stainless Steel Door

According to the architectural plans a stainless-steel door will be used in operation, isolation, laboratory rooms.

The following Figure 2.10 shows the section of the used windows (Double Glass with Aluminum- Frame)

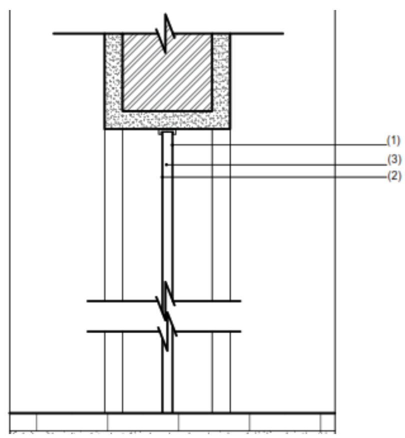

Figure 2. 10: Door(a) Section

The thermal properties (conductivity, thermal resistance) for the windows are shown in the below Table 2.10.

Table 2. 10: Materials Type and Thermal Properties for Door (a)

Number	**Material**	**Conductivity** [W/ (m.K)]	**Thickness** [m]	**Resistance** [$K.m^2$/W]	**Specific Heat** [kJ/ (kg·K)]
1.2	Stainless Steel Sheet	14.4	0.0012	8.3×10^{-5}	0.502
3	Compressed Wood Wool [18]	0.072	0.00497	0.069	2.88

b) Wood Door

All other doors in the building are made mainly from wood as given in the architectural plans

The thermal properties (conductivity, thermal resistance) for the windows are shown in the below Table 2.8b.

Table 2.10b: Materials Type and Thermal Properties for Door (b)

Number	**Material**	**Conductivity** [W/ (m.K)]	**Thickness** [m]	**Resistance** $[K.m^2/\text{W}]$	**Specific Heat** [kJ/ (kg·K)]
1.2	Wood	0.12	0.0012	0.02	1.3
3	Paper Honeycomb	0.45	0.00497	0.01	-

2.4 Load Calculations

The space cooling load is the rate at which heat must be removed from a space in order to maintain the desired conditions in the space, generally a dry-bulb temperature and relative humidity. The cooling load for a space can be made up of many components, including:

1) Conduction heat gain from outdoors through the roof, exterior walls, skylights, and windows. (This includes the effects of the sun shining on these exterior surfaces.)
2) Solar radiation heat gain through skylights and windows.
3) Conduction heat gain from adjoining spaces through the ceiling, interior partition walls, and floor.
4) Internal heat gains due to people, lights, appliances, and equipment in the space.
5) Heat gain due to hot, humid air infiltrating into the space from outdoors through doors, windows, and small cracks in the building envelope.

In addition, the cooling coil in the building HVAC system has to handle other components of the total building cooling load, including:

1) Heat gain due to outdoor air deliberately brought into the building for ventilation purposes.
2) Heat generated by the fans in the system and possibly other heat gains in the system.

These load components contribute sensible and/or latent heat to the space. Conduction through the roof, exterior walls, windows, skylights, ceiling, interior walls, and floor, as well as the solar radiation through the windows and skylights, all contribute only sensible heat to the space. The people inside the space contribute both sensible and latent heat. Lighting contributes only sensible heat to the space, while equipment in the space may contribute only sensible heat (as is the case for a laptop) or both sensible and latent heat (as is the case for a coffee maker). Infiltration generally contributes both sensible and latent heat to the space. The cooling coil has to handle the additional components of ventilation and system heat gains. Ventilation contributes both sensible and latent heat to the coil load. Other heat gains that occur in the HVAC system (from the fan, for example) generally contribute only sensible heat [19].

The space heating load is the rate at which heat must be added to a space in order to maintain the desired conditions in the space, generally a dry-bulb temperature. During this period, we will estimate the heating load for the same office space that was used for the example in Period Two.

In general, the estimation of heating loads assumes worst-case conditions for the space. The winter design outdoor temperature is used for determining the conduction heat loss through exterior surfaces. No credit is given for heat gain from solar radiation through glass or from the sun's rays warming the outside surfaces of the building. Additionally, no credit is given for internal heat gains due to people, lighting, and equipment in the space.

The heating load for a space can be made up of many components, including:

1) Conduction heat loss to adjoining spaces through the ceiling, interior partition walls, and floor.
2) Heat loss due to cold air infiltrating into the space from outdoors through doors, windows, and small cracks in the building envelope.

2.4.1 Manual Cooling Load Estimation

In addition, the heating coil in the building HVAC system has to heat up the outdoor air that is deliberately brought into the building for ventilation purposes.

For demonstration, a cooling load estimation will be computed manually according the ASRAHE CLTD Method for a patient room in the first floor shown in Figure 2.11.

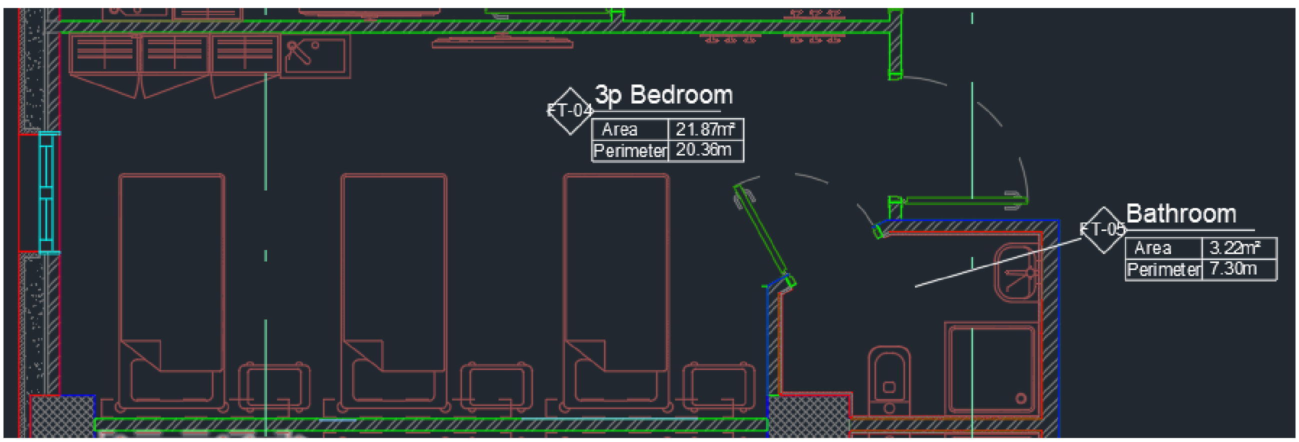

Figure 2. 11: Patient Room FT-04 Plan Layout

1) External Walls

To compute the walls external load, equation 1.1 will be used

$Q = U \times A \times CLTD_{Corr}.$ (2.1)

Where:

Q: heat gain by conduction, [kW].

U: Overall heat-transfer coefficient of the surface, [W/$m^2.°K$].

A: Area of the surface, [m^2].

CLTD: Cooling load temperature difference (CLTD).

For the sample room, the U-value of the external wall is computed according to Figure 2.2 using equation 2.2

$$U = \frac{1}{R_i + R_o + R_{Plaster} + R_{CB} + R_{Insu.} + R_{Stone}} \quad (2.2)$$

Where:
R_i: Inside still air film resistance (0.12 $[m^2.K/W]$).
R_o: Outside air resistance at the outside air conditions (0.05 $[m^2.K/W]$).
U = 0.55 $[W/m^2.K]$
The area of the external wall is directed at SW
$A_{Wall} = (3.3 \times 3.25) - 1.5 = 9.2\ m^2$
The CLTD value is obtained from
(CLTD)corr. = (CLTD + LM) k + (25.5 - T_{in}) + (T_{om} – 29.4) f (2.3)
CLTD: Cooling load temperature difference, ˚C, Table 2.12 / CLTD= 19 ˚C
LM: Latitude correction factor, from Figure 2.17
k: Color adjustment factor. / K=0.56 for Light colors.
T_{In}: Inside comfort design temperature, ˚C
f: Attic or roof fan factor. / f=1
T_{om} : Outdoor mean temperature, ˚C
T_{om}= (T_{Max} +T_{Min}) /2 (2.4)
Where:
T_{Max} : Maximum average daily temperature, ˚C
T_{Min}: Minimum average daily temperature, ˚C
T_{Max} = 33.1 ˚C and T_{Min}= 18.3 ˚C
Applying these values in equation (2.4) to obtain the outdoor mean temperature
T_{om} = 25.7 ˚C.
Substituting the other values in equation 2.3 will give a $CLTD_{Corr}$.=11.72 ˚C

Table 2. 11: Approximate CLTD Values for Walls

Daily Temperature Range[b]		Design Temperature, °C												
		29		32			35			38		41	43
		L	M	L	M	H	L	M	H	M	H	M	H
Walls and doors[c]													
N	Low	8	6	11	9	7	13	12	9	14	12	15	18
	Medium	7	6	10	8	6	13	11	9	14	12	14	17
	High	5	3	8	6	4	11	9	7	12	9	12	15
NE	Low	13	9	16	12	9	18	15	12	18	14	17	20
	Medium	11	8	14	11	9	17	14	12	16	14	16	19
	High	9	7	12	9	7	14	12	10	14	12	14	17
E	Low	18	15	21	18	15	24	21	18	23	21	23	26
	Medium	17	13	19	16	13	22	19	16	22	18	22	24
	High	13	10	16	13	10	19	16	13	18	16	18	21
SE	Low	17	15	19	17	14	23	21	17	23	21	23	26
	Medium	16	12	18	15	12	21	18	15	21	18	21	24
	High	12	9	14	12	9	18	15	12	17	15	18	21
S	Low	14	12	16	14	12	19	17	14	20	18	21	24
	Medium	12	10	14	12	10	17	14	12	17	15	18	21
	High	9	6	11	9	7	14	12	9	14	12	15	18
SW	Low	22	20	24	22	19	28	26	22	28	26	29	32
	Medium	18	16	21	19	16	24	22	19	25	22	26	29
	High	13	10	16	13	11	20	17	14	19	17	20	23

Table 2. 12: Latitude- Month Correction Factor LM

Table (A-2) Latitude-Month correction factor LM, as applied to walls and horizontal roofs, north latitudes.

Lat.	Month	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	Horizontal Roofs
16	December	−2.2	−3.3	−4.4	−4.4	−2.2	−0.5	2.2	5.0	7.2	−5.0
	Jan./Nov.	−2.2	−3.3	−3.8	−3.8	−2.2	−0.5	2.2	4.4	6.6	−3.8
	Feb./Oct.	−1.6	−2.7	−2.7	−2.2	−1.1	0.0	1.1	2.7	3.8	−2.2
	Mar/Sept.	−1.6	−1.6	−1.1	−1.1	−0.5	−0.5	0.0	0.0	0.0	−0.5
	Apr./Aug.	−0.5	0.0	−0.5	−0.5	−0.5	−1.6	−1.6	−2.7	−3.3	0.0
	May/July	2.2	1.6	1.6	0.0	−0.5	−2.2	−2.7	−3.8	−3.8	0.0
	June	3.3	2.2	2.2	0.5	−0.5	−2.2	−3.3	−4.4	−3.8	0.0
24	December	−2.7	−3.8	−5.5	−6.1	−4.4	−2.7	1.1	5.0	6.6	−9.4
	Jan./Nov.	−2.2	−3.3	−4.4	−5.0	−3.3	−1.6	−1.6	5.0	7.2	−6.1
	Feb./Oct.	−2.2	−2.7	−3.3	−3.3	−1.6	−0.5	1.6	3.8	5.5	−3.8
	Mar/Sept.	−1.6	−2.2	−1.6	−1.6	−0.5	−0.5	0.5	1.1	2.2	−1.6
	Apr./Aug.	−1.1	−0.5	0.0	−0.5	−0.5	−1.1	−0.5	−1.1	−1.6	0.0
	May/July	0.5	1.1	1.1	0.0	0.0	−1.6	−1.6	−2.7	−3.3	0.5
	June.	1.6	1.6	1.6	0.5	0.0	−1.6	−2.2	−3.3	−3.3	0.5
32	December	−2.7	−3.8	−5.5	−6.1	−4.4	−2.7	1.1	5.0	6.6	−9.4
	Jan./Nov.	−2.7	−3.8	−5.0	−6.1	−4.4	−2.2	1.1	5.0	6.6	−8.3
	Feb./Oct.	−2.2	−3.3	−3.8	−4.4	−2.2	−1.1	2.2	4.4	6.1	−5.5
	Mar/Sept.	−1.6	−2.2	−2.2	−2.2	−1.1	−0.5	1.6	2.7	3.8	−2.7
	Apr./Aug.	−1.1	−1.1	−0.5	−1.1	0.0	−0.5	0.0	5.0	0.5	−0.5
	May/July	0.5	0.5	0.5	0.0	0.0	−0.5	−0.5	−1.6	−1.6	0.5
	June	0.5	1.1	1.1	0.5	0.0	−1.1	−1.1	−2.2	−2.2	1.1
40	December	−3.3	−4.4	−5.5	−7.2	−5.5	−3.8	0.0	3.8	5.5	−11.6
	Jan./Nov.	−2.7	−3.8	−5.5	−6.6	−5.0	−3.3	0.5	4.4	6.1	−10.5
	Feb./Oct.	−2.7	−3.8	−4.4	−5.0	−3.3	−1.6	1.6	4.4	6.6	−7.7
	Mar/Sept.	−2.2	−2.7	−2.7	−3.3	−1.6	0.5	2.2	3.8	5.5	−4.4
	Apr./Aug.	−1.1	−1.6	−1.6	−1.1	0.0	0.0	1.1	1.6	2.2	1.6
	May/July	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5
	June	0.5	0.5	0.5	0.5	0.0	0.5	0.0	0.0	−0.5	1.1
48	December	−3.3	−4.4	−6.1	−7.7	−7.2	−5.5	−1.6	1.1	3.3	−13.8
	Jan./Nov.	−3.3	−4.4	−6.1	−7.2	−6.1	−4.4	−0.5	2.7	4.4	−13.3
	Feb./Oct.	−2.7	−3.8	−5.5	−6.1	−4.4	−2.7	0.5	4.4	6.1	−10.0
	Mar/Sept.	−2.2	−3.3	−3.3	−3.8	−2.2	−0.5	2.2	4.4	6.1	−6.1
	Apr./Aug.	−1.6	−1.6	−1.6	−1.6	−0.5	0.0	2.2	3.3	3.8	−2.7
	May/July	0.0	−0.5	0.0	0.0	0.5	0.5	1.6	1.6	2.2	0.0
	June	0.5	0.5	1.1	0.5	1.1	0.5	1.1	1.1	1.6	1.1

Thus, using equation 2.1, the wall load is $Q = 59.3\ W$

Since the inside of the room to the space door is an adjacent to a conditioned area, the heat gain for it will be ignored.

2) Windows

The temperature variation through the window is assumed to be steady thus

$$Q_{Window} = U \times A \times \Delta T \quad (2.5)$$

The U-value referring to Table 2.7 is U = 3.5 $[W/m^2.K]$

A=1.456 m^2

$\Delta T =$ 33.1-21=12.1 ˚C

Thus, $Q_{Window} = 61.6\ W$

3) Lights

According to ASHRAE Fundamentals, in patient room the lighting heat gain is 6.7 W/m^2 and the CLF factor is 0.92 assuming 16 hours of operation.

$Q_{Lighting} = A \times Q_{Light} \times CLF$ (2.6)

$Q_{Lighting} = 25 \times 6.7 \times 0.91 = 152.4\ W$

4) People Load (Sensible and Latent)

$Q_{People-Sensible} = N_{Prople} \times Q_{People-Seated-Sensible} \times$ CLF (2.7)

$= (3\ Patient + 2\ Nursies) \times (67.4) \times 1$

$Q_{People-Sensible} = 337\ W$

$Q_{People-Latent} = N_{Prople} \times Q_{People-Seated-Latent} \times$ CLF

$= 5 \times 35.2 \times 1$

$Q_{People-Latent} = 176\ W$

5) Electrical Equipment

$Q_{Equipments} = Q_{Equ.} \times CLF$ (2.8)

= 500 × 1

$Q_{Equipments}$ = 500 W

6) Infiltration

The air change method is the easiest, but may be the least accurate of these methods. It involves estimating the number of air changes per hour that can be expected in spaces of a certain construction quality.

Infiltration Airflow = $V \times ACH/1.7$ (2.9)

According to ASHRAE Standard 170 2019 in Appendix A1, a total minimum ACH of 4 is required for patient rooms, and thus the infiltration airflow is

Infiltration Airflow = $(25 \times 2.75 \times 4)/1.7$

= 161.76 CFM = 0.07 m^3/s

$Q_{Inf-Sensible}$ = 1,210 × airflow × ΔT (2.10)

Where:

1210 is a conversion factor.

$Q_{Inf-Sensible}$ = 1210 × 0.07 × $[33.1 - 21]$

$Q_{Inf-Sensible}$ = 1024.87 W

$Q_{Inf-Latent}$ = 3,010 × airflow× $\Delta\ \omega$ (2.10)

Where:

3010 is a conversion factor

$\Delta\ \omega$: design outdoor humidity ratio minus the desired indoor humidity ratio of dry air [grams of water/kg of dry air]

= 3,010 × 0.07 × $[17 - 14]$

= 632.1 W

7) Ventilation

Ventilation Airflow = 80.7 CFM = 0.038 m^3/s

$Q_{Vent.Sen}$ = 1,210 × Vent. Airflow × [ΔT]

= 1210 × 0.038 × [33.1-21]

$Q_{Vent.Sen}$ = 556.5 W

$Q_{Vent.Lat}$ = 3,010 × 0.038 × (17 - 14) = 343.14 W

Total Cooling Loads (Sensible and Latent without the Ventilation) = 2934.27 W = 0.84 Ton

Note: Most of the above equations are from Trane and ASHRAE

2.4.2 Load Estimation Using HAP (Hourly Analysis Program)

The same sample room FT-04 will be entered in HAP and explained in the following figures.

1) From space in Figure 2.12, the first tab is the general tab, in which we defined the following according to the architecture plan and Figure 2.11

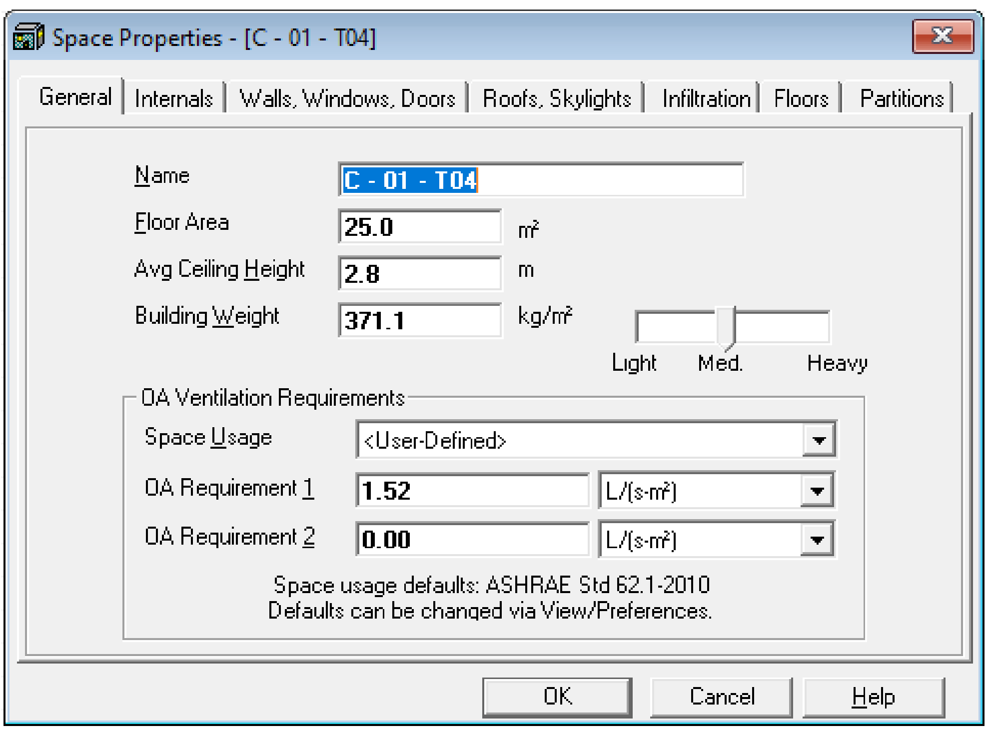

Figure 2. 12: Space – General Tab

2) Internals tab in Figure 2.13, the values are taken from ASHRAE Fundamentals [15]

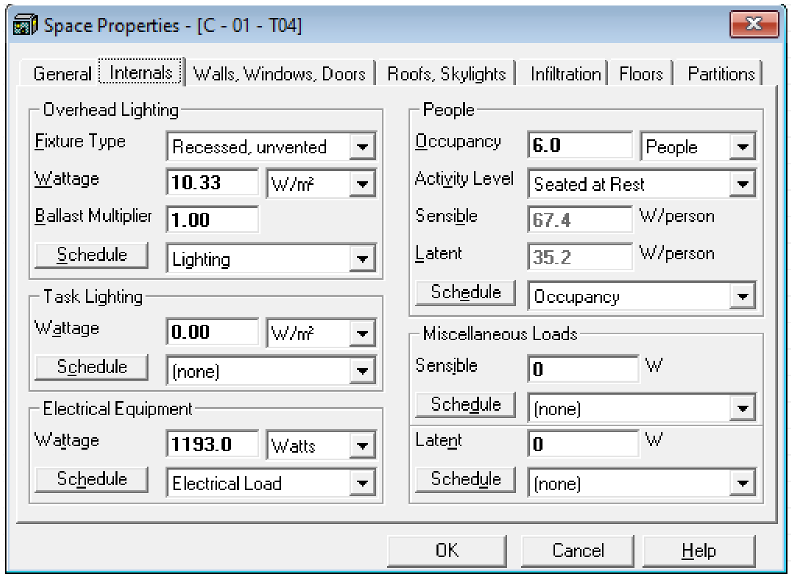

Figure 2. 13: Space – Internal Loads

3) Gross Area is the total area of the wall, and the value for the sample room is shown in Figure 2.14

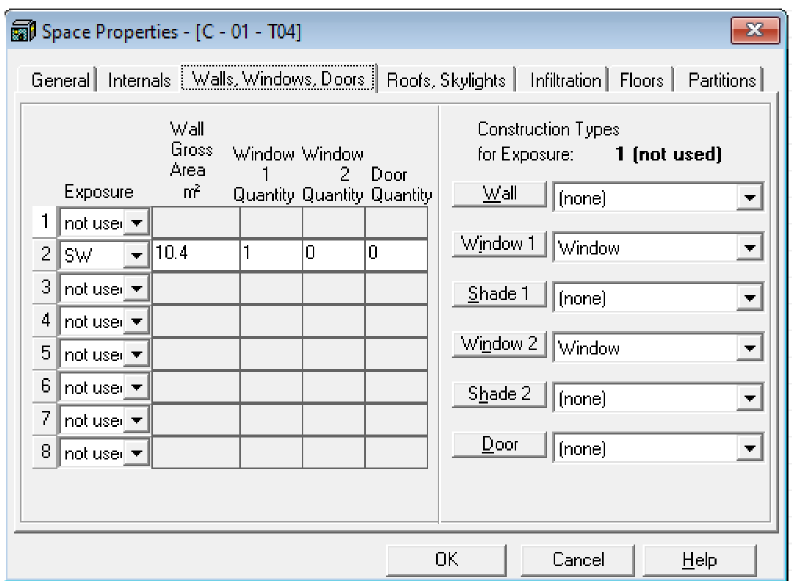

Figure 2. 14: Space – Infiltration

4) Infiltration Tab, the values were taken from HVAC Rules of Thumb

Table 2. 13: Heating Infiltration

8.01 Heating Infiltration (15 mph wind)

A. Air Change Rate Method:

1. Range 0–10 AC/Hr.
2. Commercial Buildings
    a. 1.0 AC/Hr. 1 Exterior Wall
    b. 1.5 AC/Hr. 2 Exterior Walls
    c. 2.0 AC/Hr. 3 or 4 Exterior Walls
3. Vestibules 3.0 AC/Hr.

5) System tab – General, the systems are selected as shown in Figure 2.15

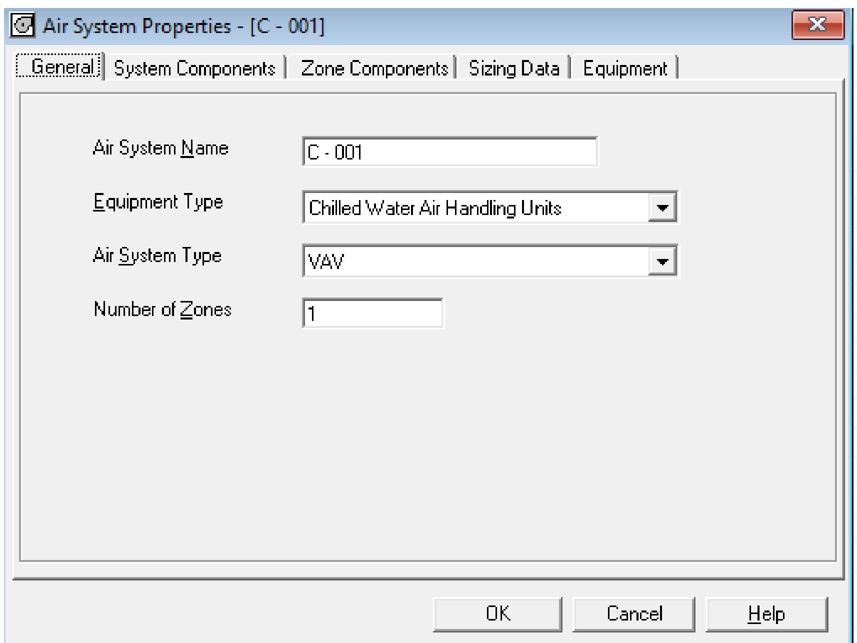

Figure 2. 15: System Tab – General

A Chilled Water system with AHU and VAV with terminal reheats units is used in the whole project according to the suggestion mentioned in HVAC Design Manual for Hospitals by ASHRAE

6) System Components – Ventilation

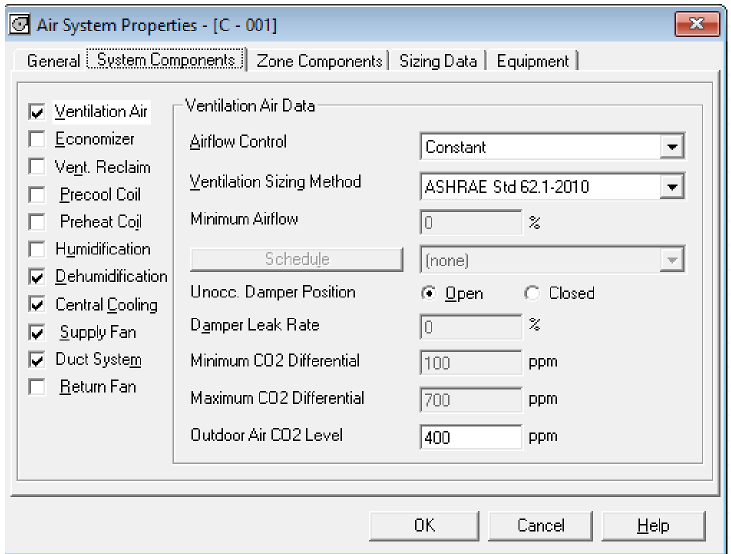

Figure 2. 16: System - Ventilation Tab

ASHRAE Standard 170 allows the user to select either “Sum of space airflows” or the 62.1 Ventilation Rate Procedure (VRP) to compute the system OA intake flow requirement (Vot). For an air system that serves multiple spaces, there is value in using the VRP approach. This is because the VRP ensures you get the specified outdoor air to the breathing zone of all spaces served by the common air system. Only the VRP considers air distribution effectiveness (air not getting to breathing zone because of stratification), and the over-supply of air needed in some spaces to get the proper airflow to the critical space in the system. “Sum of space airflows” doesn’t consider either factor. Therefore, to use the VRP in HAP, set the ventilation sizing method to ASHRAE 62.1 under the System Components tab under Ventilation Air, as indicated in Figure 2.16.

7) System Components – Dehumidification, the value of 60 relative humidity is chosen according to Figure 2.17, and the value is selected in the below Figure

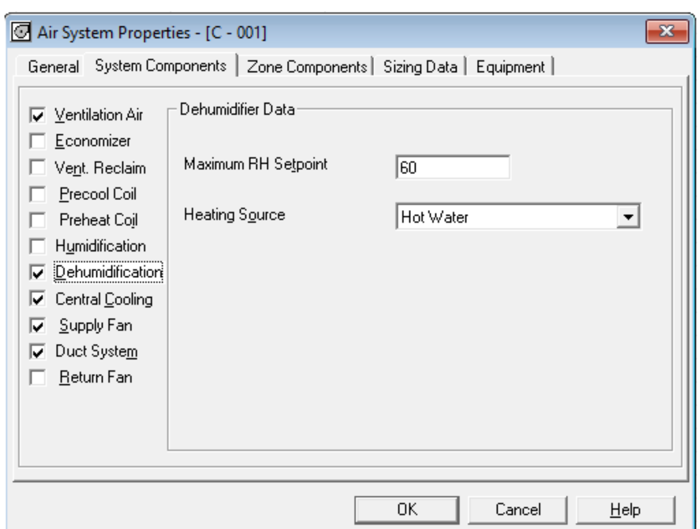

Figure 2. 17: System – Dehumidification Tab

8) System Components – Central Cooling tab is shown in Figure 2.18, and the value of supply for the chilled water system is 12-14 °C in general, it's chosen as 12.4 °C here, and might be changed after the selection if required.

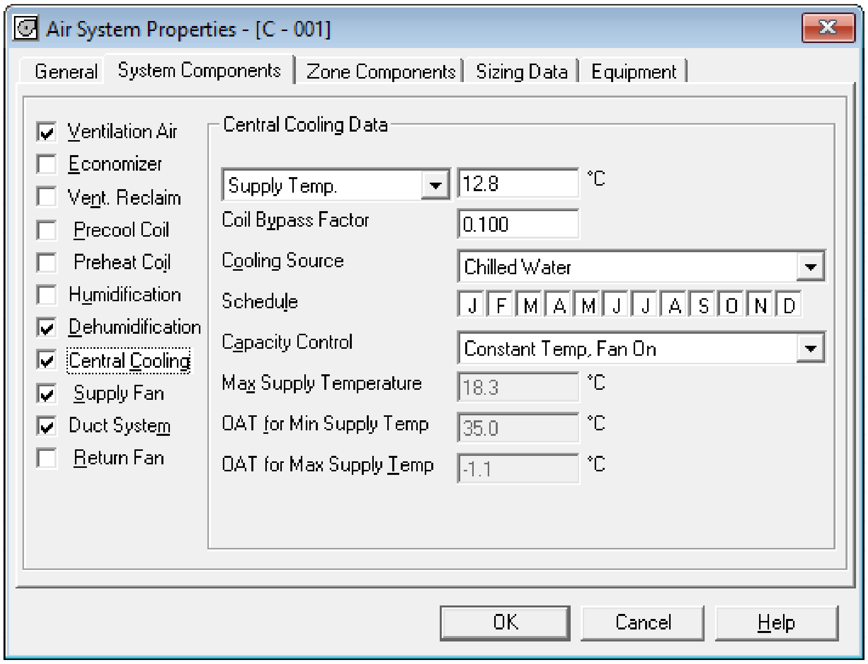

Figure 2. 18: System – Central Cooling Tab

9) System Components – Supply Fan tab, the value of the total static pressure of the fan is chosen 150 Pa as a general rule of thumb, and will be changed after the duct design and selection and so for the Overall Efficacy of the fan, Figure

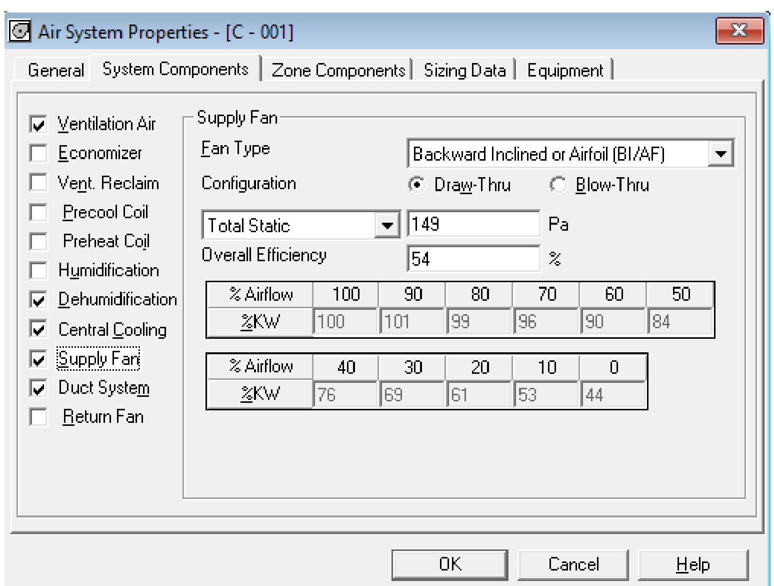

Figure 2. 19: System – Supply Fan Tab

10) System Components - Duct System tab, as shown in Figure 2.20 a value of 2% heat gain is usually a good general rule of thumb for the duct system if the ducts are installed and insulated properly.

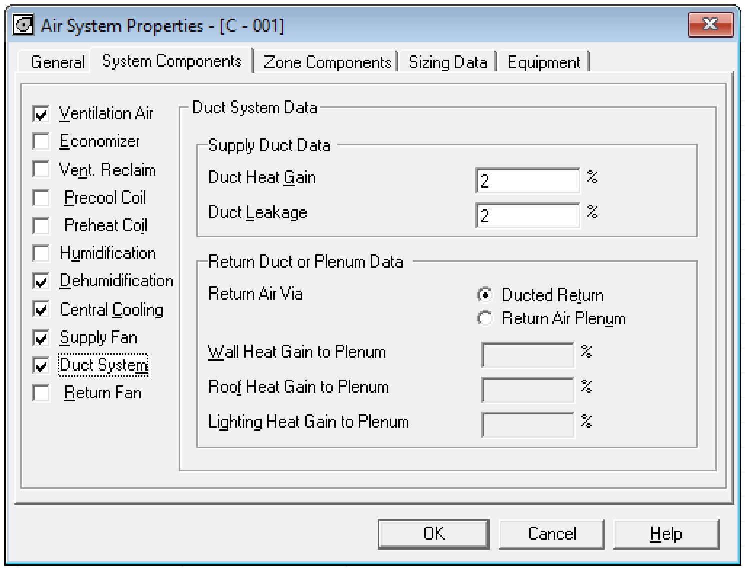

Figure 2. 20: System – Duct System Tab

11) System – Zone Components tab, the temperatures were selected as suggested in Figure 2.21 by ASHRAE, as shown in Figure 2.28

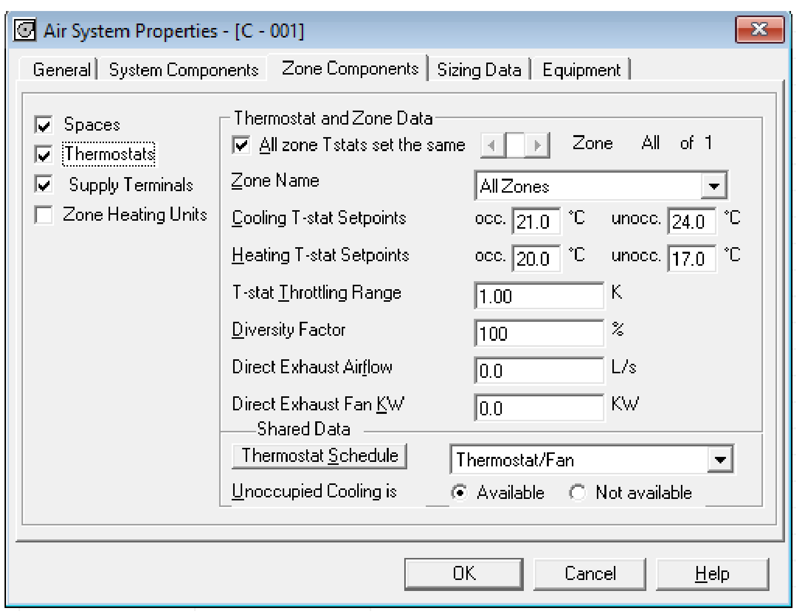

Figure 2. 21: System – Thermostat Tab

12) System – Zone Components tab, the value of Minimum Airflow shown in Figure 2.22 is chosen as 4 according to Appendix A1

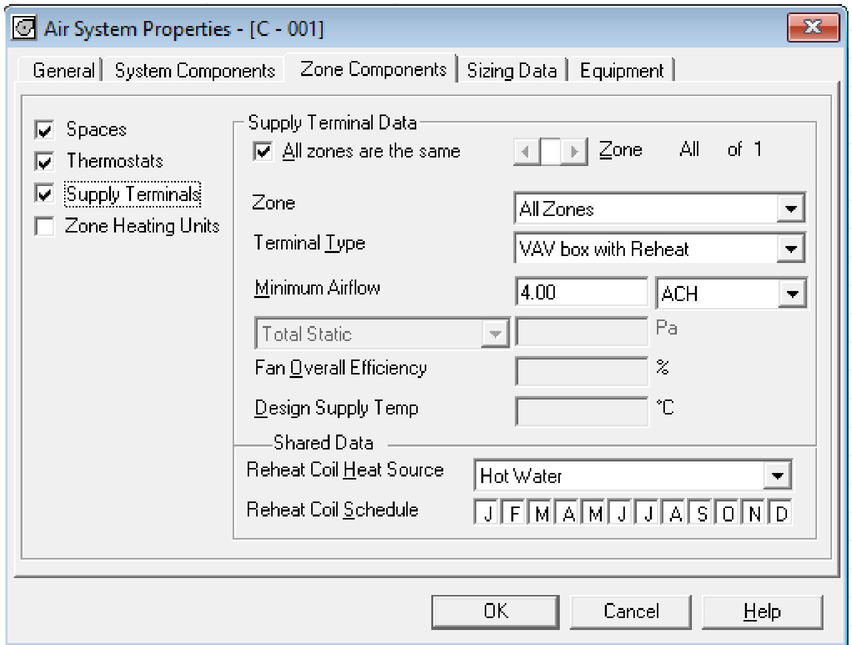

Figure 2. 22: System – Supply Terminals

2.4.3 Heating and Cooling Loads Summary

Appendix A2 summarizes the heating and cooling load obtained for HAP for each level in the hospital.

2.5 Ventilation

Ventilation (the "V" in HVAC) is the process of exchanging or replacing air in any space to provide high indoor air quality which involves temperature control, oxygen replenishment, and removal of moisture, odors, smoke, heat, dust, airborne bacteria, carbon dioxide, and other gases. Ventilation removes unpleasant smells and excessive moisture, introduces outside air, keeps interior building air circulating, and prevents stagnation of the interior air.

Ventilation often refers to the intentional delivery of the outside air to the building indoor environment. It is one of the most important factors for maintaining acceptable indoor air quality in buildings. Methods for ventilating a building are divided into mechanical/forced and natural types.

2.5.1 Ventilation of the Conditioned Spaces

The quality of the indoor air affects the human health. Children and elderly people are sensitive to quality of indoor air mostly. If occupants are provided with good quality indoor air it can have positive effects on the health, productivity and mood, and in every conditioned space in the hospital good quality fresh air is provided through ducts after going through filters and the cooling/heating coil, the required air for each space can be calculated through the following Equation 2.11

$$\dot{V} = \frac{V\,[m^3] \times ACH}{1.7} \qquad \text{Equation 2.11}$$

Where:

$\dot{V}$: Required air for the space [CFM].
V: Volume of the space [m^2].
ACH: Air changed per hour (From Appendix A1).
1.7: Conversion factor from to give the unit of $\dot{V}$ in CFM.
And the HAP report in Appendix A1 includes all spaces required ventilation air in unit of CFM

2.5.2 Ventilation of the Un-Conditioned Spaces: Exhaust and Fresh Air

Spaces such as storage rooms, toilets and technical rooms in addition to the nature air exhaust provided by doors and windows, a mechanical exhaust system provided by one of the following solutions will be used as stated:

1) Wall mounted fan in every un-conditioned space if it's location in the building is suitable and opened to the free and it's possible to discharge air at that location (no neighbors.

2) Inline fans which will be mounted in line with the ductwork, bringing air from the inside and to the inside to the outside.

Note that Equation 2.11 is also applicable for these spaces.

And for the fresh air replacement, in this project it will be provided by extra fresh air from the adjacent spaces depending on the pressure of these rooms.

The following Equation 2.12 will be used to calculate the required air volume in [CFM] for the technical room.

$$\dot{V} = \frac{H}{\rho \times C_P \times \Delta T} + \text{Combustion Air} \qquad \text{Equation 2.11}$$

Where:
$\dot{V}$: Ventilation Air [CFM]
H: Heat Radiation i.e., engine, generator. [Btu/min]
ρ : Density of Air at air temperature 38°C (100°F). The density is equal to 0.071 lb/ft^3
C_P: Specific Heat of Air 0.24 Btu/lbs./°F
ΔT: Permissible temperature rises in engine room
(**Note**: Max engine room temperature is 120°F)

For this category of spaces, the required ventilation air flow and exhaust air will be on attached shop drawing plans

2.6 Room Design

Certain rooms within a health care building should be positively or negatively pressurized with respect to surrounding areas. Positively pressurized rooms are usually designed to protect a patient, clean supplies, or equipment within the room. Negative pressure is used to contain airborne contaminants within a room. The 2014 FGI *Guidelines/*Standard 170-2013 provides lists of rooms that should be positively or negatively pressurized with respect to surrounding areas. The following are examples of positively pressurized rooms.

1) Operating rooms.
2) Delivery rooms.
3) Trauma rooms.
4) Newborn intensive care.
5) Laser eye rooms.
6) Protective environment rooms.
7) Pharmacy.
8) Laboratory, media transfer.
9) Central Medical and Surgical Supply Clean workrooms.
10) Central Medical and Surgical Supply Sterile Storage.

A room may be pressurized so that it is positive with respect to adjacent areas for several reasons. It may be done to protect patients in operating rooms and protective environment rooms from airborne pathogens that may be present in adjacent areas. It may be done to protect sterile medical and surgical supplies in supply rooms from airborne contaminants that may be present in adjacent rooms. If these rooms are not properly pressurized, airborne contaminants from adjacent areas may be pulled into them. Increased concentrations of airborne bacteria, fungi, and viruses within these rooms may contaminate clean equipment or promote increases in nosocomial infections. Positively pressurized rooms are usually the cleanest environments in a hospital. Loss of positive pressure compromises the aseptic environment within the room.

According to the FGI *Guidelines*, the following are examples of rooms in hospitals and outpatient facilities that should be negatively pressurized with respect to adjacent areas:

1) ER waiting rooms
2) Radiology waiting rooms.
3) Triage.
4) Toilet rooms.
5) Airborne infection isolation (AII) rooms.
6) Darkrooms.
7) Cytology, glass washing, histology, microbiology, nuclear medicine, pathology, and sterilizing laboratories.
8) Autopsy rooms.
9) Soiled workrooms or holding rooms.
10) Soiled or decontamination room for central medical and surgical supply.
11) Soiled linen and trash chute rooms.
12) Janitors’ closets.

Rooms such as airborne infection isolation rooms are negatively pressurized with respect to adjacent areas to prevent airborne contaminants (e.g., microbial pathogens, chemicals) from drifting to other areas. Loss of negative pressure within these rooms allows unpleasant odors to migrate through the building and may promote the spread of airborne contaminants. One common use of airborne infection isolation rooms is for patients with active tuberculosis, a disease caused by the bacteria Mycobacterium *tuberculosis*. The bacteria are spread in the air from one person to another. A patient with active tuberculosis releases *M. tuberculosis* into the air when he or she sneezes or coughs. Other people may become infected if they inhale the airborne bacteria. Pathology and histology laboratories use substantial amounts of chemicals, including formaldehyde. If formaldehyde or other airborne chemicals are allowed to drift from these laboratories, building occupants may complain of unpleasant odors. Exposure to these airborne chemicals may also cause adverse health effects.

If rooms are not properly pressurized (positive or negative), several causes are possible. An imbalance may exist between the supply and exhaust rates for the room. Supply and exhaust fans may not be operating properly. Supply diffusers and return grilles within the room should be checked for blockages; occupants may block them in an effort to improve their thermal comfort. Operation of fume hoods and biological safety cabinets within the room and in adjacent rooms should be checked, as poor performance of these units affects air balance within nearby rooms. Lastly, recent renovations may have altered the HVAC system in a manner that impacts the air balance among nearby rooms.

2.6.1 Air Movement and Pressurization

Another common method of mitigating the spread of infections is through pressure relationships. As noted in previously, many rooms require positive or negative pressure relative to adjacent spaces. As the intent of pressurization is to move potentially infectious particles from the cleanest areas to less clean areas. A clear understanding of these areas is essential. A hospital is not totally clean throughout, but has various areas—from sterile-clean to semi clean to dirty. Therefore, for example, operating rooms must be at a positive pressure relative to adjacent corridors to prevent potentially harmful microorganisms from entering the operating room. In contrast, airborne infection isolation (AII) rooms must be maintained negative because patients in these rooms may be highly infectious with diseases such as tuberculosis or SARS. Design considerations for specialty rooms are covered in more detail in Chapter 8. Many operations are carried out by surgeons wearing simple masks across their lower face. In fact, it is important that surgeons are comfortable during operations to ensure their concentration during long or complex procedures. Clean supply air from overhead helps to achieve this although it also tends to induce air from surfaces of anyone close to the table and could deposit squames on or in the patient. Memarzadeh and Manning (2003) modeled airflow in operating rooms using computational fluid dynamics (CFD). They postulated that there is a thermal plume at the patient's wound site that can have the beneficial effect of deflecting the deposition of particles away from the wound. Using the CFD model, Memarzadeh concluded that the face velocity of the diffuser above the operating table should not exceed 30 fpm [0.15 m/s] to avoid disrupting the patient's thermal plume. As described in Chapter 8, limiting diffuser face velocity is one of the basic means of designing operating room air distribution to reduce deposition. However, field research on this theory is limited. Kurz et al. (1996) provided indirect evidence of the existence of a plume. It is also noted that work within the surgical site with instruments and other devices disturbs the heat plume so that the principal method of infection control remains the high air change rate of well-filtered air delivered by a laminar flow system. Ongoing ASHRAE research project RP-1397 is investigating hospital operating room air distribution to verify CFD predictions of conditions that sustain the thermal plume. [13].

Figure 2.23 illustrates how the pressure can be maintained with relation to the room cleanness according to ASHRAE [13].

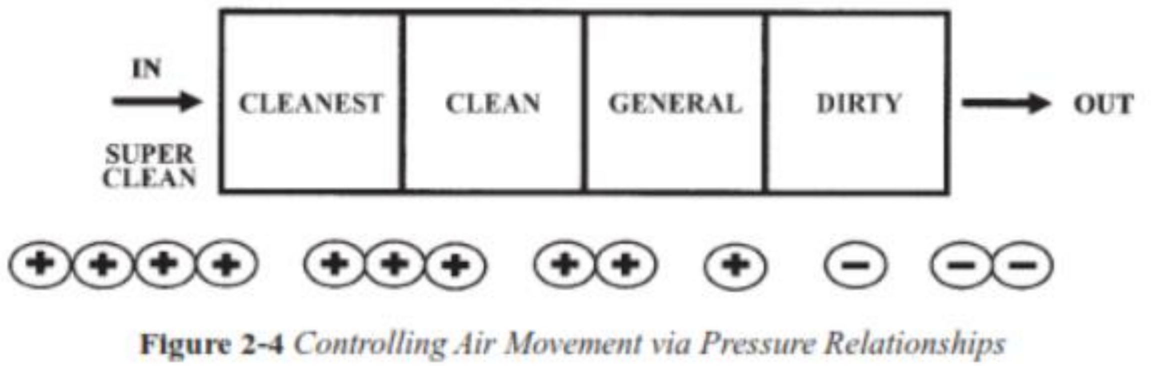

Figure 2. 23: Controlling Air Movement via Pressure Relationships

2.6.3 Room Pressurization

Measuring a differential air pressure between a room and the corridor may provide evidence that all air movement is in one direction. There are a number of factors, however, that may well allow air to escape from a room or air to enter a room in spite of a negative or positive room-to-corridor pressure relationship. One such factor is opening and closing of the room door.

The truly significant factor in determining the amount of air migration from a room to a corridor is the airflow volume differential (Hayden et al. 1998). In all cases, some air volume migration occurs through an open door when the air pressure difference is essentially zero.

An anteroom is recommended as a means of reducing airborne contaminant concentration by containment and dilution of the migrating. air and to protect the adjacent corridor from excess airflow into or out of the isolation room. In one study, for a range of room air exhaust flows from 50 to 220 cfm [24 to 104 L/s], the migration between a room and its anteroom was found to be 35 to 65 cfm [17 to 31 L/s] (Hayden et al. 1998). For example, through dilution

Provide a tight envelope to maintain desired pressurization. Walls must extend from floor to structure and openings (such as electrical and medical gas outlets) must be sealed. Maintain a specific differential airflow rate between supply and return/exhaust. Airflow from one space to another occurs through cracks or gaps in walls, ceilings, floors, and around doors. The sum of the areas of all these pathways is called the leakage area. The infiltration or exfiltration flow from a room is a function of the leakage area and the pressure differential across all surfaces of the room. Isolation is maintained only when the airflow is unidirectional on each surface. Air pressure differential is a measurable quantity and should be maintained at 0.01 in. of water [2.5 Pa] relative to adjacent spaces.

As discussed in Section 2.6.1, differential measure may be achieved by controlling supply and exhaust via a pressure monitor; or it can be accomplished with a fixed offset between supply and exhaust airflow. A minimum differential airflow rate for a very tight room is 200 cfm [94 L/s]. ASHRAE Handbook—Fundamentals (ASHRAE 2009) provides a method to estimate the allowable leakage area as follows:

$$A_L = C_s Q_r\,(\rho/2\,\Delta p_r)^{1/2}/C_D \Delta p_r$$

A_L = air leakage area, in.^{2} [cm^2]
C_s = units conversion, 0.186 [10 000]
Q_r = air leakage volume, cfm [m^3/s]
ρ = air density, 0.0724 lbm/ft^3 [1.158 kg/m^3] at normal room temperature
C_D = discharge coefficient, often set to either 1.0 or 0.6
Δp_r = reference pressure difference, in. of water [Pa]

Figure 2. 24: Room Required Pressure According to ASHRAE

The coefficient C_D depends upon the gaps through which the air flows. An estimate of this parameter, 0.186, has been made and empirically tested. The designer should estimate the leakage area $A_L$using the method from the ASHRAE Handbook—Fundamentals chapter on infiltration. Another alternative method would be to use the chart in Figure 2.25

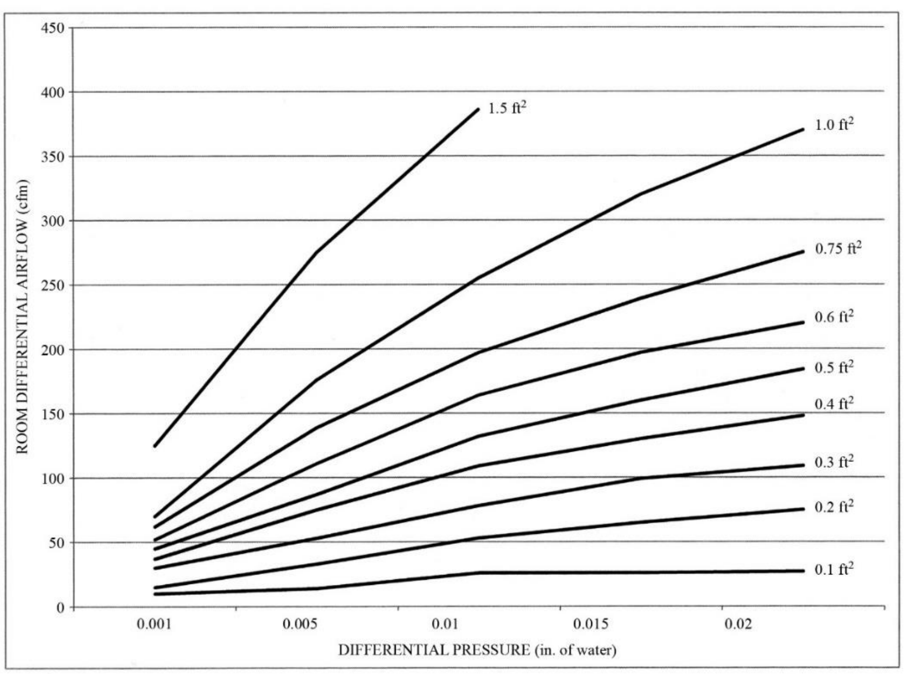

Figure 2. 25: Room Differential Airflow versus Differential

The pressure relations are satisfied in each floor by using the previous equation shown in Figure 2.24. The plus and negative signs will be shown on each space on the ventilation plans according to their pressure status to illustrates how air will move throughout the whole building.

2.7 AHU and Chiller Sizing and Selection

The heating, ventilation, and air conditioning (HVAC) system is arguably the most complex system installed in a building and is a substantial component of the total building energy use. A rightsized HVAC system will provide the desired occupant comfort and will run efficiently. Right-sizing of an HVAC system involves the selection of equipment and the design of the air distribution system to meet the accurate predicted heating and cooling loads of the building. Right-sizing the HVAC system begins with an accurate understanding of the heating and cooling loads on a space; however, a full HVAC design involves more than just the load estimate calculation—the load calculation is the first step of the iterative HVAC design procedure. Figure 2.30 shows the required data needed for equipment sizing.

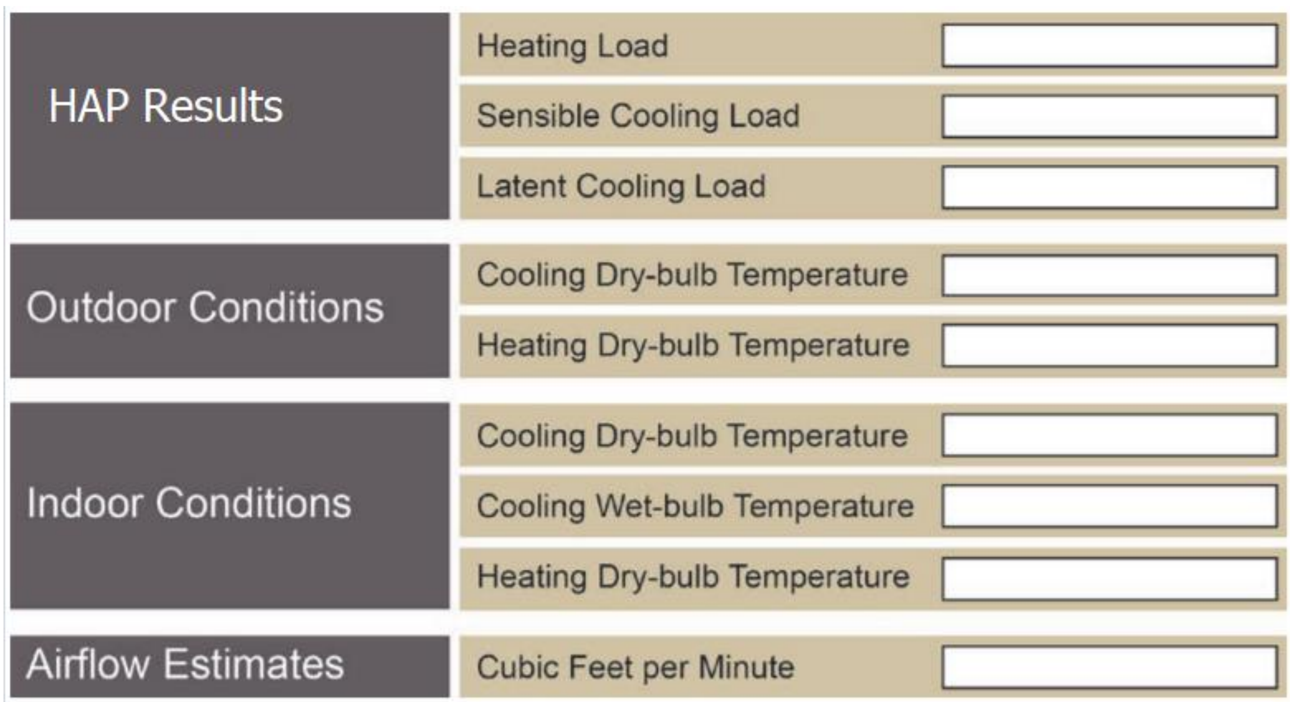

Figure 2. 26: Required Data for Sizing

2.7.1 Cooling Equipment Capacity Sensitivities

Capacities of cooling equipment are conditional based on the following operating conditions:

1) Cubic feet per minute airflow across the coil (Figure 2.27).
2) Outdoor air temperature (OAT) at the condenser (Figure 2.28).
3) Indoor wet-bulb temperature at the coil (Figure 2.29).
4) Indoor dry-bulb temperature at the coil (Figure 2.30).

Figures 2.27 through Figure 2.29 show the conditional nature of direct expansion cooling equipment and that the available latent capacity is a direct relationship to the total and sensible capacities. It is helpful to consider these relationships while searching the manufacturer's detailed cooling capacity data. This conditional nature among total, sensible, and latent capacities causes an imbalance between latent load and latent capacity, where latent capacity slightly exceeds the latent load. This can be somewhat self-correcting. Figure 2.27 shows that increasing the airflow across the coil (cfm) will increase the total and sensible capacities of the equipment. However, because the sensible capacity increases at a higher rate than the total capacity, the latent capacity available is reduced as the cfm increases. This relationship between cfm and latent capacity of the equipment is an important consideration when selecting equipment to meet the latent load [20].

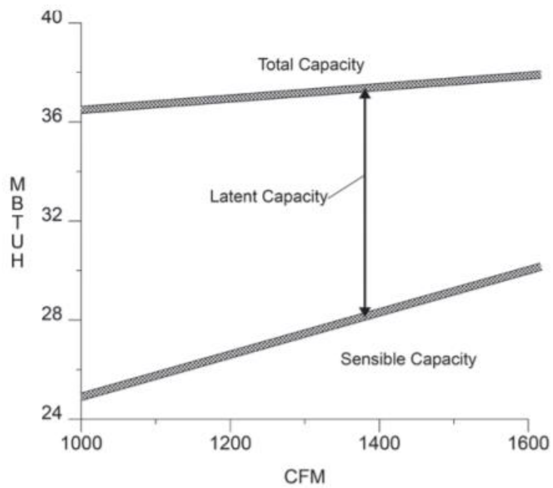

Figure 2. 27: Airflow Sensitivity Graph

Figure 2.28 shows that as the OAT at the condenser increases, the total sensible and latent capacities decrease. Because the total capacity decreases at a faster rate than the sensible capacity, the available latent capacity of the equipment is lower. Because of this effect of OAT on equipment capacity, it is critical that the same temperature used for load calculations is used for equipment selection.

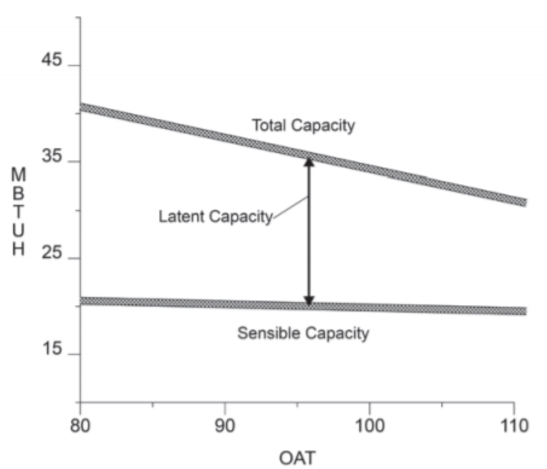

Figure 2. 28: Airflow Sensitivity Graph

As shown in Figure 2.29, higher EWB temperatures at the indoor coil will result in a higher total capacity but a lower sensible capacity. This will result in a greater available latent capacity as the difference between the total and sensible capacities increases.

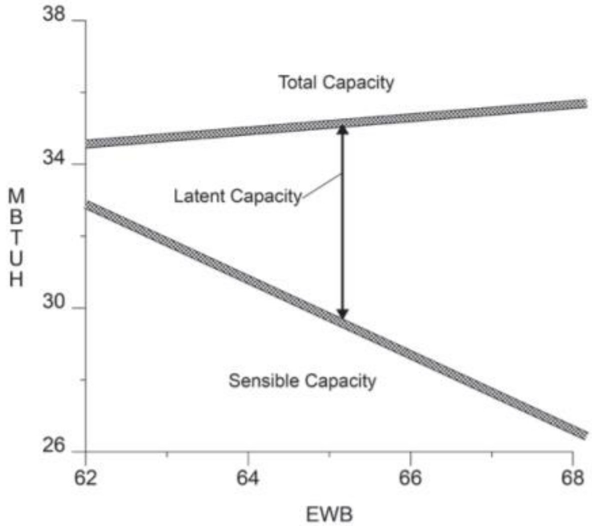

Figure 2. 29: Indoor EWB Sensitivity Graph

Figure 2.30 shows that a higher entering dry-bulb (EDB) temperature at the indoor coil will have relatively little effect on the total capacity but will increase the sensible capacity of the equipment, resulting in a lower available latent capacity.

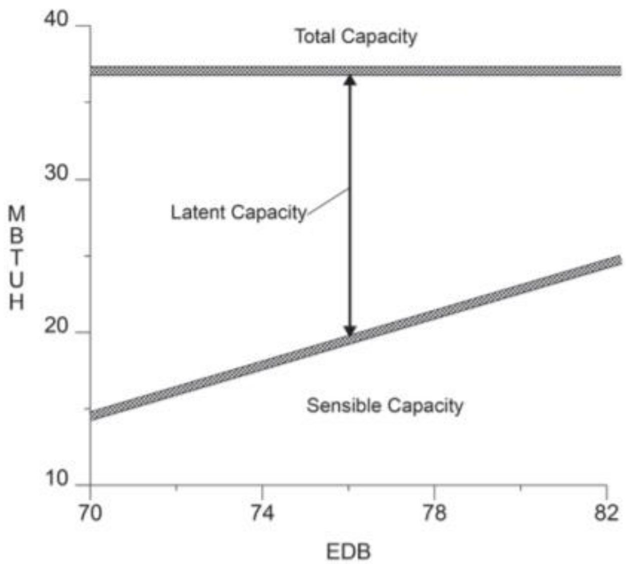

Figure 2. 30: Indoor EDB Sensitivity Graph

2.8 AHU Sizing and Selection

For the second floor AHU unit for Zone 2:
Total Coil Cooling Load [kW]: 70.3
Total Coil Sensible Cooling Load [kW]: 49

Total Coil Heating Load [kW]: 38.1
Design Airflow [L/s]: 2973
Entering Air DB [C]: 26.67

Table 2. 14: AHU - Selection Table

Table 4. Return Air

UNIT SIZE.	Air Flow	ESP	4-ROWS COOLING COIL					1-ROW HEATING COIL			MOTOR kW
			S.C	T.C.C	Water flow	WPD	Circuit	T,C	Water flow	WPD	
	LPS	Pa	kW	kW	lps	kPa		kW	lps	kPa	
0404	646	300	7.3	7.7	0.37	0.27	F	4.7	0.11	0.04	0.75
0407	1027	300	12.6	15	0.71	1.16	F	8.8	0.21	0.19	1.1
0410	1408	300	18	22.7	1.08	3.04	F	13.1	0.32	0.48	1.5
0413	1789	300	22.7	30.8	1.47	6.25	F	17.3	0.42	0.95	2.2
0707	1670	300	20.4	24.4	1.16	1.16	F	14.3	0.35	0.19	2.2
0710	2289	300	37.6	52.9	2.04	4.82	F	24.8	1.27	0.76	2.5
0713	2980	300	50.2	71.3	2.38	6.26	F	39.6	2.67	0.95	5.6
0715	3321	300	60.8	88.4	2.79	9.21	F	55.4	2.5	1.39	3
1010	3110	350	56.7	75.4	2.6	6.98	M	49.5	0.72	0.48	4
1013	3911	350	78.7	90.2	3.47	14.01	M	39	0.95	0.95	5.5
1015	4260	350	68.4	96	4.57	30.53	M	52.2	1.27	2.16	4
1019	4450	350	80	109.3	5.21	38.05	M	58.8	1.43	0.65	7.5
1021	5620	350	88.7	122	5.82	50.05	M	65.8	1.6	3.5	7.5
1315	5619	350	75.3	99.2	4.72	9.2	F	55.4	1.35	1.39	7.5
1319	7016	350	95.3	127.1	6.05	17.09	F	71.8	1.75	2.64	7.5
1321	7715	350	106.1	143.3	6.83	22.83	F	81.4	1.96	3.5	11
1519	7654	450	103.9	138.6	6.6	17.09	F	78.3	1.91	2.65	11
1521	8416	450	115.8	156.3	7.45	22.83	F	87.7	2.14	3.5	11
1819	9568	500	129.9	178.8	8.26	17.09	F	97.9	2.39	2.65	15
1821	10520	500	144.7	195.4	9.31	22.83	F	109.6	2.67	3.5	15
1823	11473	500	167.1	232.5	11.07	38.25	F	130.2	3.17	5.88	15
1827	13378	500	187.2	256.7	12.23	45.29	F	141.9	3.46	6.81	18.5
2027	14270	750	188.6	245.3	11.69	5.69	D	151.4	3.69	6.8	22
2233	19482	750	262.1	346.9	16.52	10.08	D	210.3	5.12	11.71	37

For Cooling Coil: EDB = 27deg. C, EWB = 19.5 deg. C, EWT = 7 deg. C, LWT = 12deg. C
For Heating Coil: EDB =21 deg. C, EWT = 14.1 deg. C, LWT = 50 deg. C

But since the entering temperature is 26.6 ℃ not 27 ℃ as stated in this catalogue, we will make a correction for the sensible heat using the effective sensible heat formula shown in Equation 2.12 shown below given by AIRAH Technical Handbook [21]

$$SHC_{Correction} = SHC + [1.23*10^{-3} \times (1\text{-}BPF) * \left(T_{DBT} - T_{DBT_{CATALOUGE}}\right) \times Q_{Design} \quad (2.12)$$

Where:

$SHC_{Correction}$: Sensible cooling load at the catalogue temperature [kW].
SHC: Sensible cooling load at the design temperature [kW].
BPF: Coil bypass factor.
T_{DBT}: Coil entering temperature at the design conditions [℃].
$T_{DBT_{CATALOUGE}}$: Coil entering temperature at the catalogue conditions [℃].
Q_{Design}: Required airflow [L/s].
For this case: $SHC_{Correction}$= 50.2 kW
The fan and the filter static pressure are accounted for this model in the ESP column to be 300 Pa. The fan, filters are pre-selected in the catalogue based on the model number, more details can be shown in Appendix A2.

The following Table summarizes the catalogue unit number for each zone in each floor.

Table 2. 15: AHU Selection for Each Floor

Floor	Zone	Unit Number
Basement	1	1019
	2	1013
Ground	1	715
	2	710
	3	1019
First	1	1010
	2	1015
Second	1	1010
	2	1010
Third	1	1013
Fourth	1	1015
	2	710
	3	1019

2.9 Air Cooled Chiller Sizing and Selection

Trane air-cooled Series R® chiller performance is rated in accordance with the ARI Standard 550/590-1998 Certification Program. The chiller capacity tables cover the most frequently encountered leaving liquid temperatures. Table 2.16 reflect a 10°F [5.6°C] temperature drop through the evaporator.

The following information is required:
1) Design load in tons of refrigeration.
2) Design chilled water temperature drop.
3) Design leaving chilled water temperature.
4) Design ambient temperature.

Design data:

1) Design load: 310 TR divided between two chiller and a stand by chiller, that’s three chillers with a capacity of 155 TR.
2) 12 °F.
3) 6 ℃.
4) 35 ℃.

Evaporator flow rates can be determined by using the following formulas:

$$\dot{V} = (Q_{Load} \text{ x } 24) \text{ / Temperature Drop} \quad (2.13)$$

Where:

$\dot{V}$: Evaporator flow rates [gpm]

Q_{Load}: Cooling load [TR]

Temperature Drop: Design chilled water temperature drop [°F]

Table 2. 16: Performance Data for Trane Air-Cooled Series R® Chiller

Tab. 10a – 50 Hz standard efficiency machines in English units

Evaporator Leaving Water Temperature (F)	Unit Size Model RTAC	Condenser Entering Air Temperature (F) 85			95			105			115		
		Tons	Input kW	EER	Tons	Input kW	EER	Tons	Input kW	EER	Tons	Input kW	EER
40	RTAC	134.2	144.4	10.6	124.5	158.0	9.0	114.5	173.1	7.6	104.3	189.8	6.4
	155 STD	146.7	159.3	10.5	136.1	173.7	9.0	125.3	189.9	7.6	114.2	207.8	6.4
	170 STD	159.8	174.7	10.4	148.4	190.1	8.9	136.7	207.4	7.6	124.7	226.6	6.4
	185 STD	176.5	190.4	10.6	164.2	207.0	9.1	151.6	225.7	7.7	138.6	246.5	6.5
	200 STD	194.3	206.8	10.7	181.1	224.8	9.2	167.4	244.9	7.9	153.3	267.2	6.6
	250 STD	233.2	248.3	10.7	217.0	270.9	9.2	200.3	296.1	7.8	183.1	323.9	6.5
	275 STD	260.0	279.9	10.6	241.9	304.2	9.1	223.3	331.4	7.8	204.2	361.7	6.5
	300 STD	295.0	313.3	10.7	275.0	340.0	9.3	254.4	370.1	7.9	230.9	398.6	6.7
	350 STD	326.4	354.5	10.5	303.5	385.4	9.0	279.9	420.0	7.7	254.5	456.0	6.5
42	140 STD	139.1	147.6	10.8	129.0	161.3	9.2	118.8	176.5	7.8	107.1	190.7	6.5
	155 STD	151.9	162.9	10.7	141.0	177.4	9.1	129.9	193.7	7.7	116.7	207.9	6.5
	170 STD	165.4	178.7	10.6	153.7	194.2	9.1	141.6	211.6	7.7	127.5	227.1	6.5
	185 STD	182.6	194.7	10.7	170.0	211.6	9.2	157.0	230.5	7.9	140.9	245.5	6.6
	200 STD	201.1	211.6	10.9	187.5	229.8	9.4	173.3	250.1	8.0	154.9	264.4	6.8
	250 STD	241.5	253.9	10.9	224.7	276.6	9.3	207.5	302.0	7.9	185.9	321.7	6.7
	275 STD	269.1	286.4	10.7	250.4	310.8	9.2	231.2	338.3	7.9	206.6	358.2	6.7
	300 STD	305.3	320.6	10.9	284.7	347.7	9.4	263.4	378.0	8.0	232.0	391.7	6.8
	350 STD	337.6	362.6	10.6	314.0	3393.7	9.2	289.7	428.6	7.8	256.5	448.8	6.6
43	140 STD	144.0	150.8	10.9	133.7	164.6	9.3	123.1	180.0	7.9	108.1	187.6	6.7
	155 STD	157.3	166.5	10.8	146.0	181.2	9.3	134.5	197.6	7.9	118.0	205.1	6.6
	170 STD	171.1	182.8	10.7	159.0	198.4	9.2	156.2	216.0	7.8	128.5	223.4	6.6
	185 STDr	188.9	199.2	10.8	175.9	216.2	9.3	162.5	235.3	8.0	142.5	242.7	6.8
	200 STD	208.0	216.6	11.0	193.9	234.9	9.5	179.4	255.5	8.1	155.6	259,4	6.9
	250 STD	249.8	259.5	11.0	232.6	282.5	9.5	214.8	308.1	8.0	187.6	316.8	6.8
	275 STD	278.3	293.0	10.9	259.0	317.7	9.4	239.2	345.3	8.0	207.8	351.8	6.8
	300 STD	315.7	328.1	11.0	294.4	355.5	9.5	272.4	386.1	8.1	234.1	386.4	7.0
	350 STD	349.0	370.8	10.8	324.6	402.2	9.3	299.6	437.3	7.9	258.1	440.8	6.8

2.9.1 Chiller Riser Diagram Sizing

To properly define the chilled water system, the water flow rate, pipes sizing for every pipe branch going for each AHU in every level in the hospital, finally the pump pressure drop must be calculated

2.9.1.1 Constant Flow Chilled Water System

A constant flow system is the simplest chilled water distribution scheme. Here, a set of constant speed pumps distribute fixed quantity of water at all times and the temperature varies to meet the load. The system uses 3-way control valves at air handler coils that allow some water to bypass the cooling coil during part load conditions. At low loads, the chilled water flow through the cooling coil is restricted (in response to supply air temperatures to the space) but the total quantity returned to the chiller remains constant. Figure 2.28 below shows the schematic of the constant-flow rate primary system.

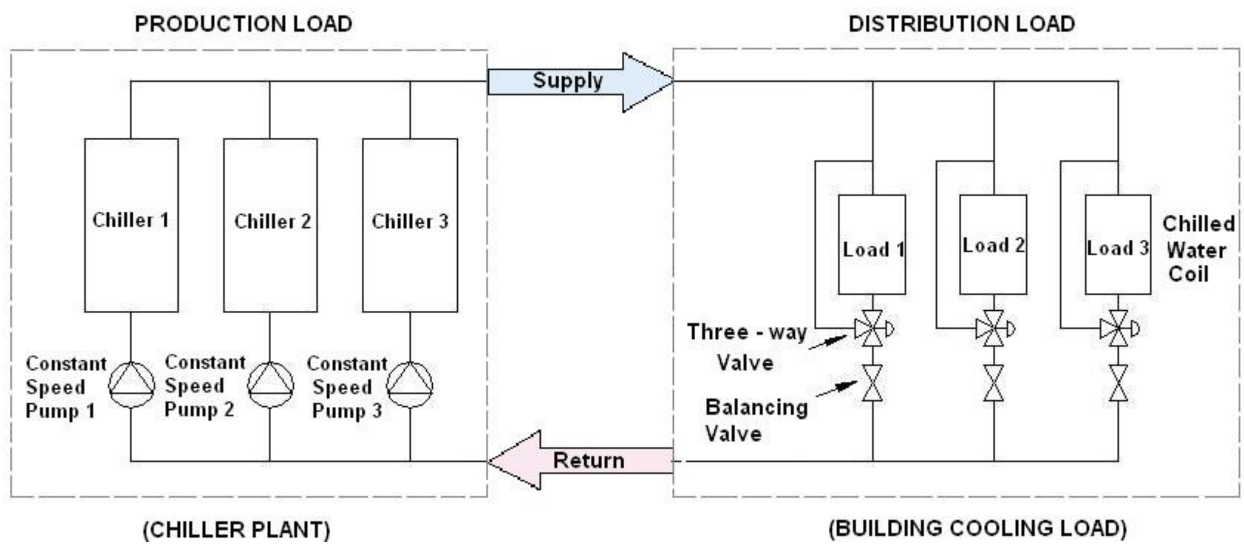

Figure 2. 31: Constant Flow Chilled Water System

Looking at Equation 2.13 that governs heat transfer, the capacity of a chiller is proportional to the product of flow rate and the temperature difference of entering and leaving chilled. In constant-flow systems, flow rate (GPM) is established for peak design condition and Delta-T (the difference between the chiller supply and return) varies in response to the load.

In air-conditioning applications, since the design conditions occur only during 1% of the operational hours in a year [i.e., 99% of the time the system runs on part load], some of the chilled water will always bypass through the three-way valve for most of coil's operational life. Higher quantities of bypassed chilled water mixes with leaving water from the cooling coil yielding lower chilled water return temperature to the plant. The lower return water temperature reduces the operating temperature differential (T) across the chiller as the supply water temperature is fixed to a setpoint. This phenomenon is termed "Low delta – T syndrome" in HVAC industry.

2.9.1.2 Pipe Sizing

The three chillers will have the same delta T, and cooling load, therefore using Equation 2.13:

$\dot{V}_{Chiller1,2,3} = 2.4\times 155 = 372$ GPM

And the same equation is used for the air handling units.

Pipe Sizer software from McQuay will be used for the pipe sizing, using a recommended velocity of 2:10 fpm with an optimum value of 4 fpm, and pressure losses of 10 ft/100 ft with an optimum value of 4 ft/100 ft [15].

Pipe Sizer interface

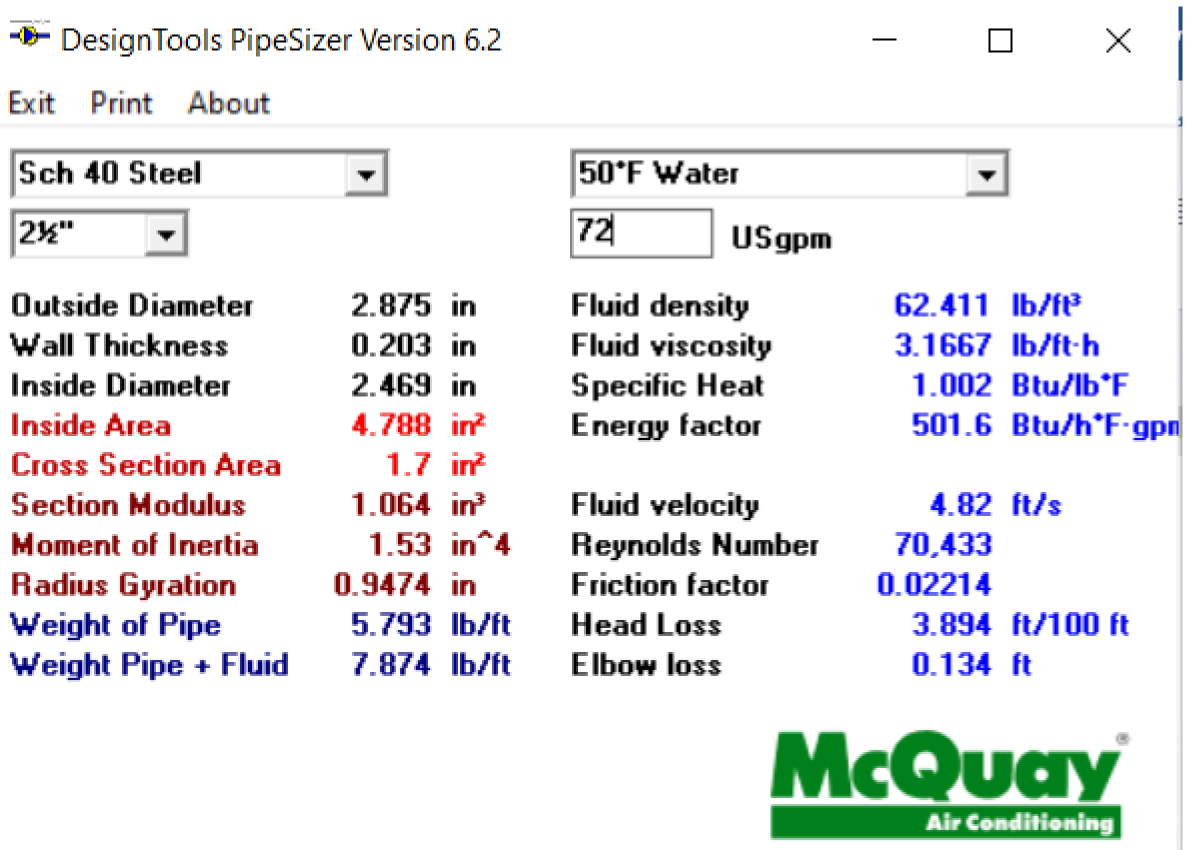

Figure 2. 32: Pipe Sizer Interface – Sample Calculation for 72 GPM

The project six levels AHU's with their cooling capacity and water flow rate are as shown in Table 2.17

Table 2. 17: AHU's Cooling Loads

Floor	Zone	Load [TR]	Water Flow [GPM]	Main Pipe Ø [in]	Head Loss [ft/100ft]
Basement	1	30	72	2 1/2	4
	2	25	60	2 1/2	2.7
Ground	1	25	60	2 1/2	2.7
	2	15	36	2	2.5
	3	30	72	2 1/2	4
First	1	22	52.8	2	2.5
	2	25	60	2 1/2	2.7
Second	1	20	48	2	4
	2	20	48	2	4
Third	1	25	60	2 1/2	2.7
	2	26	62.4	2 1/2	3
Fourth	1	15	36	2	2.5
	2	30	72	2 1/2	4
$\text{Chiller}_{1,2,3}$	-		372	5	2.5

2.9.1.3 Head Calculations

Head is the height at which a pump can raise water up. Basically, the head value must be calculated in order to select suitable pump/s. Pump plays a very important role especially in water side systems (i.e., hot water and cold-water systems) in lifting water up to the desired height range. Height could be easily calculated when there are no losses along the flow path. Since piping system includes elbows and Tee joints, frictional losses should be considered for effective selection.

$$H_P = H_S + H_{Residual} + H_{Friction} \tag{2.15}$$

Where

H_S: Static Head
$H_{Residual}$: Residual Head
$H_{Friction}$: Friction Head

But, since the chiller plant represents a closed circuit, the residual head and the static head equals zero. Therefore, the friction head is required along the toughest path, and in this case it's the longest path from the chiller to the last AHU in the basement floor. Figure 2.30 demonstrates the following calculations

Figure 2. 33: Schematic Diagram for The Chiller- AHU plant

From the project plan, after placing each AHU and drafting the chiller plant and calculating the pipes length from each section 1 to 2 and 2 to 3.etc.,

The head loss can be found through the following equation

$H_{Pump} = 2 \times 1.4 \times L \times [\Delta P/L]$
(2.16)

Where

2: To design for the return and supply pipeline.
1.4: Factor to make up the equivalent pipe length for the fittings.
$\Delta P/L$: Pressure head loss 6 ft/100 ft.
L: Pipe length according to the plan pipes routing at the toughest path through the system.

According to the drafting, L = 65 ft

Therefore, H_{Pump} = 1100 ft = 335 m

2.9.2 Pumps Set Selection

The following two curves 2.32 to 2.32 show the performance curve and the pump data.

Duty Point Flow: 760 US gpm: 3 pumps = 253.33 US gpm ea
Duty Point Head: 350 ft
Discharge Size (in): 4
Discharge Velocity (fps): 19.1
Suction Size (in): 4
Suction Velocity (fps): 19.1
Weight: 839 lb
Max Working Pressure: 362 psi
Pump Flange Rating: Class 250 / 300

Motor: 40 hp
End Of Curve: 69.7%
NPSHr (ft): 9.18
Floor Space (ft²): ---

NOL (BHP) at 2900: 32.1
NOL Flow at 2900: 338 US gpm
Runout Flow at 2900: 368 US gpm
Shutoff Head at 2900: 454 ft

Operating Point

Flow: 256 US gpm **Head:** 358 ft **Speed:** 2900 **Efficiency:** 75.4% **Point BHP:** 30.7

Figure 2. 34: Pump Data

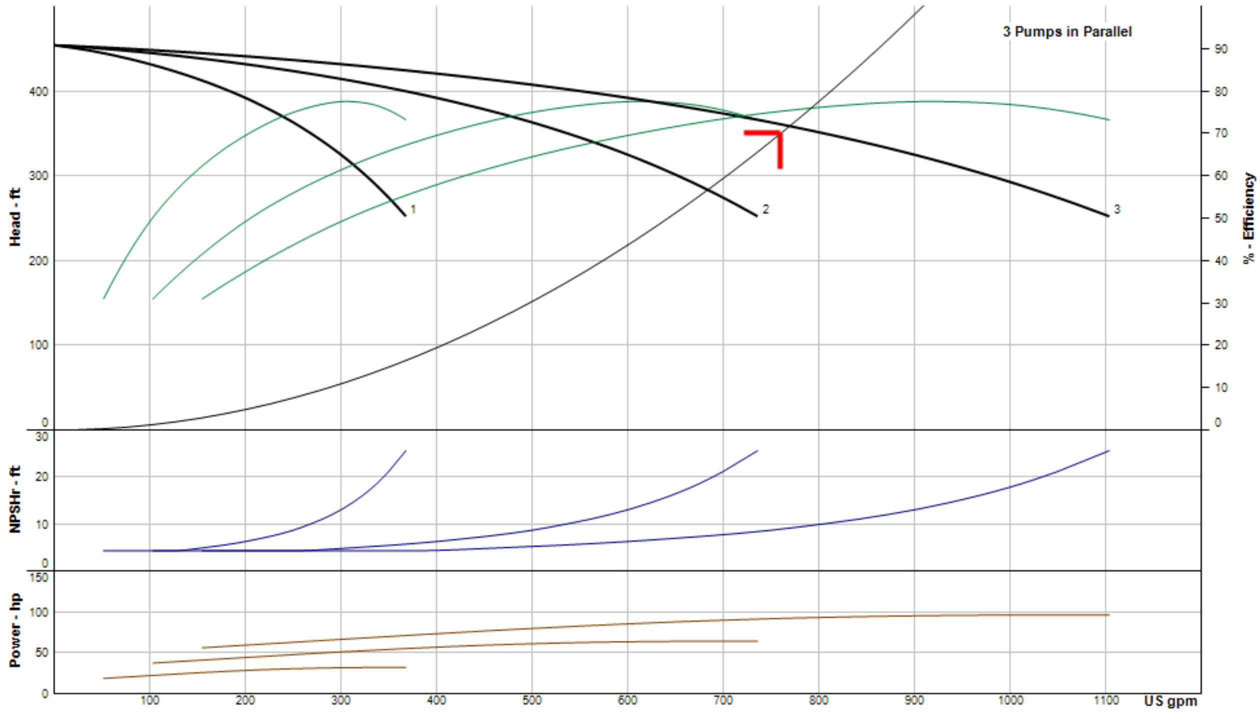

Figure 2. 35: Pump Performance Curve

2.10 Air Outlet Sizing and Selection

After the required amount of supply air has been transmitted to the conditioned space, it is critical to distribute the air properly within the conditioned space. As a result, it is critical to design an appropriate air distribution system that meets the following criteria's:

1) Create a correct combination in the occupied area of temperature, humidity and air movement. The area is defined as all the area from the ground up to 1.8 m and about 30 cm from the walls in the conditions area. The maximum temperature variation should be lower than 1 °C in the occupied zone and the velocity of the air should be between 0.15 m/s and 0.36 m/s.
2) In the occupied area, to avoid drafting. Draft is defined as a cooling or warmth sensation. Draft shall be measured above or below the controlled 24 °C room condition and the central air velocity shall be 0.15 m/s. The following Equation 2.14 gives the effective draft temperature (EDT) for comfort [15].

$$EDT = (DBT - 24) - 0.1276\times(V - 0.15) \quad (2.14)$$

Where:

DBT: is the local dry bulb temperature [°C]
V: is the local velocity (m/s).

For comfort, the EDT should be within –1.7 ℃ to +1.1 ℃ and the air velocity should be less than 0.36 m/s [15]

2.10.1 Design of Air Distribution Systems

The purpose of the air system design is to choose the air diffuser location and type of supply and the location and type of the return air grilles. At a certain point in the conditioned space the parameters affecting air velocity and temperature are [15]:

1) Velocity of air at the inlet to the supply diffuser: Noise criteria to be observed.
2) Supply to room temperature difference ($T_s - T_R$).
3) Geometry and position of air supply outlet.
4) Position of return air inlet.
5) Room geometry.
6) Room surface temperature: Lower the surface temperature (e.g., with glass) stronger are the natural convection currents.
7) Internal heat sources (e.g., people, appliances).
8) Room turbulence.

2.10.2 Types of Air Distribution Devices

1) Grilles and Registers: a grille is an air outlet for supply air or an inlet for return air. A grille with a volume control damper is a register. The front view of the horizontal and vertical vane grille is illustrated in Figure 2.29 For deflecting airflow, the valves are either fixed or adjustable. Grilles have a comparatively lower entrainment ratio, greater drop, longer throw and higher air velocities in the occupied zone and are comparatively smaller compared with slot and ceiling diffusing. Manufacturers specify grille performance in core size or core area, volumetric air flow, effective air velocity, total pressure drop, throw and noise levels. They can be mounted either on the ceiling or on the sidewalls.

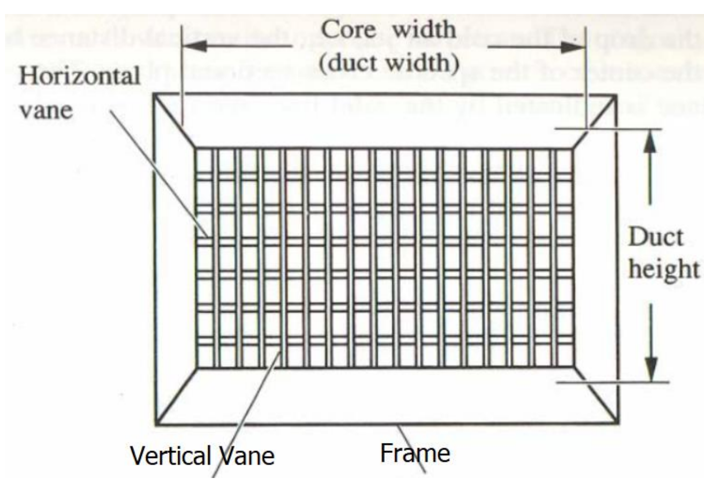

Figure 2. 36: Front View of a Supply Air Grille with Horizontal and Vertical Vanes

2) Ceiling diffusers are made up of concentric circles or inner cones that are made up of vanes that are arranged in fixed directions. Ceiling diffusers come in a variety of shapes, including circular, square, and rectangular. Figure 2.30 illustrates a square and rectangular ceiling diffuser, while Figure 2.31 illustrates a perforated ceiling diffuser. For supply air, a square diffuser is commonly used. The supply air is discharged in all directions through the concentric air passages in the diffusers. The adjustable inner cones or deflecting vanes can be adjusted to change the air distribution pattern. Ceiling diffusers are usually installed in the conditioned space's center. Ceiling diffusers have a high entrainment ratio and a short throw, making them ideal for conditioned spaces with low head space and higher supply air temperatures. As opposed to grilles and slot diffusers, ceiling diffuser can deliver more air.

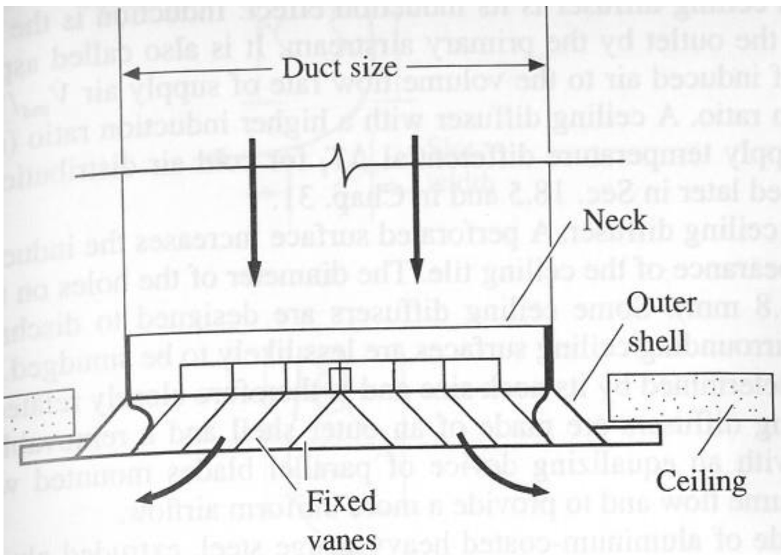

Figure 2. 37: Schematic of a Ceiling Diffuser

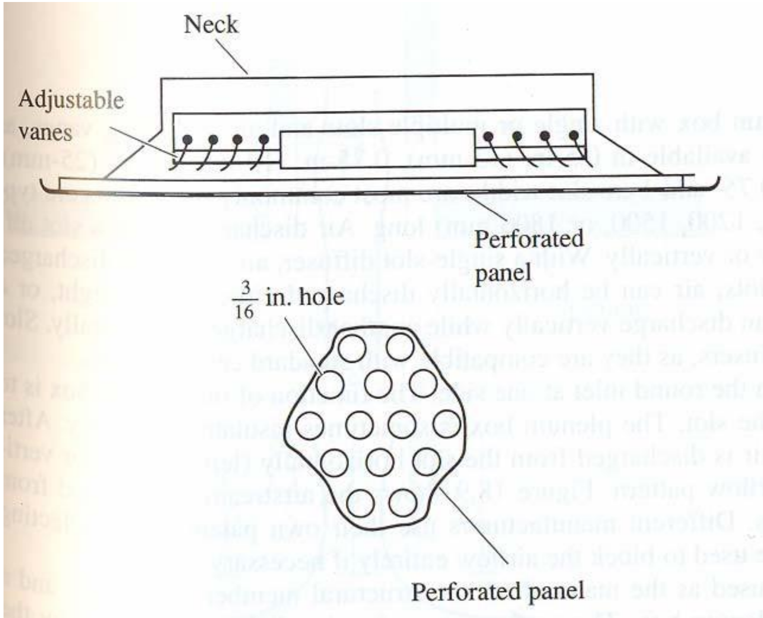

Figure 2. 38: Schematic of a Perforated Ceiling Diffuser

3) Slot Diffuser: A slot diffuser is made up of a plenum box with single or several slots and air deflecting vanes. They are mounted on the side walls or in the ceiling. The length of linear slot diffusers mounted on the sidewalls can be up to 30 meters. Can be used for both supply and return air. Linear slot diffusers are ideal for wide open areas that need flexibility to accommodate changing occupant distribution. Linear slot diffuser is shown in Figure 2.32

Figure 2. 39: Slot Diffuser

Due to the building's false ceiling tiles size, a square diffuser with a face dimensions of 24x24 inches and a neck dimensions of 18x18 inches will be used. Additionally, in every sensitive area, such as patient rooms, ICU, and operation rooms, a perforated square diffuser with the same dimensions will be used.

4) Perforated Ceiling Diffusers

The perforated ceiling diffusers are used for the HVAC ducting systems that provide for filtered air. These diffusers provide ideal discharges and are used in a variety of home and commercial applications. The diffusers may be utilized for the gentle air discharges that are often sought by building occupants since they have a low throw and a radial discharge.

The Perforated Ceiling Diffusers provide the following advantages:

1) Elegant Designs

The air diffusers have an elegant and lovely appearance. The diffusers' bodies have no apparent joints and fit in flawlessly with the decor of an existing space.

2) Simple to Install

The diffusers are simple to install and remove, requiring just the tightening of a few screws.

3) More Effective Air Discharge

The diffusers' perforated sheets are situated under the middle line. The ideal layout aids in the creation of a horizontal air flow, which is very desirable in both commercial and residential settings. For maximum air movement, SS duct manufacturers advocate using these diffusers in conjunction with high-quality stainless-steel ducts.

4) Quiet Environment

The perforated ceiling diffusers do not make any noise while they are in use. As a result, they have a wide range of applications and advantages in business and office environments, as well as in home settings.

5) Resistance to Corrosion

The perforated air diffusers are made of high-quality aluminum and other materials that do not rust after years of operation and are resistant to all types of environmental and local corrosion conditions.

6) There is no air leakage

There are no air leaks in the perforated air diffusers. As a result, they are more cost-effective and energy-efficient.

2.10.3 Return Air Inlets

Different types of return air inlets are used to return the space air to the air handling unit. Requirements of return air inlets are:

1) They should not lead to short-circuiting of supply air
2) Tobacco smoke, odors, and other undesirable materials should be allowed to travel in their natural direction so that they do not get trapped in the occupied room. The return air vent should be located at a higher position on the wall to eliminate cigarette smoke, and the return air vent should be located on the floor to remove dust particles and other particles floating in the air.

Return air inlets, like supply air outlets, are divided into grilles, registers, and diffusers. The ceiling plenum is also used as a return air plenum in industrial buildings. Return slots are used to draw return air from the roof in this situation. The air velocity in return air inlets drops dramatically as the gap from the inlet rises. If the return air inlet is within the occupied room, the air velocity should be less than 3 m/s, and if it is outside the occupied space, it should be less than 4 m/s.

2.10.4 Sizing and Selection of Supply Air Outlets

Selection depends on:

1) Requirement of indoor environment control: If the indoor environment requires controlled air movement, then a high side outlet should not be used.
2) Shape, size and ceiling height of the building: Ceiling and slot diffusers are ideal for buildings with limited ceiling height. For large buildings with large ceiling heights, high side wall mounted outlets are recommended.
3) Volume flow rate per unit floor area: Sidewall outlets are limited to low specific volume flow rates as they give rise to higher air velocities in the occupied zone. Compared to slot diffusers, the ceiling diffusers can handle efficiently a larger volumetric flow rate. Table 39.3 shows the specific volume flow rate of different outlets.
4) Volume flow rate per outlet: The volume flow rate per supply outlet depends on the throw required to provide a satisfactory room air distribution. For linear slot diffusers, the volume flow rate per unit length is important. Its value normally lies between 23 to 62 L/s.m for linear slot diffusers. In a closed office with a floor area of about 14 m 2 and only one external wall, one ceiling diffuser is normally sufficient.
5) Throw: High side wall outlets have a longer throw than ceiling diffusers. Square ceiling diffusers and circular ceiling diffusers have similar throw
6) Noise level.
7) Total pressure drops: The total pressure loss of supply air as it flows through a slot diffuser of 19 mm width is normally between 12 to 50 Pascals, whereas it is between 5 to 50 Pascals for ceiling diffuser. Normally the pressure loss across the supply outlet should not exceed 50 Pascals.
8) Cost and Appearance: Finally, the cost and appearance of the supply air outlets also have to be considered depending upon the specific application.

The following Table 2.18 Shows the recommend NC-RC values for health-care facilities according to SMACNA [22]

Table 2. 18: Recommended NC−RC Levels for Different Indoor Activity Areas

Type of Area	NC-RC Level	Approx. dBA	Type of Area	NC-RC Level	Approx. dBA
HOSPITALS & CLINICS			RESTAURANTS, LOUNGES,		
Private rooms	25-35	30-40	CAFETERIAS		
Operating rooms	30-40	35-45	Restaurants	35-45	40-50
Wards, corridors	30-40	35-45	Cocktail lounges	35-40	40-45
Laboratories	30-40	35-45	Night clubs	35-45	40-50
Lobbies, waiting rms	35-45	40-50	Cafeterias	40-50	45-55
Washrooms, toilets	40-50	45-55			

2.11 Duct Design

For years, the HVAC industry has struggled with air flow issues. No matter how much money you spend on a high-quality HVAC system, it won't operate correctly unless the ductwork is correctly planned and built. Inadequately built ducts cause discomfort, excessive energy expenses, poor air quality, and increased noise. A well-designed ducting system should provide optimum interior comfort at the lowest possible operational cost while simultaneously conserving the purity of the indoor air. The most important criteria for an air transport system are:

The following are the components of a duct system for air conditioning:

1) It should provide predetermined air flow rates to predetermined places.
2) It should be cost-effective in terms of original investment, fan operation, and building space.
3) It should not broadcast or produce distracting noise.

The balance between the original duct system cost and the energy cost of the air distribution system is a major problem. Larger ducts need a higher upfront investment, but they result in reduced fan energy expenditures throughout the system's lifetime. Other concerns include space constraints, noise levels, growth capacity, and aesthetic.

DUCT COMPONENTS & MATERIALS

The air distribution system will have a designation depending on the function of the duct. Broadly, there are five designations of ducts:

1) Supply air ductwork supplies conditioned air from the air handling unit to the conditioned area.
2) Return air ductwork removes air from the conditioned building spaces and returns the air to the air handling unit, which reconditions the air. In some cases, part of the return air in this ductwork is exhausted to the building exterior.
3) Fresh air ductwork supplies outdoor air to the air handling unit. Outdoor air is used for ventilating the occupied building space.
4) Exhaust (relief) air ductwork carries and discharges air to the outdoors. Exhaust air is taken from toilets, kitchen, laboratories and other areas requiring ventilation.
5) Mixed air ductwork mixes air from the outdoor air and the return air then supplies this mixed air to the air handling unit.

2.11.1 Duct Components

A schematic and a three-dimensional illustration of supply and return air ducting system is shown in Figure 2.33. The starting point connects the central air handling unit (AHU) to the air plenum. Return grilles are used by AHU fans to pull air in and push air out of the system. Supply diffusers carry air from the plenum into the conditioned room.

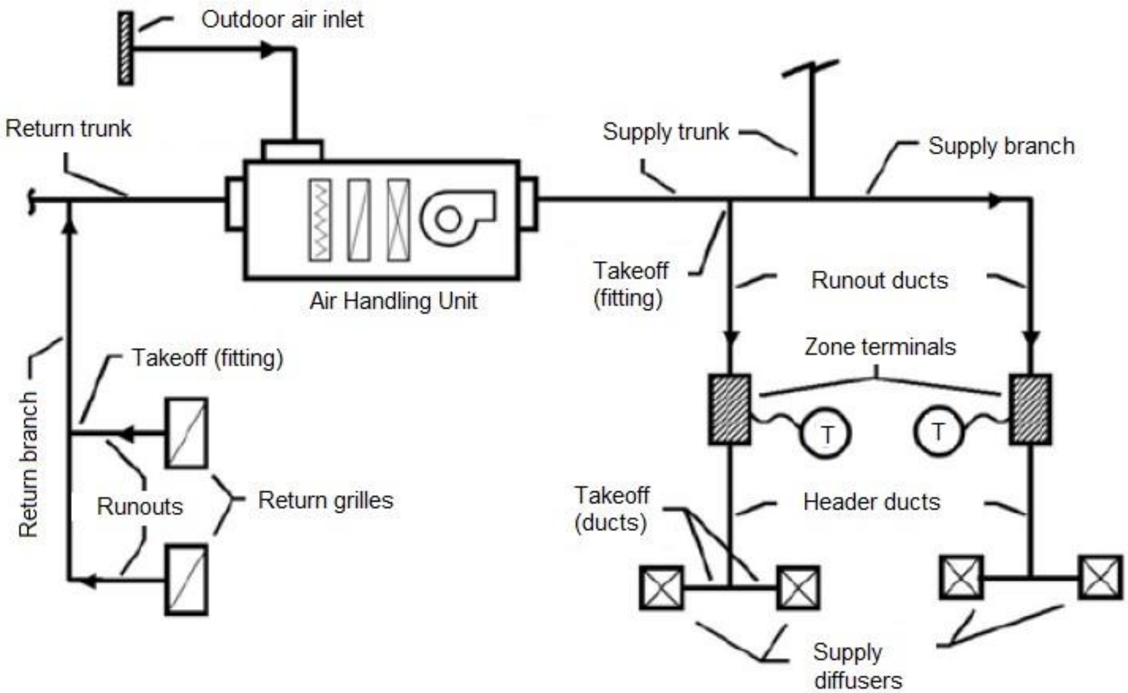

Figure 2. 40: Air Conditioning Schematic Drawing

2.11.2 Duct Materials

Ducting is generally formed by folding sheet metal into the desired shape. Traditionally, air conditioning ductwork is made of galvanized steel, next in popularity is aluminum. Other metals used under special circumstances are copper and stainless steel. Depending on the application, the ducts utilized in this project will be specified below.

1) Galvanized Steel

   It is a standard, most common material used in fabricating ductwork for most comfort air conditioning systems. The specifications for galvanized steel sheet are ASTM A653, coating G90. This type will be used for the ordinary rooms.

2) Aluminum

   It is widely used in clean room applications. These are also preferred systems for moisture laden air, special exhaust systems and ornamental duct systems. The specifications for Aluminum sheet are ASTM B209, alloy 1100, 3003 or 5052. It will be utilized for the operating rooms in this project.

3) Fabric

   Fabric ducting, also known as textile ducts, is usually made of special permeable polyester material and is normally used where even air distribution is essential. Due to the nature or the air distribution, textile ducts are not usually concealed within false ceilings. Condensation is not a concern with fabric ducts and therefore these can be used where air is to be supplied below the dew point without insulation. This type will be used in the MRI rooms.

2.11.3 Duct Sizing

The most widely used method to size ducting is the equal friction method. The other methods are velocity reduction and static regain. However, the equal friction approach will be employed in this project, despite the fact that it is not the most precise approach.

2.11.3.1 Equal Friction Method

The Equal Friction design method sizes the ducts for a constant "Friction Rate", which describes the average pressure drop per 100 feet of duct in a system. For a relatively well-designed system, a relatively typical friction rate is 0.1 in.-wc every 100 feet of duct length. Reduced friction rates of 0.05 inch-wc per 100 feet increase duct size and cost by 15%, but reduce the percentage of total pressure drop in ductwork by 50%, resulting in fan energy savings of 15% to 20%. [22].

Procedure:

The equal friction technique determines the relationship between duct size and air flow, i.e. how much air will come out of a given size duct, using a duct slide rule, duct calculator, or friction rate chart. The following is the methodology:

1) Select maximum air velocity in main duct after fan outlet according to SMACNA
2) Enter the friction chart knowing the cfm and velocity to determine the friction rate per 100 feet of duct length and select the diameter (refer to chart below in Figure 2.34).
3) From the friction rate obtained in the previous step, use the same value to determine diameters for all other sections of the ductwork.
4) The total friction loss in the duct system is then calculated by multiplying the friction loss per 100-foot of length to the equivalent length of the most critical path of the ductwork having maximum resistance.

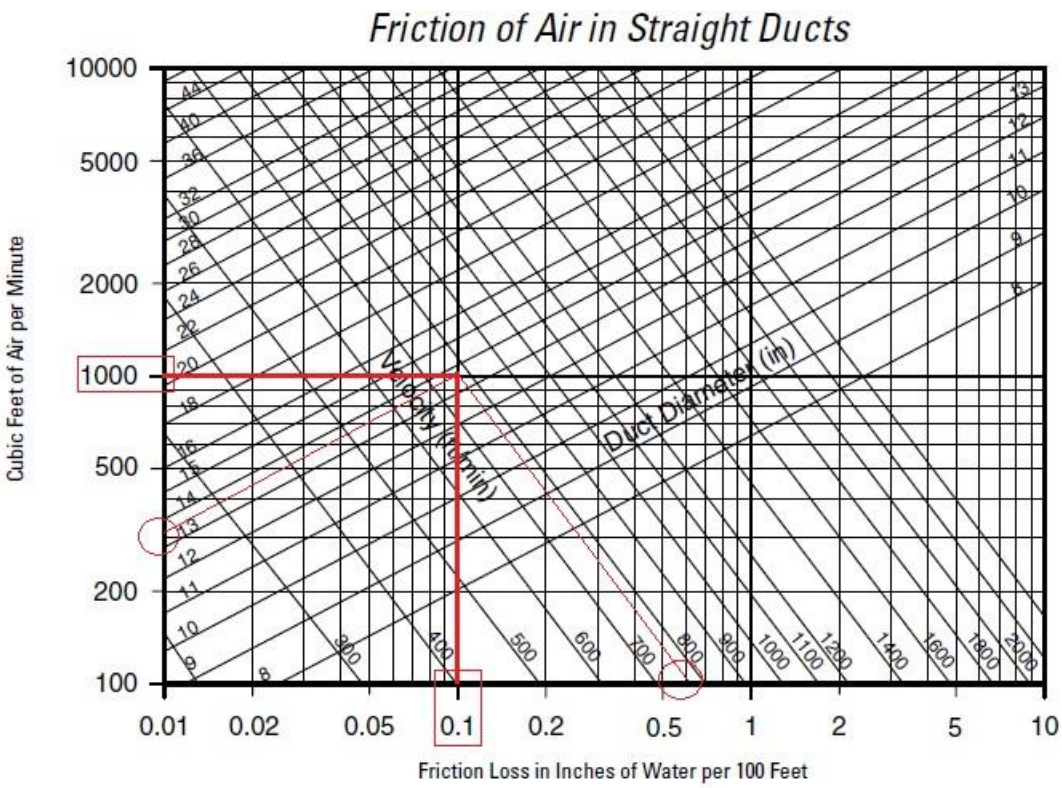

Figure 2. 41: Frication Chart – SMACNA

Advantages of the Equal Friction Method:

1) The method is straightforward and simple.
2) It automatically reduces air velocities in the direction of air flow, which in turn reduces the potential air flow generated noise.
3) It is the most appropriate method for constant air volume (CAV) systems.

Limitations of the Equal Friction Method:

1) There are no equalization of pressure drops in duct branches unless the system has a symmetrical layout. Balancing dampers must be installed to balance the system.
2) It is not recommended for VAV systems. If used for VAV supply duct design, the terminal units require pressure independent (Pi) control capability to avoid excessive flow rates when duct pressure is high.
3) It is not flexible and adaptable to future layout changes.

The following Table 2.19 includes the recommended maximum duct velocities for low velocity systems according to SMACNA [22]

Table 2. 19: Recommended Maximum Duct Velocities for Low Velocity Systems (fpm)

APPLICATION	CONTROLLING FACTOR NOISE GENERATION Main Ducts	CONTROLLING FACTOR—DUCT FRICTION			
		Main Ducts		Branch Ducts	
		Supply	Return	Supply	Return
Residences	600	1000	800	600	600
Apartments Hotel Bedrooms Hospital Bedrooms	1000	1500	1300	1200	1000
Private Offices Directors Rooms Libraries	1200	2000	1500	1600	1200
Theatres Auditoriums	800	1300	1100	1000	800
General Offices High Class Restaurants High Class Stores Banks	1500	2000	1500	1600	1200
Average Stores Cafeterias	1800	2000	1500	1600	1200
Industrial	2500	3000	1800	2200	1500

2.11.4 Duct sizing using Duct Sizer software from McQuay:

Because the project is large, manual calculation for the duct design is considered to be time consuming, therefore the Duct Sizer program will be employed, as shown in the Figure 2.35 below for a supply round duct located in the first level.

A head loss value of 0.08-0.09 in.wg/100 ft will be used for all supply ducts and a value of 0.05-0.06 for return ducts as recommended by ASHRAE

Note that all the duct sizes are shown on the plans.

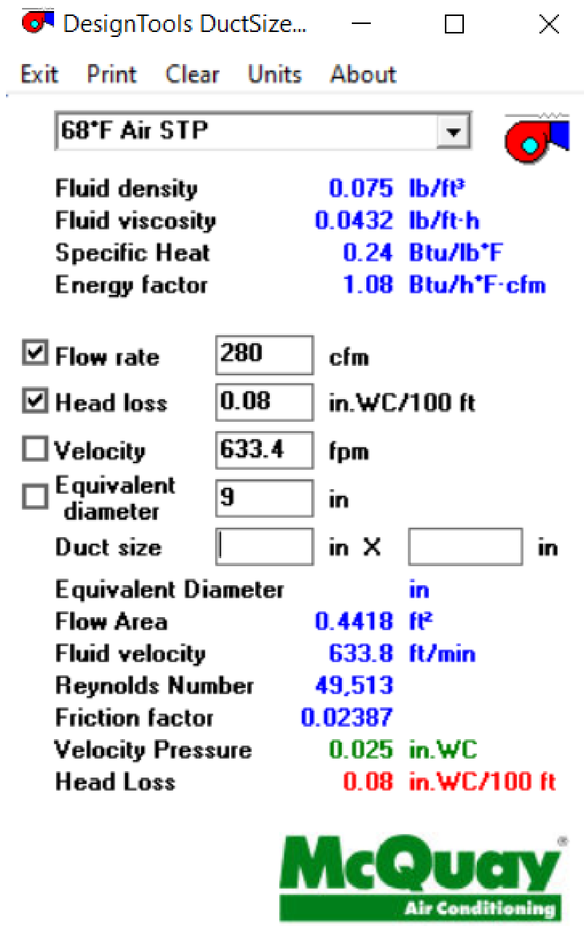

Figure 2. 42: Duct Sizer Interface

2.11.5 Plenum Box System

Because each level has at least two big AHUs, each with at least 20 TR and 5000 CFM, the duct sizing will result in a duct with massive dimensions. To prevent this, a plenum box was placed at each AHU outlet, and the following calculations were used to size it.

$$A = {}^{Q}/_{V} \qquad (2.15)$$

Where

Q: AHU flow rate [CFM]

V: Velocity at the AHU outlet [fpm]

A : Area of the plenum box [ft^2]

As per ASHARE [15] the recommended velocity at AHU is 800 fpm.

And after assuming one dimension, for example the height since we have a 18 in false ceiling height.

And taking a sample for the first level – zone one AHU of 22 TR and 6400 CFM

The area of the plenum box is 8 ft^2 which equals to 0.7 m^2 and its width is 1.4 m.

And for the length:

$$L = 2.5\times D_{\mathrm{Blower}} \tag{2.16}$$

Where D is the diameter of the fan blower in the AHU, for this sample, the fan blower has a diameter of .75 m, therefore the length of the plenum box is 1.8 m

2.12 Variable Air Volume Systems (VAV)

In central air conditioning systems, there are two fundamental techniques for supplying air to the conditioned space:

1) Constant Air Volume (CAV) Systems

Constant volume systems, as the name indicates, provide a constant air volume to the conditioned room regardless of the load, with the air conditioner cycling on and off as the load fluctuates. The fan may or may not continue to operate during the off cycle.

2) Variable Air Volume (VAV) Systems

VAV systems, on the other hand, are intended to satisfy a range of cooling and heating loads in a reasonably efficient way. The system does this by adjusting air distribution based on the cooling or heating demands of each location. The air flow variation enables you to adjust the temperature in a specific zone without affecting the temperature of the air across the system, reducing the possibility of overcooling or overheating. This adaptability has made it one of the most common HVAC systems for big buildings with changing cooling requirements, such as office buildings, schools, or hospitals as in this project.

How a VAV system works?

The use of a variable air volume box in the duct system is what differentiates a variable air volume system from other kinds of air supply systems. The primary box is an air valve (damper) enclosure, which controls the air flow in response to the thermostat of the room.

An air handling unit, AHU cools or heats air for the zone with the maximum demands and provides the air in different zones through ducts. The amount of air to provide is controlled by air valves inside a VAV box or terminal in the specific zone or space. The VAV air valve throttle the airflow according to the needs for space when the load decreases in a specific zone. When the load increases suddenly, the temperature sensor in the zone detects an increase in the temperature. The VAV box opens the air valve and increases the cool air flow.

The static pressure in an adjacent runout and trunk duct increases when the air flow through the adjacent duct increases when a VAV air valve closes. This change in airflow is going to affect the space temperature in the new zone that the duct is supplying since the zone is now covered by a higher air volume (typically cooled). This shift is finally detected by the space thermostat in this location and its air damper is re-positioned for the new reduced flow. Because of the decreased flow, static pressure in adjacent ductwork will rise even higher, increasing flow to adjacent air terminals. This impact will continue unabated, resulting in imbalance across the whole air distribution ducting. It is clear that space thermostats alone will never be able to keep a space temperature stable. As a result, the system includes an extra static pressure control that keeps the duct static pressure within a predetermined range. The rise in duct static pressure is detected by a static pressure sensor, which sends a signal to the fan controller to lower the speed. When the fan speed is reduced, the airflow is reduced in direct proportion to the speed.

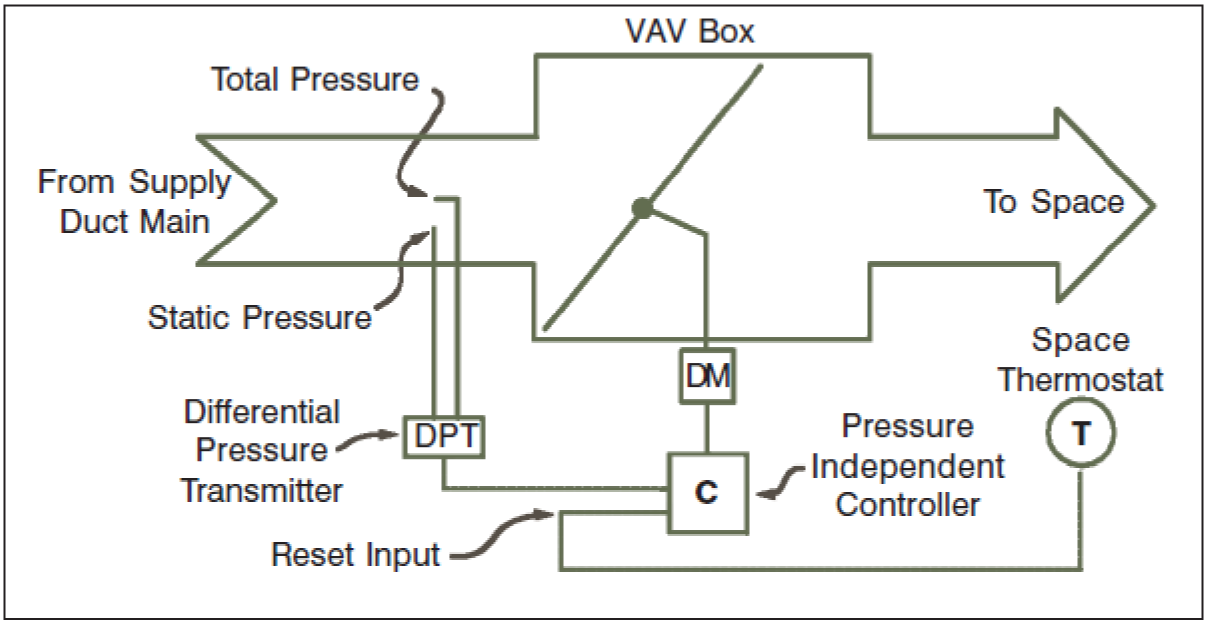

Figure 2. 43: Typical VAV Box Control

2.12.1 VAV Sizing

An accurate sizing of the VAV box results in a good thermal comfort in each zone or space that have. The following steps will be used to size every vav in the system, taking space FT-07 - zone one in level one as a sample

Cooling Load = 0.8 TR

Required Air Flow = 380 CFM

OA Flow = 20% × 0.8 = 16 CFM

the actual box minimum must be four times the value of OA above to meet the outdoor air ventilation requirements [15]. Therefore

$Q_{VAV_{MIN}}=4\times16=65$ CFM

From SystemAir company catalogues, after entering the required data as shown in Figure 2.37

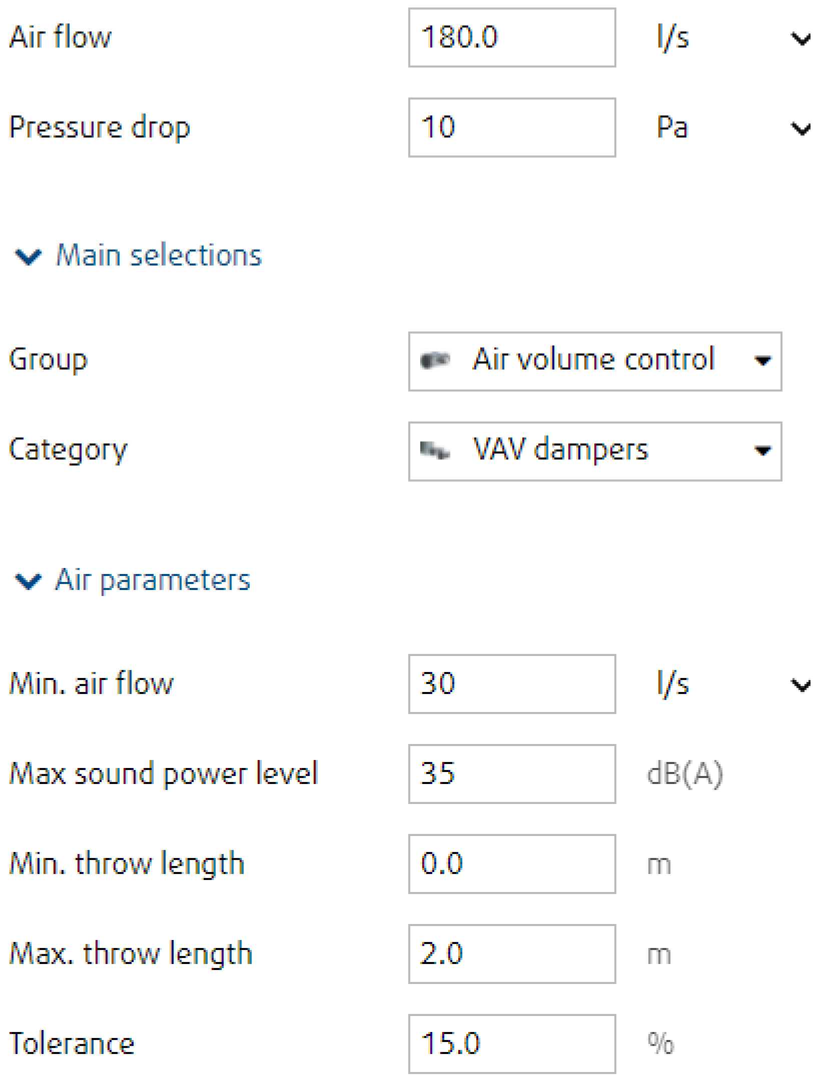

Figure 2. 44: VAV – Selection from SystemAir

The catalogue is shown in Figure 2.38

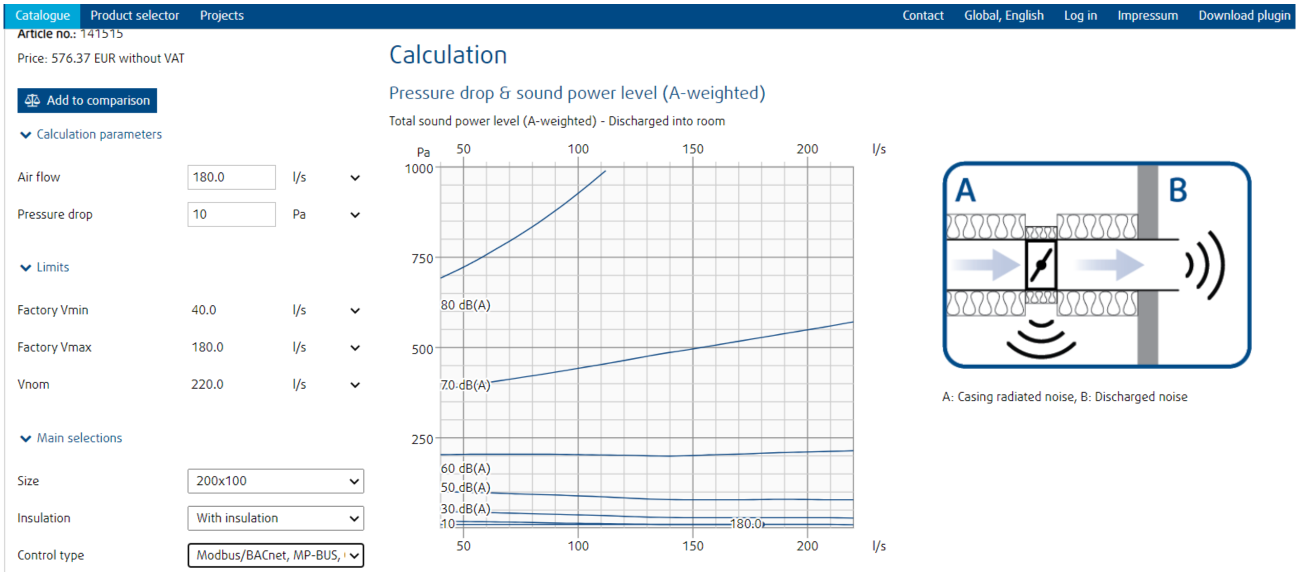

Figure 2. 45: VAV Box Catalogue

2.13 AHU Filters HVAC Systems

The air filter in the HVAC system is crucial, yet it is often neglected. Correct filter size, MERV ratings, filter material, filter type, and specific environmental circumstances are all factors to take into consideration when ensuring proper filtration. In general, the central air conditioning system, walls, ceilings, or return vents will define these criteria.

2.13.1 Defined by MERV

To address the issue of particle size, ASHRAE 52.2 was published in 1999 and revised in 2007 to allow engineers/designers to select a filter based on the actual known particle size of the contaminant to be filtered, rather than Standard 52.1, by allowing them to select a filter based on the actual known particle size of the contaminant to be filtered. The lowest point of filter effectiveness (which is usually exactly at the time of installation) is indicated by standard 52.2. The initial efficiency of filters is measured as a function of one of 12 particle size ranges. A numerical value is assigned to a filter based on this information. The MERV (Minimum Efficiency Reporting Number) is the label given to this numerical value. Specific airflow speeds must be indicated on the manufacturer's data in order for MERV ratings to be calculated [24].

2.13.2 Filter Selection

The type and size of particle/contaminant to be removed, expected filter service life, and pressure are all elements to consider when choosing a filter. ASHRAE 52.1 and 52.2 should be applied in this case. In order to create a final filter selection. The following are the recommendations to assist in the selection process:

1) Physical size of particulate. Table 2.20 should be helpful in determining the MERV rating of the filter once the particulate size has been determined. For example, if bacteria range from 0.3 microns to 4 microns, the chart indicates a MERV 13 would be the minimum rating to select, and higher MERV-rated filters should be selected with the end users' level of comfort and economics in mind [24].

Table 2. 20: Filter Selection Guideline Table

ASHRAE Application Guidelines

Std 52.2 Minimum Efficiency Reporting Value (MERV)	Std 52.2 Particle size efficiency (%)			Std 52.1 Dust Spot Efficiency (%)	Std 52.1 Average Arrestance Efficiency (%)
	E1 0.30 to 1.0 µm	E2 1.0 to 3.0 µm	E3 3.0 to 10.0 µm		
1	n/a	n/a	E < 20	< 20	< 65
2	n/a	n/a	E < 20	< 20	65 ≤ E < 70
3	n/a	n/a	E < 20	< 20	70 ≤ E < 75
4	n/a	n/a	E < 20	< 20	75 ≤ E < 80
5	n/a	n/a	20 ≤ E < 35	< 20	80 ≤ E < 85
6	n/a	n/a	35 ≤ E < 50	< 20	85 ≤ E < 90
7	n/a	n/a	50 ≤ E < 70	25 ≤ E < 30	E > 90
8	n/a	n/a	70 ≤ E	30 ≤ E < 35	E > 90
9	n/a	E < 50	85 ≤ E	40 ≤ E < 45	E > 90
10	n/a	50 ≤ E < 65	85 ≤ E	50 ≤ E < 55	E > 95
11	n/a	65 ≤ E < 80	85 ≤ E	60 ≤ E < 65	E > 95
12	n/a	80 ≤ E	90 ≤ E	70 ≤ E < 75	E > 95
13	E < 75	90 ≤ E	90 ≤ E	80 ≤ E < 90	E > 98
14	75 ≤ E < 85	90 ≤ E	70 ≤ E	90 ≤ E < 95	E > 98
15	85 ≤ E < 95	90 ≤ E	90 ≤ E	E > 95	n/a
16	95 ≤ E	90 ≤ E	95 ≤ E	n/a	n/a
17	99.97 < E	n/a	n/a	n/a	n/a
18	99.99 < E	n/a	n/a	n/a	n/a
19	99.999 < E	n/a	n/a	n/a	n/a
20	99.999 < E	n/a	n/a	n/a	n/a

"E" indicates efficiency percentage

2) Service life of filters. Review the dust holding capacity in both ASHRAE 52.1 and the manufacturer's product data to compare the relative service life of comparable filters. Additional service life can be obtained by simply increasing the depth of the filter (e.g., 2" deep to 4" deep).
3) Initial and final pressure drop of filters. Review manufacturing product data to determine initial and final pressure resistance. The system should be able to provide design airflow throughout the entire loading process of the filters. Note that increasing the number of filters, and, therefore, the total surface area, will increase the service life of the filters but will not affect the final system pressure drops.

4) Filter frame material. Determine if the filter will be in a wet or dry environment, and how it will be disposed. (For example, if incineration will be used, a metal frame would not be advisable).
5) Design airflow. Pre-filters and final filters should be matched for airflow compatibility and pressure drop.
6) Physical space allotted for filter bank. Allow space for duct transition before and after the filter bank.

2.13.3 ASHRAE Filters Selection Guidelines and Requirements in Health-Care Facilities

Table 2. 21: Minimum Filter Efficiencies

Space Designation (According to Function)	Filter Bank #1, MERV[a]	Filter Bank #2, MERV[a]
Classes B and C surgery; inpatient and ambulatory diagnostic and therapeutic radiology; inpatient delivery and recovery spaces	7	14
Inpatient care, treatment and diagnosis, and those spaces providing direct service or clean supplies and clean processing (except as noted below); AII (rooms)	7	14
Protective environment rooms (PE)	7	17 (HEPA)[c]
Laboratories; Class A surgery and associated semirestricted spaces	13[b]	N/R[d]
Administrative; bulk storage, soiled holding spaces; food preparation spaces; and laundries	7	N/R
All other outpatient spaces	7	N/R
Skilled nurses facilities	7	N/R

Source: ANSI/ASHRAE/ASHE Standard 170-2008.

Notes:

a. Minimum efficiency reporting value (MERV) is based on method of testing described in ANSI/ASHRAE Standard 52.2-2007

b. Additional prefilters may be used to reduce maintenance for filters with efficiencies higher than MERV 7

c. Filter Bank #2 may be MERV 14 if MERV 17 tertiary terminal filter is provided for these spaces

d. N/R = not required.

True HEPA (MERV 17; 99.99 %filters are only necessary for protected environment (PE) rooms, as shown in Table 2.20, however, true HEPA (MERV 17; 99.99%) filters are also necessary for pharmacies, according to US Pharmacopoeia General Chapter 797. (USP 2012). For bone marrow and organ transplant patient rooms, as well as orthopedic surgery, HEPA filters are often requested [13]. A “roughing” prefilter with a minimum efficiency reporting value (MERV) of 7 shall be installed inside or immediately downstream of the mixing box and upstream of the heating and cooling coils, according to ANSI/ASHRAE Standard 52.2-2007 (see Tables 2.20 and 2.21). Lint, dust, and other large particles are removed from the airstream before they may collect on or clog coils or other components. Throw-away, replacement cartridge filters need less maintenance than cleanable or replacement cartridge filters.

Chapter 3

Medical Gases

3.1 Introduction to Medical Gases System

The medical gases system is defined as "An assembly of equipment and piping for the distribution of nonflammable medical gasses such as oxygen, nitrous oxide, compressed air, carbon dioxide, and nitrogen according to NFPA 99C, Chapter 3, Definitions [29]

3.3 Common Medical Gas Systems

1) Oxygen (O_2).
2) Medical Air (MA).
3) Medical Vacuum (MV).
4) Nitrous Oxide (N_2O).
5) Nitrogen (N_2).
6) Instrumental Air (IA).
7) Carbon Dioxide (CO_2).
8) Waste Anesthesia Gas Disposal (WAGD or EVAC).

3.4 Medical Gases System Functions

1) Supply of right medical gases at right pressure.
2) Supply of compressed air at right pressure.
3) Supply of clinical vacuum at right pressure.
4) Proper planned maintenance of all equipment, including distribution network.
5) Optimum level of cleanliness and pollution free environment.

3.5 Medical Gases System Components

1) Source of supply: Central supply room with control equipment and panels.
2) Distribution system: piping.
3) Point of use delivery connections: Suitable station outlet valves and pendants.
4) Monitoring and control equipment and alarms.

3.6 Medical Gases Manifold Room

1) Consists of a cylinder manifold and a control panel.
2) Manifold can be of 2 banks of 2 cylinders each or 2 banks of 20 cylinders each.
3) Control panel: primary and secondary pressure regulators; warning lamp
4) Pressure gauges.
5) Vacuum Unit, consists of:

   a) Vacuum pump with an electric motor
   b) Cylindrical reservoir tank: stabilizes the pressure of the pipeline system at all outlet points
   c) Motor has switch for automatic start and stop.

Note that the vacuum pumps are duplexed.

6) Compressed air unit.

3.7 Medical Gases Outlets

The NFPA species through Table 3.1 the required medical gases outlets for oxygen and vacuum [29]

Table 3. 1: Station Outlets for Oxygen, Vacuum, and Medical Air System

Section	Location	Oxygen	Vacuum	Medical Air
7.2A	Patient rooms (medical and surgical)	1/bed	1/bed	----
7.2.B10	Examination/treatment (medical, surgical, and postpartum care)	1/room	1/room	----
7.2C/7.2.D	Isolation—infectious and protective (medical and surgical)	1/bed	1/bed	----
7.3.A	Critical care (general)	3/bed	3/bed	1/bed
7.3.A14	Isolation (critical)	3/bed	3/bed	1/bed
7.3.B	Coronary critical care	3/bed	2/bed	1/bed
7.3.D	Pediatric critical care	3/bed	3/bed	1/bed
7.3.E	Newborn intensive care	3/bassinet	3/bassinet	3/bassinet

[1] For any area or room not described above, the facility clinical staff shall determine outlet requirements after consultation with the authority having jurisdiction.

3.8 Medical Gases Flow

There are several aspects of gas flow to consider when designing the pipeline distribution system:

1) The test flow that is required at each terminal unit for test purposes (this flow is essentially to establish that the terminal unit functions correctly and that there are no obstructions; see Table 3.2).
2) The typical flow required at each terminal (this is the maximum flow likely to be required at any time in clinical use; see Table 3.2).
3) The likely numbers of terminal units in use at any time. the flow required in each sub-branch of the distribution, for example from the terminal unit or a number of terminal units (for example four in a four-bed ward) to the pipeline in the false ceiling of the ward corridor.
4) The total flow to the ward/department, that is, the sum of the diversified flows in each subbranch.
5) the flow in the main branches/risers, that is, the summation of all diversified flows.
6) the flow required at the plant. In most cases this will be the flow in (f) above except in the case of vacuum that is not used continuously.

Table 3. 2: Gas Flow – Flows Required at Terminal Units

Service	Location	Nominal pressure (kPa)	Design flow (L/min)	Typical flow required (L/min)	Test flow (L/min)
Oxygen	Operating rooms and rooms in which N_2O is provided for anaesthetic purposes	400	100(1)	20	100
	All other areas	400	10	6	40
Nitrous oxide	All areas	400	15	6	40
Nitrous oxide/ oxygen mixture	LDRP (labour, delivery, recovery, post-partum) rooms	310(2)	275	20	275
	All other areas	400	20	15	40
Medical air 400 kPa	Operating rooms	400	40(3)	40	80
	Critical care areas, neonatal, high dependency units	400	80(3)	80	80
	Other areas	400	20	10(3)	80
Surgical air/ nitrogen	Orthopaedic and neurosurgical operating rooms	700	350(4)	350	350
Vacuum	All areas	40 (300 mm Hg below atmospheric pressure)	40	40 maximum, further diversities apply	40
Helium/oxygen mixture	Critical care areas	400	100	40	80

After knowing the number of terminal units from Table 3.2, we can calculate the required flow of each gas, Table 3.2 shows the required relations to calcite the oxygen air flow, as indicated by Medical Gases Health Technical Memorandum in 02-01 [29], the tables for other medical gases are in the same standard, and will not be included in this section or any other, but will be followed to find each gas flow.

Table 3. 3: Oxygen Design and Diversified Flows

Table 13 Oxygen: design and diversified flows

Department	Design flow for each terminal unit (L/min)	Diversified flow Q (L/min)
In-patient accommodation (ward units):		
Single 4-bed rooms and treatment room	10	$Q_w = 10 + [(n-1)6/4]$
Ward block/department	10	$Q_d = Q_w[1 + (nW - 1)/2]$
Accident & emergency:		
Resuscitation room, per trolley space	100	$Q = 100 + [(n-1)6/4]$
Major treatment/plaster room, per trolley space	10	$Q = 10 + [(n-1)6/4]$
Post-anaesthesia recovery, per trolley space	10	$Q = 10 + [(n-1)6/8]$
Treatment room/cubicle	10	$Q = 10 + [(n-1)6/10]$
Operating:		
Anaesthetic rooms	100	Q = no addition made
Operating rooms	100	$Q = 100 + (nT - 1)10$
Post-anaesthesia recovery		$Q = 10 + (n-1)6$
Maternity:		
LDRP rooms:		
Mother	10	$Q = 10 + [(n-1)6/4]$
Baby	10	$Q = 10 + [(n-1)3/2]$
Operating suites:		
Anaesthetist	100	$Q = 100 + (nS - 1)6$
Paediatrician	10	$Q = 10 + (n-1)3$
Post-anaesthesia recovery	10	$Q = 10 + [(n-1)3/4]$
In-patient accommodation:		
Single/multi-bed wards	10	$Q = 10 + [(n-1)6/6]$
Nursery, per cot space	10	$Q = 10 + [(n-1)3/2]$
Special care baby unit	10	$Q = 10 + (n-1)6$

Where:

Q = diversified flow for the department.
Q_w = diversified flow for the ward.
Q_d= diversified flow for the department (comprising two or more wards).
n = number of beds, treatment spaces or single rooms in which the clinical procedure is being performed, not the individual.
numbers of terminal units where, in some cases, more than one is installed.
nS = number of operating suites within the department (anaesthetic room and operating room).
nW = number of wards.
nT = number of theatres.

3.9 Medical Gases System Calculations

A sample calculation for FT-08 room in the first level will be discoed in this section, Equation 3.1 is taken from Table 3.3

1) Oxygen demand:

$$Q_w = 10 + [(n-1)6/4] \tag{3.1}$$

$$Q_w = 10 + [\frac{(3-1)6}{4}] = 13 \text{ L/min}$$

2) Medical air 400 kPa demand:

$$Q_w = 20 + [(n-1)10/4]$$

$$Q_w = 25 \text{ L/min}$$

3) Medical Vacuum:

Q = 40 L/min, a standard value given by the Medical Gases Health Technical Memorandum in 02-01

The following table 3.4 summarize the needed flow rates of each medical gas for each floor in the hospital

Table 3. 4: Flow of Medical Gases

Floor	Oxygen [L/min]	Nitrous Oxide [L/min]	Medical Air [L/min]	Medical Vacuum [L/min]	AGS [L/min]	SA [L/min]	CO_2 [L/min]
Basement	0	0	0	0	0	0	0
Ground	750	50	420	320	815	300	150
First	820	70	550	620	718	150	0
Second	550	150	330	150	515	200	50
Third	0	0	0	0	0	0	0
Fourth	220	133	230	300	254	130	0

3.10 Medical Gases Piping Design

Using the same equations and software used in the chiller pipes sizing back in Chapter 2 Section 2.9.1.2 and 2.9.1.3 but with values of head loss of 5 ft/1000 ft and velocity of 4 fpm, the values of pipes diameter will be shown on the plan for more convenience.

3.11 Medical Gases Cylinders, Compressor, Pumps Sizing

The following Table 3.6 summarize the number of cylinders required for each gas using the following, using Equation 3.2

$$N = Q_{Gas_{Total}} \times h \times 60 \times S \times 1.8/C \tag{3.1}$$

Where:

N: Number of gas required cylinders.
$Q_{Gas_{Total}}$: Gas demand in the hospital [L/min]
C: Gas cylinder capacity.
1.8: Gas demand safety factor.
h: Demand hours in the day (10 hours).

Table 3. 5: MG Total Demand

Oxygen [L/min]	Nitrous Oxide [L/min]	Medical Air [L/min]	Medical Vacuum [L/min]	AGS [L/min]	SA [L/min]	CO_2 [L/min]
2340	403	1530	1390	2302	780	200

Table 3. 6: Number of Cylinders

Gas Type	**Number of Cylinders**
Oxygen	200
Nitrous Oxide	27

To find the flow rate the of compressors needed to supply the flow rate of the medical air in the hospital:

$Q_{comp} = 92\ m^3/h$ divided between 4 compressors.

To find the flow rate of the vacuum pump needed to supply the whole hospital:

$Q_{Pump} = 84\ m^3/h$

Chapter 4

Fire Fighting Systems

4.1 Introduction

Firefighting is the act of extinguishing fires. A firefighter fights fires to prevent loss of life, and/or destruction of property and the environment. Firefighting is a highly technical skill that requires professionals who have spent years training in both general firefighting techniques and specialized areas of expertise.

Firefighting system is the most important of the building services, as its aim is to protect human life and property, strictly in that order. firefighting systems and equipment vary depending on the age, size, use and type of building construction [30].

4.2 Science of Extinguishment

Fire elements There are four elements needed to start and sustain a fire and/or flame. These elements are classified in the “fire tetrahedron” and are:

1) Reducing agent (fuel).
2) Heat.
3) Oxidizing agent (oxygen)
4) Chemical Reaction.

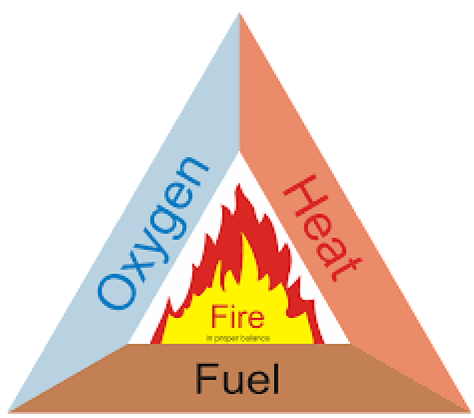

Figure 4. 1: The Fire Triangle

The reducing agent, or fuel, is the substance or material that is being oxidized or burned in the combustion process. The most common fuels contain carbon along with combinations of hydrogen and oxygen. Heat is the energy component of the fire tetrahedron. When heat comes into contact with a fuel, it provides the energy necessary for ignition, causes the continuous production and ignition of fuel vapors or gases so that the combustion reaction can continue, and causes the vaporization of solid and liquid fuels. The self-sustained chemical chain reaction is a complex reaction that requires a fuel, an oxidizer, and heat energy to come together in a very specific way. An oxidizing agent is a material or substance that when the proper conditions exist will release gases, including oxygen. This is crucial to the sustainment of a flame or fire. A fire helicopter is used to fight a wildfire. A fire can be extinguished by taking away any of the four components of the tetrahedron. One method to extinguish a fire is to use water. The first way that water extinguishes a fire is by cooling, which removes heat from the fire. This is possible through water's ability to absorb massive amounts of heat by converting water to water vapor. Without heat, the fuel cannot keep the oxidizer from reducing the fuel to sustain the fire. The second way water extinguishes a fire is by smothering the fire [31]. When water is heated to its boiling point, it converts to water vapor. When this conversion takes place, it dilutes the oxygen in the air with water vapor, thus removing one of the elements that the fire requires to burn. This can also be done with foam. Another way to extinguish a fire is fuel removal. This can be accomplished by stopping the flow of liquid or gaseous fuel or by removing solid fuel in the path of a fire. Another way to accomplish this is to allow the fire to burn until all the fuel is consumed, at which point the fire will self-extinguish. One final extinguishing method is chemical flame inhibition. This can be accomplished through dry chemical and halogenated agents. These agents interrupt the chemical chain reaction and stop flaming. This method is effective on gas and liquid fuels because they must flame to burn.

4.3 Types of Fire Fighting Systems

There are many types of firefighting systems and some important types of firefighting systems are following.

1) Fire Hydrant System
2) Fire Sprinkler System
3) Fire Alarm System
4) Deluge System
5) Foam Top pourer System
6) Vesda System
7) FM 200 System
8) CO2 Gas Suppression System
9) Fire Vehicle
10) Fire Hose cabinet.

In this project we used the following system.

1) Fire Sprinkler System (preaction + wet)
2) Fire Alarm System
3) FM 200 System
4) Extinguisher (CO2 + water mist)
5) Fire Hose cabinet.

4.3.1 Fire Sprinkler System

Automatic sprinkler systems are one of the most reliable methods available for controlling fires. Today's automatic fire sprinkler systems offer state of the art protection of life and property from the effects of fire. Sprinkler heads are now available which are twenty times more sensitive to fire than they were ten years ago. A sprinkler head is really an automatic (open once only) tap. The sprinkler head is connected to a pressurized water system. When the fire heats up the sprinkler head, it opens at a preset temperature, thus allowing pressurized water to be sprayed both down onto the fire and also up to cool the hot smoky layer and the building structure above the fire. This spray also wets combustible material in the vicinity of the fire, making it difficult to ignite, thereby slowing down or preventing fire spread and growth. When a sprinkler head operates, the water pressure in the system drops, activating an alarm, which often automatically calls the fire brigade via a telephone connection [32].

Components Of Fire Sprinkler System.

1) Piping.
2) Sprinkle.
3) Fire Alarm Check Valve.
4) Water Motor Gong.
5) Retard Chamber.
6) Cut of valves.

4.3.2 Fire Alarm System

An automatic fire alarm system is designed to detect the unwanted presence of fire by monitoring environmental changes associated with combustion. In general, a fire alarm system is classified as either automatically actuated, manually actuated, or both. Automatic fire alarm systems are intended to notify the building occupants to evacuate in the event of a fire or other emergency, report the event to an off-premises location in order to summon emergency services, and to prepare the structure and associated systems to control the spread of fire and smoke [33].

Components of Fire Alarm System.

1) Smoke Detector.
2) Heat Detector.
3) Sounder.
4) Fire Alarm Control Panel.
5) Wire.
6) Pipe.
7) Junction Box.
8) Isolator.

4.3.3 FM 200 System

FM200 fire suppression is also known as HFC227ea. FM200 is a waterless fire protection system, it is discharged into the risk within 10 seconds and suppresses the fire immediately. FM200 fire suppression is found as an active compound as a propellant in medical inhalers [34]. This is going without saying that FM200 gas is extremely safe for occupied spaces with the correct fire suppression design.

Components Of FM 200 System

1) Smoke Detector.
2) Heat Detector.
3) Manual Call point.
4) Audible alarm.
5) Visual alarm.
6) Abort Switch 8.
7) FM-200 Cylinder.
8) Manual Actuator.
9) 2-way Pneumatic Head.
10) 1-Way Pneumatic Head.
11) Extinguishing Control Panel.
12) Piping.
13) Discharge nozzles.

4.3.4 Fire Extinguisher

Portable or movable apparatus used to put out a small fire by directing onto it a substance that cools the burning material, deprives the flame of oxygen, or interferes with the chemical reactions occurring in the flame. Water performs two of these functions: its conversion to steam absorbs heat, and the steam displaces the air from the vicinity of the flame. Many simple fire extinguishers, therefore, are small tanks equipped with hand pumps or sources of compressed gas to propel water through a nozzle. The water may contain a wetting agent to make it more effective against fires in upholstery, an additive to produce a stable foam that acts as a barrier against oxygen, or an antifreeze. Carbon dioxide is a common propellant, brought into play by removing the locking pin of the cylinder valve containing the liquefied gas; this method has superseded the process, used in the soda-acid fire extinguisher, of generating carbon dioxide by mixing sulfuric acid with a solution of sodium bicarbonate [35].

4.4 Standards of Designing

To provide a reasonable degree of protection for life and property from fire through standardization of design, installation, and testing requirements for sprinkler systems, there are Three Classifications of Occupancies [36].

1) Light Hazard Occupancies.
2) Ordinary Hazard (Group 1).
3) Ordinary Hazard (Group 2).
4) Extra Hazard (Group 1).
5) Extra Hazard (Group 2).

4.5 Fire Fighting in Hospital

Millions have been spent on high-tech medical equipment and systems to make hospitals the therapeutic flagships of the healthcare system. These investments must be protected so that clinics can work unfailingly and uninterruptedly. The well-being of patients and staff is also a focal point of fi re protection concepts. Minimax has accepted this challenge with a holistic fi re protection plan which intelligently links a whole range of modern technology solutions [37].

1) **Patient Rooms.**

   Bedridden patients rely on outside help. Minimax smoke detectors keep a watchful eye on possible fire incidents and the signals are directly transmitted to the nurses' room and specialist personnel.

   Risks: Carelessness or technical defects can lead to fire in patient rooms.

   Fire protection: The extinguishing system with its fire detectors and sprinklers is immediately engaged and the evacuation of patients starts.

2) **Nurses' Rooms.**

   Nurses have a whole range of tasks to fulfil and are constantly kept busy keeping patient records up to date in addition to caring for patients.

   Risks: Technical defects or carelessness can lead to fire in the nurses' rooms.

   Fire protection: The extinguishing system with its fire detectors and sprinklers is immediately engaged and the evacuation of people starts.

3) **Laboratories.**

   The equipment pool in clinical diagnostics, along with the equipment in the laboratories of modern hospitals, has become far more sophisticated over the past few years in terms of quantity and scale. The risk of a fi re starting and destroying expensive investments has, however, also increased. Such losses would also affect patients, who would then miss out on critical treatment and diagnostic procedures.

   Risks: Electrical defects – strip conductors and cables can heat up and start a fi re. Carelessness when handling chemical substances can be another cause. Extinguishing water on sensitive and expensive equipment often damages the equipment completely.

Fire protection: Minimax opts for extinguishing agents which work without leaving any residue. Argotic fire extinguishing systems, for instance, can either work with the non-toxic and therefore harmless gases argon or nitrogen. Or, alternatively, the MX 1230 fire extinguishing system (Novec™ 1230) can be used.

4) **Operating theatres and treatment rooms.**

The complex technology used in the operating theatre also presents a risk of fire and malfunction: short circuits in life-saving medical equipment start fires, the equipment's malfunction puts patients' lives at risk and the fire destroys expensive investments.

Fire protection: The extinguishing system with Preaction sprinklers offers double protection against damage. Their structure combines two separately arranged sprinklers. Only when both open does the extinguishing process start. Rooms with highly valuable facilities, e.g. sensitive high-tech equipment, can therefore be protected against the discharge of water and other damage.

5) **IT areas.**

These are now full of computers and servers for saving important data for the administration and treatment of patients, and are especially at risk if there is a fire.

Risks: Faulty or overloaded electronic components can easily cause a smoldering fire or open-flame fire.

Fire protection: The MX 1230 fire extinguishing system can be adapted to each individual area; nozzle holes and container filing quantities are the result of object specific design calculations and the hallmark of a system which has been optimized down to the smallest detail. Because of the charging pressure of up to 50 bar, multi-zone systems and longer pipes can be installed. No separate room is required to supply the extinguishing agent; this can take place in the protected area itself. The extinguishing agent, NovecTM 1230, is colorless and virtually odorless, and gaseous at room temperature. Its molecules are composed of carbon, fluorine and oxygen. NovecTM 1230 deprives the flame of heat, thereby interrupting the combustion reaction.

6) **MR Rooms.**

Automatic Sprinkler Selection for Magnetic Resonance (MR) System.

The design of automatic sprinkler systems has always been a technically challenging and demanding process. Advances in computer technology, construction processes and modern sprinkler innovations have added significantly to the considerations that must be taken into account during the sprinkler system design and installation. This is particularly true in healthcare environments where Magnetic Resonance (MR) system rooms are being constructed. The increased use of MR scanners in hospitals and outpatient clinics adds another level of consideration into the sprinkler systems design that is not covered in NFPA 13 Standard for the Installation of Sprinkler Systems. In addition to the performance and design of the sprinkler system, the fire protection designer may also be required by the project specification to identify and provide sprinkler system components and materials that will not present a potential safety hazard for the occupants of the MR area or have a negative impact on the performance of the MR system [38].

Fire protection: The MX 1230 fire extinguishing system can be adapted to each individual area; nozzle holes and container filing quantities are the result of object specific design calculations and the hallmark of a system which has been optimized down to the smallest Or FM 200 with non-Ferrous Metals [39].

4.6 Fire Fighting System design

4.6.1 Project Data

a) Sprinkler System Type: Wet Pipe Sprinkler System.

b) Description Of Hazard: Ordinary hazard 1.

c) Building Type: Hospital.

From the following Table 4.1, the maximum protection area and maximum spacing between sprinklers.

Table 4. 1: Ordinary hazard 1

Construction Type	System Type	Protection Area		Maximum Spacing	
		ft^2	m^2	ft	m
All	All	130	12.1	15	4.6

Maximum Protection Area Per Sprinkler: 12.1 m^2.
Maximum Spacing Between Sprinklers: 4.6 m.

4.6.2 Sprinklers Destruction Configuration.

a) Spacing between sprinklers along the branch:3m.

b) Spacing between branches: 4m.

c) No. of sprinklers in operation area

$$\text{Total Sprk to Calculate} = \frac{AD}{AS} \qquad (4.1)$$

Where:

A_D: The desgin area .
A_S: Protection area of one sprinklers.

No. of sprinklers in operation area =139/12.1 =11.6 (say = 12 sprinkler).

Actual protection area per sprinkler = 4 x 3 = 12 m^2.

4.6.3 Design Area

It depends on occupancy hazard

1) From chart Figure 4.2 the minimum design area for light hazard =1500ft^2 that equal 140 m^2 that's give (0.15 GPM/ft^2) design density
2) Select the further area from pumps which must be rectangular as possible
3) Length of design area = 1.2 $\sqrt{AD}$ = 1.2 * $\sqrt{140}$ = 14 .2 m (4.2)
4) Width of design area = 140/14.2 = 9.86 m
5) No. of sprinklers in design area = 12 sprinklers.

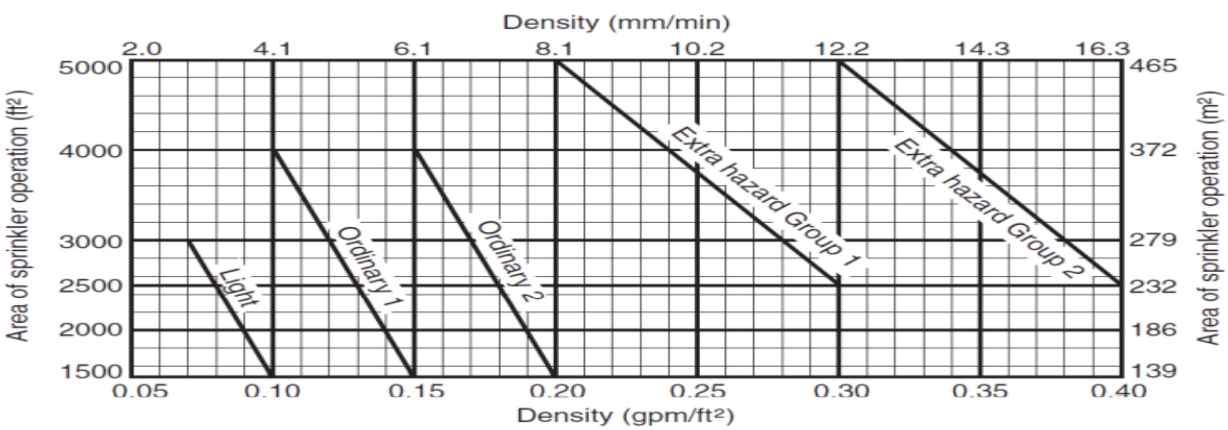

Figure 4. 2: Density and The Design Area

4.6.3 Sizing of Pipes

To determine the size of system pipes according to next schedule Table 4.2.

Table 4. 2: Wet steel Schedule for Ordinary hazard 1

Steel		Copper	
1 in.	2 sprinklers	1 in.	2 sprinklers
1¼ in.	3 sprinklers	1¼ in.	3 sprinklers
1½ in.	5 sprinklers	1½ in.	5 sprinklers
2 in.	10 sprinklers	2 in.	12 sprinklers
2½ in..	20 sprinklers	2½ in.	25 sprinklers
3 in.	40 sprinklers	3 in.	45 sprinklers
3½ in.	65 sprinklers	3½ in.	75 sprinklers
4 in.	100 sprinklers	4 in.	115 sprinklers
5 in.	160 sprinklers	5 in.	180 sprinklers
6 in.	275 sprinklers	6 in.	300 sprinklers
8 in.	See Section 8.2	8 in.	See Section 8.2

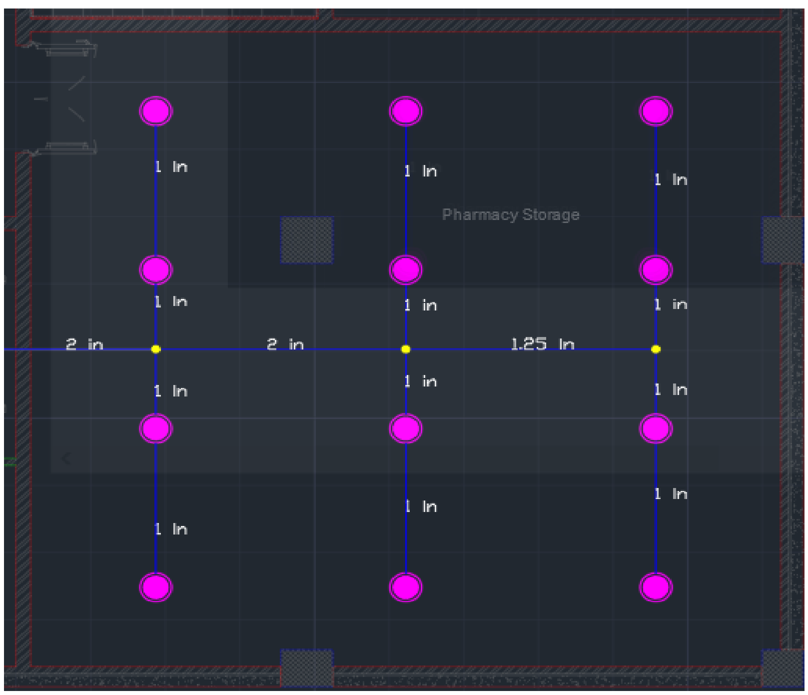

Figure 4. 3: Pipe Sizing in the design area

4.6.3 Hydraulic Calculation

Equations used in calculations:

4.6.3.1 Friction Loss Formula

Pipe friction losses shall be determined on the basis of the Hazen Williams formula as follows.

$$P = \frac{4.52\ Q^{1.85}}{C^{1.85}\ d^{4.87}} \qquad (4.2)$$

Where:

p = Frictional resistance in psi per foot of pipe.

Q = Flow in GPM.

C = Friction loss coefficient =120.

d = Actual internal diameter of pipe in inches.

Pipe or Tube	*C Value**
Unlined cast or ductile iron	100
Black steel (dry systems including preaction)	100
Black steel (wet systems including deluge)	120
Galvanized steel (dry systems including preaction)	100
Galvanized steel (wet systems including deluge)	120
Plastic (listed) all	150
Cement-lined cast- or ductile iron	140
Copper tube, brass or stainless steel	150
Asbestos cement	140
Concrete	140

Table 4. 3: Hazen-Williams C Value.

4.6.3.2 Sprinkler hydraulic formula

$$Qst. = K\ \sqrt{Pst}. \qquad (4.3)$$

Where:
K= Discharge coefficient.

Pst = Static Pressure.

NOMINAL ORIFICE SIZE (IN)	ORIFICE TYPE	K FACTOR	PERCENT OF NOMINAL 1/2" DISCHARGE
1/4	Small	1.3 – 1.5	25
5/16	Small	1.8 – 2.0	33.3
3/8	Small	2.6 – 2.9	50
7/16	Small	4.0 – 4.4	75
1/2	Standard	5.3 – 5.8	100
17/32	Large	7.4 – 8.2	140

Table 4. 4: Discharge coefficient

Take K = 5.65

4.6.3.3 Equivalent Pipe Lengths of Valves and Fittings:

Pipe fittings (tees, elbows, etc.) create turbulence in the water flow that causes pressure loss. These losses are not friction losses per se. However, they are calculated in terms of the equivalent friction loss of a length of pipe. NFPA 13 (27.2.3.1.1) says that losses due to certain fittings and valves should be understood in terms of Schedule 40 steel pipe based on the table below [40].

Table 4. 5: Equivalent Schedule 40 steel pipe length

	Fittings and Valves Expressed in Equivalent Feet (Meters) of Pipe														
	½ in.	*¾ in.*	*1 in.*	*1¼ in.*	*1½ in.*	*2 in.*	*2½ in.*	*3 in.*	*3½ in.*	*4 in.*	*5 in.*	*6 in.*	*8 in.*	*10 in.*	*12 in.*
Fittings and Valves	*(15 mm)*	*(20 mm)*	*(25 mm)*	*(32 mm)*	*(40 mm)*	*(50 mm)*	*(65 mm)*	*(80 mm)*	*(90 mm)*	*(100 mm)*	*(125 mm)*	*(150 mm)*	*(200 mm)*	*(250 mm)*	*(300 mm)*
45° elbow	—	1 (0.3)	1 (0.3)	1 (0.3)	2 (0.6)	2 (0.6)	3 (0.9)	3 (0.9)	3 (0.9)	4 (1.2)	5 (1.5)	7 (2.1)	9 (2.7)	11 (3.3)	13 (4)
90° standard elbow	1 (0.3)	2 (0.6)	2 (0.6)	3 (0.9)	4 (1.2)	5 (1.5)	6 (1.8)	7 (2.1)	8 (2.4)	10 (3)	12 (3.7)	14 (4.3)	18 (5.5)	22 (6.7)	27 (8.2)
90° long-turn elbow	0.5 (0.2)	1 (0.3)	2 (0.6)	2 (0.6)	2 (0.6)	3 (0.9)	4 (1.2)	5 (1.5)	5 (1.5)	6 (1.8)	8 (2.4)	9 (2.7)	13 (4)	16 (4.9)	18 (5.5)
Tee or cross (flow turned 90°)	3 (0.9)	4 (1.2)	5 (1.5)	6 (1.8)	8 (2.4)	10 (3)	12 (3.7)	15 (4.6)	17 (5.2)	20 (6.1)	25 (7.6)	30 (9.1)	35 (10.7)	50 (15.2)	60 (18.3)
Butterfly valve	—	—	—	—	—	6 (1.8)	7 (2.1)	10 (3)	—	12 (3.7)	9 (2.7)	10 (3)	12 (3.7)	19 (5.8)	21 (6.4)
Gate valve	—	—	—	—	—	1 (0.3)	1 (0.3)	1 (0.3)	1 (0.3)	2 (0.6)	2 (0.6)	3 (0.9)	4 (1.2)	5 (1.5)	6 (1.8)
Vane type flow switch			6 (1.8)	9 (2.7)	10 (3)	14 (4.3)	17 (5.2)	22 (6.7)	—	30 (9.1)	—	16 (4.9)	22 (6.7)	29 (8.8)	36 (11)
Swing check*	—	—	5 (1.5)	7 (2.1)	9 (2.7)	11 (3.3)	14 (4.3)	16 (4.9)	19 (5.8)	22 (6.7)	27 (8.2)	32 (10)	45 (14)	55 (17)	65 (20)

4.6.3.4 Manual Sample Calculations

Determine the amount of water on farther sprinkler head using the flowing formula:

$$Qst. = A_s \text{ x } D_d \quad (4.4)$$

Where:

$Qst.$: minimum flow required.

A: area of coverage.

D_d: required density.

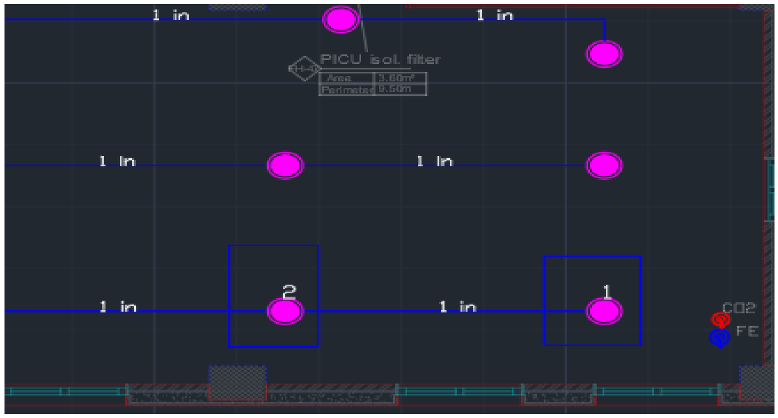

Figure 4. 4: furthest sprinkler

Flow and pressure calculations at the furthest sprinkler:

1) Flow on farther sprinkler.

$Qst.$ = A_s x D_d = 139 ft^2 x 0.15 GPM/ft^2
$Qst.$ = 20.85 GPM.

2) Pressure on farther sprinkler.

Note: the pressure calculated must not be less than 7 psi and it's the minimum pressure.

$$Pst. = \frac{Qst.^2}{K^2} \quad (4.5)$$

Pst = $(20.85/ 5.65)^2$

Pst = 13.6 psi.

3) From sprinkler (1) to (2):

$P_2 = P_1 + P_{drop}$

$P_{drop} = P_F$ x L_{equ}

$$P_F\ (1\text{-}2) = \frac{4.52\ x\ (20)^{1.85}}{(120)^{1.85}\ x\ (1)^{4.87}}$$

P_F (1-2) = 0.2 psi/ft .
$P_{drop} = P_F$ x L_{equ}
There are 1ft pipe , elbow 90 1", 52 and pipe with 3m length.

L_{equ} = 4.26x3.281 + 1 + 2 = 16.97 ft.

P_{drop} = 0.16 x 16.97 = 2.71 psi.

P_2 = 13.6 +2.71= 16.3 psi

$Q_2 = K\sqrt{P2} = 21.88$ GPM.

$Q_3 = Q2 + Q1 = 42.73$ GPM.

4.6.3.5 Sample Calculations Using Program Elite Fire

1) The first tab is the general tab.

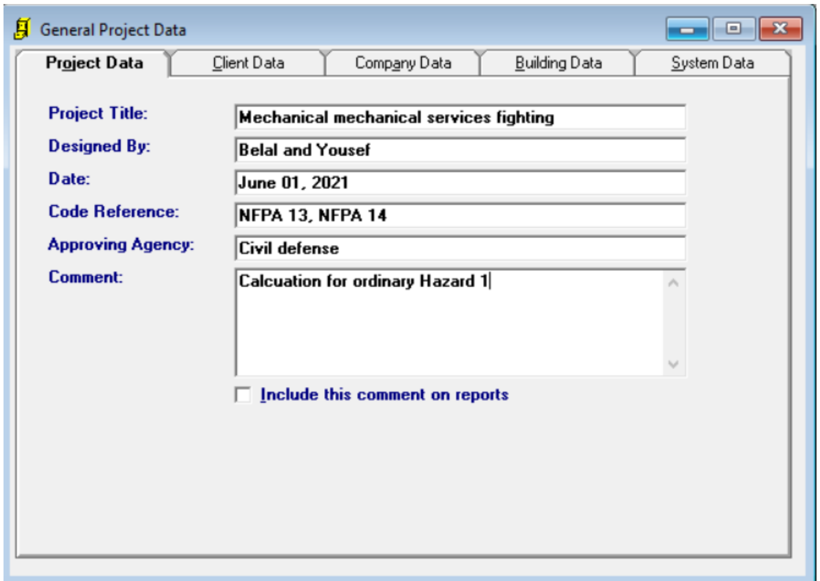

Figure 4. 5: General Tab

2) The second tab is the system data tab.

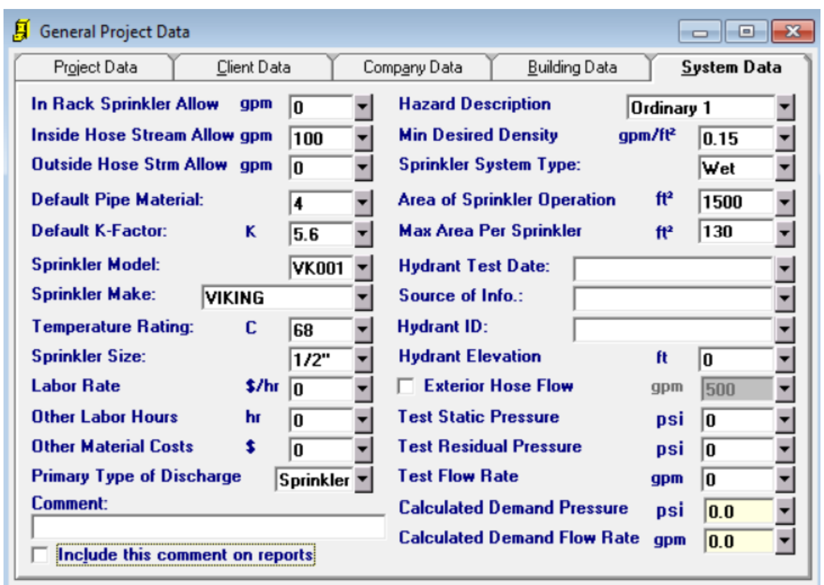

Figure 4. 6: System Data Tab

3) This tab is for system pipe data.

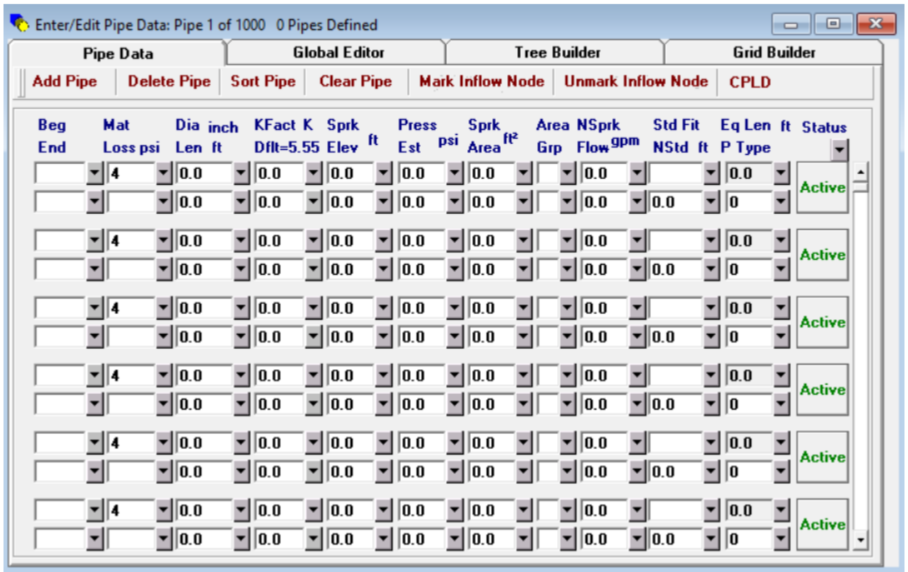

Figure 4. 7: System Pipe Data

4) This is the system pipe data entry:

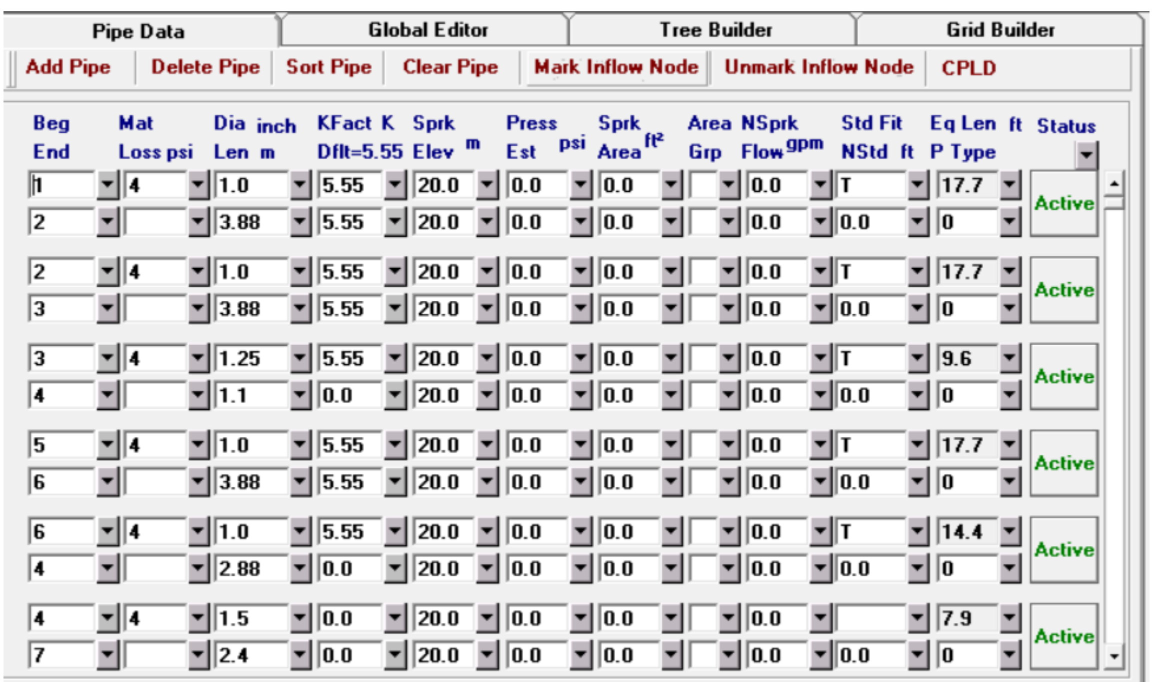

Figure 4. 8: Data Pipe (a)

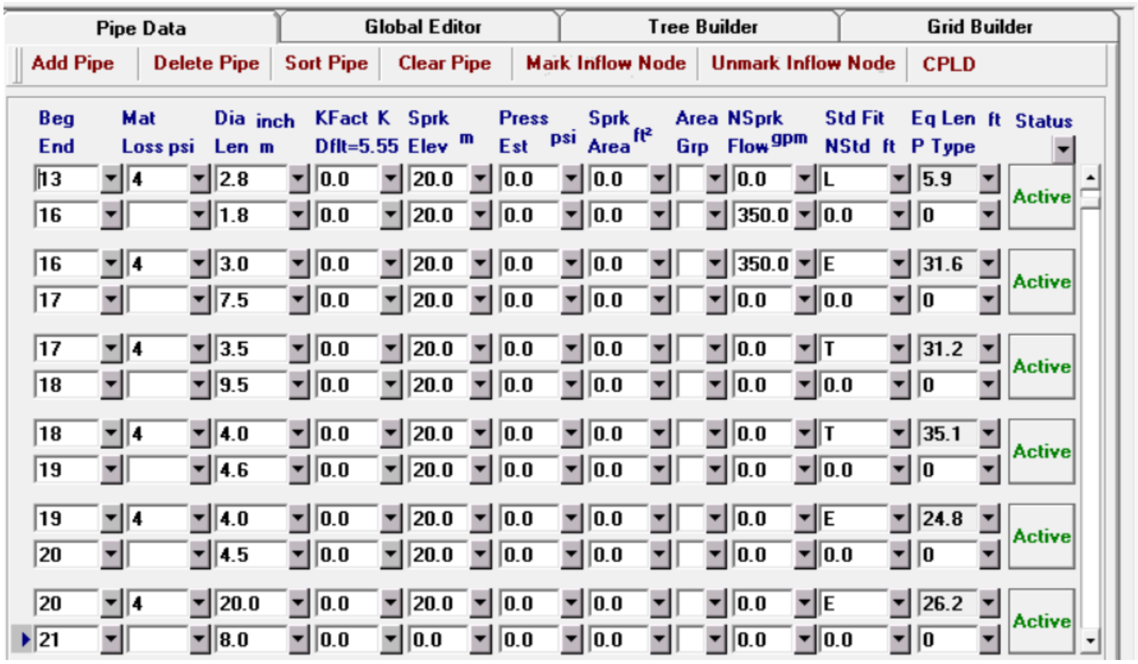

Figure 4. 9: Data Pipe (b)

5) This is the calculation tab:

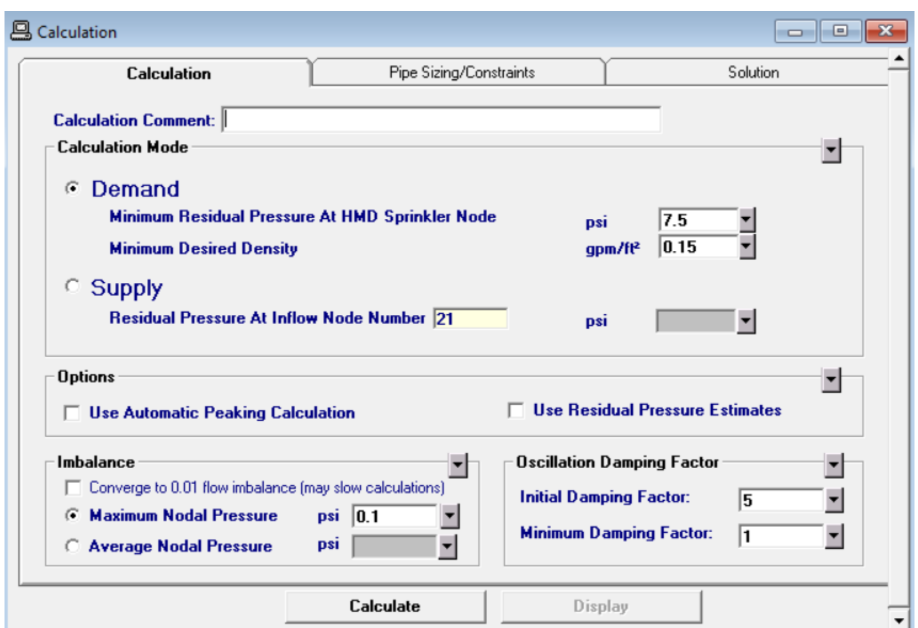

Figure 4. 10: Calcualtion

6) This tab shows the results:

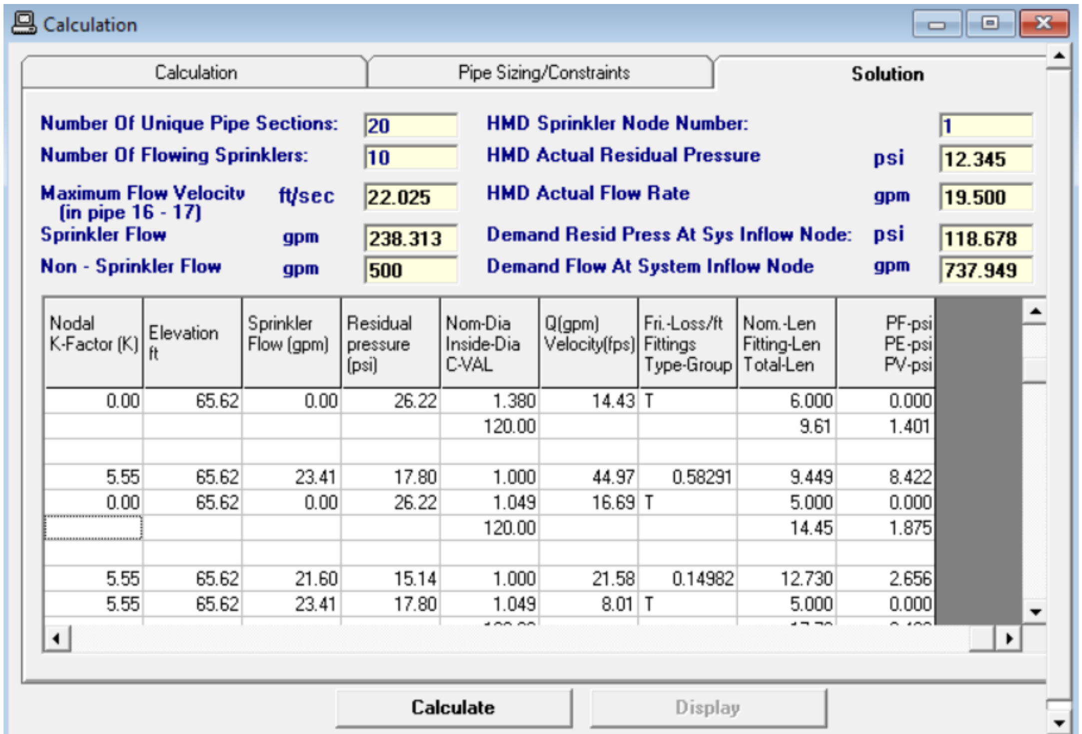

Figure 4. 11: Results

7) Report

General Project Data Report

General Data

Project Title:		Project File Name:	Untitled.hid
Designed By:		Date:	June 02, 2021
Code Reference:		Approving Agency:	
Client Name:		Phone:	
Address:		City, State Zip Code:	
Company Name:		Representative:	
Company Address:		City And State:	
Phone:			
Building Name:		Building Owner:	
Contact at Building:		Phone at Building:	

Project Data

Description Of Hazard:			Sprinkler System Type:		
Design Area Of Water Application:	1500	ft²	Maximum Area Per Sprinkler:	130	ft²
Default Sprinkler K-Factor:	5.56	K	Default Pipe Material:	SCHED 40 WET STEEL	
Inside Hose Stream Allowance:	100.00	gpm	Outside Hose Stream Allowance:	0.00	gpm
In Rack Sprinkler Allowance:	0.00	gpm			

Sprinkler Specifications

Make:	VIKING	Model:	VK001	
Size:		Temperature Rating:	154	F

Water Supply Test Data

Source Of Information:					
Test Hydrant ID:			Date Of Test:		
Hydrant Elevation:	0	ft	Static Pressure:	0.00	psi
Test Flow Rate:	0.00	gpm	Test Residual Pressure:	0.00	psi
Calculated System Flow Rate:	737.95	gpm	Calculated Inflow Residual Pressure:	118.68	psi
Available Inflow Residual Pressure:	0	psi			

Calculation Project Data

Calculation Mode:	Demand				
HMD Minimum Residual Pressure:	7.50	psi	Minimum Desired Flow Density:	0.15	gpm/ft²
Maximum Water Velocity:	30.00	ft/s	Maximum Frictional Loss / 100 feet:	0.00	psi
Number Of Active Nodes:	21				
Number Of Active Pipes:	20		Number Of Inactive Pipes:	0	
Number Of Active Sprinklers:	10		Number Of Inactive Sprinklers:	0	

Figure 4. 12: Report

4.7 Pump Room

4.7.1 Component and equipment used According to the drawing (Mechanical Room – Basement Floor)

Part 1: Pumps

1) Jockey pump
2) Diesel pump
3) Electrical pump

Part 2: Valves section line:

1) OS&Y (gate valve).
2) Flexible connection.
3) Reduce.

Part 3: Valves discharge Line:

1) OS&Y (gate valve).
2) Flexible connection.
3) Pressure gauge.
4) Check valve

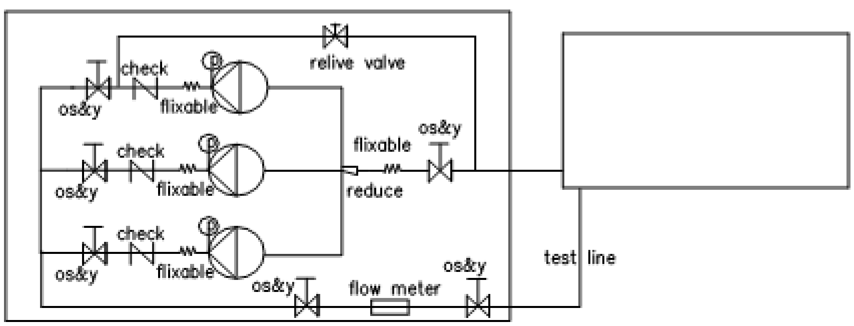

Figure 4. 13: Pump Room

4.7.2 Pump selection

A fire pump is a part of a fire sprinkler system's water supply and powered by electric, diesel or steam. The pump intake is either connected to the public underground water supply piping, or a static water source (e.g., tank, reservoir, lake). The pump provides water flow at a higher pressure to the sprinkler system risers and hose standpipes. Operation: Fire pumps may be powered either by an electric motor or a diesel engine, or, occasionally a steam turbine. If the local building code requires power independent of the local electric power grid, a pump using an electric motor may utilize, when connected via a listed transfer switch, the installation of an emergency generator.

NFPA 20 puts some conditions on fire pump selection and they should take into account at any selection of the pumps [41]:

1) The pump must verify required flow and the desired head.
2) when the flow increase to 150% the head must not be less than 65%.
3) The shut of head ranges from 101% to 140%.

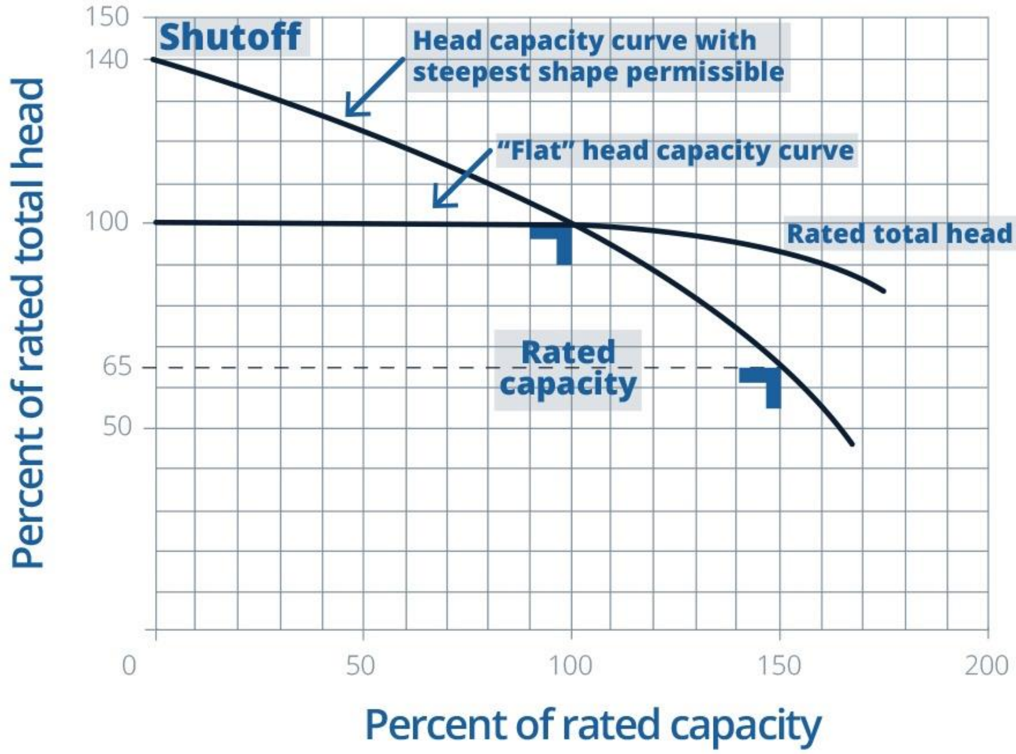

Figure 4. 14: Firefighting characteristic curve

The Data of the pump.

1) Q = 738 GPM.
2) P = 119 psi.

The Desired Point of the Pump by following the Code NFPA20

1) Q = 738 x 1.5
   Q = 1107 GPM
2) P = 119 x 0.65
   P = 77.35 psi

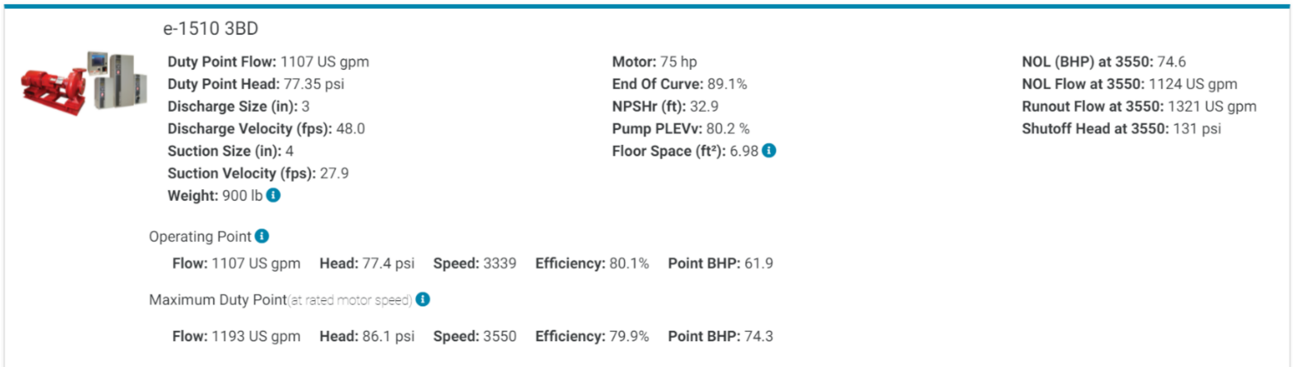

Figure 4. 15: Data of Selection Pump

Selection of The Pump Type : e-1510 3BD [42].

4.7.3 Sizing of Valves

Schedule of NFPA

Table 4.27(a) Summary of Centrifugal Fire Pump Data (U.S. Customary)

	Minimum Pipe Sizes (Nominal) (in.)						
Pump Rating (gpm)	Suction[a,b,c]	Discharge[a]	Relief Valve	Relief Valve Discharge	Meter Device	Number and Size of Hose Valves	Hose Header Supply
25	1	1	¾	1	1¼	1 — 1½	1
50	1½	1¼	1¼	1½	2	1 — 1½	1½
100	2	2	1½	2	2½	1 — 2½	2½
150	2½	2½	2	2½	3	1 — 2½	2½
200	3	3	2	2½	3	1 — 2½	2½
250	3½	3	2	2½	3½	1 — 2½	3
300	4	4	2½	3½	3½	1 — 2½	3
400	4	4	3	5	4	2 — 2½	4
450	5	5	3	5	4	2 — 2½	4
500	5	5	3	5	5	2 — 2½	4
750	6	6	4	6	5	3 — 2½	6
1000	8	6	4	8	6	4 — 2½	6
1250	8	8	6	8	6	6 — 2½	8
1500	8	8	6	8	8	6 — 2½	8
2000	10	10	6	10	8	6 — 2½	8
2500	10	10	6	10	8	8 — 2½	10
3000	12	12	8	12	8	12 — 2½	10
3500	12	12	8	12	10	12 — 2½	12
4000	14	12	8	14	10	16 — 2½	12
4500	16	14	8	14	10	16 — 2½	12
5000	16	14	8	14	10	20 — 2½	12

Figure 4. 16: Sizing of Valve

1) Suction =4 in.
2) Discharge =3.5 in.
3) Relief valve = 3.5 in.
4) Relief valve discharge = 3.5 in.

4.7.4 Calculation of The Tank Capacity

Q=738 GPM.
Time = 30 min.
Tank volume=Q x Time. (4.6)
Tank Capacity =738 x 30=22140 Gallon.
Tank Volume = 84 m^2.

4.8 Selections of Fire Extinguisher

1) Fire extinguisher FE-36

MODEL	4KG	6KG	8KG
Capacity	4KG	6KG	8KG
Extinguishing Agent	Clean Agent FE 36		
Propellant	Clean Agent FE 36		
Operation Method	Stored Pressure		
Test Standard	EN 3		
Body Diameter	161 MM	161 MM	175 MM
Total Height	510 MM	510 MM	605 MM
Total Weight	7.32 KG	9.32 KG	12 KG
Operating Temperature	-20°C to 60°C		
Discharge Time	20s	32s	32s
Range	3M	5M	5M
Working Pressure	6 Bar	9 Bar	9 Bar
Fire Rating	5A 21B	13A 34B	13A 55B
PART NO	CONTACT US		

Figure 4. 17: FE-36

2) Fire extinguisher CO_2.

CARBON DIOXIDE (CO_2) PORTABLE TYPE

Specifications	2 kg	3 kg	4.5 kg	4.5 kg (Aluminium)
Fire Rating	8B	13B	21B	34B
Working Temp.	-30°C to +55°C			
Burst Pressure	337.5 bar min., 350 bar (actual) approx			
Cylinder Testing Pressure	250 bar			
Service Pressure	50 kgf/cm²			
Min. Effective Discharge Time	8 sec.			
Discharge	2 mtr. min.			
Gross Weight	9 kg approx	12.5 kg approx	17 kg approx	13 kg approx
Charge	Carbon Dioxide			

Figure 4. 18: FE-CO_2

Chapter 5

Building Management System (BMS)

5.1 Introduction

Building management system shortly known as BMS or sometimes referred as building automation system or BAS is a computer-based control system that is installed in commercial and industrial buildings to control and monitor the building's mechanical and electrical equipment such as lighting, power systems, HVAC, fire systems, and security systems.

BMS systems are "Intelligent" microprocessor-based controller networks installed to monitor and control a buildings technical systems and services such as air conditioning, ventilation, lighting and hydraulics. More specifically they link the functionality of individual pieces of building equipment so that they operate as one complete integrated system. Now installed in every major building or facility with the availability of direct integration into all other building services such as security, access control, CCTV, fire, Lifts and other life and safety systems. Current generation BMS systems are now based on open communications protocols and are WEB enabled allowing integration of systems from multiple system vendors and access from anywhere in the world.

Buildings represent over 40% of the total energy consumption on the planet. Systems linked to BMS represent 45% of a building's energy usage; if lighting is included, this number approaches to 70%.

5.2 Disciplines of BMS

Most older buildings must be retrofitted to incorporate building management systems. Today, however, it's rare for a new building to be built without an integrated BMS, where all the capabilities are incorporated into the building from day one, and the components are controlled by a master control system.

The primary function of building management systems is most often to control the HVAC, heating, and ventilation systems, but there are other functions as well. The main components of a building management system and their basic functionalities are as follows:

1) Boiler controls—maintain a constant temperature and switch boilers on/off at certain times.
2) HVAC—maintain a specified air state with regard to temperature and humidity; control fans and dampers; control air handling units and fan coil units.
3) Lighting control—turn lights on/off according to a specified schedule.
4) Electric power control—control and monitor core electrical and mechanical equipment.
5) Heating—schedule the system on and off; maintain a set temperature point.
6) Ventilation—adjust based on occupancy controls.
7) Security and observation—access control; surveillance and intrusion detection.

8) Fire alarm system—smoke control system; active alarm locations.
9) Elevators—elevator video display; status system.
10) Plumbing and water monitoring—detect hydraulic flows; open/close valves automatically; monitor/observe temperature deviations.

Many building management systems have additional capabilities and features; some can even be designed specifically for the facility itself. Typically, these types of systems use a combination of hardware and software to monitor and manage, including a central server or servers, monitoring stations (for systems administrators), and remote sensors, as well as software that allows you to interact with the system.

5.3 Main Components of BMS

1) Hardware.

a) DDC-Direct digital controller.
b) Sensors.
c) Actuators.
d) Cables to connect sensors, actuators to DDC.
e) HMI display-Human machine interface.
f) PC Workstation.
g) Server to save the extensive database.

2) Software.

a) Programming or configuration tools.
b) Graphics or User interface.

3) Networking Protocols.

a) TCP/IP– Transfer control protocols/Internet Protocol.
b) b) BACnet– Building automation controller network-ASHRAE.
c) Modbus.
d) LonWorks.
e) CANbus.

5.3 Layer of BMS

5.3.1 Centralized WorkStation Computer.

A smart building can be seen as an example of a distributed control system, where dozens of distributed computations, sensing and actuation modules [43] are exploited to increase the safety, the comfort and the efficiency of the construction itself. Figure 4.1 represents the standard architecture of a smart building: the system is composed of different sensors and actuators, coordinated by a central Building Management System (BMS).

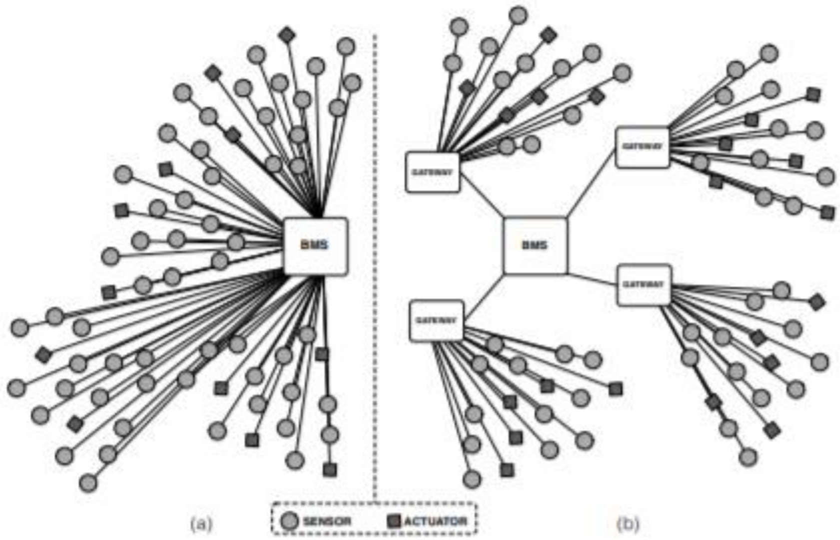

Figure 5. 1: Centralized and distributed BMS architectures.

The BMS is responsible for the gathering of the data from the sensors, for the decision-making process (where the actions to be executed on the building are computed) and for the delivery of these actions to the actuators. In addition, the BMS is also responsible for the APIs used to expose information that could be relevant for the building's users [44]. A network of sensors is generally used to distributive collect useful data (such as rooms temperature and humidity, user's location, etc.) the sensor network is indeed usually composed of occupancy, temperature, luminosity, humidity weather sensors and appliances monitors [45]. Finally, an actuators network is available to make it possible to apply the actions coming out from the decision-making phase[46]. Typical actuators are the HVAC systems, lights, windows and smart appliances (which are defined as the appliances that can be controlled remotely).

5.3.2 DDC (Direct Digital Control) Controllers

DDC systems consist of a central computer workstation that monitors HVAC, lighting, or other system functions via a series of sensors. These sensors transmit data back to the workstation, where sophisticated software monitors performance and makes operational adjustments as necessary.

From the central workstation, staff can oversee HVAC system performance in real-time and perform manual program changes when required. DDC systems typically allow for a great deal of flexibility while their primary purpose is building automation and systems integration, they also enable staff to respond to unique conditions, troubleshoot errors, and take care of basic maintenance from a single point that provides system-wide visibility.

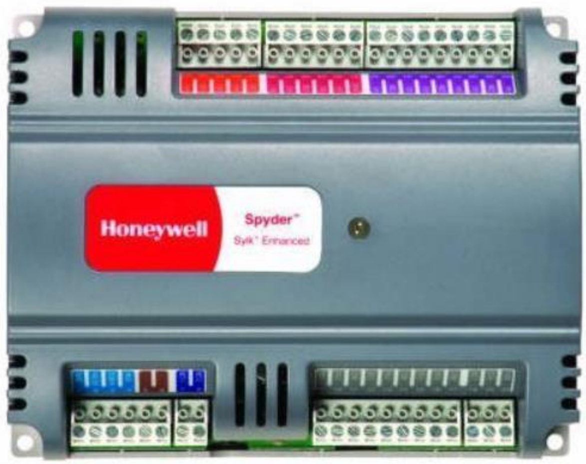

Figure 5. 2: DDC Controllers

5.3.3 Filed Devices

5.3.3.1 Sensors

Sensors and Switches Considers Always as Input devices in BMS.

Sensors Classification:

1) Passive Sensor
   passive sensor does not need any external power for their operation.
   It produces a change in passive electrical quantity such as: resistance, capacitance, or inductance in response to environmental variable.
   Most of passive sensors are direct sensors. They are cheap and easy to install.

2) Active Sensor
   The active sensors need external power for their operation, which is called an excitation signal. That signal is modified by the sensor to produce the o/p signal.

5.3.3.1.1 Types of Control Signals in Sensors

a) Digital Signal Input.

ON/OFF, High/Low, True/False, Alarm/Normal

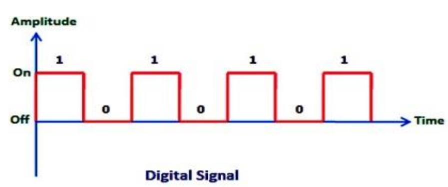

Figure 5. 3: Digital Signal

Types of Digital Sensors:

1) Duct Smoker Detector.

2) Air/Water Pressure Switch.
3) Diff Pressure Switch.
4) Air Flow Switch.

b) Analog Signal Input.

Voltage signal 0-10V, Current signal 0 or 4-20mA

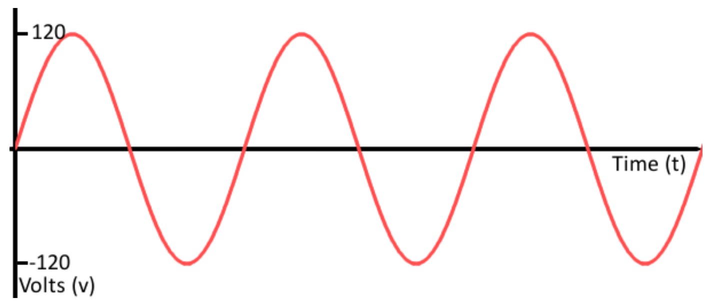

Figure 5. 4: Analog Signal

Types of Analog Sensors.

1) Temperature Sensor.
2) Pressure Sensor.
3) Diff Pressure.
4) Gas Detector.

5.3.3.2 Actuators

Actuators Considers Always as Output devices in BMS. An actuator is a device that converts electric or pneumatic energy into a rotary or linear action. Electric control actuators are two-position, floating, or proportional. They are Electro-mechanical or Electro-hydraulic. Electric actuators are bidirectional, which means they rotate one way to open the valve or damper, and the other way to close the valve or damper.

5.3.3.2.1 Control Types in Actuators

1) On/Off or two position control (Digital Output ON/OFF)
   A simple two-position control system in which the device being controlled is either full on or full off with no intermediate operating positions.

   In two position control, the response curve is always cycling between two limits "ON" & "OFF". The difference between these limits (temperatures for ex) at which controller turns on & off is called the differential or dead band.

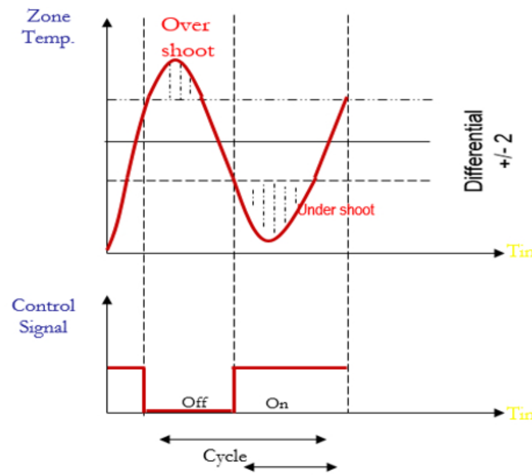

Figure 5. 5: On/Off or two position control

2) Floating control or Three position control.

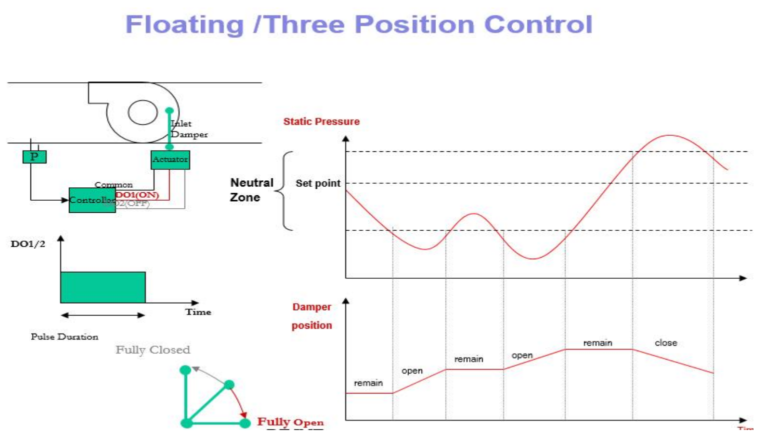

Figure 5. 6: Floating control

3) Modulating control.

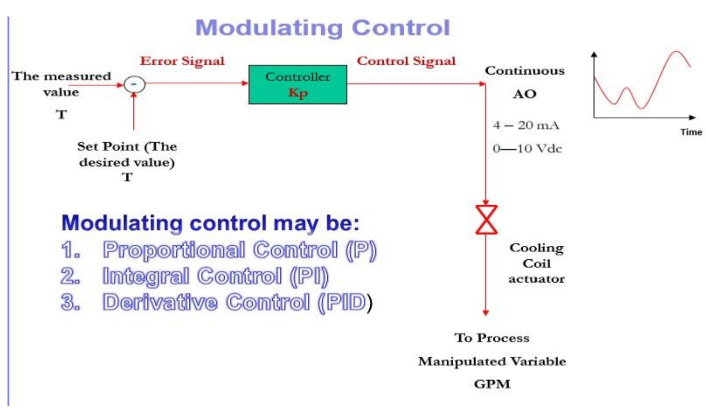

Figure 5. 7: Modulating Control.

Types of Actuators:

1) Modulating Valves.
2) Modulating Dampers.
3) Variable Speed Drive.

5.4 BMS Systems Design

5.4.1 BMS Design for HVAC System

5.4.1.1 AHU System

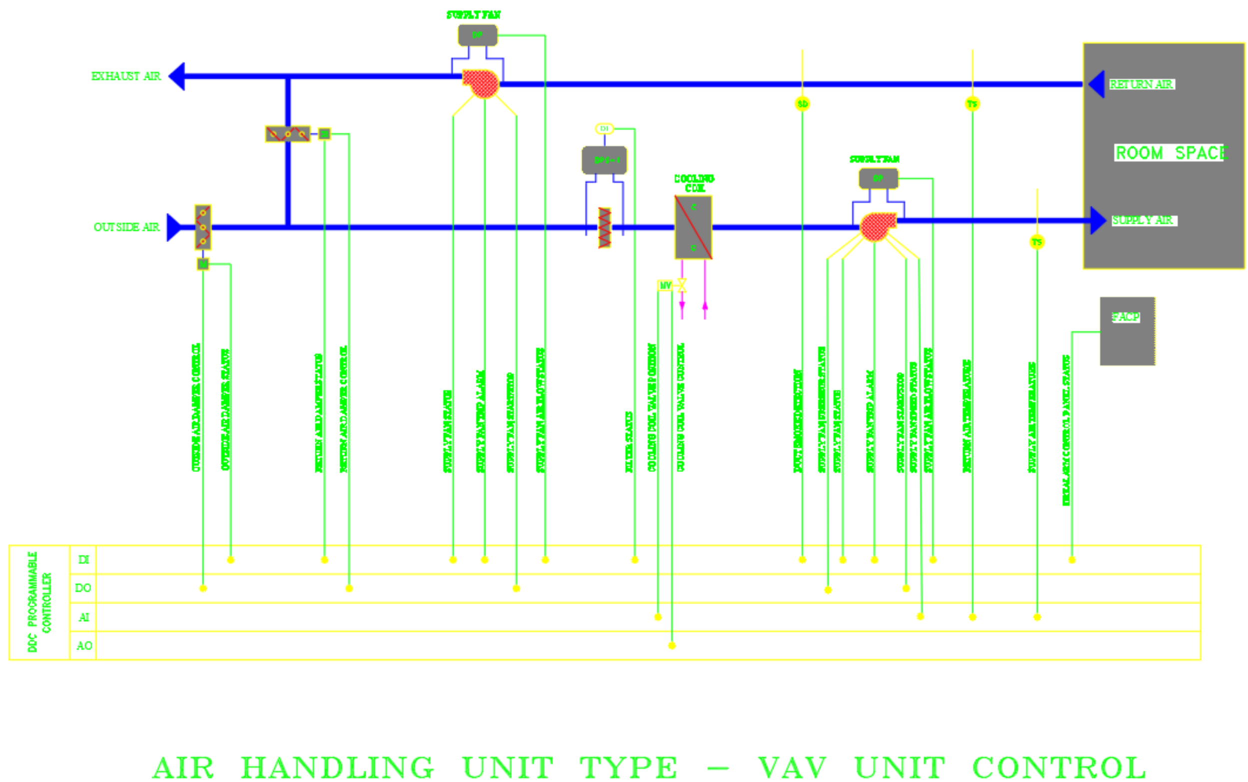

Figure 5. 8: BMS Design for AHU System.

The Sequence of Operation:

Air handling unit daytime will start according to an adjustable time channel based on a 7-day program, with the possibility of exception programs for holidays.

Day time program will open & close the fresh, the mixing & exhaust air dampers. In case of satisfying certain adjustable air quality inside the room, these dampers will modulate to open or close according to energy recovery sequence which is controlled by both of outside, & room air temperature sensors, while the fresh air damper will modulate in a way that satisfies the required air quality inside the room as a 1st priority, hence follows the energy recovery sequence.

Day time program will start & stop both of supply & return fans, and one or more alarms will be issued after a dedicated time delay [- if any of or both of the two fans fail to return a status during daytime, And/or if any of or both of the two fans trip for any reason during the daytime, And/or if there is no air flow in one of or both of two fans during day time, which is indicated by a differential pressure switch for each fan]. The supply fan no flow will cause to interlock the whole controlled AHU.

Heating valve will not operate unless the system is in heating mode. Heating coil valve actuator will act only if there is supply air flow. Return temperature sensor will control the valve output modulation according to adjustable return temperature set point.

Cooling valve will not operate unless the system is in cooling mode. Cooling coil valve actuator will act only if there is supply air flow. Return temperature sensor will control the valve output modulation according to adjustable return temperature set point.

Bag Filter flow is indicated by differential pressure switch mounted across the filter section. Dirty filter alarm will be issued via the differential pressure switch.

Upon the arrival of a fire signal the supply fan will be forced to stop, while the return fan will be forced to start, & the exhaust air damper will forced to open to its maximum.

5.4.1.2 Chilled Water System

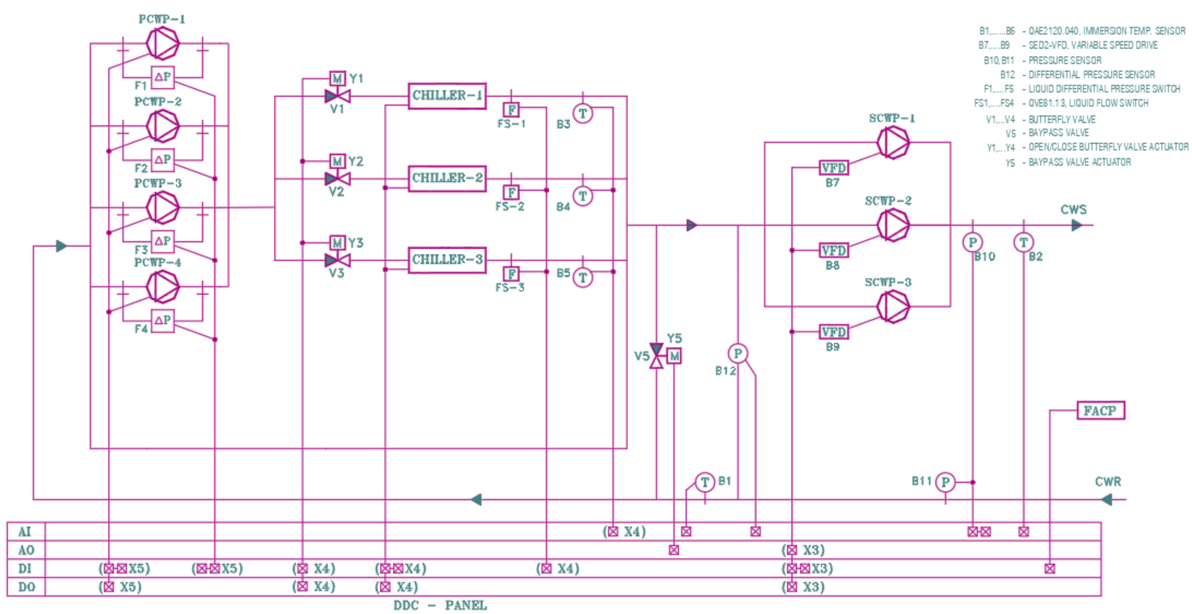

Figure 5. 9: BMS Design for Chilled Water System.

The Sequence of Operation:

Daytime program will enable the pumps & chillers sequence, the system shall run a least one primary pump with its corresponding valve & one butterfly valve.

Return load chilled water temperature will control the number of required chillers to cool the load in a sufficient way, chiller will not start unless (chilled water primary pump status is on, the corresponding Chiller butterfly valve open & the corresponding Chiller flow switch detects flow.

The number of butterfly valves will be determined according to no. of chillers required & by (lead/lag sequence) at least 1 active if return temperature less than its setpoint, the valve won't be opened if failure occurred in corresponding chiller.

If the load conditions require only one active chiller, the active chiller will be determined depending on a time base sequence (lead/lag sequence), i.e. the chiller that has the less operating hours is the chiller that has the highest priority to be commanded to start.

The system consists of 3 primary chilled water pumps (2 Duty & 1 standby) at least one pump with its corresponding valve operates with time & the no of pumps equal to the no. of chillers required, Lead/lag sequence will decide which pump will start, the active pumps will be determined depending on lead/lag sequence, i.e., the pump which has greatest operating hours is the pump that not to be commanded.

Load flow (Differential pressure sensor) will control the number of required secondary pumps (2 Duty & 1 standby), the active pumps will be determined depending on (lead/lag) sequence, i.e., the pump which has greatest operating hours is the pump that not to be commanded.

Load flow (Differential pressure sensor) will control secondary pumps speed (VSD) according to adjustable diff. pressure set point to maintain a fixed diff. pressure on the system (The speed of sec. pump will decrease if Diff. pressure greater than pressure set point).

Any failed/failed to start pump must be directly disabled and the next pump as per lead/lag sequence must start to replace the failed one for each pump in the chilled water system, Trip alarm will be issued whenever pump trips.

For each pump in the chilled water system, Alarm will be issued whenever pump status indicates off, while the pump is commanded to start.

For each chiller, trip alarm will be issued whenever chiller trips.

For each chiller, Alarm will be issued whenever chiller’s status indicates off, while the chiller is commanded to start.

For each chiller's flow switch detects alarm whenever flow switch's status indicates no flow, while corresponding chiller’s butterfly valve status indicates on.

Chiller's outlets chilled water temperatures are monitored.

If expansion tank pressure is greater than its high limit, alarm will be issued.

5.4.1.3 Vav Box

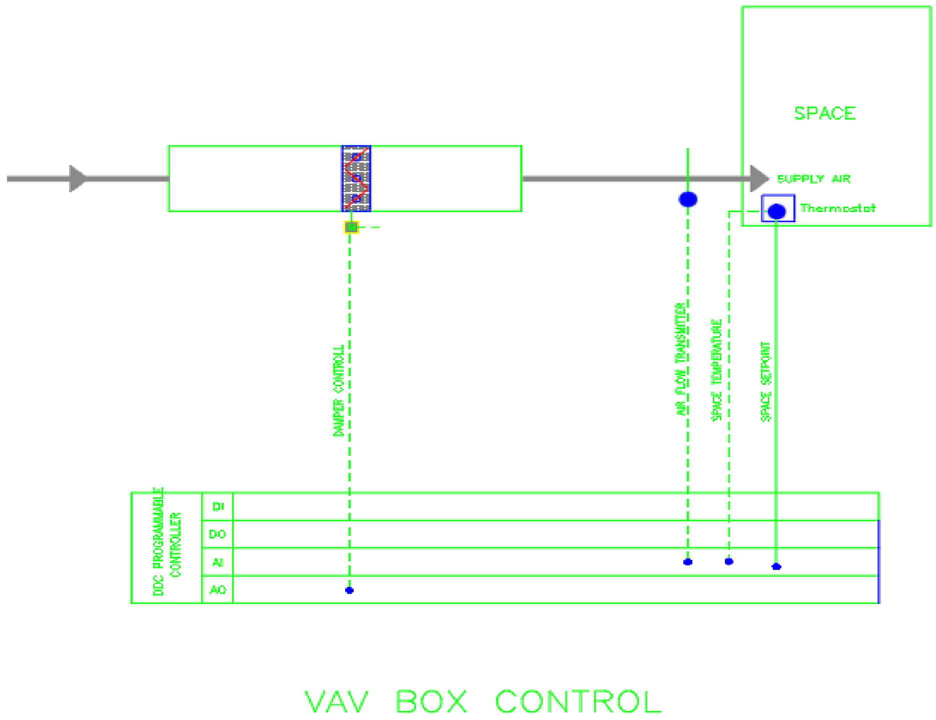

Figure 5. 10: BMS Vav Box.

The Sequence of Operation:

Occupied mode: when the room temperature is inside the setpoint bias, the vav controller sets the box damper at minimum cfm and fully closes the reheat valve. on a rise in room temperature above the setpoint, the vav controller modulates the box damper to increase the cfm. the reheat valve remains fully closed. on a drop in room temperature below the setpoint, the vav controller modulates the reheat valve and controls the damper at minimum cfm.

Warmup mode: when the air handling unit starts in warmup mode, all vav controllers are indexed to warmup mode: the vav controller modulates the box damper to maintain the occupied setpoint. the reheat valve is disabled (heating is provided by the air handler). at the completion of warmup mode, the individual vav controllers are indexed to either occupied or shutdown mode, depending on the status of the air handling unit.

Shutdown mode: when the air handling unit shuts down, all of the DDC box controllers are indexed to shutdown mode whereby the box dampers and reheat valves are fully closed.

5.4.1.4 Exhaust Fan

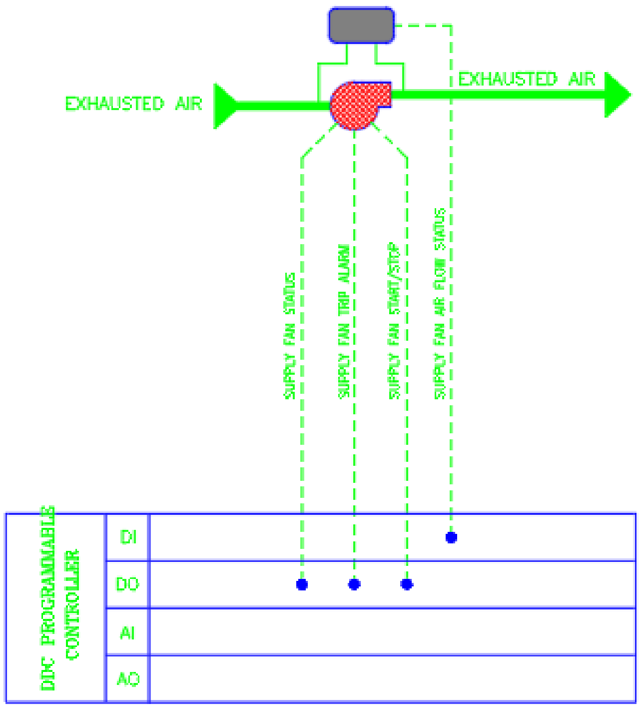

Figure 5. 11: BMS Design for Exhaust Fan.

The Sequence of Operation:

Day time program will fire a signal for the fan to start & stop. Then, trip alarm will be issued whenever fan trips. After that, the alarm will be issued whenever fan status indicates off, while the fan is commanded to start.

5.5 Electrical and Control Diagrams for the BMS

The electrical and control diagrams for the BMS systems for the lighting, HVAC and firefighting disciplines are shown in details in the plans and a simple of these diagrams is provided previously in this chapter.

5.6 Selection of Component

The Selection of Component for Filed Devices, DDC, Valves are shown in details in the plans.

5.7 BACnet Protocol

BACnet is "a data communication protocol for building automation and control networks." A data communication protocol is a set of rules governing the exchange of data over a computer network that covers everything from what kind of cable to use to how to form a particular request or command in a standard way. What makes BACnet special is that the rules relate specifically to the needs of building automation and control (BAC) equipment, i.e., they cover things like how to ask for the value of a temperature, define a fan operating schedule, or send a pump status alarm.

BACnet was developed by a committee formed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). The committee's main objective was to create a protocol that would allow building systems from different manufacturers to interoperate, that is to work together in a harmonious way. Prior to the advent of BACnet there was simply no practical way to achieve this goal.

To achieve interoperability across a wide spectrum of equipment, the BACnet specification consists of three major parts. The first part describes a method for representing any type of building automation equipment in a standard way. The second part defines messages that can be sent across a computer network to monitor and control such equipment. And the third part defines a set of acceptable LANs that can be used to convey BACnet communications. Let's look at each of these components of the BACnet spec in a bit more detail.

BACnet currently defines 35 message types, or "services," that are divided into 5 classes. For example, one class contains messages for accessing and manipulating the properties of the objects described above. A common one is the "Read Property" service request. This message causes the server machine to locate the requested property of the requested object and send its value back to the client. Other classes of services deal with alarms and events; file uploading and downloading; managing the operation of remote devices; and virtual terminal functions (accessing equipment across the network as if you were using a directly-connected terminal or laptop).

Note that the ability to read and write binary, analog, and text data; schedule control actions; send event and alarm notifications; and similar functions are required by all kinds of BAC equipment, not just HVAC gear. Nonetheless, the committee realized that these capabilities might not cover all situations and developed the standard with an eye toward accommodating future, unknown building automation and control applications. As a result, one of the real strengths of the BACnet object and services model is that it can be easily extended. If a vendor comes up with some new functionality for which communication is required, the vendor can add new properties to existing object types or create new object types that are accessed in exactly the same way as the eighteen defined in the standard. Moreover, a vendor could even dream up new services that go beyond the standard ones. Of course, proprietary features may not be interoperable without vendor cooperation.

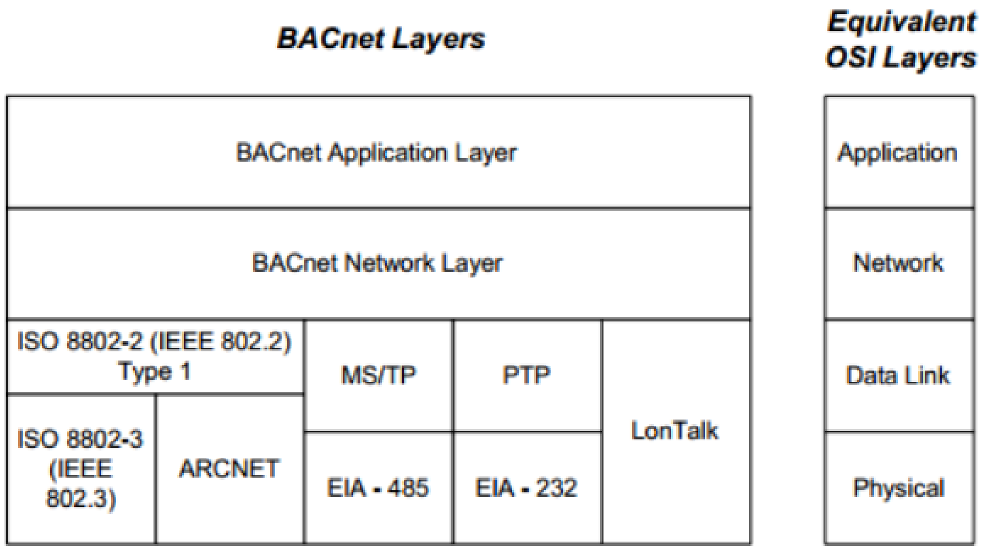

Figure 5. 12: BACnet Collapsed Architecture.

Conclusion and Future Work

This project investigates the role of Building Management System (BMS) and implantation over different systems' control and monitoring in hospitals settings and it affects the safety and the comfort of patients, caretakers, and visitors in terms of firefighting, managing medical gases systems and energy consumption. Also, the application of the BMS as the best controls and monitoring systems suitable for the HVAC and its impact on energy consumption which can be a money-solving solution for hospitals.

Due to the recent pandemic in the world, COVID-19, it is evident that tackling this issue in hospitals is more important than ever. It presented a lack of research over this topic and its relations to hospitals settings in case of emergencies such as a global pandemic and its effects on anyone that enters hospitals in terms of safety and health.

Some challenges were evident throughout this project. We have had an issue in allocating the diffusors and sprinkles. However, it is not an issue of an engineering prospect but that of timing and that it takes a long time to implement. Hence, our future plans are to create software that is able to aid in simulation and the distribution of diffusers and sprinkles using macro language on AutoCAD or Python.

We were able to achieve the design of the BMS system and apply it to the most important application in our opinions under current circumstances, which is hospitals. A HVAC (Heating, ventilation, and air conditioning) system is a very important component of a healthy, comfortable, and energy-efficient building. There are various types of HVAC installations depending on the location and size of a building. The three common types are centralized, packaged and individual or decentralized. Since HVAC systems are the largest energy consumers in a building, it is important to ensure that energy efficiency methods are in place to ensure reduction in energy consumption, costs and greenhouse gas emissions.

A Building Management System (BMS) offers greater visibility and control of energy use. A fully integrated solution can have up to 84% of a building's energy consuming devices directly under its control. The data it produces allows facilities managers to better analyze, understand, reconfigure and improve their site's energy usage and costs, by having them presented in an organized and informative way.

Since Palestine suffers from energy restrictions, the next step for this project is to open a start-up company which can work on the installation and designing of this system and increase its capabilities and apply it to hospitals and medical facilities in Palestine. Also, we are hoping to move beyond medical facilities for it to include all structures in the community- governmental and otherwise- and with this we will be able to take Palestine and our company to the next level and catch up the expanding science and technology of BMS that is used in the world.

Appendix

Appendix Outline:

A-1 Ventilation Requirement per ASHRAE Standard 170.1 2017
A-2 Cooling and Heating Loads Summary
A-3 Duct Sizing Summary
A-4 Pipe Sizing Summary
A-5 AHU’s Catalogues with the Required Accessories
A-6 Chillers Catalogues with the Required Accessories
A-7 Sensors Catalogues

Table A1: Ventilation Requirement in Hospital Spaces

Table 7.1 Design Parameters—Hospital Spaces

Function of Space	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ach	Minimum Total ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	Design Relative Humidity (k), %	Design Temperature (l), °F/°C
SURGERY AND CRITICAL CARE							
Critical and intensive care	NR	2	6	NR	No	30–60	70–75/21–24
Delivery room (Caesarean) (m), (o)	Positive	4	20	NR	No	20–60	68–75/20–24
Emergency department decontamination	Negative	2	12	Yes	No	NR	NR
Emergency department exam/treatment room (p)	NR	2	6	NR	NR	Max 60	70–75/21–24
Emergency department public waiting area	Negative	2	12	Yes (q)	NR	Max 65	70–75/21–24
Intermediate care (s)	NR	2	6	NR	NR	Max 60	70–75/21–24
Laser eye room	Positive	3	15	NR	No	20–60	70–75/21–24
Medical/anesthesia gas storage (r)	Negative	NR	8	Yes	NR	NR	NR
Newborn intensive care	Positive	2	6	NR	No	30–60	72–78/22–26
Operating room (m), (o)	Positive	4	20	NR	No	20–60	68–75/20–24
Operating/surgical cystoscopic rooms (m), (o)	Positive	4	20	NR	No	20–60	68–75/20–24
Procedure room (o), (d)	Positive	3	15	NR	No	20–60	70–75/21–24
Radiology waiting rooms	Negative	2	12	Yes (q), (w)	NR	Max 60	70–75/21–24
Recovery room	NR	2	6	NR	No	20–60	70–75/21–24
Substerile service area	NR	2	6	NR	No	NR	NR
Trauma room (crisis or shock) (c)	Positive	3	15	NR	No	20–60	70–75/21–24
Treatment room (p)	NR	2	6	NR	NR	20–60	70–75/21–24
Triage	Negative	2	12	Yes (q)	NR	Max 60	70–75/21–24
Wound intensive care (burn unit)	NR	2	6	NR	No	40–60	70–75/21–24
INPATIENT NURSING							
AII anteroom (u)	(e)	NR	10	Yes	No	NR	NR
AII room (u)	Negative	2	12	Yes	No	Max 60	70–75/21–24
Combination AII/PE anteroom	(e)	NR	10	Yes	No	NR	NR
Combination AII/PE room	Positive	2	12	Yes	No	Max 60	70-75/21-24

Note: NR = no requirement

Table 7.1 Design Parameters—Hospital Spaces *(Continued)*

Function of Space	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ach	Minimum Total ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	Design Relative Humidity (k), %	Design Temperature (l), °F/°C
Continued care nursery	N/R	2	6	N/R	No	30–60	72–78/22–26
Labor/delivery/recovery (LDR) (s)	NR	2	6	NR	NR	Max 60	70–75/21–24
Labor/delivery/recovery/postpartum (LDRP) (s)	NR	2	6	NR	NR	Max 60	70–75/21–24
Newborn nursery suite	NR	2	6	NR	No	30–60	72–78/22–26
Nourishment area or room	NR	NR	2	NR	NR	NR	NR
Patient corridor	NR	NR	2	NR	NR	NR	NR
Patient room	NR	2	4 (y)	NR	NR	Max 60	70–75/21–24
PE anteroom (t)	(e)	NR	10	NR	No	NR	NR
Protective environment room (t)	Positive	2	12	NR	No	Max 60	70–75/21–24
Toilet room	Negative	NR	10	Yes	No	NR	NR
NURSING FACILITY							
Bathing room	Negative	NR	10	Yes	No	NR	70–75/21–24
Occupational therapy	NR	2	6	NR	NR	NR	70–75/21–24
Physical therapy	Negative	2	6	NR	NR	NR	70–75/21–24
Resident gathering/activity/dining	NR	4	4	NR	NR	NR	70–75/21–24
Resident room	NR	2	2	NR	NR	NR	70–75/21–24
Resident unit corridor	NR	NR	4	NR	NR	NR	NR
RADIOLOGY							
Darkroom (g)	Negative	2	10	Yes	No	NR	NR
X-ray (diagnostic and treatment)	NR	2	6	NR	NR	Max 60	72–78/22–26
X-ray (surgery/critical care and catheterization)	Positive	3	15	NR	No	Max 60	70–75/21–24
DIAGNOSTIC AND TREATMENT							
Autopsy room	Negative	2	12	Yes	No	NR	68–75/20–24
Bronchoscopy, sputum collection, and pentamidine administration	Negative	2	12	Yes	No	NR	68–73/20–23

Note: NR = no requirement

Table 7.1 Design Parameters—Hospital Spaces *(Continued)*

Function of Space	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ach	Minimum Total ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	Design Relative Humidity (k), %	Design Temperature (l), °F/°C
Dialysis treatment area	NR	2	6	NR	NR	NR	72–78/22–26
Dialyzer reprocessing room	Negative	NR	10	Yes	No	NR	NR
ECT procedure room	NR	2	4	NR	NR	Max 60	72–78/22–26
Endoscope cleaning	Negative	2	10	Yes	No	NR	NR
Gastrointestinal endoscopy procedure room (x)	NR	2	6	NR	No	20–60	68–73/20–23
General examination room	NR	2	4	NR	NR	Max 60	70–75/21–24
Hydrotherapy	Negative	2	6	NR	NR	NR	72–80/22–27
Laboratory work area, bacteriology (f), (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory work area, biochemistry (f), (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory work area, cytology (f), (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory work area, general (f), (v)	Negative	2	6	NR	NR	NR	70–75/21–24
Laboratory work area, glasswashing (f)	Negative	2	10	Yes	NR	NR	NR
Laboratory work area, histology (f), (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory work area, media transfer (f), (v)	Positive	2	4	NR	NR	NR	70–75/21–24
Laboratory work area, microbiology (f), (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory work area, nuclear medicine (f), (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory work area, pathology (f), (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory work area, serology (f), (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory work area, sterilizing (f)	Negative	2	10	Yes	NR	NR	70–75/21–24
Medication room	NR	2	4	NR	NR	Max 60	70–75/21–24
Nonrefrigerated body-holding room (h)	Negative	NR	10	Yes	No	NR	70–75/21–24
Nuclear medicine hot lab	Negative	NR	6	Yes	No	NR	70–75/21–24
Nuclear medicine treatment room	Negative	2	6	Yes	NR	NR	70–75/21–24
Pharmacy (b)	Positive	2	4	NR	NR	NR	NR

Note: NR = no requirement

Table 7.1 Design Parameters—Hospital Spaces *(Continued)*

Function of Space	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ach	Minimum Total ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	Design Relative Humidity (k), %	Design Temperature (l), °F/°C
Physical therapy	Negative	2	6	NR	NR	Max 65	72–80/22–27
Special examination room (aa)	NR	2	6	NR	NR	Max 60	70–75/21–24
Treatment room	NR	2	6	NR	NR	Max 60	70–75/21–24
STERILIZING							
Sterilizer equipment room	Negative	NR	10	Yes	No	NR	NR
STERILE PROCESSING DEPARTMENT [z]							
Clean workroom	Positive	2	4	NR	No	Max 60	68–73/20–23
Decontamination room	Negative	2	6	Yes	No	NR	60–73/16–23
Sterile storage room	Positive	2	4	NR	NR	Max 60	Max 75/24
SERVICE							
Bathroom	Negative	NR	10	Yes	No	NR	72–78/22–26
Bedpan room	Negative	NR	10	Yes	No	NR	NR
Clean linen storage	Positive	NR	2	NR	NR	NR	72–78/22–26
Dietary storage	NR	NR	2	NR	No	NR	72–78/22–26
Food preparation center (i)	NR	2	10	NR	No	NR	72–78/22–26
Janitor's closet	Negative	NR	10	Yes	No	NR	NR
Laundry, general	Negative	2	10	Yes	No	NR	NR
Linen and trash chute room	Negative	NR	10	Yes	No	NR	NR
Soiled linen sorting and storage	Negative	NR	10	Yes	No	NR	NR
Warewashing	Negative	NR	10	Yes	No	NR	NR
SUPPORT SPACE							
Clean workroom or clean holding	Positive	2	4	NR	NR	NR	NR
Hazardous material storage	Negative	2	10	Yes	No	NR	NR
Soiled workroom or soiled holding	Negative	2	10	Yes	No	NR	NR

Note: NR = no requirement

Table A-2 Cooling and Heating Loads Summary

A-2A: Basement Thermal Loads Data

Basement Floor		
Zone 1		
Room Name	Supply Air [CFM]	Fresh Air [CFM]
B14	590	118
B15	910	182
B16	630	126
B17	350	70
B18	420	84
B19	190	38
B26	490	98
B27	540	108
B28	2150	430
B33	1740	348
B34	685	137
B35	760	152
B55	680	136
B56	230	46
Total Coil Cooling Load [TR]:		30
Total Coil Cooling Load [kW]:		105.5
Total Coil Sensible Cooling Load [kW]		80.6
Total Coil Sensible Cooling Load [MBH]		275
Total Coil Heating Load [TR]:		16.7
Total Coil Heating Load [kW]:		58.6
Total Coil Heating Load [MBH]:		200
Design Airflow [CFM]:		9322
Design Airflow [m3/s]:		4.4
Design Airflow [L/s]:		4400.0
Entering Air DB [F]		80.4
Entering Air DB [C]		26.89
Entering Air WB [F]		65.5
Entering Air WB [C]		18.6
Leaving Air DB [F]		52.8
Leaving Air DB [C]		11.6
Leaving Air WB [F]		51.6
Leaving Air WB [C]		10.9

Basement Floor		
Zone 2		
Room Name	Supply Air [CFM]	Fresh Air [CFM]
B01	740	148
B02	665	133
B04	865	173
B05	920	184
B08	1940	388
B09	310	62
B10	250	50
B12	260	52
B13	280	56
B21	707	141.4
B22	1350	270
B23	760	152
B32	300	60
B54	160	32
Total Coil Cooling Load [TR]:		25
Total Coil Cooling Load [kW]:		87.9
Total Coil Sensible Cooling Load [kW]		57.4
Total Coil Sensible Cooling Load [MBH]		196
Total Coil Heating Load [TR]:		10.7
Total Coil Heating Load [kW]:		37.5
Total Coil Heating Load [MBH]:		128
Design Airflow [CFM]:		8280
Design Airflow [m3/s]:		3.9
Design Airflow [L/s]:		3908.2
Entering Air DB [F]		80.6
Entering Air DB [C]		27.00
Entering Air WB [F]		65.5
Entering Air WB [C]		18.6
Leaving Air DB [F]		53
Leaving Air DB [C]		11.7
Leaving Air WB [F]		52.5
Leaving Air WB [C]		11.4

A-2B: Ground Floor Thermal Loads Data

Ground Floor		
Zone 1		
Room Name	Supply Air [CFM]	Fresh Air [CFM]
G50	240	48
G59	430	86
G62	1350	270
G87	140	28
G89	220	44
G94	200	40
G96	1475	295
G97	265	53
G98	3150	630
G99	360	72
G101	170	34
Total Coil Cooling Load [TR]:		25
Total Coil Cooling Load [kW]:		87.9
Total Coil Sensible Cooling Load [kW]		59.5
Total Coil Sensible Cooling Load [MBH]		203
Total Coil Heating Load [TR]:		15.0
Total Coil Heating Load [kW]:		52.8
Total Coil Heating Load [MBH]:		180
Design Airflow [CFM]:		6800
Design Airflow [m3/s]:		3.2
Design Airflow [L/s]:		3209.6
Entering Air DB [F]		80.4
Entering Air DB [C]		26.89
Entering Air WB [F]		66.5
Entering Air WB [C]		19.2
Leaving Air DB [F]		55
Leaving Air DB [C]		12.8
Leaving Air WB [F]		54
Leaving Air WB [C]		12.2

Ground Floor		
Zone 2		
Room Name	Supply Air [CFM]	Fresh Air [CFM]
G03	580	116
G05	1170	234
G14	150	30
G15	400	80
G16	370	74
G17	260	52
G19	150	30
G20	890	178
G21	600	120
G25	210	42
G26	160	32
G32	280	56
Total Coil Cooling Load [TR]:		15
Total Coil Cooling Load [kW]:		52.8
Total Coil Sensible Cooling Load [kW]		36.9
Total Coil Sensible Cooling Load [MBH]		126
Total Coil Heating Load [TR]:		7.1
Total Coil Heating Load [kW]:		24.9
Total Coil Heating Load [MBH]:		85
Design Airflow [CFM]:		4780
Design Airflow [m3/s]:		2.3
Design Airflow [L/s]:		2256.2
Entering Air DB [F]		80.4
Entering Air DB [C]		26.89
Entering Air WB [F]		66.5
Entering Air WB [C]		19.2
Leaving Air DB [F]		55
Leaving Air DB [C]		12.8
Leaving Air WB [F]		54
Leaving Air WB [C]		12.2

Ground Floor		
Zone 3		
Room Name	Supply Air [CFM]	Fresh Air [CFM]
G02	500	100
G03	500	100
G04	650	130
G06	400	80
G07	350	70
G09	260	52
G10	100	20
G27	1700	340
G29	3800	760
G30	310	62
G31	200	40
G32	300	60
Total Coil Cooling Load [TR]:		30
Total Coil Cooling Load [kW]:		105.5
Total Coil Sensible Cooling Load [kW]		79.1
Total Coil Sensible Cooling Load [MBH]		270
Total Coil Heating Load [TR]:		13.8
Total Coil Heating Load [kW]:		48.7
Total Coil Heating Load [MBH]:		166
Design Airflow [CFM]:		9500
Design Airflow [m3/s]:		4.5
Design Airflow [L/s]:		4484.0
Entering Air DB [F]		73.4
Entering Air DB [C]		23.00
Entering Air WB [F]		60.7
Entering Air WB [C]		15.9
Leaving Air DB [F]		55
Leaving Air DB [C]		12.8
Leaving Air WB [F]		54
Leaving Air WB [C]		12.2

A-1 2C: First Floor Thermal Loads Data

First Floor		
Zone 1		
Room Name	Supply Air [CFM]	Fresh Air [CFM]
T02	730	146
T04	480	96
T07	380	76
T08	500	100
T12	410	82
T13	410	82
T15	410	82
T19	360	72
T21	230	46
T23	670	134
T26	160	32
T27	220	44
T33	1820	364
T36	100	20
T37	150	30
T70	900	180
Total Coil Cooling Load [TR]:		22
Total Coil Cooling Load [kW]:		77.4
Total Coil Sensible Cooling Load [kW]		55.7
Total Coil Sensible Cooling Load [MBH]		190
Total Coil Heating Load [TR]:		13.8
Total Coil Heating Load [kW]:		48.4
Total Coil Heating Load [MBH]:		165
Design Airflow [CFM]:		6350
Design Airflow [m3/s]:		3.0
Design Airflow [L/s]:		2997.2
Entering Air DB [F]		80
Entering Air DB [C]		26.67
Entering Air WB [F]		65.8
Entering Air WB [C]		18.8
Leaving Air DB [F]		55
Leaving Air DB [C]		12.8
Leaving Air WB [F]		54
Leaving Air WB [C]		12.2

First Floor		
Zone 2		
Room Name	Supply Air [CFM]	Fresh Air [CFM]
T42	400	80
T43	400	80
T45	510	102
T46	230	46
T49	580	116
T53	460	92
T55	760	152
T56	760	152
T59	510	102
T60	480	96
T61	440	88
T62	460	92
T65	1850	370
T66	200	40
T67	740	148
Total Coil Cooling Load [TR]:		25
Total Coil Cooling Load [kW]:		87.9
Total Coil Sensible Cooling Load [kW]		76.2
Total Coil Sensible Cooling Load [MBH]		260
Total Coil Heating Load [TR]:		12.5
Total Coil Heating Load [kW]:		44.0
Total Coil Heating Load [MBH]:		150
Design Airflow [CFM]:		9000
Design Airflow [m3/s]:		4.2
Design Airflow [L/s]:		4248.0
Entering Air DB [F]		80
Entering Air DB [C]		26.67
Entering Air WB [F]		65.8
Entering Air WB [C]		18.8
Leaving Air DB [F]		55
Leaving Air DB [C]		12.8
Leaving Air WB [F]		54
Leaving Air WB [C]		12.2

A-1 2C: Second Floor Thermal Loads Data

Second Floor		
Zone 1		
Room Name	Supply Air [CFM]	Fresh Air [CFM]
S4	360	72
S7	360	72
S10	500	100
S11	430	86
S16	600	120
S18	640	128
S27	430	86
S28	430	86
S30	180	36
S31	300	60
S32&2	780	156
S33	560	112
S70	3220	644
Total Coil Cooling Load [TR]:		20
Total Coil Cooling Load [kW]:		70.3
Total Coil Sensible Cooling Load [kW]		49.8
Total Coil Sensible Cooling Load [MBH]		170
Total Coil Heating Load [TR]:		10.8
Total Coil Heating Load [kW]:		38.1
Total Coil Heating Load [MBH]:		130
Design Airflow [CFM]:		6300
Design Airflow [m3/s]:		3.0
Design Airflow [L/s]:		2973.6
Entering Air DB [F]		80
Entering Air DB [C]		26.67
Entering Air WB [F]		65.8
Entering Air WB [C]		18.8
Leaving Air DB [F]		55
Leaving Air DB [C]		12.8
Leaving Air WB [F]		54
Leaving Air WB [C]		12.2

Second Floor		
Zone 2		
Room Name	Supply Air [CFM]	Fresh Air [CFM]
S34	120	24
S35	220	44
S43	580	116
S44	200	40
S47	580	116
S48	275	55
S50	2500	500
S51	420	84
S52	120	24
S53	100	20
S54	310	62
S55	310	62
S58	400	80
S59	140	28
S60	340	68
S71	265	53
Total Coil Cooling Load [TR]:		20
Total Coil Cooling Load [kW]:		70.3
Total Coil Sensible Cooling Load [kW]		52.7
Total Coil Sensible Cooling Load [MBH]		180
Total Coil Heating Load [TR]:		12.5
Total Coil Heating Load [kW]:		44.0
Total Coil Heating Load [MBH]:		150
Design Airflow [CFM]:		6200
Design Airflow [m3/s]:		2.9
Design Airflow [L/s]:		2926.4
Entering Air DB [F]		80
Entering Air DB [C]		26.67
Entering Air WB [F]		65.8
Entering Air WB [C]		18.8
Leaving Air DB [F]		55
Leaving Air DB [C]		12.8
Leaving Air WB [F]		54
Leaving Air WB [C]		12.2

A-1 2D: Third Floor Thermal Loads Data

Third Floor		
Zone 1		
Room Name	Supply Air [CFM]	Fresh Air [CFM]
T02	1730	346
T06	2000	400
T12	4000	800
T14	140	28
T16	220	44
T17	140	28
T19	380	76
T21	420	84
T22	250	50
Total Coil Cooling Load [TR]:		25
Total Coil Cooling Load [kW]:		87.9
Total Coil Sensible Cooling Load [kW]		64.5
Total Coil Sensible Cooling Load [MBH]		220
Total Coil Heating Load [TR]:		10.0
Total Coil Heating Load [kW]:		35.2
Total Coil Heating Load [MBH]:		120
Design Airflow [CFM]:		8000
Design Airflow [m3/s]:		3.8
Design Airflow [L/s]:		3776.0
Entering Air DB [F]		80
Entering Air DB [C]		26.67
Entering Air WB [F]		65.8
Entering Air WB [C]		18.8
Leaving Air DB [F]		55
Leaving Air DB [C]		12.8
Leaving Air WB [F]		54
Leaving Air WB [C]		12.2

A-1 2E: First Floor Thermal Loads Data

Fourth Floor		
Zone 1		
Room Name	Supply Air [CFM]	Fresh Air [CFM]
F12	2140	428
F13	2030	406
F15	670	134
F17	3800	760
F57	670	134
Total Coil Cooling Load [TR]:		26
Total Coil Cooling Load [kW]:		91.4
Total Coil Sensible Cooling Load [kW]		63.9
Total Coil Sensible Cooling Load [MBH]		218
Total Coil Heating Load [TR]:		10.0
Total Coil Heating Load [kW]:		35.2
Total Coil Heating Load [MBH]:		120
Design Airflow [CFM]:		9000
Design Airflow [m3/s]:		4.2
Design Airflow [L/s]:		4248.0
Entering Air DB [F]		80
Entering Air DB [C]		26.67
Entering Air WB [F]		65.8
Entering Air WB [C]		18.8
Leaving Air DB [F]		55
Leaving Air DB [C]		12.8
Leaving Air WB [F]		54
Leaving Air WB [C]		12.2

Fourth Floor		
Zone 2		
Room Name	Supply Air [CFM]	Fresh Air [CFM]
F38	300	60
F39	285	57
F41	280	56
F42	260	52
F43	280	56
F45	300	60
F47	260	52
F48	500	100
F49	2480	496
F50	260	52
F51	260	52
Total Coil Cooling Load [TR]:		15
Total Coil Cooling Load [kW]:		52.8
Total Coil Sensible Cooling Load [kW]		36.9
Total Coil Sensible Cooling Load [MBH]		126
Total Coil Heating Load [TR]:		7.9
Total Coil Heating Load [kW]:		27.8
Total Coil Heating Load [MBH]:		95
Design Airflow [CFM]:		4800
Design Airflow [m3/s]:		2.3
Design Airflow [L/s]:		2265.6
Entering Air DB [F]		80
Entering Air DB [C]		26.67
Entering Air WB [F]		65.8
Entering Air WB [C]		18.8
Leaving Air DB [F]		55
Leaving Air DB [C]		12.8
Leaving Air WB [F]		54
Leaving Air WB [C]		12.2

Fourth Floor		
Zone 3		
Room Name	Supply Air [CFM]	Fresh Air [CFM]
F10-11	590	118
F18	180	36
F19	160	32
F2	2930	586
F20	350	70
F23	160	32
F24	180	36
F25	180	36
F32	180	36
F33-32	180	36
F35	245	49
F36	460	92
F44	180	36
F46	180	36
F55-56-34-46-44	350	70
F6	2690	538
Total Coil Cooling Load [TR]:		30
Total Coil Cooling Load [kW]:		105.5
Total Coil Sensible Cooling Load [kW]		74.7
Total Coil Sensible Cooling Load [MBH]		255
Total Coil Heating Load [TR]:		19.2
Total Coil Heating Load [kW]:		67.4
Total Coil Heating Load [MBH]:		230
Design Airflow [CFM]:		9000
Design Airflow [m3/s]:		4.2
Design Airflow [L/s]:		4248.0
Entering Air DB [F]		80
Entering Air DB [C]		26.67
Entering Air WB [F]		65.8
Entering Air WB [C]		18.8
Leaving Air DB [F]		55
Leaving Air DB [C]		12.8
Leaving Air WB [F]		54
Leaving Air WB [C]		12.2

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