UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHILLED WATER SYSTEM DESIGN AND PROPOSAL FOR HEALTHCARE FACILITY

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (REFRIGERATION AND AIR-CONDITIONING SYSTEMS) WITH HONOURS

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Faculty of Mechanical Technology and Engineering

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A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering Technology (Refrigeration And Air-Conditioning System) with Honours

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DECLARATION

I declare that this entitled "Chilled Water System Design And Proposal For Healthcare Facility" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : HARISHWAR A/L MOHAN

Date : 17/01/2024

APPROVAL

I hereby declare that I have checked this thesis and, in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Refrigeration and Air Conditioning System) with Honors.

Signature	:	
Supervisor Name	:	*DR. NOOR SAFREENA BT HAMDAN*
Date	:	17/01/2024

DEDICATION

I'm dedicating this thesis to all the students and educators who have spent countless hours within computer classrooms. Your dedication to learning and teaching inspires me to strive for excellence in my research. This work is a tribute to your perseverance and commitment to education.

I might want to offer my most profound thanks to my loved ones for their steadfast help, support, and understanding all through this scholastic excursion. Your adoration and faith in me have been my consistent inspiration.

I am indebted to my thesis advisor for their guidance, expertise, and patience. Their invaluable mentorship has shaped my research and expanded my intellectual horizons. I am grateful for the opportunities provided to me, and for their unwavering belief in my potential.

Finally, this thesis is dedicated to all those who understand the how a chilled water system function. May this work contribute to the advancement of knowledge and the improvement chilled water system customized design for commercial buildings.

ABSTRACT

This essay presents a comprehensive analysis and proposal for the design and implementation of a chilled water system tailored specifically for healthcare facilities. The primary focus is on achieving optimal energy efficiency, reliability, and sustainability to meet the unique demands of healthcare environments. The proposal integrates cutting-edge technologies and industry best practices to create a state-of-the-art chilled water system that ensures a stable and comfortable climate within the healthcare facility while minimizing environmental impact. The essay begins by outlining the critical factors influencing the design of chilled water systems in healthcare settings. Emphasis is placed on the need for precision temperature control, humidity management, and reliability to support the well-being of patients and the efficiency of medical equipment. Additionally, the essay explores the challenges posed by the varying cooling loads in different areas of a healthcare facility, necessitating a tailored and flexible design. The proposed chilled water system incorporates the latest advancements in HVAC (Heating, Ventilation, and Air Conditioning) technology, leveraging variable speed pumps and advanced control systems to dynamically adjust the cooling capacity based on real-time demand. By employing energy-efficient chillers with a focus on utilizing low Global Warming Potential (GWP) refrigerants, the system aims to significantly reduce its environmental impact while complying with evolving sustainability standards. To enhance system resilience, the proposal introduces redundancy measures such as backup chillers and thermal energy storage systems, ensuring uninterrupted operation even during maintenanceor unforeseen equipment failures. Additionally, the essay discusses the integration of smart monitoring and predictive maintenance tools, allowing for proactive identification of potential issues and minimizing downtime. The economic feasibility of the proposed chilled water system is also addressed, considering the initial investment costs, expected energy savings, and potential incentives for adopting sustainable technologies. A detailed cost-benefit analysis illustrates the long-term advantages of the proposed design, highlighting its potential for a rapid return on investment and substantial lifecycle cost savings. In conclusion, this essay provides a comprehensive overview of the optimal chilled water system design for healthcare facilities, offering a proposal that aligns with the industry's evolving needs. By prioritizing energy efficiency, reliability, and sustainability, the proposed system aims to create a comfortable and healing environment for patients while contributing to the facility's long-term operational and environmental goals.

ABSTRAK

Esei ini membentangkan analisis dan cadangan yang komprehensif untuk reka bentuk dan pelaksanaan sistem air sejuk yang disesuaikan khusus untuk kemudahan penjagaan kesihatan. Fokus utama adalah untuk mencapai kecekapan, kebolehpercayaan, dan kemampanan tenaga yang optimum untuk memenuhi permintaan unik persekitaran penjagaan kesihatan. Cadangan ini mengintegrasikan teknologi canggih dan amalan terbaik industri untuk mewujudkan sistem air sejuk yang canggih yang memastikan iklim yang stabil dan selesa dalam kemudahan penjagaan kesihatan sambil meminimumkan kesan alam sekitar. Esei ini bermula dengan menggariskan faktor-faktor kritikal yang mempengaruhi reka bentuk sistem air sejuk dalam tetapan penjagaan kesihatan. Penekanan diberikan kepada keperluan kawalan suhu ketepatan, pengurusan kelembapan, dan kebolehpercayaan untuk menyokong kesejahteraan pesakit dan kecekapan peralatan perubatan. Di samping itu, esei meneroka cabaran yang ditimbulkan oleh beban penyejukan yang berbeza-beza di pelbagai bidang kemudahan penjagaan kesihatan, yang memerlukan reka bentuk yang disesuaikan dan fleksibel. Sistem air sejuk yang dicadangkan menggabungkan kemajuan terkini dalam teknologi HVAC (Pemanasan, Pengudaraan, dan Penyaman Udara), memanfaatkan pam kelajuan berubah-ubah dan sistem kawalan canggih untuk menyesuaikan kapasiti penyejukan secara dinamik berdasarkan permintaan masa nyata. Dengan menggunakan penyejuk cekap tenaga dengan fokus untuk menggunakan penyejuk Potensi Pemanasan Global (GWP) yang rendah, sistem ini bertujuan untuk mengurangkan kesan alam sekitar dengan ketara sambil mematuhi piawaian kelestarian yang berkembang. Untuk meningkatkan daya tahan sistem, cadangan itu memperkenalkan langkah-langkah redundansi seperti penyejuk sandaran dan sistem penyimpanan tenaga haba, memastikan operasi tanpa gangguan walaupun semasa penyelenggaraan atau kegagalan peralatan yang tidak dijangka. Di samping itu, esei membincangkan integrasi pemantauan pintar dan alat penyelenggaraan ramalan, yang membolehkan pengenalpastian proaktif mengenai isu -isu yang berpotensi dan meminimumkan downtime. Kemungkinan ekonomi sistem air sejuk yang dicadangkan juga ditangani, memandangkan kos pelaburan awal, penjimatan tenaga yang dijangkakan, dan insentif yang berpotensi untuk menerima pakai teknologi mampan. Analisis kos-faedah terperinci menggambarkan kelebihan jangka panjang reka bentuk yang dicadangkan, menonjolkan potensinya untuk pulangan pelaburan yang cepat dan penjimatan kos kitaran hayat yang besar. Kesimpulannya, esei ini memberikan gambaran menyeluruh mengenai reka bentuk sistem air sejuk yang optimum untuk kemudahan penjagaan kesihatan, menawarkan cadangan yang sejajar dengan keperluan industri yang berkembang. Dengan mengutamakan kecekapan tenaga, kebolehpercayaan, dan kemampanan, sistem yang dicadangkan bertujuan untuk mewujudkan persekitaran yang selesa dan penyembuhan bagi pesakit sambil menyumbang kepada matlamat operasi dan alam sekitar jangka panjang kemudahan.

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I begin by expressing my utmost gratitude to the Almighty for bestowing upon me strength, guidance, and blessings throughout this research journey. The divine presence has been my constant source of inspiration and comfort, guiding me through the challenges and illuminating my path.

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D,d	-	Diameter
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CHAPTER 1

INTRODUCTION

1.1 Background

To maintain patient comfort, equipment functionality, and the overall well-being of residents, healthcare facilities require tight environmental control. Chilled water systems provide the foundation for maintaining the temperature levels required for medical equipment, pharmaceutical storage, and patient and healthcare staff comfort. Healthcare facilities operate in a highly required and sensitive environment where maintaining precise temperature and humidity level is critical for various types of departments. Proper air conditioning in medical care facilities aids in illness prevention and treatment. Patients recover more quickly in a regulated setting than in an uncontrolled environment (Alahmer & Alsaqoor, 2019). Advanced medical equipment, such as MRI machines, CT scanners, and laboratory instruments, often generate significant heat during operation. A reliable chilled water system is essential to dissipate this heat, ensuring optimal performance and longevity of the equipment.

Chilled water systems are often used in large commercial buildings and healthcare facilities to effectively regulate indoor temperatures. These systems use chilled water to absorb and transfer heat, which ensures a uniform and pleasant climate in the building. A well-designed cooling water system not only increases passenger comfort, but also contributes to energy efficiency and operating cost savings. Several challenges are faced by healthcare facilities when it comes to their heating, ventilation, and air conditioning (HVAC) systems. Aging infrastructure, rising energy costs, and increasing environmental concerns necessitate a reevaluation and modernization of existing systems. In healthcare settings, where precision climate control is crucial, outdated, or inefficient systems can result in suboptimal conditions that may impact patient recovery and compromise the effectiveness of medical equipment (Robert McDowall,2006).

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1.2 Problem Statement

A chilled water system selection/proposal contains a lot of procedures and steps to choose the right one following a building's specification. When a consultant or contractor proposed a non-efficient chilled water system it might affect the occupant's comfort and might affect the building's health as well. Most building owners face a problem where they can't get the desired indoor temperature while the building is occupied. This happens after 1 or 2 years of chilled water system installation. Mostly the non-efficient chilled water system proposed due to low cost. So that, this project mainly proposes a chilled water system design for a Government Hospital Pasir Gudang which follows the requirement requested by Kementerian Kesihatan Malaysia (KKM).

Even some of the healthcare facilities facing some challenges in budgetary constraints. Budgetary constraints often limit the extent to which healthcare facilities can invest in state-of-the-art chilled water systems. As a result, some facilities may compromise the quality and sophistication of their systems, potentially sacrificing long-term efficiency and performance for short-term cost savings (Mills et al., 2015). They're also facing some maintenance challenges in which proper maintenance is crucial for the sustained performance of chilled water systems. However, some healthcare facilities may face challenges in implementing regular maintenance schedules due to limited resources or competing priorities. Inadequate maintenance can lead to system failures, increased energy consumption, and disruptions in critical healthcare operations (Wang and Zhang, 2016).

Many healthcare facilities still grapple with outdated chilled water systems that are inherently energy inefficient. Inefficient systems not only contribute to higher operational costs but also have environmental implications, aligning poorly with the growing emphasis on sustainability in healthcare (Debnath et al., 2020).

1.3 Research Objective

The objectives of this project are as follows:

a) To design and propose a efficient chilled water system which fullfills ASHRAE requirments for a hospital.

b) To identify type of chilled water systems applicable for a healthcare facility using HAP 5.1.

1.4 Scope of Research

The scope of this research as it follows:

The project will focus on chilled water system design for a healthcare facility cooling load and specific chiller type. These parameters would be defined throughout analysis to understand their specific requirements as well as specifications. This project will comprehensively assess the indoor and outdoor specifications of ASHRAE and KKM that significantly influence chilled water system sizing and design in Hospital Pasir Gudang. Floor area, air change per hour, minimum and maximum temperature, chiller type and etc will be studied and analysed to design an efficient chilled water system for healthcare facility.

This project will involve collecting quantitative data. Quantitative data will be gathered through using proper software's. Quantitative data collection would be collecting precise measurement of indoor and outdoor parameters. The project focusses more on parameters and design consideration for critical areas located in healthcare facilities.

The scope of this project will be limited by floors. Floor 1 and floor 6 will be focussed to create a chilled water system design. This ensures a focused and contextualized investigation into the specific challenges and requirements of these hospital Pasir Gudang floor 1 and 6, allowing for targeted recommendations and guidelines. By narrowing the scope, the project can delve into the intricacies of the infrastructure, operation hours, and activities specific to healthcare facility. This contextualized approach enables a more thorough understanding of the factors affecting indoor cooling load and comfort levels in a healthcare facility.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Healthcare facilities play a pivotal role in promoting healing, wellness, and patient care. Among the critical infrastructure components that contribute to the overall functionality of these facilities, chilled water systems stand out as a fundamental element. Chilled water systems are essential for maintaining optimal environmental conditions, ensuring the comfort of patients and healthcare professionals, and supporting the proper functioning of medical equipment. This study explores the importance of chilled water systems in healthcare facilities, chiller modelling for healthcare facilities, drawing on relevant research and industry practices.

2.2 Temperature and Humidity

Chilled water systems are integral to the precise control of temperature and humidity levels within healthcare facilities. Optimal conditions in critical areas such as operating rooms, laboratories, and patient rooms are crucial for patient comfort and well-being. Importance of maintaining specific temperature and humidity ranges to create an environment conducive to healing and recovery (Wang et al. (2018)).

I. Operating Rooms:

Operating rooms (ORs) are high-stakes environments where surgical procedures are conducted. Maintaining specific temperature and humidity levels in ORs is essential for several reasons. Firstly, the comfort of both the surgical team and the patient is paramount. Uncomfortable temperatures or improper humidity levels can lead to stress and distraction, potentially impacting the efficiency and focus of the surgical team. Secondly, stringent infection control measures are necessary in the sterile environment of an operating room. Properly controlled temperature and humidity help minimize the risk of microbial growth, reducing the likelihood of surgical site infections. Significance of maintaining specific environmental conditions in ORs to ensure the success of surgical procedures and the well-being of patients (Wang et al.). the vulnerability of certain equipment to temperature fluctuations, underscoring the necessity of precise environmental control in ORs. Chilled water systems emerge as indispensable components, ensuring the optimal functionality of medical equipment critical to the success of surgical interventions (Gracia 2019).

II. Laboratories:

Laboratories within healthcare facilities house sensitive equipment and experiments that often require controlled environmental conditions. Temperature and humidity fluctuations can adversely affect the accuracy and reliability of laboratory results. Additionally, certain experiments or processes may be highly sensitive to environmental variations. Maintaining specific temperature and humidity ranges in laboratories is essential not only for the functionality of equipment but also for the integrity of scientific research conducted within healthcare institutions (Wang et al). implementation of energy-efficient technologies, such as variable speed pumps, to reduce energy consumption. This not only aligns with broader sustainability goals within healthcare facilities but also contributes to cost savings (Lee, 2019).

III. Patient rooms:

Patient comfort and well-being are central to the mission of healthcare facilities. In patient rooms, personalized temperature and humidity control contribute significantly to the overall patient experience and recovery. Patients may have varying comfort preferences, and maintaining an environment that aligns with their preferences can positively impact their emotional state and, consequently, their recovery. Moreover, proper temperature and humidity control play a role in preventing conditions such as dry air that could lead to respiratory discomfort or skin-related issues. Patient preferences in terms of temperature and humidity vary widely, and recognizing this diversity is foundational in providing personalized comfort. In a critical situation it might affect the patient’s mental health. maintaining a comfortable and personalized environment positively affects patients' mental states, potentially accelerating the recovery process (Smith and Brown (2020)). Chilled water systems, as integral components of temperature control, contribute to the creation of healing environments within patient rooms, fostering a holistic approach to healthcare delivery (Ulrich et al. (2018)).

IV. Conductive environment for healing and recovery:

The nuanced relationship between temperature, humidity, and the healing process is a focal point (Wang et al). Optimal environmental conditions are argued to contribute positively to patient recovery. Patients in environments with well-regulated temperature and humidity levels are likely to experience reduced stress, improved sleep quality, and an overall more comfortable and supportive setting for healing. This aligns with the broader understanding in healthcare that patient outcomes are influenced not only by medical interventions but also by the holistic care environment provided. well-regulated conditions positively influence stress levels in patients. Reduced stress is not only conducive to a more comfortable healing environment but also has potential implications for shorter recovery times. This insight underscores the broader understanding that the holistic care environment significantly shapes patient outcomes beyond medical interventions (Johnsons (2019).

2.3 Inadequate insulation and heat loss

In many cases, buildings in Malaysia may have inadequate insulation or inappropriate materials, leading to increased heat transfer. This results in higher energy consumption for cooling systems, contributing to elevated electricity bills and environmental impact. The increased energy demand resulting from inadequate insulation contributes to higher utility bills. Occupants may find themselves paying more for heating or cooling due to the inefficiency of the building envelope (International Association of Certified Home Inspectors, 2018). As an environmental impact, higher energy consumption not only affects financial aspects but also contributes to a larger environmental footprint, the increases use of energy, often derived from non-renewable sources. The increased use of energy, often derived from non-renewable sources, leads to higher greenhouse gas emissions (United Nations Environment Program, "Buildings and Climate Change: Summary for Decision-Makers," 2007).

Inadequate insulation in walls and roofs is a significant contributor to heat loss in buildings, impacting energy efficiency and overall thermal comfort. The lack of proper insulation allows heat to escape more easily during colder seasons and infiltrate during warmer seasons, leading to increased energy consumption and discomfort for occupants.

During warmer seasons, inadequate insulation allows external heat to penetrate indoor spaces, necessitating more extensive use of air conditioning systems to cool the building. This lack of thermal control not only affects the occupants' comfort but also significantly increases the energy demand associated with both heating and cooling processes (U.S Department of Energy).

Windows and doors are essential components of any building, serving as portals to connect indoor and outdoor environments. However, their role goes beyond aesthetics and functionality; they play a pivotal role in regulating temperature within a structure. Inefficient windows and doors with poor insulation properties can become significant contributors to heat loss, compromising energy efficiency and increasing heating costs.

Inefficient windows and doors often harbor gaps and lack proper sealing, providing pathways for heat transfer. These gaps allow warm indoor air to escape during the cold months and permit external heat to infiltrate during warmer periods. Poorly sealed windows and doors can account for a substantial percentage of overall building heat loss (Levinson et al., 2005). Materials used in windows and doors play a crucial role in heat transfer. Conductive materials allow heat to pass through more easily, contributing to increased energy consumption. Moreover, convection currents within poorly insulated windows can facilitate heat exchange between indoor and outdoor environments. the impact of material selection on energy-efficient building design (DOE, 2020).

One crucial aspect of building performance is the effectiveness of its envelope in preventing the infiltration of outside air. Gaps, cracks, and poor sealing compromise the building envelope's integrity, leading to the escape of conditioned indoor air and the intrusion of unconditioned outdoor air. Effective air sealing is essential for preventing the unwanted exchange of air between the interior and exterior of a building. Gaps and cracks in the building envelope can result in a substantial increase in energy consumption for heating and cooling, contributing to discomfort and escalating utility bills (Dutt and Reddy, 2017). Inconsistency of indoor temperature would be one of the deficiencies due to a improper air sealing. Air leaks disrupt the balance of indoor temperature, creating discomfort for occupants. This inconsistency hinders the building's ability to maintain a stable and comfortable indoor environment (Dutta et al., 2018).

2.4 Hourly Analysis Program (HAP)

Energy Performance Analysis is one of the primary applications of HAPs in assessing the energy performance of buildings. These programs simulate the hourly energy consumption of HVAC systems, lighting, and other equipment, allowing designers and engineers to identify peak loads, energy wastage, and opportunities for optimization. In the realm of sustainable architecture and building design, the utilization of advanced tools and technologies is imperative for achieving energy efficiency goals. Hourly Analysis Programs (HAPs) have emerged as pivotal tools that play a crucial role in predicting the hourly energy consumption of various building components (Li et al (2019)).

HAPs provide a comprehensive understanding of the complex interplay between environmental conditions and energy demands within a building. HAPs to simulate and predict cooling and heating loads under varying conditions. This simulation capability enables designers and engineers to gain insights into the dynamic nature of energy consumption, considering factors such as external weather conditions, internal occupancy patterns, and specific architectural features (Zhang, Y., et al. (2020)).

The accuracy achieved by HAPs in simulating and predicting energy loads empowers designers and engineers to make informed decisions throughout the building design process. By having a detailed understanding of how different components contribute to the overall energy consumption, professionals can optimize the design of HVAC systems to meet specific energy efficiency objectives. This optimization not only reduces operational costs but also aligns with the broader goal of creating environmentally sustainable and energy-efficient buildings.

In the current era, where environmental sustainability is a top priority, the integration of HAPs in building design becomes even more crucial. By optimizing HVAC systems based on accurate predictions from HAPs, designers contribute to the reduction of greenhouse gas emissions associated with energy consumption. This aligns with global efforts to mitigate the environmental impact of buildings and move towards more sustainable and eco-friendly construction practices. While hospitals are essential for public health, they are also substantial consumers of energy and resources, contributing to environmental degradation. The environmental impact of healthcare facilities, emphasizing the need for sustainable practices to minimize their carbon footprint (Vakili et al. (2018)).

One of the primary strategies to address environmental concerns in hospital buildings is enhancing energy efficiency and adopting green building design principles. Implementing energy-efficient technologies, such as LED lighting and efficient HVAC systems, can significantly reduce energy consumption (Mumovic et al., 2015). The Leadership in Energy and Environmental Design (LEED) certification is a widely recognized standard that promotes sustainable building practices in healthcare facilities. Table 2.1 shows international rating systems for hospital buildings

Table 1. Healthcare-specific rating systems.

Country/Title	Type	Versions/Year	Elements and points	Ratings and level of certification
UK BREEAM (new builds, extensions & major refurbishments)	Environmental Assessment	Healthcare 2008 2008	Management (12), Health and Wellbeing (15), Energy (19), Transport (8), Water (6), Materials (12.5), Waste (7.5), Land Use & Ecology (10), Pollution (10), Innovation (10). Total points = 110	Unclassified <30 Pass ≥30 Good ≥45 V Good ≥55 Excellent ≥70 Outstanding ≥85
US LEED (new construction and major renovations)	Environmental Assessment	Healthcare v2009 2009	Sustainable Sites (18), Water Efficiency (9), Energy and Atmosphere (39), Materials and Resources (16), Indoor Environmental Quality (18), Innovation In Design (6), Regional Priority Credits (4). Total points = 110	Certified 40-49 Silver 50-59 Gold 60-79 Platinum 80 and above
AUSTRALIA Green Star (building at the design phase as well as post construction phase 'As-Built')	Environmental Assessment	Healthcare v1 2009	Management (17), Indoor Environment Quality (32), Energy (29), Transport (12), Water (14), Materials (35), Land use &Ecology (8), Emissions (20), Innovation (5). Total points = 172	Best Practice (4 star) 45-59 Australian Excellence (5 star) 60-74 World Leadership (6 star) 75-100

Figure 2.1 International Healthcare Rating System

2.5 Chiller selection

The selection of appropriate chiller technologies for hospital buildings in Malaysia is a critical aspect of ensuring optimal indoor environmental conditions, energy efficiency, and sustainable cooling solutions. The various chiller technologies applicable to hospital preferences in Malaysia, which focusing on their performance, energy efficiency, and suitability for the tropical climate.

I. Vapor Compression Chillers

Vapor compression chillers, including air-cooled and water-cooled variants, remain widely used in hospital buildings due to their efficiency and reliability (Chan et al., 2018). the efficiency of vapor compression chillers, underscoring their ability to meet the rigorous cooling demands of medical facilities. The precise temperature control afforded by these systems is crucial for maintaining a stable environment, particularly in areas where stringent temperature regulation is imperative, such as operating rooms, laboratories, and storage spaces for pharmaceuticals (Chan et al. 2018). Air-cooled and water-cooled vapor compression chillers both contribute to the overall efficiency of hospital HVAC systems. Air-cooled systems, for instance, are well-suited for facilities where water availability is limited or expensive. On the other hand, water-cooled systems, although dependent on water sources, tend to be more energy-efficient and may be preferred in settings where water usage is sustainable. The reliability of vapor compression chillers is paramount in healthcare settings, where uninterrupted operation is essential for patient well-being and the functionality of medical equipment. The robustness of these systems, emphasizing their ability to provide consistent and reliable cooling across various load conditions (Ahmad et al. 2020).

II. Variable Refrigerant Flow systems

VRF systems are gaining popularity in the healthcare sector due to their flexibility, zoning capabilities, and energy efficiency (Suhaimi et al., 2019). One of the key attributes that make VRF systems appealing in healthcare settings is their inherent flexibility. Unlike traditional HVAC systems, VRF systems can simultaneously heat and cool different zones within a hospital building, responding dynamically to varying thermal loads. VRF systems are characterized by their unparalleled flexibility, allowing simultaneous heating and cooling of distinct zones within hospital facilities. especially in healthcare environments with diverse thermal requirements across different spaces such as patient rooms, surgical suites, and administrative areas. The adaptability of VRF systems to varying thermal loads ensures optimal performance and comfort throughout the hospital (Nguyen, T. M., et al. (2020)). The precision of temperature control and the ability to tailor conditioning to specific zones contribute significantly to overall energy savings. By avoiding unnecessary heating or cooling of unoccupied spaces, VRF systems exemplify operational efficiency and are recognized as a cost-effective choice for healthcare institutions seeking to reduce energy consumption.

2.6 Air change per hour

Air change, often measured as air changes per hour (ACH), plays a crucial role in maintaining a safe and healthy environment in hospitals. The significance of proper ventilation and air exchange in healthcare facilities cannot be overstated. One of the primary reasons why air change is crucial in hospitals is its direct impact on infection control. Hospitals are susceptible to the spread of airborne pathogens, including bacteria and viruses, due to the proximity of patients and the constant flow of healthcare personnel, visitors, and patients. A direct correlation between ventilation rates and the transmission of infectious diseases in healthcare settings (Rutala & Weber, 2016).

Air quality and ventilation directly influence patient outcomes. Patients in hospitals are often vulnerable, with compromised immune systems. Inadequate air change rates can lead to the accumulation of pollutants and allergens, exacerbating respiratory conditions and hindering the recovery process. The importance of sufficient ventilation in reducing the risk of respiratory infections among hospitalized patients, ultimately impacting their recovery and outcomes (Loveday et al., 2014). Proper air change ensures a healthier environment for patients, contributing to better recovery rates and overall well-being.

The CDC, a leading public health institution in the United States, has been instrumental in formulating guidelines for infection control in healthcare settings. The CDC's "Guidelines for Environmental Infection Control in Health-Care Facilities" provides comprehensive recommendations for ventilation systems, emphasizing the need for adequate air changes to mitigate the risk of airborne infections (CDC, 2003). These guidelines are regularly updated to align with the latest scientific evidence and emerging infectious threats.

Similarly, the WHO, as a global health authority, contributes to the establishment of international standards for healthcare facilities. The WHO's "Natural Ventilation for Infection Control in Health-Care Settings" document outlines principles for achieving effective ventilation, including air exchange rates, to reduce the concentration of airborne pathogens (WHO, 2009). Both the CDC and WHO guidelines underscore the importance of proper air change in preventing and controlling infectious diseases within healthcare facilities.

Regulatory bodies recognize the dynamic nature of healthcare environments and continuously update guidelines to address emerging challenges. For example, during the COVID-19 pandemic, both the CDC and WHO issued specific recommendations for ventilation in healthcare settings to reduce the transmission of the virus (CDC, 2020; WHO, 2020). This responsiveness underscores the commitment of regulatory bodies to adapt guidelines to safeguard public health.

2.7 Capacity and Load Calculations

According to ASHRAE standards, particularly ASHRAE Handbook - Fundamentals (2017), accurate load calculations are imperative for proper chiller sizing in any facility, including hospitals. Hospitals present a unique challenge due to the dynamic nature of their thermal loads, influenced by factors such as occupancy variations, medical equipment, lighting requirements, and geographical location.

Capacity planning involves estimating the maximum output a healthcare facility can achieve, considering available resources and infrastructure. an effective capacity planning strategy should encompass both physical and human resources. Physical capacity involves the number of beds, equipment availability, and overall infrastructure, while human capacity focuses on the staffing levels and skill mix Smith et al. (2019). To calculate physical capacity, one must consider the facility's design capacity (Thompson 2020). Design capacity refers to the maximum output a facility can achieve under ideal conditions. However, practical capacity, influenced by factors such as maintenance, renovations, or unexpected events, is a more realistic measure.

Load calculations involve assessing the demand placed on healthcare facilities by patients. Accurate predictions of patient demand are essential for maintaining an appropriate balance between capacity and service levels (Adam, 2021). Several mathematical models, such as queuing theory and simulation modeling, can aid in load calculations. Queuing theory helps analyze waiting times and patient flow through different stages of care, while simulation modeling provides a dynamic representation of healthcare processes, allowing for scenario testing (Dougherty et al., 2018).

CHAPTER 3

METHODOLOGY

3.1 Introduction

Hospital Pasir Gudang consists of six floors with different functions allocated for each unit in that building. Hospital Pasir Gudang is a newly built building with zero equipment, occupancy, and any systems. HVAC system for a healthcare facility is a special case everywhere in Malaysia cause, must comply Malaysian Standard in order to build a HVAC system for a hospital. An efficient chilled water system holds paramount significance in healthcare settings due to its critical role in maintaining optimal environmental conditions and safeguarding the integrity of medical equipment. In healthcare facilities, precise temperature control is imperative for creating a comfortable and hygienic environment essential for patient well-being.

The chilling system ensures that temperature-sensitive medications, diagnostic instruments, and life-support equipment are stored and operated within specified temperature ranges, thereby preserving their efficacy and reliability. Moreover, an effective chilled water system contributes directly to infection control measures. Maintaining consistent temperatures in critical areas helps mitigate the proliferation of pathogens and supports a sterile environment crucial for patient recovery. The system's reliability is pivotal in emergency situations, ensuring uninterrupted operation of essential medical equipment that can be lifesaving. From an operational standpoint, an energy-efficient chilled water system aligns with healthcare facilities' commitment to sustainability and cost-effectiveness.

Efficient cooling mechanisms reduce energy consumption, lowering operational expenses and promoting environmentally responsible practices. In essence, the efficient design and operation of a chilled water system in healthcare settings not only uphold medical standards but also play a pivotal role in enhancing patient care, ensuring equipment reliability, and aligning with broader healthcare sustainability goals.

3.2 Research Flow Chart

The flow of research methodology of this study to summaries the process of design chilled water system design for hospital Pasir Gudang. Flowchart of the projects includes with the fulfilled objectives, which related to designing chilled water system.

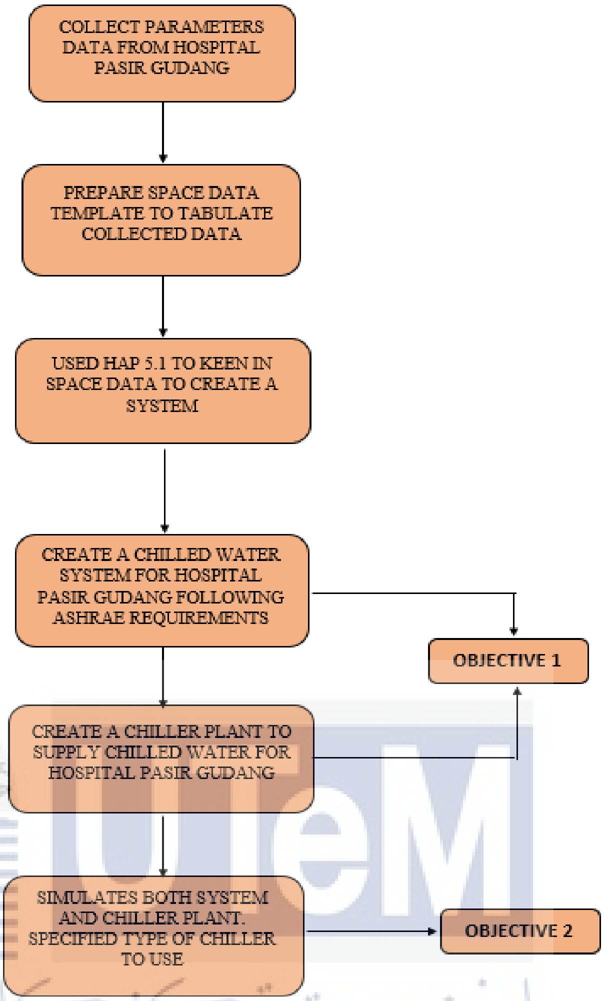

Figure 3.1 Flow Chart Process

3.3 Space Data

In space data measured room area, external perimeter, external wall area, partition perimeter, partition area, window10, fresh air change per hour fresh air airflow, minimum air change per hour, minimum airflow (cfm) and room temperature. Room area, external perimeter, external wall area, partition perimeter, partition area and windows measured using Autodesk DWG Trueviewer. The ACH must follow ASHRAE Standards for different workspace. Desired temperature is standardized by activity done in that specific room. The external wall area and partition area find out using a formula.

$$External\ Perimeter(ft) \times Ceiling\ Height(ft) = External\ Wall\ Area(ft^2)$$

$$Partition\ Perimeter(ft) \times Ceiling\ Height(ft) = Partition\ Area(ft^2)$$

$$Fresh\ air\ change(hr) \times Ceiling\ Height(ft) \times Floor\ Area\ (ft^2) = Freshair\ Airflow\ (cfm)$$

$$Minimum\ (ACH) \times Ceiling\ Height(ft) \times Floor\ Area\ (ft^2) = Minimum\ Airflow\ (cfm)$$

Equation 3.1 (External and partition area), (Fresh and Minimum airflow)

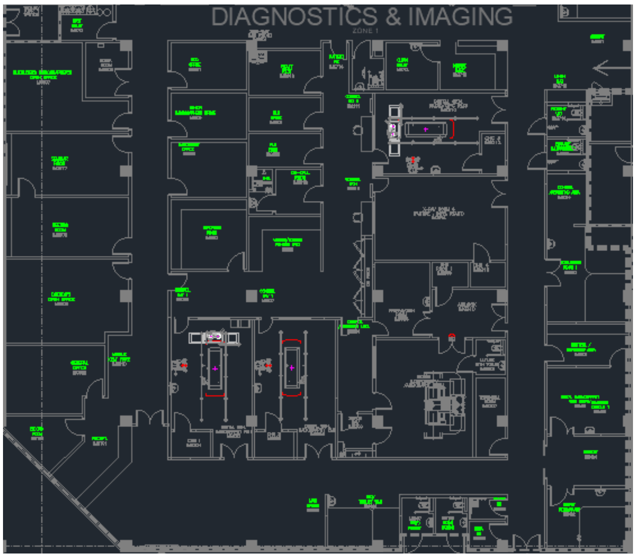

Figure 3.2 Hospital Pasir Gudang sample floor plan

3.3.1 Hourly Analysis Program

Hourly Analysis Program is a program created by Carrier. The features can be done for cooling load, energy efficiency, annual cost calculations, chiller analysis and cooling tower analysis. There are few components parameters which might be different for each project. All components contribute to a larger or smaller size for cooling load calculations. For the project chilled water system design and proposal for a healthcare facility must focused on weather, spaces, systems and chillers. The space data is collected through hospital Pasir Gudang detailed floor plan.

Table 1: Building Envelope Design Recommendations for Achieving 30% Energy Savings in Small Hospitals and Healthcare Facilities

<table>
<tr><th rowspan="3">Item</th><th rowspan="3">Component</th><th colspan="8">Recommendations from the ASHRAE Advanced Energy Design Guide for Small Hospitals and Healthcare Facilities (<90,000 sq ft)</th></tr>
<tr><th colspan="8">Climate Zone</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th></tr>
<tr><td rowspan="2">Roof</td><td>Insulation above deck</td><td colspan="3">R-25*</td><td colspan="3">R-30*</td><td colspan="2">R-35*</td></tr>
<tr><td>Solar reflectance index (SRI)</td><td colspan="3">78</td><td colspan="5">Comply with Standard 90.1**</td></tr>
<tr><td rowspan="3">Walls</td><td>Mass (HC >7 Btu/ft²)</td><td>R-5.7*</td><td>R-7.6*</td><td>R-11.4*</td><td colspan="2">R-13.3*</td><td colspan="2">R-19.5*</td><td>R-25*</td></tr>
<tr><td>Steel-framed</td><td colspan="4">R-13 + R-7.5*</td><td>R-13 + R-15.6*</td><td colspan="2">R-13 + R-18.8*</td><td>R-13 + R-21.6*</td></tr>
<tr><td>Below grade walls</td><td colspan="2">Comply with Standard 90.1**</td><td colspan="3">R-7.5*</td><td>R-12.5</td><td>R-15*</td><td>R-17.5*</td></tr>
<tr><td rowspan="2">Floors</td><td>Mass</td><td>R-4.2*</td><td>R-10.4*</td><td>R-12.5*</td><td>R-14.6*</td><td>R-16.7*</td><td>R-19.5*</td><td>R-20.9*</td><td>R-23*</td></tr>
<tr><td>Steel-framed</td><td>R-19</td><td colspan="2">R-30</td><td colspan="2">R-38</td><td>R-49</td><td colspan="2">R-60</td></tr>
<tr><td>Slabs</td><td>Unheated</td><td colspan="3">Comply with Standard 90.1**</td><td colspan="2">R-15 for 24"</td><td colspan="2">R-20 for 24"</td><td>R-20 for 48"</td></tr>
<tr><td rowspan="2">Doors</td><td>Swinging</td><td colspan="3">U-0.70</td><td colspan="5">U-0.50</td></tr>
<tr><td>Non-swinging</td><td>U-1.450</td><td colspan="7">U-0.50</td></tr>
<tr><td rowspan="5">Vertical Fenestra-tion</td><td>Total fenestration to gross wall area ratio</td><td colspan="8">40% maximum</td></tr>
<tr><td>Thermal transmittance (all types and orientations)</td><td colspan="3">U-0.43</td><td colspan="4">U-0.29</td><td>U-0.20</td></tr>
<tr><td>SHGC (all types and orientations)</td><td colspan="3">SHGC-0.26</td><td colspan="4">SHGC-0.34</td><td>SHGC-0.40</td></tr>
<tr><td>Visible transmittance</td><td colspan="3">VT-0.63</td><td colspan="4">VT-0.69</td><td>VT-0.65</td></tr>
<tr><td>Exterior sun control (SE & W only)</td><td colspan="7">Projection factor >0.5</td><td></td></tr>
<tr><td rowspan="3">Skylights</td><td>Area (percent of roof area)</td><td colspan="8">3% maximum</td></tr>
<tr><td>Thermal transmittance (all types and orientations)</td><td colspan="2">U-0.75</td><td>U-0.65</td><td colspan="5">U-0.6</td></tr>
<tr><td>SHGC (all types and orientations)</td><td colspan="3">SHGC-0.35</td><td colspan="3">SHGC-0.4</td><td colspan="2">Comply with Standard 90.1**</td></tr>
<tr><td rowspan="2">Daylighting</td><td rowspan="2">Design the building to maximize access to natural light through sidelighting and toplighting:
• Staff areas (exam rooms, nurse stations, offices, and corridors)
• Public spaces (waiting and reception)</td><td colspan="8">Diagnostic and treatment block: Shape the building footprint such that the area within 15 ft of the perimeter exceeds 40% of the floorplate</td></tr>
<tr><td colspan="8">Inpatient units: Ensure that 75% of the occupied space not including patient rooms lies within 20 ft of the perimeter</td></tr>
</table>

*c.i. or Continuous Insulation

**Comply with the more stringent of either the applicable edition of ASHRAE 90.1 or the local code requirement

Figure 3.3 ASHRAE Recommendation for 30% energy savings

Figure 3.3 shows the requirement for hospital in order to save 30% energy usage. These requirements are applicable for a healthcare facility which smaller than 90000sqft. This envelope is prapred to reduce energy usage by chiller. This recommendation won’t affect a chiller perfomance and will give some impact for annual power consumption of chiller.

3.3.1.1 Weather

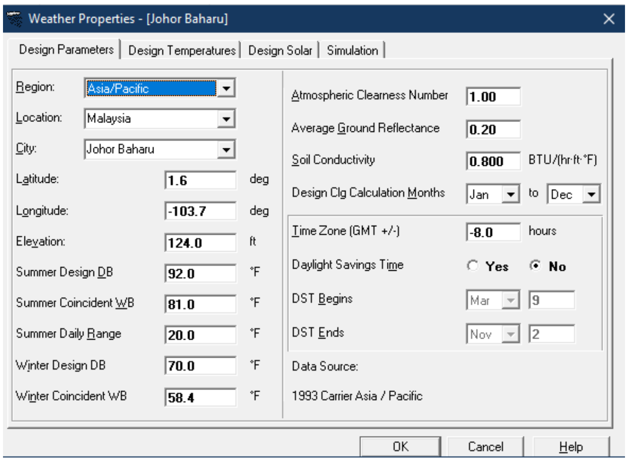

Figure 3.4 Weather Properties

For Hospital Pasir Gudang which located Johor Baharu religion is Asia/Pacific and location is over Malaysia and city chosen as Johor Baharu. The time zone, latitude, longitude and etc will be define as default location. The simulation tab is to simulate the exact weather at Johor Baharu with a add on file from HAP.

3.3.1.2 Spaces

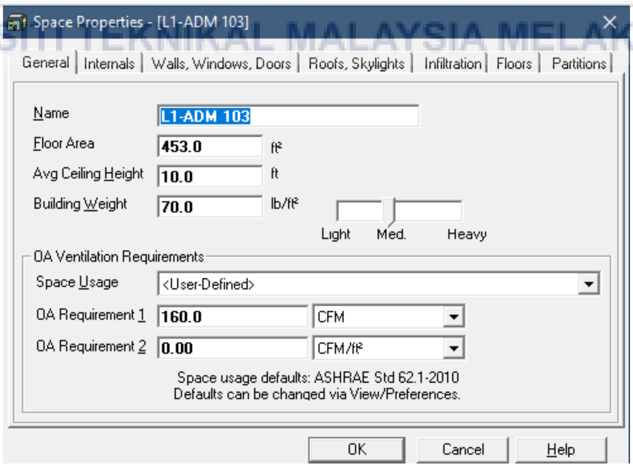

Figure 3.5 Space Properties

Space properties follows the indoor or outdoor spaces in a hospital Pasir Gudang which needed to be calculate cooling load. The floor area can be measured manually or with the help of Trueviewer DWG. Average ceiling height for hospital is approximately 10ft. Building weight can be determined by the material used to build a building. As a default setting medium weight will be chosen. Space usage is to determine the activity done in a specific space. Outdoor air requirement 1 is fresh air that need to be supplied to a space in cfm.

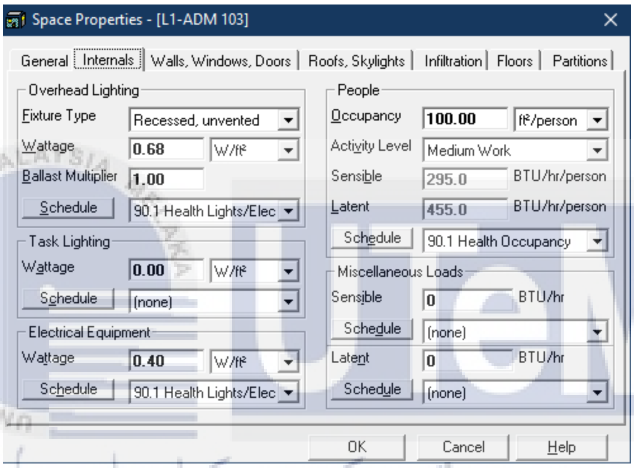

Figure 3.6 Internal Parameters

Internal parameters shown in Figure 3.6 is to determine the equipment and lighting weightage, occupancy, activity level, sensible and laten heat produced in a space. The option schedule can determine the usage time of equipment and lighting. In the case of occupancy schedule is to determine number of occupants at each one hour. This can be used to determine the peak time of the indoor space.

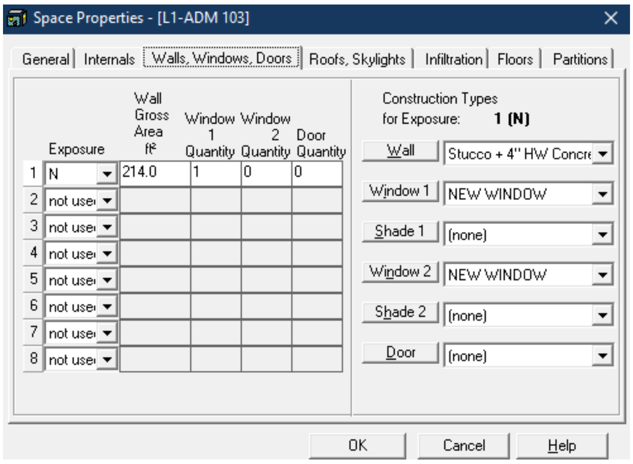

Figure 3.7 Walls, Windows, Door parameters setup

Figure 3.7 indicates the interface in HAP 5.1 to insert parameters for walls, windows and doors which measured using a floor plan. The exposure might be different for each unit in hospital depends on wall facing outdoor with an exposure of sunlight. The type of wall and window can do set for our preference following type of material used in Hospital Pasir Gudang.

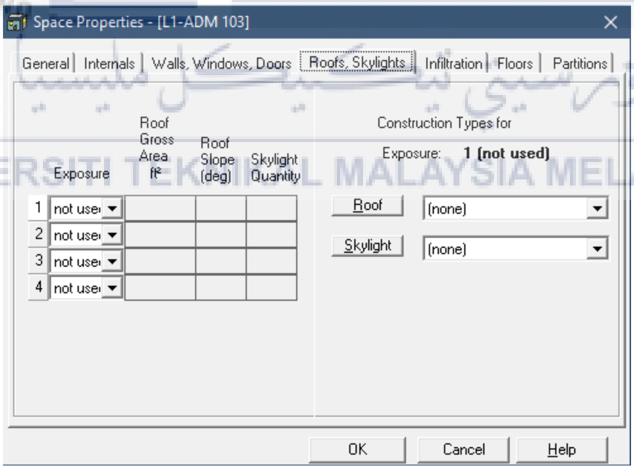

Figure 3.8 Roof, Skylights setup

As shown in Figure 3.8 roofs would be in usage for floor 6. Floor 1 to 5 doesn't require any roof set up cause of above conditioned space. Type of roof for hospital can be in medium color with higher absorptivity which is 0.900 SA. The value range is between 0-1. Higher the value better the absorptivity.

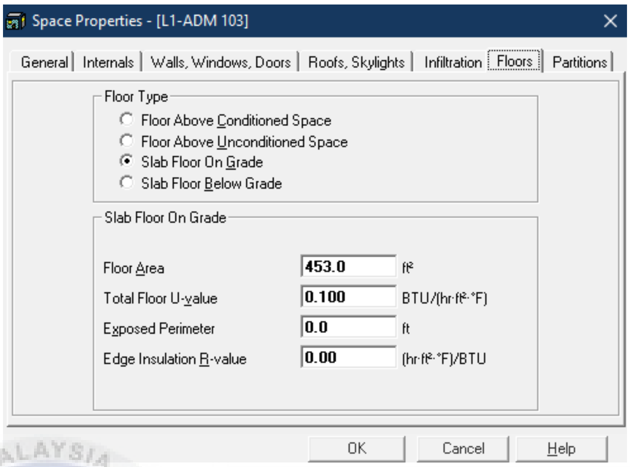

Figure 3.9 Floors parameter setup

In this floor properties shown in figure 3.9 floor type must be identified. Floor above conditioned space means the lower floor is occupied with air condition systems. Floor above conditioned space mentions upper floor has an air conditioning system. Slab on grade is a concrete slab in contact with soil. Slab floor below grade indicating ground floor which might be with a conditioning system or not. This floor type identifies the heat transfers happens in between floors. The covered floor area should be filled up along with total floor U-Value. The U-value of the floor assesses the amount of heat loss/gain throughout the thickness of the floor. For new building likely Hospital Pasir Gudang U-value shouldn't exceed 0.25W/m^2K.

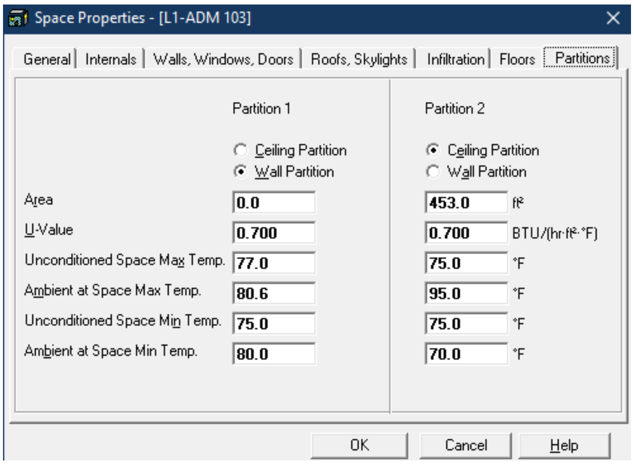

Figure 3.10 Partitions setup

Partitions can be divided into two which is ceiling partition and wall partition. Ceiling partition for hospital Pasir Gudang can be fulfilled from floor 1 to 5. Wall partition is a wall in between 2 rooms and wall partition considered when unit beside air-conditioned space is non-air-conditioned space. So that the heat transfer from a non-conditioned space would be considered. U-value for ceiling and a partition considered to be lesser than roof.

3.3.1.3 Systems

An air system is the equipment and controls which provide cooling and heating to a region of a building. An air system serves one or more zones; each zone is a group of one or more spaces having a single thermostatic control. Examples of air systems include central station air handlers, packaged rooftop units, packaged vertical units, split systems, packaged DX fan coils, hydronic fan coils and water source heat pumps. Components in an air system include fans and coils as well as the associated ductwork, supply terminals and controls.

When performing an energy analysis, the DX cooling, heat pump, electric resistance heating and combustion heating components are considered part of the air system.

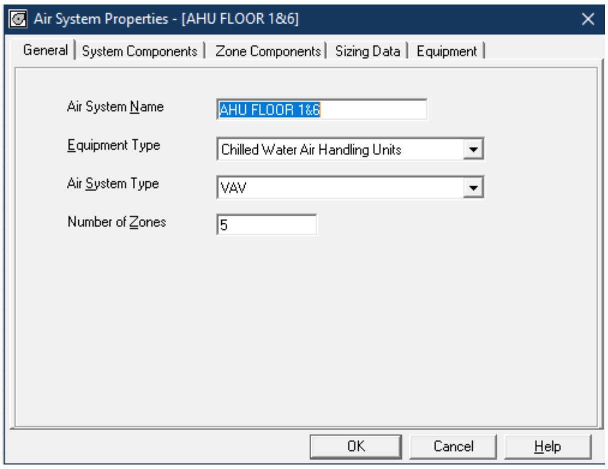

Figure 3.11 Air system properties

For Hospital Pasir Gudang chilled water air handling units were choose as equipment type and vav selected as the air system type. For floor 1 and floor 6 there's got 5 zones. This zone indicates the departments in floor 1 and floor 6. For hospitals is remmended to use variable air volume cause vav systems supply air at varaible temperature and airflow from the air handling unit (AHU).

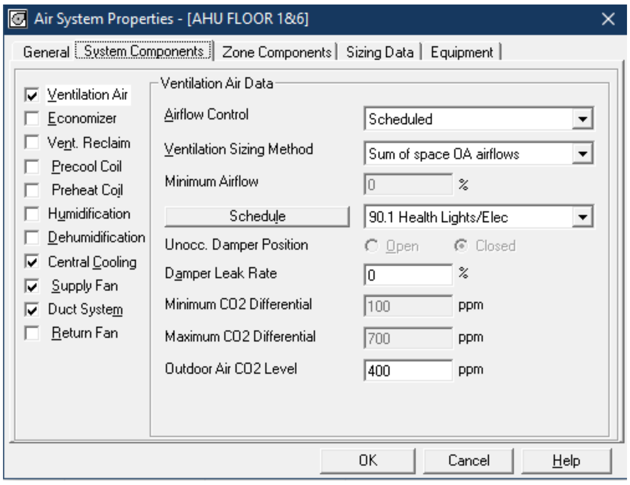

Figure 3.12 System Components (Ventilation)

The System Components tab on the System Form contains information about centrally located components in the system such as fans and coils, and information about the distribution duct system. This system components can be set different for each room in the rooms located in floor 1 and floor 6. Scheduled ventilation is placed for Hospital Pasir Gudang follows ASHRAE 90.1 Health Light/Elec.

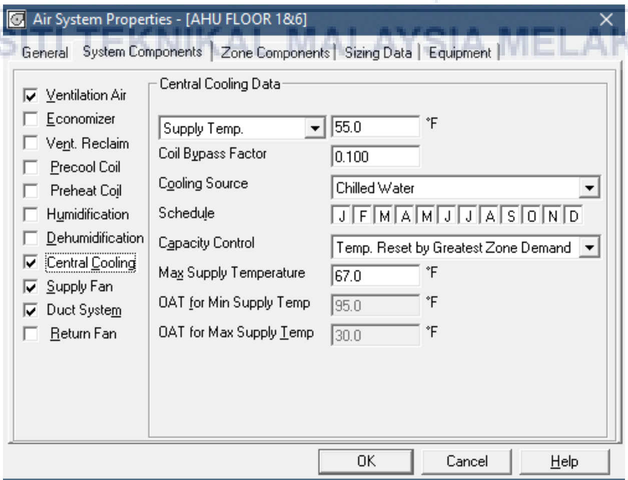

Figure 3.13 System Components (Central Cooling)

The Central Cooling data view contains information about the central cooling coil and related control and sizing characteristics. The capacity control temperature reset by greatest zone demand is happens during occupied system operating hours, the system runs continuously to condition and ventilate. The supply air temperature is reset according to the greatest sensible cooling load among zones served by the system. Maximum supply temperature can be 67 F.

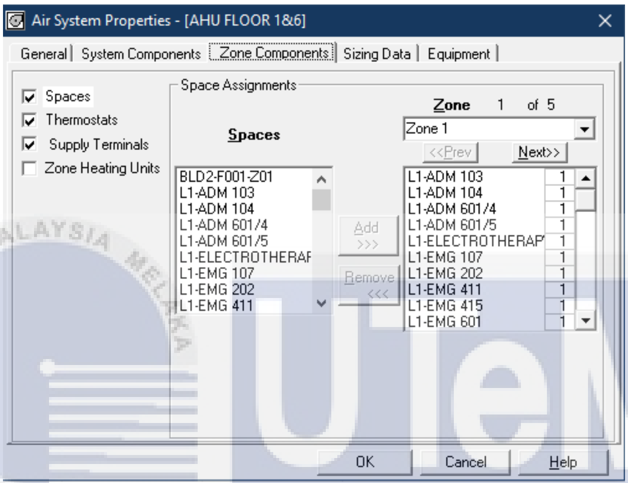

Figure 3.14 Zone components

The Zone Components shows in figure 3.14 is the System Form contains information about components located in or adjacent to zones served by the system. This includes supply terminals, thermostats, supplemental heating units and the spaces included in the zone. The total number of rooms in floor 1 & floor 6 zone out in 5 separate zones.

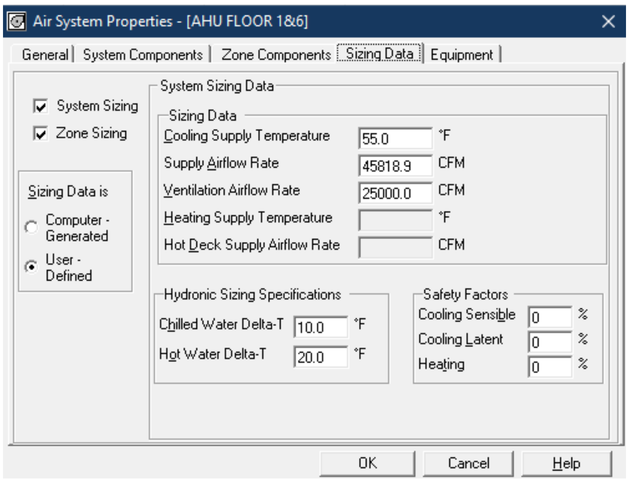

Figure 3.15 System Sizing Data

System sizing data interface shown in figure 3.15 Supply Airflow Rate is the design airflow rate delivered by the central supply fan. In a 2-Fan Dual Duct system this refers to the design airflow rate for the cooling supply fan. This item is not applicable for terminal unit systems.

3.4 Summary

Chilled water system is proposed for hospital Pasir Gudang because it's more efficient when compare with air cooled chiller. Some more , this chiller is more user friendly and doesn't impact the environment of the healthcare facility. For this design preparation used HAP to calculate cooling load which can be used in hospital Pasir Gudang. In general, the method used to design a chilled water system design is initiated with collecting hospital indoor and outdoor parameters. Those parameters are important in calculate a load profile for commercial building.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and analysis on the chilled water system design for Hospital Pasir Gudang, Johor Baharu. This chilled water system design was proposed for floor 1 and 6 in the hospital. As mentioned earlier in this Hospital planned to propose a chilled water system instead of air system. This is due to the efficiency and lifespan of a chiller. Chilled water system is more efficient because it condenses depends on the ambient dry bulb temperature. On other hand, the usage of water base system requires less space when compared with air cooler system. For this hospital had some modifications in entering condenser water temperature (ECWT) and leaving chilled water temperature (LCHWT).

For hospital Pasir Gudang applied water cooled centrifugal chiller due to the efficiency purpose. Commercial buildings like heavy workload office, shopping mall and hospital are more recommended to use centrifugal chillers. Cause these buildings sets their chiller lifespan for more than 5 year and need to achieve desired temperature in a short period due to the higher occupancy level. The theoretical value of energy efficient rating (EER) these centrifugal chiller can reach is 6.99.

The value of cooling coil load from the result obtained for hospital Pasir Gudang is 243.1tons. For this value of load decided to propose 2 chiller which works 60% of chiller 1 and 40% of chiller 2 which work as a part load. As a limitation purpose cooling tower and air distribution system are not included in these results.

4.2 Results and discussion

a) Air system simulation

Table 4.1 Monthly air system simulation

Month	Central Cooling Coil Load (kBTU)	Supply Fan (kWh)	Lighting (kWh)	Electric Equipment (kWh)
January	767613	26900	23195	27808
February	727059	25059	20485	24560
March	827129	27942	22760	27287
April	787934	26248	21525	25806
May	872602	27767	23195	27808
June	788013	26258	21857	26204
July	807177	27192	22428	26889
August	811960	27318	23195	27808
September	733931	25933	21090	25285
October	790246	26853	23195	27808
November	707995	25279	22291	26725
December	716716	26295	21993	26368
Total	**9338374**	**319044**	**267208**	**320358**

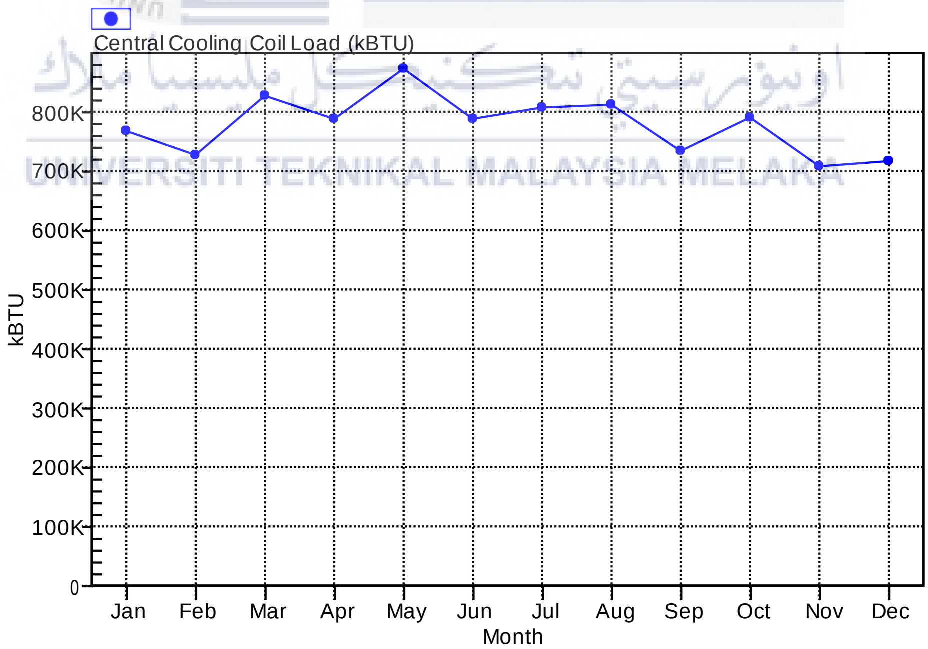

Figure 4.1 Central cooling coil monthly load (kBtu)

From Table 4.1 the data showed central cooling coil load, supply fan, lighting and electric equipment. Central cooling coil load differs from January to December, which weather is one of the factors for the load values. While in May recorded the higher value of cooling load where on May the workload is more compare with other months. This can be proven through the graph 4.1. While that the lowest central cooling coil load was detected for December. This might be a reason of weather and occupant most likely patients, staffs and doctors. When the number occupant decreases cooling load increase as well. Annually the central cooling coil data tabulated as 9338374 (kBtu). Lighting and electric equipment were calculated as well to identify amount of energy released by.

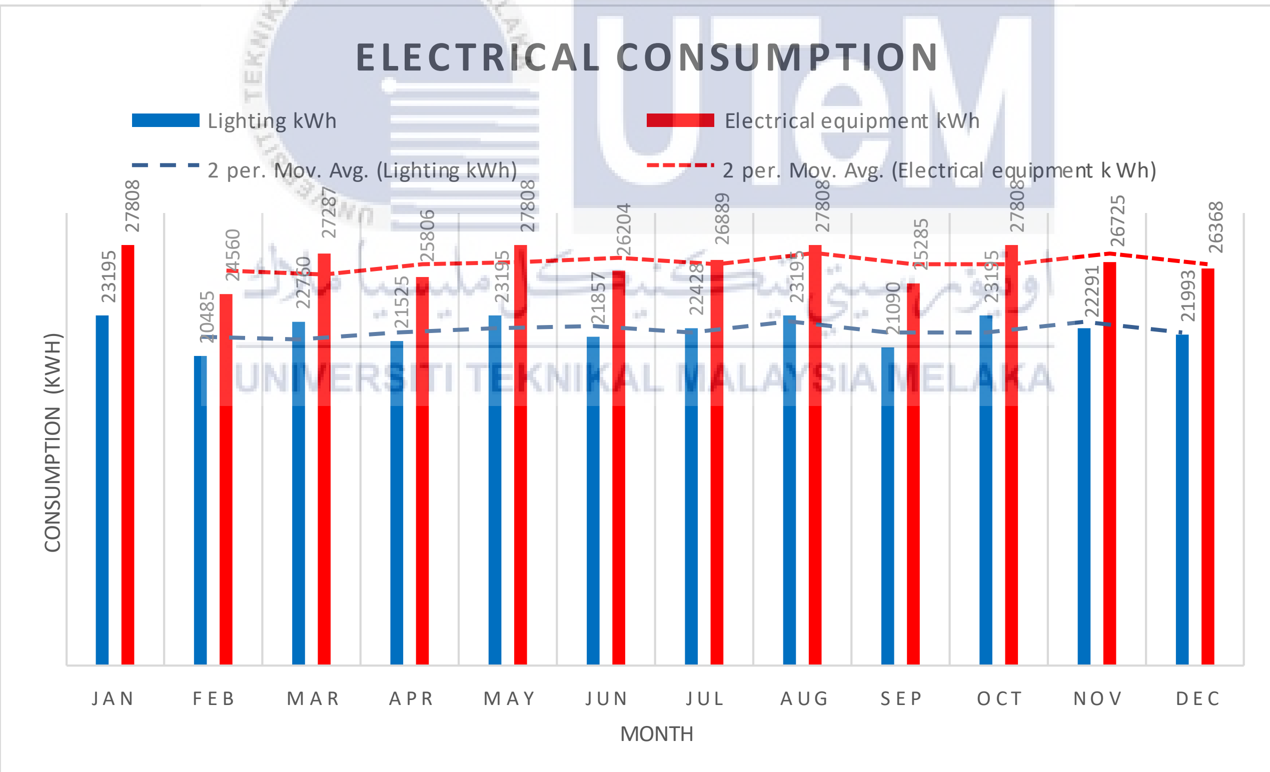

Figure 4.2 Anually Electrical Consumption

The above graph describes electrical consumption from January till December. This graph illustrates lighting and electrical equipment consumption. The least electrical consumption was detected in February. As a prediction scenario, in February in hospital

Pasir Gudang had the least occupants all over the year. When there are fewer occupants the lighting and equipment schedule won't function 100%. While that the higher consumption of electrical equipment and lighting were recorded in May and October. Power consumption increases when usage of electricity in the hospital is not limited. Higher electrical usage in hospitals will affect ambient temperature by the heat emitted by the electrical equipment and lightings. This might affect annual cost for electrical billing and chiller maintenance.

Table 4.2 Hourly air system simulation for May

Hour	Dry-Bulb Temp (°F)	Central Cooling Coil Load (MBH)	Supply Fan (kW)	Lighting (kW)	Electric Equipment (kW)
0000	81.9	585.1	34.8	4.3	5.1
0100	81.5	565.4	34.7	4.3	5.1
0200	81.1	553.6	34.1	4.3	5.1
0300	80.7	536.8	34.0	4.3	5.1
0400	80.4	527.0	33.5	4.3	5.1
0500	79.3	511.7	33.2	4.3	5.1
0600	78.1	498.4	32.7	4.3	5.1
0700	77.7	483.7	32.5	4.3	5.1
0800	80.1	554.5	33.2	8.5	10.2
0900	83.4	573.9	32.6	8.5	10.2
1000	84.6	570.2	33.3	8.5	10.2
1100	85.7	587.1	33.2	8.5	10.2
1200	86.4	602.7	33.9	8.5	10.2
1300	86.0	614.0	34.0	8.5	10.2
1400	86.5	618.0	34.7	8.5	10.2
1500	87.3	647.1	35.1	8.5	10.2
1600	87.1	578.5	34.9	4.3	5.1
1700	86.2	583.0	35.8	4.3	5.1
1800	84.5	595.0	35.5	4.3	5.1
1900	82.2	589.0	35.7	4.3	5.1
2000	81.1	582.7	35.1	4.3	5.1
2100	81.1	569.0	35.0	4.3	5.1
2200	80.9	558.5	34.4	4.3	5.1
2300	80.1	538.4	34.1	4.3	5.1
Total		13623.3	820.0	136.3	163.5

Table 4.2. shows hourly simulated air system in May. The highest dry bulb temperature detected at 1500hrs with 87.3 (°F). At this time the central cooling coil load was 647.1MBTU. As well as lighting and electric equipment higher consumption of 8.5kW and 10.2kW occurred in the morning till evening 1500hrs.

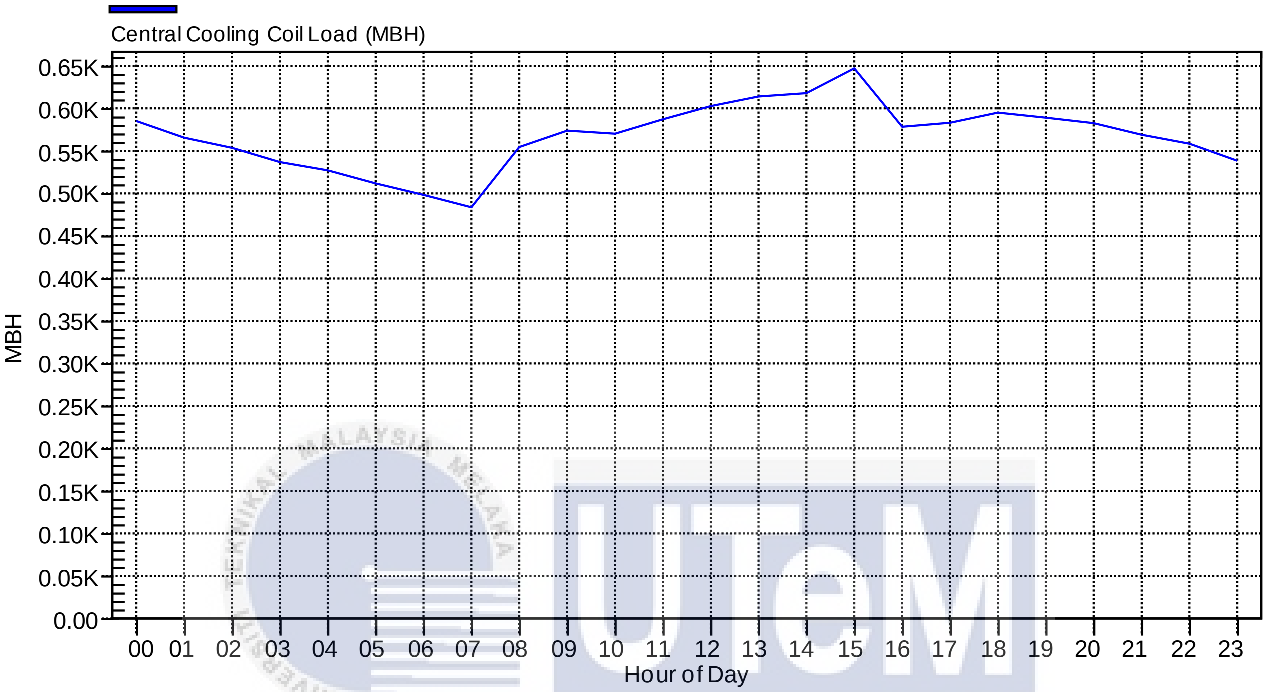

Figure 4.3 Hourly Simulation Results for May

As shown in graph 4.3 the higher MBH required is at 1500hrs. This can happen due to the activity level of occupants and number of occupants as well higher exposure to sunlight might transfer the heat from outdoor to indoor through walls and windows. The occupant's activity might be heavy work, likely major cleaning or waiting for registration at level 1. While the patients might be scheduled to do any activity at that specific time.

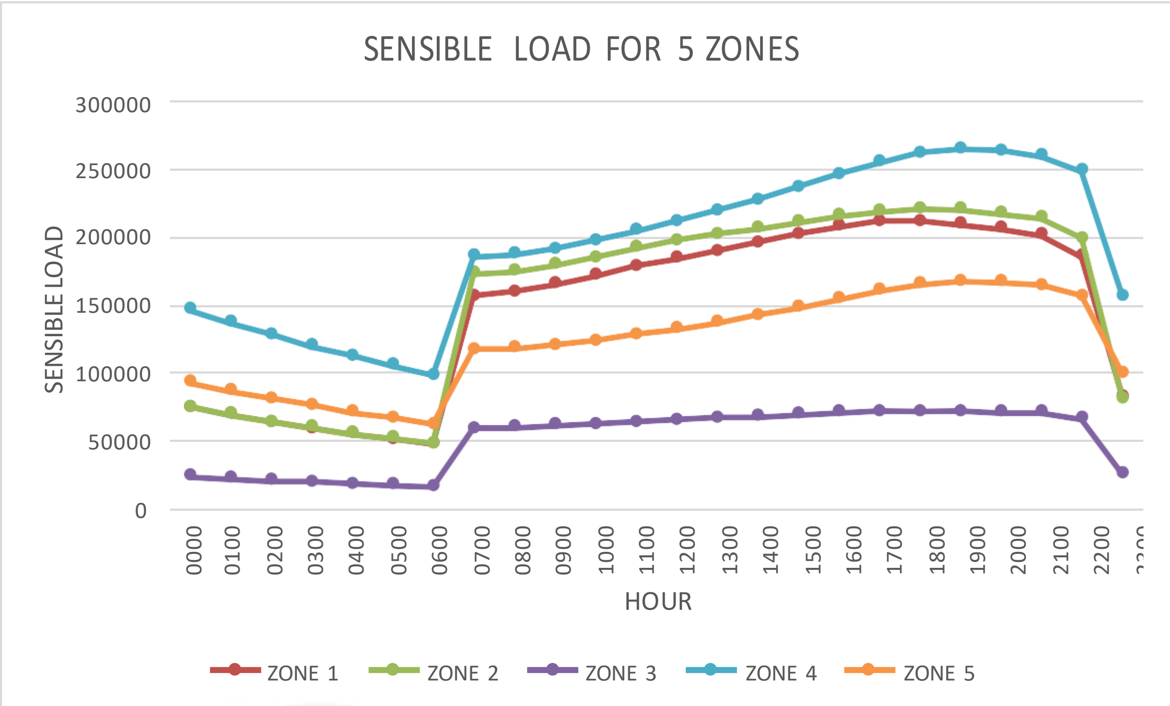

Figure 4.4 Hourly sensible load for 5 zones

The graph above shows the hourly sensible load for 5 zones in hospital Pasir Gudang. Zone 4 indicates has the most occupant and electrical usage compared to other zones. Zone 4 is in floor 6. Floor 6 is mostly built with isolation room, large patient room and doctor or nurse offices. Another factor of higher sensibility is because of outdoor air temperature. At zone 5 in May the higher temperature exceeds 87F which might transfer some heat into the hospital building through windows and walls. Because the wall in hospital Pasir Gudang is built with Stucco + 4" HW Concrete Block where the outside surface color is medium. The thickness of 4-in common brick is 4.00in and 1-in stucco at 1.00in as well. Meanwhile, the absorptivity is stated as 0.675. On other hand, floor 6 is located below roof where most of the heat transfer can take place. The roof details applied for hospital Pasir Gudang is shown in table 4.3.

Table 4.3 Roof layer details

Layers	Thickness in	Density lb/ft³	Specific Ht. BTU / (lb·°F)	R-Value (hr·ft²·°F)/BTU	Weight lb/ft²
Inside surface resistance	0.000	0.0	0.00	0.68500	0.0
4-in LW concrete block	4.000	38.0	0.20	1.51515	12.7
2-in HW concrete	2.000	140.0	0.20	0.16700	23.3
4-in face brick	4.000	125.0	0.22	0.43290	41.7
4-in LW concrete block	4.000	38.0	0.20	1.51515	12.7
0.5-in slag or stone	0.500	55.0	0.40	0.05000	2.3
Outside surface resistance	0.000	0.0	0.00	0.33300	0.0
Totals	**14.500**			**4.69820**	**92.6**

b) Plant Simulation

A Plant is the equipment and controls which provide chilled water to cooling coils, hot water, or steam to heating coils, or chilled and hot water to coils in one or more air systems. Plant simulation required to create a new chiller property for the space in floor 1 and 6.

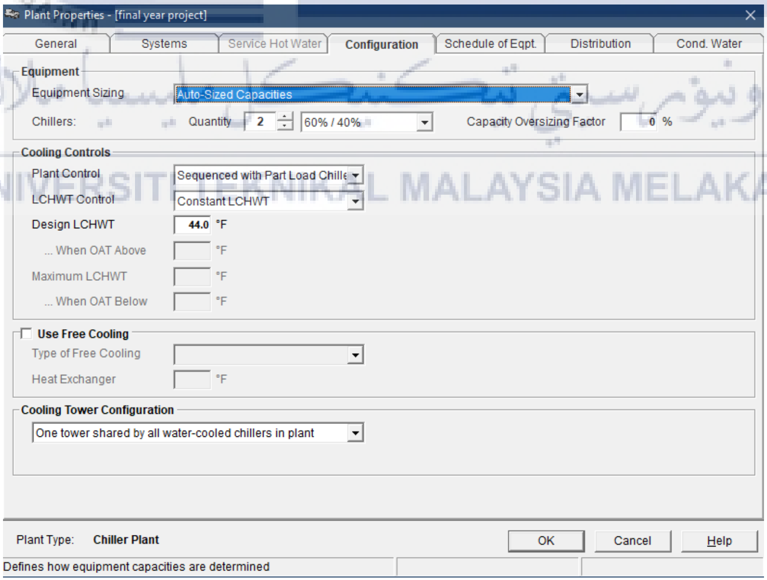

Figure 4.5 Plant Properties

This plant's properties can be changed for different project. Normally for a building one extra chiller will be purchased to run at part load. This situation happens to a larger size building. Normally in a building part load chiller as an extra will be placed to prevent another chiller running at full capacity. Running at constant speed will reduce the lifespan of the chiller plant. The plant was sized into 60% and 40% which means chiller 1 would be work for 60% to supply chilled water and chiller 2 will be a part load which works 40% to supply chilled water. In chillers, part load defines most of the time the chiller won't reach its full capacity running till outdoor temperature reaches as per design. This type of sizing doesn't cost a lot on the chiller system and just needs one cooling tower system which can be shared by two chillers. Basically, this type of standby chiller is made up in every industry due to any maintenance issue on any one of the chillers. So that, another chiller can work normally to supply chilled water system.

Table 4.4 cooling load for floor 1 & 6

Air System Name	Mult.	System Cooling Coil Load [Tons]
AHU FLOOR 1&6	1	243.1

The cooling load required for floors 1 and 6 is 243.1 Tons. The tonnage is quite high due to the occupant, electrical equipment, and lighting in each room. Floor 1 had more room when compared with floor 6.

CH-1	**243.1**	Tons
Part-Load	**100.0**	Tons
Total:	**343.1**	Tons

This is the designed chiller plant for floor 1 & 6. While chiller 1 is on full capacity than part load is at 100tons. The total weightage of the selected chiller is 343.1 Tons. The second chiller will be function when there's less sensible heat which had to remove from the indoor to outdoor space. Upsizing a chiller is due further improvement of building in future.

Cooling Plant Sizing Data:

Maximum Plant Load	**243.1**	Tons
Load occurs at	May **1600**	
ft²/Ton	**252.7**	ft²/Ton
Floor area served by plant	**61450.0**	ft²

The above details show cooling plant sizing data which maximum plant load of the system for floor 1 and 6 is 243.1Tons. This specific full load occurred in May at 1600. For a total area 61450.0ft² from floor 1 and floor 6 is served by this plant with 252.7ft² /Ton.

Full Load LCHWT	**44.0**	°F
Full Load Entering Condenser Temp	**87.0**	°F
Full Load Capacity	**243.1**	Tons
Full Load Input Power	**855.0**	kW
Average Operating Loss	**10.0**	%
Chilled Water Supply Flow Rate	**2.400**	gpm/Ton
Condenser Flow Rate	**3.000**	gpm/Ton

The input above is made up for chiller design in hospital Pasir Gudang. The leaving chilled water temperature is set at 44F and entering condenser temperature set about 87F. Chilled water supply for cooler is 2.400 gpm/ton while condenser flow rate is set about 3 gpm/ton. The flow rate of water or refrigerant is important to take in order where proper flow is essential for efficient heat exchange within the chiller.

Table 4.5 Cooling Perfomance

Entering Condenser Temp (°F)	Max Cap	100%	90%	80%	70%	60%	50%	40%	30%	20%
115.0	1153.9	1153.9	1009.1	878.7	767.9	666.7	579.1	515.7	444.9	388.1
100.0	1004.3	1004.3	877.0	765.9	669.1	578.7	504.3	449.0	388.9	338.8
90.0	904.6	904.6	791.1	690.7	603.3	521.4	454.5	404.6	350.9	305.4
85.0	854.8	854.8	747.5	653.0	570.4	492.3	429.5	382.4	332.1	288.9
80.0	804.9	804.9	705.2	615.4	537.5	464.1	404.6	360.1	312.8	272.1
75.0	756.5	756.5	661.6	577.8	504.6	435.9	379.7	338.5	293.6	255.6
70.0	706.6	706.6	619.3	540.2	471.7	407.7	355.4	316.3	274.4	238.8
60.0	608.3	608.3	532.1	465.0	405.9	350.5	305.6	272.4	236.3	205.7

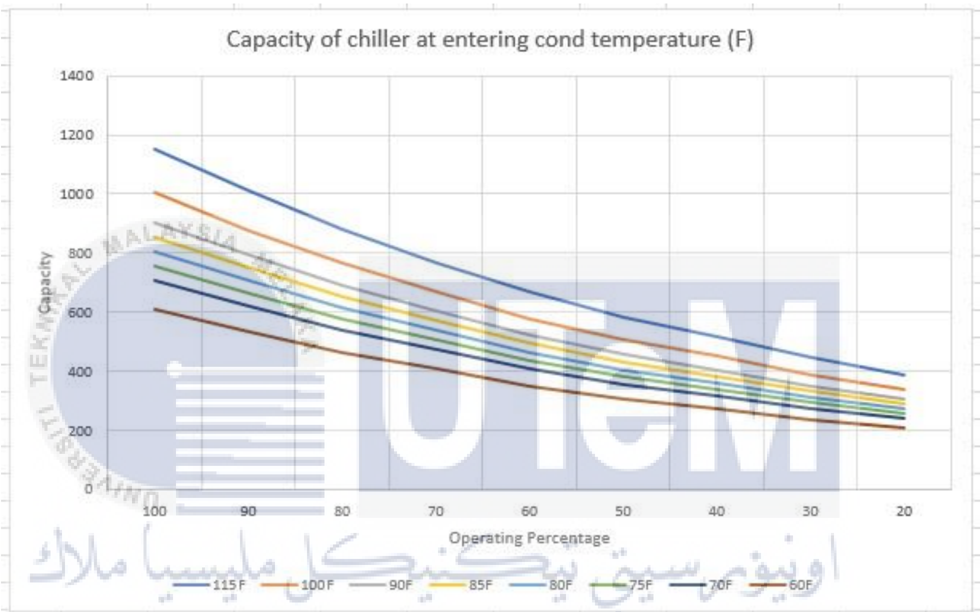

Figure 4.6 Capacity of chiller at entering condser temperature (F)

The maximum capacity of chiller for hospital Pasir Gudang results were presented in input power (kW) which is 1159.3kW. This chiller will be running at 1153.9kW at 100% with minimum condenser entering temperature of 60 F. 20% capacity of chiller is required to run at 205.7 kW with condenser entering temperature 60 F. Figure 4.6 shows reduction of capacity directly proportional with condenser entering temperature. As the 60F is the minimum temperature the capacity of the chiller starts to drop at 608.3 when 100% capacity of running capacity. When the condenser entering temperature at 115F, the chiller performs

1153.9kW at 100% full load. While the chiller performs 388.1kW at 20% of chiller capacity and condenser entering temperature was 115F. The chiller performs at 205.7kW when at 20% of the chiller capacity with entering condenser temperature of 60F. This is a good sign for a performing chiller cause the chiller limited it performance when theirs is less cooling load to inject. This can avoid a chiller compressor to work overload and can prevent from overflow.

Table 4.6 Chiller hourly load profiles

	DESIGN MONTH: MAY	
Hour	OA TEMP [°F]	TOTAL COOLING [Tons]
0000	72.6	58.2
0100	71.6	56.4
0200	70.6	53.5
0300	69.8	51.1
0400	69.2	48.7
0500	69.0	46.8
0600	69.4	45.1
0700	70.4	116.9
0800	72.2	126.3
0900	74.8	141.2
1000	77.8	158.1
1100	81.2	178.2
1200	84.4	196.6
1300	86.8	211.4
1400	88.4	222.3
1500	89.0	228.7
1600	88.4	229.3
1700	87.0	225.9
1800	84.8	217.5
1900	82.2	206.1
2000	79.6	193.2
2100	77.4	181.4
2200	75.4	161.9
2300	73.8	61.6
	Total Ton-hrs	3416.3

This hourly load profile is addressing total cooling loads for an hour and expected outdoor air temperature from morning till night 0000. In the morning the total cooling is still at low range and at 0700 in the morning the total cooling raise drastically to 116.9Tons. The value gets to lower at 2300 night with the outdoor air temperature 73.8 F.

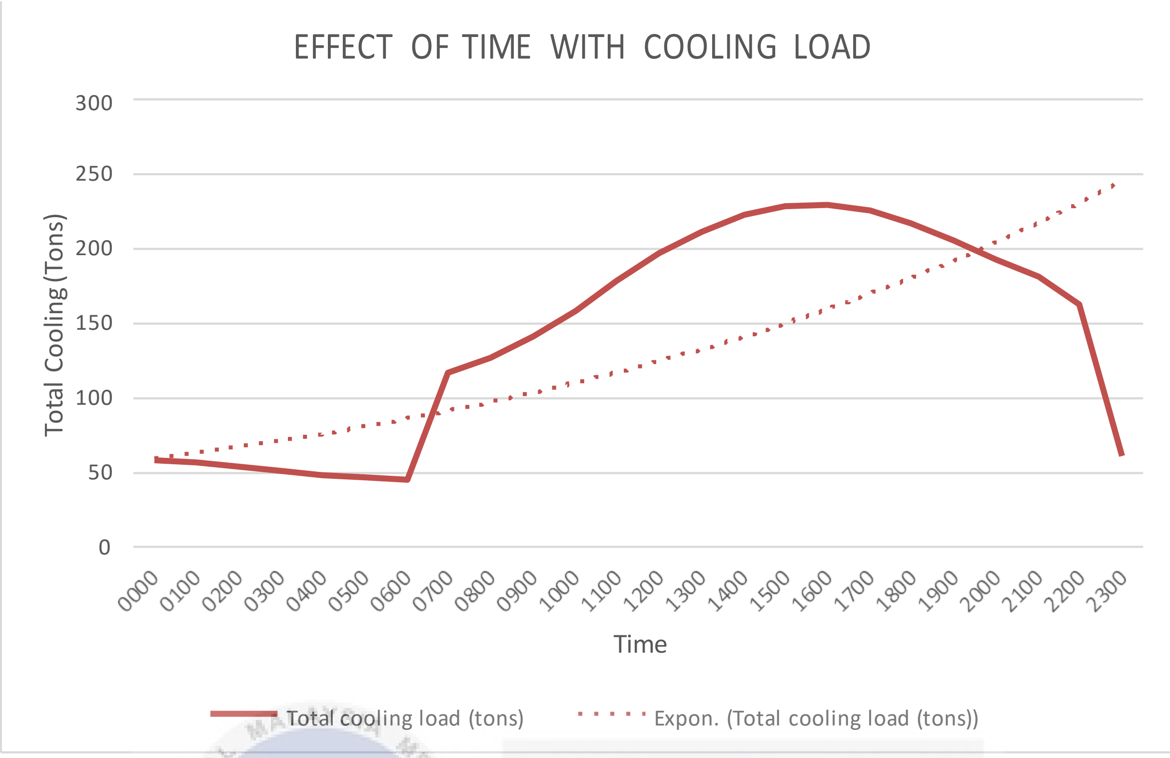

Figure 4.7 OA Temperature VS total cooling tons

Graph 4.7 show the total cooling (Tons) different time zone. The total cooling performance is measured throughout the day in hospital Pasir Gudang. When referred from the trendline shown in graph above for total cooling load, peak time indicates nearly full load capacity of running chiller. In this case the peak time starts at 1300 with the total cooling load 211.4 Tons. Meanwhile between 1500 and 1600 the total cooling of the building reaches 228.7 Tons to 229.3 Tons. This time zone is the peak hour for hospital Pasir Gudang. There are some factors which can make the chiller run at maximum capacity. Firstly, the factor which can be observed is temperature. As per collected data, at a time 1500 and 1600 the approximate time would be 89F. When focused occupant it might be one of the factors which affects the chiller operating efficiency to a higher grade. The time exactly after lunch break there'll be more occupant when compared with normal working hours. Even more doctors and nurses will be on duty at that time to assist the patients. Lastly, equipment usage would be one of the factors which forces chiller to run at maximum capacity to reject the heat.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the design and proposal for implementing a chilled water system in a healthcare facility underscore the critical importance of creating a sustainable and efficient environment to ensure optimal functioning of medical equipment, enhance patient comfort, and promote the overall well-being of both patients and healthcare professionals.

The comprehensive analysis of the healthcare facility's requirements has led to the development of a tailored chilled water system that not only meets the immediate cooling needs but also anticipates potential future expansions and technological advancements. The emphasis on energy efficiency, environmental sustainability, and cost-effectiveness has been a guiding principle throughout the design process.

By incorporating state-of-the-art technologies, such as variable speed pumps, energy recovery systems, and smart control systems, the proposed chilled water system not only minimizes operational costs but also contributes to the facility's commitment to reducing its carbon footprint. The focus on reliability and redundancy ensures that critical areas within the healthcare facility, such as operating rooms and diagnostic suites, maintain optimal temperatures consistently.

Moreover, the collaborative approach involving various stakeholders, including engineers, architects, and healthcare professionals, has been instrumental in creating a design that seamlessly integrates with the existing infrastructure while addressing the unique challenges of a healthcare setting.

As the healthcare industry continues to evolve, the implementation of an advanced chilled water system is poised to enhance the overall resilience and adaptability of the facility. The proposed solution not only aligns with current best practices in healthcare infrastructure but also positions the facility for future advancements in medical technology and increased patient demands.

In essence, the chilled water system design and proposal presented in this thesis serve as a robust foundation for creating a sustainable and technologically advanced environment within healthcare facilities. Through careful consideration of energy efficiency, environmental impact, and the unique needs of healthcare settings, this proposal aims to contribute to the continuous improvement of healthcare infrastructure for the benefit of both patients and healthcare professionals.

5.2 Recommendations

As a improvement in designing a chilled water system for a commercial buildings projects few recommendations can be implement;

i) Include implementation of smart control system that utilize real-time data analytics and predictive modeling to optimize the chilled water system's performance.

ii) Including regular maintenance and monitoring protocols for a comprehensive maintenance schedule and monitoring protocols for the chilled water system components. Regular inspections, preventive maintenance, and swift resolution of any issues will ensure the system operates at peak efficiency, minimizing downtime and potential disruptions to critical healthcare operations.

iii) Include training programs for facility staff including engineers, technicians and operational personnel to ensure they are well-versed in the operation, maintenance, and troubleshooting of the chilled water system.

iv) Include flexibility for future expansions where This proactive approach will mitigate the need for major retrofitting or system overhauls in the face of evolving healthcare demands.

v) Including continous monitoring of energy consumption to identify opportunities for further energy savings, optimize system performance, and align with sustainability goals.

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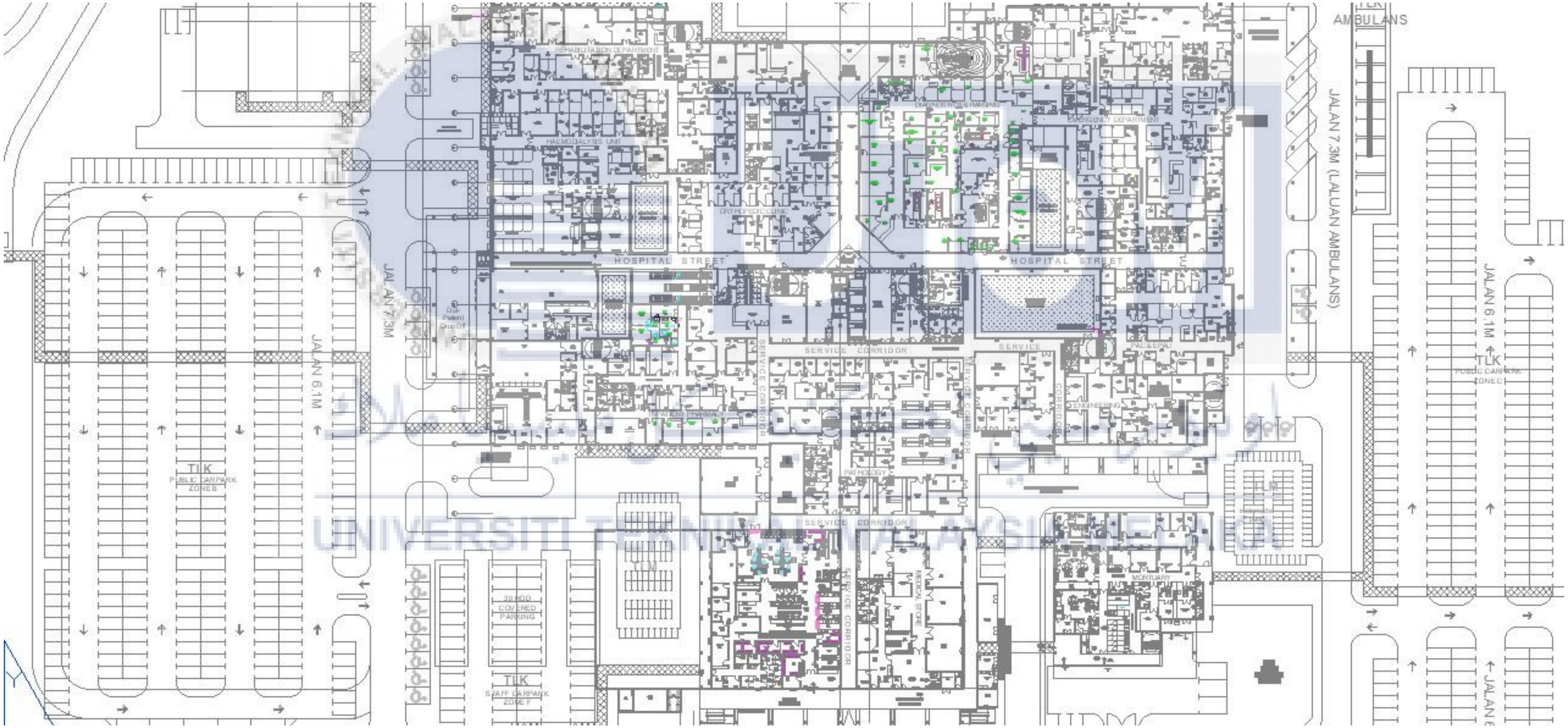
APPENDICES

APPENDIX A Floor Plan (FLOOR1)



FLOOR PLAN (FLOOR 6)

SPACE DATA TEMPLATE FOR HOSPITAL PASIR GUDANG

Deapartment	Space	ROOM NO	Area (ft2)	Height (ft)	Wall Orient	External Perimeter (ft)	External Wall Area (ft2)	Partition Perimeter (ft)	Partition Area (ft2)	Total Partition Area	Window (%)	FACH	FA Airflow (cfm)	Min ACH	Min Airflow (cfm)	ft2/person	Room Temp (C)
REHABILITATION	BEDROOM	RHB 503	95	10.0	W	8.86	88.58				1	2	40	4	70		23
	KITCHEN W/DINING	RHB 505	201	10.0	N	12.55	125.49					2	70	10	340		24
	EQUIP ROOM	RHB 316	71	10.0				8.74 (E)	87.40 (E)			2	30	10	120		25
	HOU (OT)	RHB 204	100	10.0				10.00 (N)	100.03 (N)			2	40	4	70		23
	HOU (PSYIO)	RHB 203	95	10.0				10.00 (N)	100.00 (N)			2	40	4	70		23
	HOD	RHB 201	118	10.0				15.01 (E)	150.07 (E)			2	40	6	120		23
	SEMINAR ROOM	RHB 213	165	10.0				10.35 (N), 15.45 (W)	103.48 (N), 154.46 (W)	257.9		2	60	6	170		23
	OCUPATIONAL THERAPY		771	10.0								2	260	6	780		23
	ELECTROTHERAPHY		770	10.0								2	260	6	780		23
HAEMODIALYSIS UNIT	CLEAN UTILITY	HAE210	92	10.0								2	40	4	70		25
	EQUIPMENT STORE	HAE309	101	10.0								2	40	6	110		25
	FLUID STORE	HAE308	383	10.0	W	15.01	150.10					12	770	10	640		25
	OPEN TREATMENT BAY	HAE203, HAE203A, HAE208	2,402	10.0	W	70	13701.2				9	2	810	6	2410		22
	NURSE STATION	HAE201	137	10.0								2	60	6	160		23
ORTHOPEDIC CLINIC	CLEAN UTILITY	SCO418	103	10.0								2	40	4	70		25
	EQUIPMENT STORE	SCO421	113	10.0								2	40	6	120		25
	C/E ROOM 1	SCO405	160	10.0								2	60	6	170		23
	C/E ROOM 2	SCO406	160	10.0								2	60	6	170		23
	C/E ROOM 3	SCO407	160	10.0								2	60	6	170		23
	C/E ROOM 4	SCO408	160	10.0								2	60	6	170		23
	C/E ROOM 5	SCO409	160	10.0								2	60	6	170		23
	C/E ROOM 6	SCO410	160	10.0								2	60	6	170		23
	C/E ROOM 7	SCO411	160	10.0								2	60	6	170		23
	C/E ROOM 8	SCO412	160	10.0								2	60	6	170		23
	WAITING AREA	SCO402	660	10.0								2	230	4	450		23
	RECEPTION	SCO401	193	10.0								2	70	4	130		23

GANTT CHART

MID-SEM BREAK/STUDY WEEK	

GANTT CHART															
PSM 2															
PROJECT ACTIVITY	OCTOBER			NOVEMBER				DECEMBER				JANUARY			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Problem statement															
Project objective and Scope															
Study past related projects															
Methodology															
Progress Report															
Submit Logbook															
Submit Report PSM 2															
Presentation PSM 2															