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Kale Mawlood MINA

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Kale Mawlood MINA

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İmza

Danışman :Prof. Dr. Hüsamettin BULUT .....

Üye :Prof. Dr. Refet KARADAĞ .....

Üye :Dr. Öğr. Üyesi Cuma ÇETİNER .....

Bu Tezin Makine Mühendisliği Anabilim Dalında Yapıldığını ve Enstitümüz Kurallarına Göre Düzenlendiğini Onaylarım

Doç. Dr. İsmail HİLALİ
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Signature

Supervisor :Prof. Dr. Hüsamettin BULUT .....

Member :Prof. Dr. Refet KARADAĞ .....

Member : Asst. Prof. Cuma ÇETİNER .....

I confirm that this thesis was made in the Mechanical Engineering Department and it was organized according to the rules of our Institute.

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ÖZET

Yüksek Lisans Tezi

HASTANELERDE İKLİMLENDİRME UYGULAMALARININ ENERJİ VE EKSERJİ ANALİZİ

Kale Mawlood MINA

Harran Üniversitesi
Fen Bilimleri Enstitüsü
Makina Mühendisliği Anabilim Dalı

Danışman: Prof. Dr. Hüsamettin BULUT
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Günümüzde artan çevre, enerji ve ekonomik sorunlara çözüm için ısıl sistemlerde enerji ve ekserji analizinin yapılmasını gerektirmektedir. Hastaneler ve sağlık tesisleri, ısıtma, soğutma, klima ve havalandırma sistemleri (HVAC) için en önemli uygulama alanlarıdır. HVAC sistemleri hastanelerde yoğun olarak kullanılmakta ve önemli bir miktarda enerji tüketmektedirler. Dolayısıyla hastanelerdeki HVAC sistemlerinin enerji ve ekserji analizinin yapılması gerekmektedir. Bu çalışmada hastanelerde kullanılan HVAC sistem ve uygulamaları anlatılmış ve Irak, Süleymaniye'deki Qaladze hastanesindeki termal şartlarla birlikte kullanılan HVAC sistemlerinin termodinamiğin birinci ve ikinci yasalarına göre enerji ve ekserji analizleri yapılmıştır. Yapılan analizlere göre kazan ve klima santralleri için ortalama ısıl enerji ve ekserji verimleri sırasıyla %89, %19.5 ve %81.5, %24; chiller grubunun soğutma performans katsayısı ortalama 4.82 olarak hesaplanmıştır. Hastane iklimlendirilmesinde kullanılan HVAC sistemleri incelenmiş, standartlar ve enerji açısından problemlere çözümler sunulmuştur. Hastanenin değişik mahallerinde sıcaklık, bağıl nem ve hava hızı ölçümleri yapılmış ve ölçüm sonuçları standartlarla karşılaştırılarak analiz edilmiştir. Genelde iç ortamdaki sıcaklık, bağıl nem ve hava hızlarının standartlarda belirlenen sınırlar arasında olduğu tespit edilmiştir. Yaz ve kış mevsiminde değişiklik olmasına rağmen ölçüm sonuçlarına göre bağıl nemin ortalama %30 ve oda sıcaklıklarının ise 24ºC civarında olduğu görülmüştür. İç ortam sıcaklık ve bağıl nemdeki değişimin hastanedeki yoğunluğa bağlı olduğu belirlenmiştir. Hastanedeki değişik odalardaki iç hava kalitesini ve ısıl koşullarını iyileştirmek ve parametrelerin satandartlardaki maksimum ve minimum değerler arasında kalmasını sağlamak için klima santrali ve HVAC sistemlerinin tüm bileşenlerinin sürekli kontrol edilmesi gerektiği görülmüştür. Ayrıca enerji verimliliği açısından tesisatın ve cihazların periyodik bakımlarının yapılması, tesisat izolasayonun yapılması ve tesisatta yanlış uygulamaların düzeltilmesi gerekir.

ANAHTAR KELİMELER: Hastane, Enerji, Ekserji, İklimlendirme, İç Hava Kalitesi

ABSTRACT

MSc Thesis

ENERGY AND EXERGY ANALYSIS OF HVAC APPLICATIONS IN HOSPITALS

Kale Mawlood MINA

Harran University
Graduate School of Natural and Applied Sciences
Department of Mechanical Engineering

Supervisor: Prof. Dr. Hüsamettin BULUT
Year: 2020, Page: 101

Nowadays, with increasing environmental, energy and economic problems were require energy and exergy analysis in thermal systems. Hospitals and healthcare facilities are the most important application areas for heating, cooling, air conditioning and ventilation systems (HVAC). HVAC systems are used extensively in hospitals and consume a significant amount of energy. Therefore, energy and exergy analysis of HVAC systems in hospitals should be carried out. In this study, HVAC systems and applications used in hospitals are explained and energy and exergy analysis of HVAC systems used in Qaladze hospital in Sulaymaniyah, Iraq were done in accordance with the first and second laws of thermodynamics with the thermal conditions. According to the analysis, the average values of thermal energy and exergy efficiencies for the boiler and air handling units were 89%, 19.5% and 81.5%, 24%, respectively; The cooling performance coefficient of the chiller group was calculated as 4.82 on average. HVAC systems used in hospital air conditioning have been examined, and solutions have been presented for problems in terms of standards and energy. Temperature, relative humidity, and air velocity measurements were made in different parts of the hospital and analyzed under comparison the standards. In general, it has been determined that the indoor temperature, relative humidity, and air velocities are within the limits determined in the standards. Despite the changes in summer and winter seasons, the relative humidity was found to be around 30% and room temperatures around 24ºC. It was determined that the change in indoor temperature and relative humidity depends on the density in the hospital. All components of the air handling unit and HVAC systems should be constantly checked to improve the thermal conditions and indoor air quality in the various rooms in the hospital and to keep the parameters between the maximum and minimum values in the standards. Also, in terms of energy efficiency, periodic maintenance of the installation and equipments, isolation and wrong applications in the installation must be corrected.

KEYWORDS: Hospital, Energy, Exergy, HVAC, Indoor Air Quality

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SYMBOLS

Symbols	Definition	Units
φ	Chemical energy factor	-
$\dot{E}_{AHU\ w/a}$	Energy air handling unit water/air	kW
$\dot{E}b_{fuel}$	Boiler fuel energy	kW
$\dot{E}b_{w}$	Boiler water energy	kW
$\dot{m}_{fuel}$	Mass flow of fuel	kg/s
$\dot{m}_{bw}$	The mass flow rate of water	kg/s
$\dot{W}_{c}$	Work of compressor	kJ/kg
$\dot{Ex}_{cp}$	Exergy compressor	kW
$E_{X_{AHU_{w/a}}}$	Exergy air handling unit water/air	kW
E_{i}	Input energy	kW
E_{L}	Energy losses	kW
E_{o}	Output energy	kW
E_{X}	Exergy	kW
h_{i}	Input enthalpy	kJ/kg
H_{net}	Calorific value	kJ/kg
h_{o}	Output enthalpy	kJ/kg
Q_{Cd}	Power of condenser	kW
Q_{Cp}	Power of compressor	kW
Q_{e}	Power of evaporator	kW
T_{0}	Environmental temperature	°C
T_{BST}	Boiler surface temperature	°C
$\dot{Ex}_{cd}$	Exergy condenser	kW
η_{I}	Energy efficiency (thermal efficiency).	%
η_{II}	Exergy efficiency	%
COP	Coefficient of performance	
Ex_{0}	Outlet exergy	kW
Ex_{i}	Inlet exergy	kW
h	Enthalpy	kJ/kg
P	Pressure	Pa
QL	Exergy obtained by fuel combustion of value for exergy in the boiler house.	kW
RH	Relative Humidity	%
S	Entropy	kJ/kg.K
$\dot{Ex}_{ex.v}$	Exergy expansion valve	kW
$\dot{Ex}_{ev}$	Exergy evaporator	kW

ABBREVIATIONS

AC	: Air Conditioning.
ACH	: Air Changes per Hour.
AFI	: American Filter Institute.
AHU	: Air Handling Unit.
AM	: Average Arrestance Efficiency for Coarse Filters.
ASHRAE	: American Society of Heating Refrigerating and Air-conditioning Engineers.
BMS	: Building Management Systems.
CAV	: Constant Air Volume.
CCU	: Cardiac/Coronary Care Unit.
CFD	: Computational Fluid Dynamics.
CFU	: Colony-Forming Unit
CHS	: Central Heating System
CSSD	: Central Sterile Services Department.
EM	: Average Efficiency for Fine Filters.
fpm	: Feet Per Minute.
HEPA	: High-Efficiency Particulate Air Filter.
HVAC	: Heating, Ventilating, and Air-Conditioning.
IAQ	: Indoor Air Quality.
ICU	: Intensive Care Unit.
IEQ	: Indoor Environmental Quality.
IEST	: Institute of Environmental Sciences and Technology.
MERV	: Minimum Efficiency Reporting Value.
MPPS	: Most Penetrating Particle Size.
N/A	: Not Available.
N/D	: Not Defined.
NBS.	: National Bureau of Standards.
OR	: Operating Room.
PE	: Protective Environment.
RH	: Relative Humidity.
ULPA	: Ultra Low Penetration Air Filter.
UV	: Ultraviolet Irradiation.
UVGI	: Ultraviolet Germicidal Irradiation.
VAV	: Variable Air Volume.

1. INTRODUCTION

Hospitals are a vital part of any modern health and service system along with growing the world population and industrialization in the countries. Increasing energy needs and energy costs turned the eyes to the heating, cooling, ventilation, and air-conditioning (HVAC) system in the hospitals. Analysis of energy and exergy in HVAC systems according to thermodynamic laws are used to evaluate suitable devices for air conditioning and ventilating of the hospital. Energy is needed to maintain the operation with indeed to available work of the HVAC system. Exergy is another name to obtainable energy in the thermodynamic terms during the work of the HVAC system. The minimum work needs to supply the system undergoes process between the specific initial and final states in terms of thermodynamics, when analyzed energy and exergy of the HVAC systems (Alhazmy, 2006).

HVAC systems in the hospital are very demanding and play a determinant role in indoor environmental quality (IEQ). Also, energy efficiency in the HVAC system is required to affect the supply of air system and indoor air quality (IAQ), with increasing the effectiveness of ventilation to improving thermal comfort in hospitals. The thermal comfort to occupant comfort is acceptable ranges for temperature and humidity in the spaces of the hospital. Also, in hospitals, the amount of energy is required to properly all parameters when usage in air-conditioning must be according to standards in the world. Commonly air conditioning and ventilation are used to control of parameters of the hospital. Ventilation requirements and optional points are comparatively easy to achieve the perfect room air distribution and room conditions. The room condition was a general guide for 80% of the occupants in usual office spaces and thermal environments over a wide range of the parameters (Rock, 2006; Rock, 2002).

In ASHRAE standard-62, ventilation and indoor air quality (IAQ) are to accept in the low-rise, and have important roles with minimum rations for mechanical and natural ventilation systems and building envelope to provide accepts of the IAQ. Ventilations were applied from the spaces intended to the occupancy within the

single-family of houses and low-rise multifamily buildings (ASHRAE, Standard-62, 2004). IAQ is the process of air comfort that gives in every system and does not cause negative health effects or disease in the hospitals. Also, IAQ is used to control (i.e. protects to airborne hazards such as tuberculosis bacteria and other infectious or chemical agents like anesthetic gases and pharmaceuticals that may become airborne during operation) and parameters (i.e. temperature, humidity, and air velocity) were to maintain indoor comfort conditions. The parameters for energy conservation must not adversely affect the patient's health, safety or accepted personal comfort levels of air in hospitals (ASHRAE, 1999a). The air in the hospital must be aseptic, at a constant temperature and humidity, and have relatively low velocity. The proper air for indoor comfort conditions (thermal, visual, and acoustical) and IAQ should be suitable environments of the hospitals especially in the operating room (OR).

The facilities of IAQ must be provided to a proper comfort condition in any situation of the hospitals (ASHRAE, 1999b). The regulation of facilities are specified that the air in the rooms with usable types of filters in air handling units (AHUs). The types and number of filters in the (AHUs) are used to critical design areas to serve sterile spaces in the hospital. Types and number of filters are used to prevent air pollution in the rooms (ASHRAE, 2004; Williams, 1992). The applications of room air and air distribution are depending on air velocity by occupied zone in any spaces, and locations of space layout equipment may differ cause of applications in outdoor conditions (ASHRAE, 2011). Air distribution inside of the hospital especially in the (OR) was to protect the patient and medical staff while maintaining occupant comfort and not affecting surgical tasks. In ORs, HEPA-filtered air and vertical (downward) laminar airflow are often used to achieve the unidirectional flow of fresh air from the ceiling, washing over the patient and flowing out of exhaust vents on the sidewalls (Zhai, 2013; ASHRAE, 2004). The applications directional of air is related to the HVAC system between the designed criteria of areas and energy conservation can be reduced energy consumption (Karimipanah, 2008; VDI, 2004).

The aim of this study is to the analysis of energy and exergy for the HVAC system and revealing all applications when creating on the HVAC systems with keeping sterile spaces to the stability of environmental conditions for all patients and medical staff in the hospital. Also, the goals of this study are given details information about heating and cooling of air-conditioning and ventilation by using thermodynamic laws for analyzed energy and exergy in HVAC systems of the hospital Qaladze in Sulaymaniyah from Iraq. The amount of analysis energy and exergy are revealed from the tables, diagrams, and figures in the results. The HVAC systems must be very careful about the selection to correct devices and compliance with related standards. Therefore the HVAC system should be given hygienic air conditioning in the hospital building in terms of health and comfort conditions because in the hospital air must be fresh 100%. The air of the hospital must be aseptic to low velocity, constant temperature, and relative humidity, therefore the recommendation values must be accepted under the standards and guidelines. HVAC systems for comfort conditions were focused on the increasing or decreasing of parameters, such as temperature, relative humidity, mass flow, the velocity of air, etc. which of them are used to optimum work of HVAC system in the hospitals. The quality of the HVAC system must be provided to the proper environment occupancy of the hospital. Moreover, this paper is presented the amount of energy and exergy analysis, and major problems of HVAC systems during seasons master planning and including space layout function within the relation of the HVAC system and the parameter applications in the hospital.

2. PREVIOUS STUDIES

Hospital and health buildings are places with special indoor environments and complex of the mechanical installations. The illustrative examples for HVAC system applications are used energy and exergy analysis with the effect of parameters when used to air-conditioning in hospitals. Besides, air-conditioning system in hospital is considered in terms of ventilation and IAQ in the study domestics and mostly related to the HVAC systems. Some valuable studies illustrated the subject are given below.

First et al. (1999), presented some invaluable information about the type and number of filters and filter groups are used to in air handling unit (AHU) and designated to serve an OR must demand of similar only to cleanroom application and the filters must maintain the high air quality. The filters must be maintained and properly to their optimum performance. Installations that gave an equivalent number of air changes based on equivalent levels of the lessening in airborne microorganisms and bacteria hazardous can be available.

Memarzadeh (2002), previewed that the laminar flow is the beast comfort condition in the operating room during an experimental study using the computational fluid dynamics (CFD) in an airflow modeling to comparison the risks in OP and back table for different ventilation systems. He was thought that the air supply from diffusers varied within sizes and geometry depends on the specific design position and the number of diffusers. So, the air return units also vary in size and geometry, depending on the function spaces. Subsequently, he was investigating two air exhaust outlets inside the surgical suite and failure of air exhaust are about 25% of the ceiling level air outlet and 75% of the floor level air outlets.

Dharan and Pittet (2002), carried out of the experimental study were that the tables related to the classification of the operating rooms in the surgical site. According to their risks of the category are investigated the levels of airborne particles when presented in the University Geneva Hospitals in Switzerland. They are tested and found that of set bacterial levels for probably ventilated in the ORs and most recommendations such as 20 ACH to get 50-150 cfu/m^3 to the air.

Chengqin et al. (2002), determined another name for exergy available energy to produce useful work in the HVAC system and improved indoor thermal conditions in the hospital. In the experimental study presented that of indoor thermal condition for the 20 ORs of the Hellenic Hospitals, and indicated indoor temperature by ranged 13.8-28.98°C, relative humidity 13-80%, when averaging 22-8°C and 37%, and the number of air changes per hour (ACH) ranged 3.2-58, respectively. Besides, they are indicating to indoor conditions of majority ORs did not conform to the strict optimum in indoor thermal conditions under international standards.

The levels of microbiological contamination in the operation rooms (ORs) are important. It recommended that to specify condition during rest was 35 cfu/m^3 of the OR and the amount of microbiological should not exceed 180 cfu/m^3 in OR from the UK. When are used ultra-clean of the laminar flow for the OR the amount of microbiological levels should be 10 cfu/m^3 under maximum conditions, and the levels of microbiological at rest of the OR should be 20 cfu/m^3 for the clean area (Chow and Yang, 2005).

Balaras et al. (2007), illustrated that the levels of a particle in the operating room according to ISO 14644-1. This standard is taken to the classification of air cleanliness for the Classrooms in the type operating room. The Classroom should not be greater than Class 7 of the operating room since cleanliness must be very high in the OP rooms. So, they indicated that the surgery carried out much of the downward and outward of the airflow to the prevented effect of microbiologically when are avoided hold wound and sepsis since the clean area should be raised.

Stevenson (2008), carried out in an experimental study and analyzed a CFD to determine the airflow patterns around the patient in the operating room. He found in both experimental data CFD analysis and floating flow that did not play a leading role in keeping the surgical site especially in the operating room conditions should be under the limit of standards of the hospital. It recommended that furthermore, research should be utilizing particle tracking to determine flow particles within the airflow in the hospital operating rooms.

HVAC systems are the biggest consumer for energy in hospital buildings and account for nearly 30% of the total building energy consumption. Furthermore, the energy intensity of hospital HVAC systems is more than times that of dwellings. A considerable body of research carried out to found reliable solutions and decreased energy consumption. It indicated that the climate of the hospital plays a major role when deciding energy-conserving HVAC systems for the hospital under mentioned specifically designed to certain climates (Bartley 2010; Ozyogurtcu 2011).

Wu et al. (2012), carried out in an experimental study to determine all the components of air-cooled water chiller. Furthermore, they investigated the angle configuration for condenser coils with the potential enhancement of the overall performance efficiency and the energy conversion efficiency for each component. Subsequently, they determined the amount of energy for the components, which were condenser 579.5 kW, evaporator 439.5 kW, compressor 140 kW, COP 2.93%, and amount for exergy destruction were 40.6 kW for the compressor, 20.3 kW for the condenser, 17.4 kW for the throttling device, and 6.5 kW for the evaporator. Thus, it was improved of overall performance approximately 3.4%, and the total irreversibility reduced by approximately 2.7% in the air-cooled water chiller. Also, carried out the study was found that for average wind speed over condenser coils raised up 1%, therefore, the overall performance of the air-cooled chiller was higher 0.43%, and total irreversibility was reduced by 0.35%.

Ergün et al. (2015), carried out in an experimental study multipurpose building for 3 years needs heating in an area of 80.000 m^2, in Ankara, Turkey. Also, it indicates the importance of analysis energy and exergy in HVAC systems and used in a central heating system (CHS) for heating. CHS's are generally designed for usage (First and second law) in thermodynamics. They are shown that the lowest efficiency in the heating exchanger and the highest efficiency in the boiler when analyzed of energy. Also, the exergy analysis was more realistic than energy analysis, and system performance increased by improving the boiler. The total amount of thermal and exergy efficiency of the boiler was 90 %, and 23 %, and so for the AHU were 73%, and 46%, respectively.

Altundağ et al. (2015), carried out in an exergy analysis are used a heating line in the air handling units (AHUs) for a surgery room in İstanbul Başkent Hospital. They handled an AHU that has a 3500 m3/h flow rate and a natural gas-fired boiler in their study. According to exergy analysis calculations, the exergy destruction and exergy efficiencies for the boiler and AHU were found that 554.28 kW and 3.11 kW, and 21.92% and 20.22%, respectively.

Misevičiūtė and Rynkun (2016), illustrated the important role of the ventilation system in providing the appropriate indoor climate in buildings. For improving energy efficiency in the building sector, which are responsible for the large percentage of global energy consumption. Therefore, in the study work focuses on the assessment of ventilation AHU and exergy analysis used to evaluate the performance of the AHU. They are indicating that the efficiency of ventilation should be related local climate and maybe varying with the values of temperature. It was calculated the seasonal exergy efficiency gives of the AHU analysis.

Chiang et al. (2017), established successfully verify a complete evaluation process for energy savings and increased efficiency for the large-scale hospital empowerment project in Taiwan. So, indicated that the energy-saving by integrating of the hot water system, (i.e. water source heat pump, WSHP) with the existing HVAC systems, and ability to separately supply cooling and hot water with a higher safety margin. Besides, it has found that providing efficient cooling with the integrated system, considering that useful cooling in certain areas of the hospital, such as the intensive care unit or operating room.

Hazim (2017), overviewed in an experimental study used a type of mechanical ventilation to the air distribution system in the buildings. He was briefly defined to the performance of some types of ventilation and IAQ providing and estimating performance for air distribution systems in the rooms. The air distribution systems are used two parts a landscape of the room environment. One method is used to a uniform environment and the other for both uniform and non-uniform conditions. These methods showed that the air distribution from the different room types while to the comparison of the term IAQ.

González et al. (2018), carried out the analysis of energy consumption for 23 municipal hospitals in Germany from the period 2005 to 2015, according to weather conditions, settled surface area, gross domestic product (GDP), geographic location (GL), number of beds and employees. Furthermore, average annual energy consumption in the hospital found that were 0.27 MWh/m^2, 14.37 MWh/worker, and 23.41 MWh/bed, in the normal conditions. In addition, they are indicating that the number of beds dependent on the reference when are measuring the energy consumption from the hospital has proven to be optimal.

Sözen (2018), investigated how to all air processes on the psychometric diagrams for the air conditioning unit and all air systems including in the special areas (operating room, intensive care) of the hospital. He also mentioned the importance of maintaining hygiene and sterility protection in the air-conditioning of equipment can directly affect the validation measurements into the hospitals. Also, the effect of the factors on the parameters and the applications are presenting in the graphics and diagrams from the result.

The aim of this study is to carry out energy and exergy analysis of HVAC applications in the hospital. Investigation of the parameters that affect the thermal performance of HVAC systems is another purpose of this study.

3. MATERIALS AND METHODS

3.1. Importance First and Second Laws of Thermodynamics for Energy and Exergy Analysis

Energy and exergy analysis of HVAC system application with all technologies when are related to the subject can be analyzed in the Qaladze Hospital of Sulaymaniyah from Iraq. Since analysis energy and exergy of the HVAC system in hospitals have a very desirable role in the environmental quality (IEQ). The quality of HVAC equipment should be provided with a suitable environment for the patients, hospital staff, employees according to the function of the hospital. The functions of the hospital for indoor comfort conditions depended on the design criteria of the HVAC system for accepted the levels of the personal condition of the room patients. The levels maintained to design criteria play a major role in maintaining the hygiene of the environment as can directly affect the validation of parameters. The parameters are related to the thermodynamic equations when analyzed energy and exergy in the HVAC system. The energy and exergy analysis were evaluated in the actual energy consumption for thermal systems in the central heating systems of the hospital (CHSs) (Özgener, 2003). The exergy analysis could be used to evaluate the performance of HVAC systems. The series of exergy analysis applications showed effectiveness in the HVAC system (Kanoglu et al., 2004).

Material and Method are divided into two parts, the first part consists of outdoor parameters of HVAC system, and the second part consists of the indoor parameters of HVAC system. The analysis of energy and exergy for each part can be mentioned to a specified work of the HVAC system in the Qaladze Hospital of Sulaymaniyah from Iraq. In this study, when taking a measurement of parameters such as temperature, relative humidity, mass flow, and air velocity are indicated the works of HVAC system of the hospital. Besides, the operation of HVAC systems may be involved in applications therefore the parameters may be raising or lowering during master planning. The application of parameters is indicated for the heating and cooling process of air conditioning in the hospital.

3.1.1. Energy and Exergy Analysis

Energy defined as the capacity for the work, and an important part of the daily life. Therefore, it is important to a good understanding of the renovation of energy, and analysis into HVAC system components. Consequently, the components of HVAC system such as mass flow can be considering that the form of energy used in a closed system (a fixed mass) in two different forms of heating and cooling process when transferred by energy. Besides, for control volumes, energy can be transferred by mass flow (Çengel and Boles, 2008). Also, the energy transfer of the closed system is caused by a temperature difference between out and in for both cycle heating and cooling in the HVAC system.

Energy, entropy and exergy concepts stem from thermodynamics and apply to all fields of science and engineering. The exergy analysis is more useful for system optimization because it can be defined for useful work and energy. It is increasingly important to enhance the use of exergy to other disciplines and develop exergy to achieve better design and analysis, better efficiency, better cost-effectiveness, better environment, better energy security, and better sustainability. This chapter focuses on the portion of the analyzed thermodynamic laws at the intersection of energy, entropy, and exergy fields. The scope of the Figure (3.1) below can be illustrated energy and exergy analyzed.

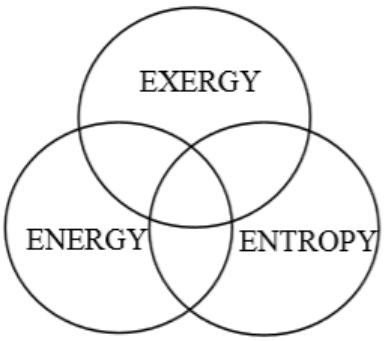


Figure 3.1. The intersection among the energy, entropy, and exergy (Dinçer and Rosen, 2007).

3.1.2. Thermodynamic Analysis (Analysis of First and Second Laws)

The thermodynamic analysis is expressed to the availability of energy and exergy. The first law of thermodynamics is used to calculation of energy balance capacity of the HVAC system. The second law of thermodynamic is also used to calculate of exergy when energy destroyed of the HVAC system. Also, the first and second laws of thermodynamics are used to calculate energy and exergy efficiency and information about to work of the HVAC systems. It is no provides information about the inability of any thermodynamic process to convert at fully into mechanical work, or any insight into mixtures cannot naturally separate (Aydın et al., 2007).

3.1.2.1. Energy Balance

The concept of energy conservation can be previously expressed by energy balance equations, and the balance of energy is used to solve many problems. When the first law of thermodynamics is applied to gas-vapor mixtures, vary to calculate of internal energy and enthalpy, it can be helpful to realize because of our assumption that ideal gases are involved, the various components can be treated separately (Sonntag and Wylen, 1991). The conservation of energy is express as follows: The net change (increase or decrease) in the total energy of the system is equal to the difference between the total energy entering and leaving the system during that process (Çengel and Boles, 2008).

$$\left[\begin{array}{c}\text{Total energy}\\ \text{entering the system}\end{array}\right] - \left[\begin{array}{c}\text{Total energy}\\ \text{leaving the system}\end{array}\right] = \left[\begin{array}{c}\text{Change in the total}\\ \text{energy of the system}\end{array}\right] \quad (1)$$

Note that energy is a property, and the value of the property does not change unless the state of the system changes. Where measuring and analyzing the energy consumption of different activities, therefore energy change of a system may be zero if the state of the system does not change during the process. The success is using the relation to solve problems depends on understanding the various forms of recognizing energy transfer.

3.1.2.2 Energy Analysis (First Law of Thermodynamics)

The energy analysis is used in the operation of materials to transfer the conversion of energy. The energy analysis is presented a percentage of energy losses and first law efficiency of the thermodynamic analysis. The first law thermodynamic as known energy analysis should be equal to the amount of energy inlet and outlet (Şahin et al., 2007), also called energy conservation that is expressed below:

$$\Sigma E_i = \Sigma E_o \quad (2)$$

The left side and right side of the equation express total energy input and output. The difference between them gives the total amount of energy loss that as follows:

$$\Sigma E_i - \Sigma E_o = \Sigma E_L \quad (3)$$

Where, ΣE_i is input energy, ΣE_o is output energy and ΣE_L is an energy loss. The efficiency of systems or devices is equal to the energy ratio of the outlet and inlet of system and devices. The efficiency of the first law can be determined by the following:

$$\eta_I = \frac{E_o}{E_i} \quad (4)$$

Where, η_I is thermal efficiency, or energy efficiency.

3.1.2.3 Exergy Analysis (Second Law of Thermodynamic)

The exergy analysis is also expressed a percentage of exergy losses and second law efficiency of the thermodynamic analysis. Exergy defined by the maximum work obtains due to the irreversibility of the work HVAC systems. Exergy analysis is an important device for evaluating and analyzing processes by identifying flaws due to thermodynamic irreversibility (Demircioğlu, 2010; Menlik, 2013). The equation specific exergy can be calculated from the following below (Şahin, 2007).

$$E_x = (h - h_0) - T_0(S - S_0) \quad (5)$$

Where, E_x: is exergy of the second law, h: is the enthalpy, T_o environmental temperature, and s is entropy. The exergy difference between inlet and outlet of points for the device can be expressed irreversibility (I):

$$I = \sum Ex_{inlet} - \sum Ex_{outlet} \quad (6)$$

The thermal efficiency is not an adequate criterion alone to evaluate exergetic efficiency, irreversibility (second law efficiency), is required (Çengel, 2008).

$$\eta_{II} = \frac{\text{useful work output}}{\text{maximum possible (reversible) work output}} \quad (7)$$

Where, η_{II} is exergy efficiency of the second law, $\sum Ex_{inlet}$ is total inlet exergy, $\sum Ex_{outlet}$ is the total outlet exergy. The exergy ratio is expressed as follows (Çomaklı, 2007).

$$\eta_{II} = \frac{Ex_0}{Ex_i} \quad (8)$$

3.1.3. Energy and Exergy Analysis of the Boiler

Energy and exergy analysis are considered of the heating system in the hospital building. The heating system of the hospital building is used for the heating process of air-conditioning in the winter season of the hospital. The hot water in the boiler enters the main heating and distributed to the boiler line, Air Handling Unit, and diffusers, as shown in Figure (3.2). The range of water temperature between 50-65°C, is produced from that the boiler.

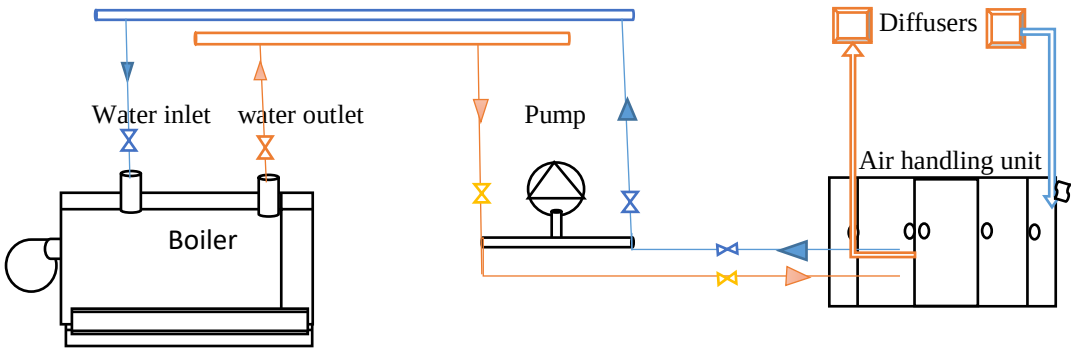


Figure 3.2. Schematic of a typical heating system with the boiler, AHU, and diffusers.

Figure (3.2) can be indicated that the process of heating in the boiler and then analyzed energy and exergy from the materials or devices. Boiler inlet energy is the amount of fuel combustion ($Eb_i = \dot{E}_{bfuel}$), and it can be calculated as follow:

$$\dot{E}b_{fuel} = \dot{m}_{fuel} \, X \, H_{net} \quad (9)$$

Where, $\dot{E}b_{fuel}$ is boiler fuel energy, $\dot{m}_{fuel}$ is mass flow fuel, and H_{net} is the net calorific value of (diesel fuel). The boiler output energy is the amount of energy when to the separating of water in boiler ($\dot{E}_{B_o} = \dot{E}_{bw}$) and it can be calculated as follow:

$$\dot{E}_{bw} = \dot{m}_{bw}[h_o - h_i] \quad (10)$$

Where, $\dot{E}_w$ is energy boiler water, $\dot{m}_{wB}$ is the mass flow rate of water. Eq. (3) can be reformulated according to Eq. (9) and (10), equation energy loss in the boiler can be acquired that form as follow:

$$\dot{E}_{b_L} = \dot{E}_{b_{fuel}} - \dot{E}_{bw} \quad (11)$$

Where, $\dot{E}_{B_L}$ is the energy boiler loss

Exergy analysis is used for calculation of second law efficiency of the boiler (Ergün, 2010). Inlet and outlet of total exergy in the boiler as shown in Figure (3.3).

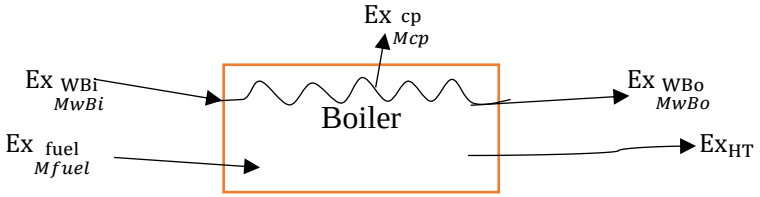


Figure 3.3. Exergy analysis for inlet and outlet of the boiler.

According to Figure (3.3), inlet exergy is the energy composes of fuel combustion ($Ex_{b\,fuel}$) and inlet exergy of fluid to the boiler (Ex_{bwi}). On the other hand outlet, exergy is the energy of combustion products (Ex_{bCP}), outlet exergy of fluid to the boiler (Ex_{bwo}) and heat transfer of boiler surface to the environment (Ex_{bHT}) (Çomaklı, 2002). The following equation is given as a total of exergy losses, acquired by reformulating eq. (6):

$$Ex_{b\,total} = Ex_{bfuel} + Ex_{bwi} - (Ex_{bwo} + Ex_{bHT} + Ex_{bCP}) \quad (12)$$

Exergy Analysis in Burned Fuel, the exergy of burned fuel can be indicated that the work of the boiler, as diesel fuel when connected with oxygen and nitrogen during comprising of a combustion natural gas fuel equation as seen the follows below (Çalışkan, 2009).

$$Ex_{bfuel} = \dot{m}_{fuel} * H_{net} * \varphi \quad (13)$$

Where Ex_{bfuel} is exergy boiler fuel, φ is chemical energy factor taken as (1.04) (Çomaklı, 2002; Kotaş, 1985), and H_{net} is the net calorific value of diesel fuel (UNECFE, 1978).

Exergy Analysis for Water Flow of the Boiler, the exergy of boiler inlet and outlet of water calculated from the equations below:

$$E_{Xb_{w_i}} = \dot{m}_{bw} [(h_{wi} - h_0) - T_0(S_{wi} - S_0)] \quad (14)$$

$$E_{Xb_{w_o}} = \dot{m}_{bw} [(h_{wo} - h_0) - T_0(S_{wo} - S_0)] \quad (15)$$

Where, $E_{X_{w_i}}$ is input exergy boiler water, $E_{X_{w_o}}$ is output exergy boiler water, $\dot{m}_{wB}$ is mass flow rate water of boiler, T_0 is the dead state or environmental temperature.

Exergy Analysis by Heat Transfer in the Boiler Surface, the exergy of heat transfer from boiler surface to the environment, this transition called as exergy losses on the surface of the boiler, and calculated as follows:

$$\sum Ex_{HT} = \dot{Q}_L \left(1 - \frac{T_0}{T_{BST}}\right) \quad (16)$$

$$\dot{Q}_L = \dot{m}_{fuel} \, x \, H_{net} - \left(\dot{E}x_B + \left(\dot{m}_{N_2} \cdot \Delta h_{N_2} + \dot{m}_{CO_2} \cdot \Delta h_{CO_2} + \dot{m}_{H_2O} \cdot \Delta h_{H_2O}\right)\right) \quad (17)$$

Where Ex_{HT} is the heat transfer exergy boiler kW, T_{BST} is the boiler surface temperature can be varied according to To environment, $\dot{m}_{cp}$ is the molecular mass flow of combustion product in the boiler, h is enthalpy combustion product in the boiler. So, Q_L acquired by subtraction of exergy by fuel combustion of value for exergy in the boiler, and equation (17) calculated by (Çalışkan, 2009).

Exergy Analysis for Combustion Product of the Boiler, the Exergy of combustion products in the boiler calculated in the following equation:

$$\sum Ex_{bc_P} = \sum \dot{M}_i \text{ x } Ex_i \quad (18)$$

Where $\sum Ex_{bc_P}$ is the total exergy of combustion product kW, $\sum \dot{M}_i$ is the total mass flow of combustion products kg/s, and Ex_i is the exergy of combustion products kJ/kg. The actual combustion of an equation is known to calculate the exergy value of the combustion product. This type of boiler should be used the equation of diesel fuel for the combustion product equation as shown in the following (UNECFE, 1978).

$$C_{12}H_{23} + 17.75(O_2 + 3.76N_2) \rightarrow 12CO_2 + 11.5H_2O + 66.74\, N_2 \quad (19)$$

After the calculation of total mass combustion of products found the percentage of total mass for each combustion product calculated by the following equation:

$$y_i = \frac{\dot{M}_i}{\dot{M}_{tot}} \quad (20)$$

$$\dot{M}_{tot} = \left(12 * \dot{M}_{CO_2}\right) + \left(11.5 * \dot{M}_{H_2O}\right) + \left(66.74 * \dot{M}_{N_2}\right) \quad (21)$$

Where, y_i is the mass fraction, $\dot{M}_{tot}$ is the total molecular mass of combustion products kg/kmol. The average yield is 1 % for natural gas combustion, the mass of combustion products is taken 0 loss during the combustion process (Ergün et al., 2015)

$$\dot{M}_{Cp} = \left(\dot{M}_{fuel} + \dot{M}_{air}\right) \text{ x } 1* \quad (22)$$

*in this equation, reacting of $\dot{M}_{air}$ with fuel can be ignored that from in eq. (22).

For calculation mass flow rate combustion of products and percentage values as follows:

$$\dot{M}_i = \dot{M}_{cp} \cdot y_i \quad (23)$$

Table 3.1. Mass flow rate and percentages of combustion products.

CP	M_i g	M_{tot} g	$y_i = \frac{\dot{M}_i}{\dot{M}_{tot}}$ (%)	$\dot{M}_{CP}$ kg/s	$\dot{M}_i = \dot{M}_{cp} \cdot y_i$ Kg/s
N_2	1868.72	2603.72	71.7712	0.0085	0.006101
H_2O	207	2603.72	7.95016	0.0085	0.000676
CO_2	528	2603.72	20.2787	0.0085	0.001724

The exergy of combustion products equals the addition of thermodynamic and chemical exergy. Combustion products' thermodynamic and chemical exergy total exergy value of flue gases acquired from that follow:

$$\sum Ex_{bc_P} = \dot{M}_{N_2} \text{ x } Ex_{totN_2} + \dot{M}_{CO_2} \text{ x } Ex_{totCO_2} + \dot{M}_{H_2O} \text{ x } Ex_{totH_2O} \quad (24)$$

3.1.4. Energy and Exergy Analysis of the Chiller

Chiller plants should be sized possible with current cooling loads when used to air-conditioning of the hospitals. The cooling system is used for the cooling process in the summer season of the hospital building. The chiller has three cycles to produce cooling water. The cold water of the chiller is pathed to the main cooling collectors and transfer to the chiller line and air-handling unit (AHU), as shown in Figure (3.4).

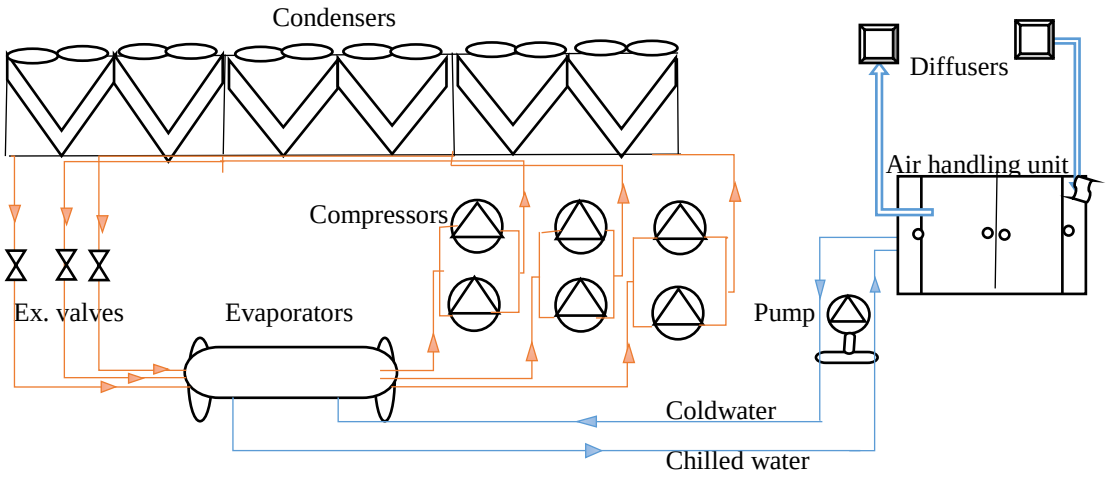


Figure 3.4. Schematic of a typical cooling system for the chiller, AHU, and diffusers.

From Figure (3.5) have an air-cooled water chiller, and energy and exergy analysis were done for all components of chiller such as compressor, condenser, expansion valve, and evaporator. The overall performance for the air-cooled water chiller is also calculated. So, T-s and P-h diagrams can be illustrated in the chiller cycle as seen in Figure (3.6).

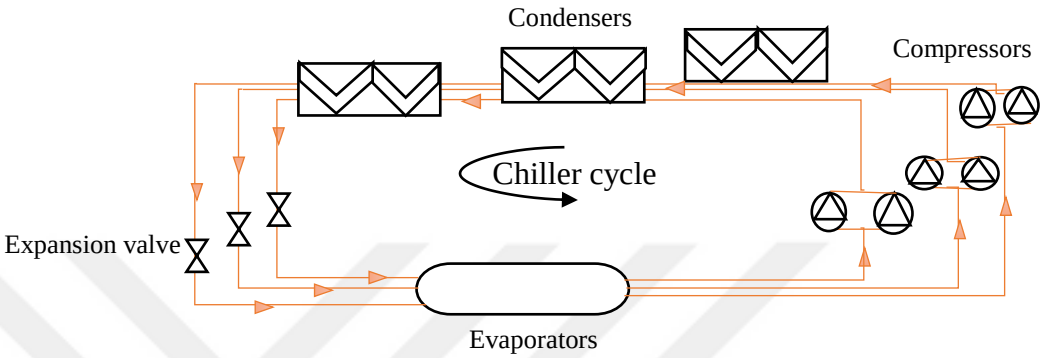
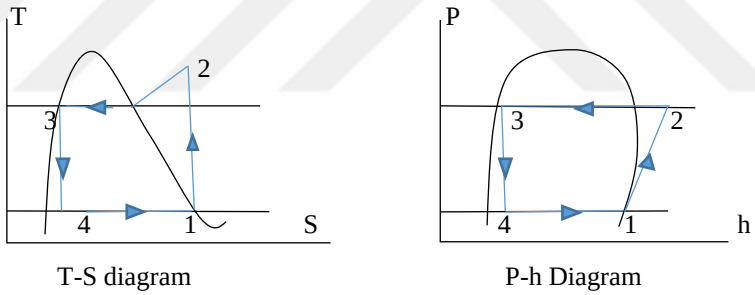


Figure 3.5 Sketch for air-cooled water chiller.



T-S diagram P-h Diagram

Figure 3.6. T-s and P-h diagram of the air-cooled water chiller.

The parameters and equations for energy and exergy analysis for the components in the chiller are given in Table (3.2) (Brown, 2001).

The coefficient of performance (COP) is used to evaluate the overall performance of the air-cooled chiller. COP is calculated as the ratio of evaporator capacity to the total consumption of the compressors as seen from the equation below (Lee, 2010; Wu et al., 2012).

Table 3.2. Equations of Energy and Exergy Analysis for Chiller Components.

Components	Mass Balance	Energy analysis	Entropy	Exergy analysis.
Compressor	$\dot{m}_2 = \dot{m}_1$	$W_{Cp} = \dot{m}_1(h_2 - h_1) + Wn$	$\phi_1 - \phi_2 = (h_2 - h_1) - T_o(s_2 - s_1)$	$\dot{E}x_{cp} = Wn - [\dot{m}_1(\phi_1 - \phi_2)]$
Condenser	$\dot{m}_3 = \dot{m}_2 + \dot{m}_1$ $\dot{m}_{ai} = \dot{m}_{ao} = \dot{m}_a$	$Q_{Cd} = \dot{m}_3(h_3 - h_2)$ $= \dot{m}_a c_{pa}(h_{ao} - h_{ai})$	$\phi_2 - \phi_3 = (h_2 - h_3) - T_o(s_2 - s_3)$ $\phi_{ai} - \phi_{ao} = (h_{ai} - h_{ao}) - T_o(s_{ai} - s_{ao})$	$\dot{E}x_{cd} = \dot{m}_3(\phi_2 - \phi_3) + \dot{m}_a(\phi_{ai} - \phi_{ao})$
Throttling valve	$\dot{m}_4 = \dot{m}_3$	$(h_3 = h_4)$	$\phi_3 - \phi_4 = (h_3 - h_4) - T_o(s_3 - s_4)$	$\dot{E}x_{ex.v} = \dot{m}_3(\phi_3 - \phi_4)$
Evaporator	$\dot{m}_4 = \dot{m}_3$ $\dot{m}_{w1} = m_{wo} = \dot{m}_w$	$Q_{ev} = \dot{m}_4(h_1 - h_4)$ $= \dot{m}_a c_{p\omega}(T_{w0} - T_{wi})$	$\phi_1 - \phi_4 = (h_1 - h_4) - T_o(s_1 - s_4)$ $\phi_{wi} - \phi_{wo} = (h_{wi} - h_{wo}) - T_o(s_{wi} - s_{wo})$	$\dot{E}x_{ev} = \dot{m}_4(\phi_1 - \phi_4) + \dot{m}_w(\phi_{wi} - \phi_{wo})$

Where, $\dot{m}$ is the mass flow rate in chiller kg/s, W_{Cp} is the energy of compressor kW, Wn is the power consumption of compressor kW, ϕ is a flow of exergy kW/kg, h: is the enthalpy kJ/kg, T_o: is the environmental temperature °C, S is the entropy kJ/kg.K. Q_{Cd} is the energy of the condenser kW, Q_{ev} is the energy of the evaporator kW, $c_{p\omega}$ is the specific heat capacity of water kJ/kg.K, c_{pa} is the specific heat capacity of air kJ/kg.K, $\dot{E}x_{des}$ is the exergy destruction kW.

$$COP = \frac{\dot{Q}_e}{\dot{W}_{c1+}\dot{W}_{c2}} \tag{25}$$

Where, COP is a coefficient of performance, $\dot{Q}_e$ is the capacity of the evaporator, and $\dot{W}_{c1}$, $\dot{W}_{c2}$ are the work of compressors.

3.1.5. Energy and Exergy Analysis of the Air Handling Unit (AHU)

AHU is used to transform of hot and cold water for hot and cold air, and distributed from the diffusers. The air must be sprayed through the processes of AHU to produce air-conditioning in the hospital. Additionally, the primary energy demand for heating and cooling of air-conditioning that can be transmitted fluid/air to elements of AHU contains two main supply and exhausts energetic analysis. So, exergy value is used to revealing the irreversibility of the operation AHUs. Besides, AHU is used for heating and cooling processes of air-conditioning in the hospital.

The energy equations for AHU are given below (Altundağ et al., 2015):

$$\dot{E}_{AHU\ water} = \left[\dot{m}_{AHU_w}\ x\ (h_{wo} - h_{wi})\right] \quad (26)$$

$$\dot{E}_{AHU\ air} = \left[\dot{m}_{AHU_a}\ x\ (h_{ao} - h_{ai})\right] \quad (27)$$

$$\eta_{AHUI} = \frac{\dot{E}_{AHU\ o}}{\dot{E}_{AHU\ i}} \quad (28)$$

Where, $\dot{E}_{AHU\ water/air}$ are the energy of water/air in AHU kW, $\dot{m}_{AHU_{w/a}}$ is the mass flow rate of water/air in AHU kg/s, $h_{wo,i/ao,i}$ enthalpy of water/air and output/input in AHU kJ/kg, η_{AHUI} is the energy efficiency of AHU %.

Exergy analysis in the AHU has excellent insulation, heat losses to the environment may be neglected that from elements as shown in Figure (3.7).

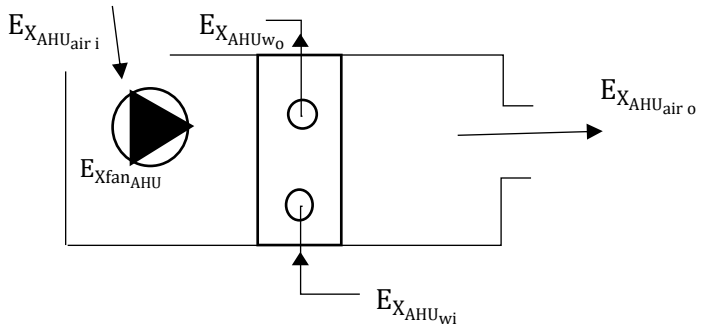


Figure 3.7. Exergy analysis for inlet and an outlet of the AHU.

Also, exergy value in the AHUs for the heating and cooling process of water air conditioning in the spaces could be calculated from the following equations:

$$E_{X_{AHUw_i}} = \dot{m}_{AHUw}\,[(h_{wi} - h_0) - T_0(S_{wi} - S_0)] \quad (29)$$

$$E_{X_{AHUw_o}} = \dot{m}_{AHUw}\,[(h_{wo} - h_0) - T_0(S_{wo} - S_0)] \quad (30)$$

When calculating the air part in AHU, exergy is assumed to be 0, because the air is drawn from the atmosphere (Altundağ et al., 2015). Exergy for the outlet of AHU as shown in equations below:

$$E_{X_{AHU_{air}}} = \dot{m}_{AHUa}\,[(h_{ao} - h_0) - T_0(S_{ao} - S_0)] \quad (31)$$

Where, $E_{X_{AHU_{wi,o/ai,o}}}$ are exergy water/air and output/input in the AHU kW, $\dot{m}_{w/aAHU}$ mass flow rate of water/air in AHU kg/s, $h_{wi,o/ao}$ enthalpy water/air and output/input in AHU kJ/kg, $S_{wi,o/ao,i}$ entropy water/air and output/input in AHU kJ/kg.K.

The power fan of AHU is equal to (3, 5.5, 11) kW from the catalog values can be using in the calculations, it could be varying according to the size of AHU. The Following statements, the total exergy equation and exergy efficiency for AHUs have calculated from that the following equations (Ergün et al., 2015).

$$Ex_{AHUt} = Ex_{AHU_{air_i}} + Ex_{AHU_{water_i}} + Ex_{AHU_{fan_i}} - (Ex_{AHU_{air_o}} + Ex_{AHU_{water_o}}) \quad (32)$$

$$\eta_{AHUII} = \frac{E_{X_{AHU_o}}}{E_{X_{AHU_i}}} \quad (33)$$

Where, Ex_{AHUt} is the total exergy in AHU kW, $\eta_{II\,AHU}$ is the exergy efficiency in the AHU, $Ex_{AHU_{fan}}$ is the exergy fan in the AHU.

3.2. Importance of IAQ and Air-Conditioning in the Hospital

The importance of indoor thermal conditions, ventilation, and IAQ should be considered in the design stage criteria of HVAC systems for each separate area in the hospital. Generally, ventilation systems should supply air for each section of the medical areas of the hospital. Since in the air handling plant for all medical areas should be 'blow-through' type with only cold coil and pre-filter upstream of the fan to certify no inward leakage of air downstream of the coils and main filter. Also, supplies of air for health care buildings have overall positive or neutral pressure and the extracted air exchanged by treatment to make-up air supplied, for example, internal areas, staff base in the ward areas. Therefore, outlets supplying air to ultra-clean areas such as operating sites, ICUs should be located on the ceiling, and outside or more exhaust outlets should be near the floor. So, the arrangement delivers were to the downward of clean air through the breathing and working zones for the floor area to the exhaust (ASHRAE, 2009).

3.2.1. Indoor Air Quality (IAQ) in the Hospital

Indoor air quality is very important for comfort conditions and for all occupants in hospitals. The indoor air quality is more complex due to the impurities of populations. Hospital buildings can suffer from the moisture damage due to some typical building structures. The renovations are complicated in the hospital surroundings to the processes that can be disrupted in the spaces. There are not enough spaces during some phases, such as microbes or molds that can spread throughout the indoor air. Indoor air problems have become a considerable challenge to occupational health causing significant impairment in hospitals such as employees, health, welfare, and productivity. Occupational health has an important role in recognizing and solving indoor air problems (Weschler et al., 2006; Weschler et al., 2011).

3.2.1.1. Prevention and Treatment to Diseases of Air Conditioning

Air conditions in the hospital should be identical to the patient rooms in the spaces. Consider locating the spaces are directly above from the treatment chair, and provided with the thermostat for individual patient control. Therefore, control the air over the patients can be provided to separate zone and control staff desks from the areas. Hospitalization is a clinical to separate areas dedicated to diseases of treatment and serious care of respiratory must be maintained the stability of levels RH at around 30-60%. In the room patient of treatment temperature and RH should be 32°C and 35%, therefore air must be positive of the hot dry air environment. All patients are needed oxygen to rehabilitation because they are required special care to ensure air simulation. Also, cold dry air is presented a dangerous situation of oxygen bypassing the nasopharyngeal mucosa of the hospitals. Both cases cold and hot dry were rebreathing procedures to reduced anesthesia gases and heat loss in beneficial environments. In addition, burn patients are needed a high relative humidity and hot environment such as room temperature should be up to 32°C, relative humidity up to 95% (Burch and Pasquale, 1962).

3.2.2. Indoor Air Quality in the Office Building

Indoor Air Quality (IAQ) is an impact concern to increasing health comfort and work-performance in office-like environments with the most force of workers. The Scientific Committee on Indoor Air Quality and Health has discussed the assessment and management for IAQ problems. Also, IAQ is recommended that integrates into the building assessment, inspection by walk-through of the office workplace, questionnaire survey, and environmental measurements. The workers are required to maintain a good IAQ, therefore they should be protecting the air when the diseases linked to the IAQ such as recurrent inflammation, infection of eyes, respiratory airway effects, and sensorial disturbances. Also, environmental and personal factor risks should be compiled and assessed from that IAQ (ASHRAE, 2011).

3.2.3. Parameters for Indoor Air Quality

HVAC systems must be avoided by air pollutions especially of the dust, dirt, odor, and chemical dangerous pollutants. The effects are mentioned to design parameters for the thermal comfort conditions in the hospital.

3.2.3.1. Outdoor Air Intakes

The outdoor air intake is adjacent areas visually examined to limit cleanliness at a minimum of every six months that need to be cleaned especially within the hospital. Because the air is more complex in the hospital when removed the visible debris of biological material. Outdoor air intakes should be located a minimum of 8 feet, (2.4 m) above grade 10ft, (3m) according to some codes of criteria. Intakes must not be located near potential contaminant sources, such as boiler and generator, laboratory exhaust vents, plumbing vents, and loading docks. Many information sources by accepted criteria to minimum distances from outdoor air intake to ensure separation and dilution. These spacing are varied such as 10 to 75ft, (3 to 23 m), with 25ft, (7.6 m) recommended by the FGI Guidelines and 30ft, (9.1 m) suggested by the ASHRAE Handbook-HVAC Applications (ASHRAE, 2011).

3.2.3.2. Temperature and Humidity

All codes and values for filter types are indicated in Table (3.3) according to standards and guidelines when specified the levels of temperature and relative humidity design range criteria in some areas were measured to comfort conditions under by standards. According to standards and guidelines are recommend different values for levels of temperature and RH of the hospitals. The ranges temperature and relative humidity can vary when used from the areas in the hospital for example, in the ASHRAE 18-26 °C and 30-60 %, AIA 20-23 °C and 30-60 %, DIN 19-26 °C and 30-60%, VDI 18-24°C and 30-50%, and NBR 19-24°C and 45-60%, were recommended ranges of temperature and RH, respectively (ASHRAE, 2011).

3.2.3.3. Air Filters

The air filters are collected tough of permeable material to remove solid particulates such as dust, pollen, mold, and bacteria from the air. The types and number of filters are accessible for shaping the efficiency of filters to removing particulates from an airstream. All central ventilation or air-conditioning systems should be prepared with types and number of filters as given in Table (3.3). Also, types and the number of filers based on desire codes under the standards of the word (ANSI/ASHRAE Standard-52.2, 2007; IEST., 1993; SN EN., 779; SN EN., 1822).

3.2.3.3.1. Particulate Filtration

The particulate filtration is needed to the removal of pollutants that could foul the HVAC system and it can be preserved of the afterward filters.

3.2.3.3.2. Pre-filtration

Pre-filter is used to remove dirt, debris, and organic matter from the harvested water. Pre-filtration is required to fouling in the cooling coils and build-up of dust in the fan, ductwork, or other HVAC components. It is also required to protect and prolong the functional service life of gas-phase filters and fine-particulate filters. The fouling-size of particles is generally considering the MERV range particles, the range size of particles should be under 3 to 10 µm size range as seen in Table (3.3).

3.2.3.3.3. Fine-particulate Filtration

Filtration technology has advanced to meet the demand to remove small particles at low concentrations. Besides, Fine-particulate filtrations are used to micro enclosures with minimal airflow and separate filtration. It is used to remove efficiencies of a minimum of 85% of the E-1 range, MERV 15 filters are minimum 85% in the E-1 range and minimum 90% in both E-2 (1-3 µm) and E-3 (3-10 µm) ranges. The particle size is commonly used in the MERV E-1 range of particles (0.3-1 µm). In some collections is required higher efficiency than the MERV 15 to the long-term protection.

3.2.3.3.4. HEPA filter

HEPA air filters are installed in HVAC systems to remove the maximum amount of contaminants from the air stream for applications that require very clean air. The maximized indoor air quality and keeps the contaminants from building up in the equipment and damaging it. HEPA filtration is used to a final filtration stage and Pre-filtration should be protected life of HEPA filters. Sometimes it used to identify the clean substance, inpatient rooms, and type of surgery. Also, HEPA filters are required for protective environment rooms (PE). HEPA filters have removed the particles below Minimum Efficiency Reporting Value (MERV) 14 and particles range from 0.3-1.0 μm as given in Table (3.3) (ANSI/ASHRAE, 2007).

3.2.3.3.5. Gas-Phase Filtration

It is used to outside air infiltration of gaseous pollutants, materials off-gassing in the new building, similar off-gassing of fittings, and cleaning agents. The primary compounds are included such as acetic acid, formaldehyde, hydrogen sulfide, nitrogen dioxide, ozone, and sulfur dioxide, which are removable to molecular filtration. The specific sorbent must choose various gaseous contaminants original to the facility because removal and retention properties are not the same. Some gases are easily removed with activated carbon may require treated carbon or potassium permanganate beds (ASHRAE, 1992).

3.2.3.3.6 ULPA Filter

ULPA filter is used to prevent many airborne and removed 100% of air viruses because it has sub-micron size. This filter is very important in the hospital because the efficiency of ULPA is higher than the efficiency of HEPA as seen from Table (3.3).

Table 3.3. Types and number of filters under code standards (ANSI/ASHRAE Standard 52.2-2007; IEST, 1993; SN EN, 779; SN EN, 1822).

Classification	Arrestance or Dust Spot Efficiency	USA ASHRAE 52.2	European Union EN779 Class		Typical Controlled Contaminant	Application
PRE Filter (G Class)	AFI < 65%	MERV1	G1	AM < 65%	Particle bigger than 10.0 μm (Pollen, Spanish moss, Dust bugs, Smoothing dirt, Bunch Coat dirt, Material grit).	Gross filter, Domestic and Profitable.
	AFI 65 % - 70%	MERV2	G2	65%≤ AM < 80%		
	AFI 70 % - 75%	MERV3				
	AFI 75 % - 80%	MERV4				
	AFI 80 % - 85%	MERV5	G3	80%≤ AM < 90%	Particle size within 3.0 μm-10.0μm (Mold, Spores, Hair spray, Cement dust, Snuff, Powdered milk).	Commercial Industrial, Paint shop.
	AFI 85 % - 90%	MERV6				
	NBS 25 % - 30%	MERV7	G4	90% ≤ AM		
	NBS 30 % - 35%	MERV8				
MEDIAM Filter (F Class)	NBS 40% - 45%	MERV9	F5	40%≤ EM <60%	Particle size within 1.0 μm-3.0μm (Lead dust, Milled flour, coal dust, Auto emissions, Nebulizer drop, Welding fumes).	IAQ concerned Commercial & Industrial, Medical.
	NBS 50% - 55%	MERV10				
	NBS 60% - 65%	MERV11	F6	60%≤ EM< 80%		
	NBS 70% - 75%	MERV12				
	NBS 80% - 85%	MERV13	F7	80%≤ EM <90%	Particle size within 0.3μm-1.0μm (All bacteria, cooking oil, most Smoke, copier toner, Most face Powder, Most paint pigments).	IAQ concerned Commercial & Industrial, Medical, food etc.
	NBS 90% - 95%	MERV14	F8	90%≤ EM <95%		
	NBS > 95%	MERV15	F9	95% ≤ EM		
		MERV16				
Classification	Mean Fractional Efficiency	IEST RP-CC001.3	European Union EN 1822 Class		Typical Controlled Contaminant	Application
HEPA Filter (H Class)	≥95% at 0.3μm	n/a	H10	≥85% at MPPS	Particle size bigger than 0.3μm (Virus (unattached), Carbon dust, Sea salt, All combustion smoke, Radon progeny).	All types of cleanrooms
	≥98% at 0.3μm		H11	≥95% at MPPS		
	≥99.97% at 0.3μm	TYPE A				
	≥99.99% at 0.3μm	TYPE C	H12	≥ 99.5 % at MPPS		
	≥99.995% at 0.3μm		H13	≥ 99.95 % at MPPS		
	≥99.999% at 0.3μm	TYPE D	H14	≥ 99.995 % at MPPS		
ULPA Filter (U Class)	≥99.9995% at 0.12μm	TYPE F	U15	≥ 99.9995 % at MPPS	Particle size bigger than 0.12μm	Super clean room
	=99.99995% at 0.12μm		U16	= 99.99995 % at MPPS		
	≥99.999995% at 0.12μm		U17	≥ 99.999995 % at MPPS		

3.2.3.4 Protective Environment (PE) rooms

The Protective Environment rooms are hospital rooms designed to protect a high-risk immunocompromised patient from human and environmental airborne pathogens. Also, PE rooms are a specialized application of a hospital's HVAC system, where the airflow supplied into the room is balanced with exhaust airflow to create positive differential pressure with respect to an adjacent space, usually the corridor or hallway. The gentle flow of air was under a closed doorway and into the hallway so that no airborne particulates can enter into the patient's room. In addition, in PE rooms, HEPA filters are usually applied to increase the equivalent room air exchange, and outdoor air changed to clean air. Constant airflow volume (CAV) is commonly used in PE rooms, but there are requirements in healthcare codes to reduce air changes per hour when the room is unoccupied in order to save energy (Rhame, et al., 1984). Design considerations for a PE room are similar for all rooms of the hospital: (1) room air pressure control, is positive pressure concerning all adjoining spaces; and (2) an air distribution pattern within the room that is favorable to airborne infection control in protection of the patient, as seen in Figure (3.8).

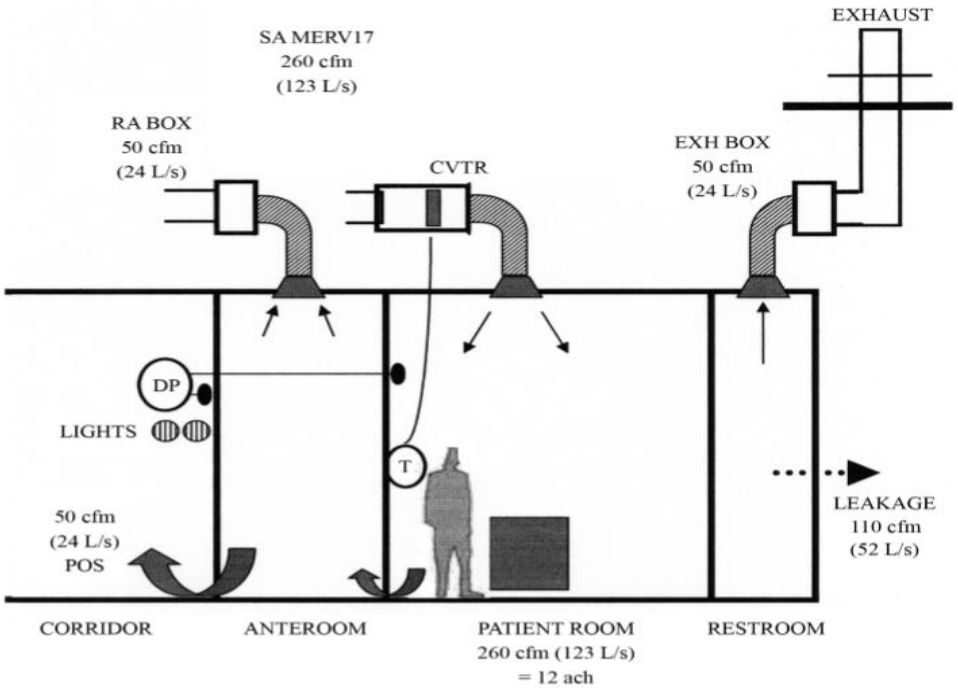


Figure 3.8. Schematic Diagram of PE Room (Rhame et al., 1984).

3.2.3.5. Air Movement

The hospital environment has more effects on normal patient care such as bacterial counts were by airflow in the hallway. Unwanted airflow is difficult to controlling between the rooms and floors due to open the door, movement of medical staff, temperature differentials, etc. Specialization of patient care areas should be appropriate ventilation to control the air quality of the hospital. Sometimes in the noncritical patient care, areas and medical staff may be used a variable air volume (VAV). VAV systems can be controlled pressure relationships and minimum ventilate for exhaust and return air under codes in the hospital (Lewis 1988).

3.2.3.5.1. Air Velocity

The air velocity of the room is separate from the occupied area to ensure airflow could be measured air volumes in the room air throw distribution. Throw of the room is a distance from the center face outlet to the topic, where the velocity of air stream can reduce to a specified velocity, always 150 [0.75], 100 [0.5]fpm, or [0.25 m/s] (AHRI Standard-855; ASHRAE, 2011).

3.2.3.5.2. Air Pressure

Air pressure of the room can be created a low differential pressure due to airborne particles chemical gases where recirculated in the rooms. Also, the differential pressure may have between inside or outside of a differing area of the building should be controlled by regulating supply and return air in the rooms. Besides, the supply and return air in the room can be transferred more air polluting, therefore it should be used filtration stage according to the suggestion of standards and guidelines.

3.3. Importance of Ventilation and Design Criteria for Sterile Spaces in Hospital

Ventilation is considered a significant factor for IAQ in the hospital. Also, ventilation is used extensively in all types of healthcare locations to provide a safe and comfortable and safe environment for patients and medical staff in the hospital. More specialization of ventilation can be provided to primary patient treatment areas such as isolation units and critical areas in the operating room. Besides, ventilation is supplied to fresh air for human beings and removed all dilutes or pollutants that were generated indoors such as (pollutants from people, building materials, furniture, cleaning products, and the ingress of soil gasses such as radon). Ventilation has also an important role to control humidity control and preventing the growth of dust bugs, as well as microbial growth in building structures. In addition, it used to control the levels of pressure in buildings in order to prevent pollutants from dispersion. It also often used to control temperature and relative humidity in the room. Also, the HVAC components are related to moisture when the poorly maintained may be caused to the indoor air contaminants (Mendell et al., 2008).

3.3.1. Design Conception and Criteria

Criteria for HVAC design in sterile rooms of hospitals have indoor air parameters such as temperature, room pressure, stage of filtration, humidity, and fresh air change rates. The effects of parameters are mentioned to design criteria of the infection control and thermal comfort in the hospital. The design criteria of HVAC systems are focus on three parameters for a comfortable indoor condition such as temperature, relative humidity, fresh air rate. Though, the sterile space of the HVAC system can be an additional number of parameters such as supply air velocity, air distribution, number of particles, types, and number of microorganisms, and the pressure difference between the sterile of neighboring spaces. Therefore, design sterile space applications for HVAC system is more difficult for the comfort condition in the hospital. In addition, design criteria are related by indoor environmental parameters and it can be indicated a lack or improper operation of equipment, poor indoor lighting, and noise-related to the problem of parameters of the HVAC system in the hospital (Chengqin et al., 2002).

3.3.2. Surgery Rooms and Critical Care

All areas of the hospital must be more careful to control aseptic conditions, especially in the surgical suite. HVAC systems are used to serving conditions into operating rooms, including cystoscopic and fracture rooms, that require careful design to minimize the attention of airborne organisms. The greatest amount of bacteria is found in the operating room comes from the surgical team and activities during surgery. During most operations, members of the surgical team were near the operating table, and creating the undesirable situation of focused contamination may be a highly sensitive area (ASHRAE, 2011). There are three classifications for surgery care areas class A, B, and C (ACS 2000):

• **Class A surgery:** is involved minor surgical procedures performed under topical, local, or regional anesthesia without preoperative sedation and excluded are intravenous, spinal, and epidural procedures, which are Class B or C surgeries.

• **Class B surgery:** is provided minor or major surgical procedures performed in conjunction with oral, parenteral, or intravenous sedation, patient under analgesia or dissociative drugs.

• **Class C surgery:** is involved major surgical procedures required general or regional block anesthesia and/or support of the vital bodily function as seen in Table (3.4).

3.3.3. Sterile Spaces in Hospital Hygiene

There are many have various risks of sterile spaces in hospital hygiene and many differential spaces are required a high level of hygiene in the hospital. According to the standard of DIN 1946-4 can be classified the spaces into two groups Class I, and Class II, high or very high need of hygiene, and normal levels of hygiene, respectively. The spaces Class I is very important during the sterile design of the hospital. The lists of space Class I of the hospital are included operating sites such as ICU rooms, delivery rooms, isolation rooms, and central service sterile (DIN, 1999; AIA, 2006; ASHRAE, 2003).

3.3.3.1. Operating Site of the Hospital

The operating site is considering a special space department for a surgical procedure in the hospitals. Also, the operating site is a space within a hospital where the surgical operations carried out in an aseptic spaces environment. Operating sites of the hospital are included as OP room, pre and post OP room, anesthesia equipment room, sterile and solid equipment rooms, staff support areas, and corridors and halls (ASHRAE, 2003).

3.3.3.1.1. Operating Room

The operating room is the important space of the hospital and the levels of hygiene should be very high because the surgical procedure is carried out inside it. Therefore, in the OP room, all personals must be wear protected garments such as gloves, shoe covers, masks, caps, etc. Also, OP rooms are one of the most significant of the operating site because most standards and guidelines are given information about it.



Figure 3.9. Operating room (Qaladze Hospital, 2010).

3.3.3.1.2. Pre and Post Operative Recovery Rooms

Pre and Post, Operative Recovery rooms are used to combination with OP rooms during surgical producer. Sometimes, in the recovery rooms are created the smell of residual anesthesia causes odor problems. Besides, the patients have transferred some problems to the pre and post-operative room and complexed with air treatment in the operating room. In this room, patients may be involved effects of anesthesia due to transmigration the first to second spaces of medication.



Figure 3.10. Pre and Post OP room (Qaladze Hospital, 2010).

3.3.3.1.3. Soiled and Sterile Equipment Rooms

The soiled equipment room is used to composed and stored, and returnable equipment sending for cleaning by sterilization. This room must be under negative pressure with respect to near the spaces to keep airborne. Also, the sterile equipment room holds sterile tools and medical supplies when used during surgical procedures. The levels of hygiene in the sterile equipment room should be equal to or higher than the operating room. Besides, the spaces of the sterile equipment room should be positive pressurized and the direction of airflow should be outwards.

3.3.3.2. Delivery Room

The delivery room is identical space to a general operating room when used for cesarean deliveries and breech birth. The design of the delivery room should be obeyed and require the same operating room of the hospital. The delivery room is included two types such as an alternative and traditional hospital. The alternative delivery room design (Labor/Delivery/Recovery [LDR]) is a quantified type for the patient room. The traditional delivery room some designer are including a post-partum phase in which a mother and baby for their stay in the single LDR unit are called LDRP, (Labor/Delivery/Recovery/Post-Partum) of the hospital. The types of delivery rooms are used normal surgical procedures, therefore the levels of hygiene should be high in the room (ASHRAE, 2003).



Figure 3.11. Delivery Room. (Qaladze Hospital, 2010).

3.3.3.3. Isolation Rooms

Isolation rooms are used to keep a health care worker, patients, and visitors from any exposure of airborne of the hospital. Isolation rooms carry out to transfer all types of microorganisms due to air. Also, isolation rooms have two types of negative pressure room (or infection of airborne isolation room) and a positive pressure room (or protective environment room PE). Both types of isolation rooms are aimed to controls airflow and reduce the infectious airborne in the rooms (ASHRAE, 2003).

3.3.3.4. Intensive Care Unit Room (ICU)

The ICU rooms are spaces where patients stay 24 h continuously and necessary for life-support patients of the hospital. ICU room has more types each of them used to a different purpose such as surgical intensive care, cardiac care unit, medical intensive care, post-anesthesia care, burn and wound intensive care, and neurological intensive care. The effects of HVAC system may differ according to types of ICU rooms for example in the burn intensive care unit needed high levels of hygiene and RH.



Figure 3.12. Intensive Care Unit (Qaladze Hospital, 2010).

3.3.3.5 Central Sterile Services

The central sterile services are the department liable for some cases of serve equipment of the sterile delivery room. Also, the central sterile department is used to cleaning prepare instruments, equipment while used in surgical procedures, delivery, and emergency care. Besides, in the central sterile equipment storage, the levels of hygiene must be higher than the OP rooms. This room should be positively pressurized to the neighboring spaces (ASHRAE, 2003).



Figure 3.13. Central sterile services storage (Qaladze hospital).

3.3.4. Parameters of Ventilation for Sterile Spaces in Hospitals

The HVAC system must provide to prevented air pollute virtually used by parameters. Therefore, the design criteria of HVAC system must be used parameters under desire code standards and guidelines. The parameters for design criteria of HVAC system are indicated below:

3.3.4.1. Room Temperature

The room temperature directly affects the thermal comfort of the medical staff and patients of the hospital. Thermal comfort is important, especially in the OP room because the medical staff wear garments and work under high radiant lighting. Also, the levels of room temperature should be controlled individually for each of the OP rooms and delivery rooms of the hospital (AIA, 2006). Besides, the levels of room temperature between 24-26°C were suitable thermal comfort for both medical staff and patients while the levels of room temperature below 21°C cause to increases risk of hypothermia. Generally, the thermal comfort of the room temperature is greatly reduced with the surgical staff (activity load) usually higher than 23°C (Melhado and Loomans, 2006).

3.3.4.2. Relative Humidity

Same as room temperature, the relative humidity is acted on thermal comfort for the patients and the medical staff of the hospital. The levels of relative humidity is very important during the cooling process of air. Besides, high levels of relative humidity are needed during eye surgeries or tissue transplant operations for burn wounds, when air drying cannot desire the wound, for example up to 95% RH used in burn patients. Consequently, low levels of relative humidity can also be acted on the patient wound especially during surgery producer. Besides low levels of relative humidity may require therefore the microbial cannot grow (ASHRARE, 2011). Average values for relative humidity ranges between 30% to 60% according to more standards and guidelines.

3.3.4.3. Room Filtration

The air in the hospital must be fresh 100% of the hospital, therefore all rooms should be used filtration stages of the hospital. The sterile space in the hospital is closed environments since the particle concentration transported easily due to mechanical ventilation of air in the hospitals. To prevent the particle concentration, the air supply should be filtered appropriately along with the particle transportation in the sterile space of the hospital. (ASHRAE, 2003). Also, to prevent airborne and viruses should be sub-micron size by used HEPA and ULPA filters because of having a minimum efficiency.

3.3.4.4. Air Velocity and Air Distribution of the Room

The air velocity is a significant reason for the air distribution, and important for sterile spaces due to the influence on the thermal comfort patient and medical staff in the rooms. The applications of air distribution are mentioned to the filtration of air supply near the door and exhaust near the patient bed of the room. Therefore, the supply air should be above from the patient bed and exhaust near the door (ASHRAE, 2003). The levels of air velocity should be decreased because more effective waste anesthetic gases removed to the exhaust air in the rooms (Melhado et al. 2005).

For sterile space, have two types of air distribution profiles laminar and turbulent flow. Generally, the turbulent air distribution is used for more of sterile spaces in the operating site such as post-operation, sterile equipment room, and adult operating rooms. Also, ventilation in the room turbulent flow does not require a high level of hygiene but in the room laminar flow is required a high level of hygiene in the rooms. The particles are spread and distribute equivalently of the operating room air distribution profile as seen in Figure (3.14) (ASHRAE, 2003).

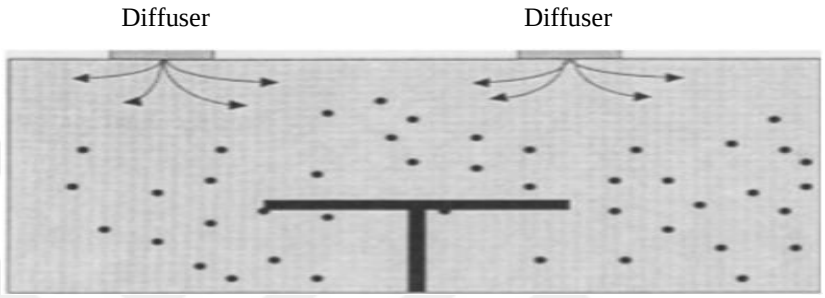


Figure 3.14. Turbulent airflow distribution (ASHRAE, 2003).

In the laminar flow room, the levels of airflow are down to the floor and exhausted by a low level recodes. The air filtration and low particle concentration are supplied above the patients in the laminar flow room. Therefore, the air velocity must be always lower than the room temperature to provide comfort conditions in the rooms. The laminar flow room has two types of horizontal and vertical laminar flow rooms where used in the surgical site. The horizontal laminar flow is impossible to move air of the surgical site room because the movement of medical staff and medical equipment can be increased particle concentration in the room. But, vertical laminar flow is possible to ventilate the air in the surgical site (Melhado and Loomans, 2006).

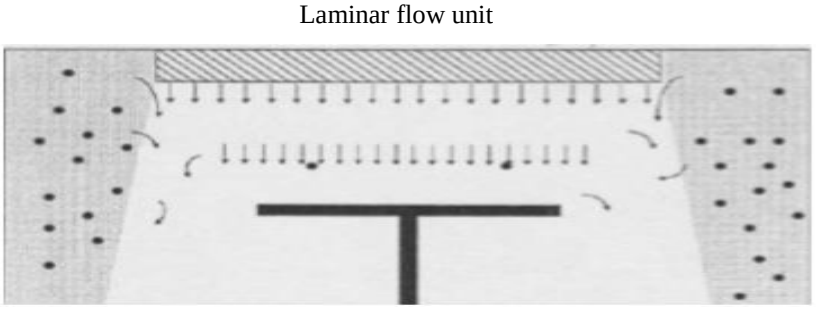


Figure 3.15. Laminar airflow distribution (ASHRAE, 2003).

3.3.4.5. Pressurization of the Room

Pressurization is required to a specific room in a hospital usually expert under most codes by providing differential airflow rates of exhaust, supply, and return air. There are two kinds of room differential pressure, positive and negative pressure rooms. The pressure difference between the spaces required to maintain stability constant under standards and guidelines (ASHRAE, 2003). When the air of the room is considered by a positive pressurized, the room air should be the supply air volumetric flow rate into the room is more than the sum of return and exhaust air volumetric flow rates out of the room. In addition, the negative pressurized room should be the supply air volumetric flow rate is less than the sum of exhaust and return air of the room. Generally, the pressure differential in the patient room is 50 to 100cfm [24-47 L/s], and for a normal room, 5% to 10% supply flow should be lager the rooms. The room differential pressure must be high enough and can be measured to control typical test and balance equipment with normal range sensing (ASHRAE, 2010a). Also, for design balancing air system should be minimized a shaft opening to enclosed rooms while created to positive and negative pressure in the room areas (Murray et al. 1988).

3.3.4.6. Total and Fresh Air Change of the Room

The total and fresh air change rates are significant to conserve the requirement of the sterile spaces in the hospital. Fresh air in the hospital must be 100% fresh air filtered by mechanically supplied air when taking into the rooms. Consequently, the supply of fresh air may create problems by increasing the amount of oxygen and chemical gas diluting both of them cause the raising of particles in the room air of the hospital. 100% inside of the surgical site should behave at least two air exhaust outlets of the rooms to improve fresh air. Exhaust and return openings should be kept that the levels of area and clear from any obstructions, especially that one near the floor level (Memarzadeh, 2002).

Table (3.4) Generally, illustrative of parameters for some location areas in a hospital.

Table 3.4. Design criteria of HVAC system for sterile space in some part of the hospital.

(ASHRAE, 2011) Space Function	Design Temperature °C	Relative Humidity %	Air recirculated by means room units	All room air exhausted directly outdoors	Pressure Relationship Adjacent Areas	Minimum Outdoor ACH	Minimum Total ACH
Surgery and critical care							
Class A Operating/Procedure room	21 to 24	30 to 60	No	N/R	Positive	3	15
Classes B and C Operating room	20 to 24	30 to 60	No	N/R	Positive	4	20
Operating/surgical cystoscopic room	20 to 24	30 to 60	No	N/R	Positive	4	20
Delivery room (Caesarean)	20 to 24	30 to 60	No	N/R	Positive	4	20
Sub sterile service area	N/R	N/R	No	N/R	N/R	2	6
Recovery room	21 to 24	30 to 60	No	N/R	N/R	2	6
Newborn intensive care	21 to 24	30 to 60	No	N/R	Positive	2	6
Treatment room	21 to 24	30 to 60	N/R	N/R	N/R	2	6
Radiology waiting rooms	21 to 24	max 60	N/R	Yes	Negative	2	12
X-Ray (S/critical care and catheterization)	21 to 24	Max 60	No	N/R	Positive	3	15
Labor/Delivery/Recovery/Postpartum	21 to 24	Max 60	N/R	N/R	N/R	2	6
Laboratory, general	21 to 24	N/R	No	N/R	Negative	2	6
Pharmacy	N/R	N/R	N/R	N/R	Positive	2	4
Soiled workroom or soiled holding	N/R	N/R	No	Yes	Negative	2	10
Medication room	21 to 24	Max 60	N/R	N/R	Positive	2	4
Sterilizer equipment room	N/R	N/R	No	Yes	Negative	N/R	10
Medical/anesthesia gas storage	N/R	N/R	N/R	Yes	Negative	N/R	8
Corridor*	N/R	N/R	N/R	N/R	N/R	N/R	2

Note: N/R= no requirement

*AII rooms described in ASHRAE Standard170 should use to isolate the airborne spread of infectious diseases, such as measles, varicella, or tuberculosis. The design of AII rooms should include the provision for normal patient care during periods not requiring isolation precautions.

3.4. Standards of IAQ and Thermal Conditions for Hospitals

Many countries have norms, codes of building, standards, and guidelines, which are changing to the temperature, humidity, airflows, and pressure each of them used in thermal comfort for the hospital rooms. The parameters for thermal comfort condition according to standards and guidelines are given below in details:

3.4.1. Investigation for Detailed Some Standards of the World

In this chapter, information about compare among the standards can be detailed to all the parameters of sterile spaces of the hospital. Recommendation value each of them can be revealed from the tables below.

3.4.1.1. ASHRAE Standard and AIA Guideline

According to the ASHRAE standard and AIA guideline, the operating room can be classified into three groups such as Class A, B, and C, before explained which of them (AIA, 2006 and ASHRAE, 2003).

3.4.1.2. Germany DIN 1946-4 Standard

Germany has released the standard DIN 1946-4 it has two classes for cleanrooms.

Class I is subdivided into Ib “high level of air cleanliness” and Ia "very high level of air cleanliness". They differ from each other by different types of airflow. In rooms of class Ia, used a laminar or low turbulent airflow, but in-room class Ib used a turbulent.

Class II ventilation in rooms of class II (except for special facilities, such as laboratories, kitchens, and pharmacies) is installed two-stage air purification. The first filter should be at least F5-F7 to protect the air conditioner, and the second F9 is to prevent air pollution particles (DIFN, 1999).

3.4.1.3. Germany VDI 2167 Guideline

German VDI 2167, is used to building equipment in hospitals and made accordingly to Swiss SWKI 99-3. The flow of supply air is 800-1200 m^3/h, average air velocity is 0.24-0.30 m/s, and placing of the air conditioner inside the room should be used as a Class I, the temperature of supply air has no indications when using of the air conditioning (VDI, 2004).

3.4.1.4. France Standard

French standard NF S 90-351 is used to clean rooms of the building. The name of it is "Health care-zones of environment control-requirements to the control of air pollution" According to the French standard, an air of the room should be passed a three-stage cleaning used by filter stages (Melhado et al., 2005; Dorchies, 2005).

3.4.1.5. ISO-14644 Standard

The international organization ISO has released the new standard ''Cleanrooms and Associated Controlled Environments'' which are considered international. ISO 14644-1 divided by 9 parts, gives the information about classification of cleanrooms and the amount of particles as seen in Table (3.5) (Balaras and Gaglia, 2007).

Table 3.5. Classification of cleanrooms according to ISO-14644.

The cleanliness classes ISO	The maximum allowable concentration of particles in one m3, with dimensions equal to or greater than the following values. µm					
№	0,1	0,2	0,3	0,5	1,0	5,0
ISO Class 1	10	2	-	-	-	-
ISO Class 2	100	24	10	4	-	-
ISO Class 3	1000	237	102	35	8	-
ISO Class 4	10000	2370	1020	352	83	-
ISO Class 5	100000	23700	10200	3520	832	29
ISO Class 6	1000000	237000	102000	35200	8320	293
ISO Class 7	-	-	-	352000	83200	2930
ISO Class 8	-	-	-	3520000	832000	29300
ISO Class 9	-	-	-	35200000	8320000	293000

3.4.2 Operating Room (OP)

The operating room is classified by two Classes according to DIN standard 1946-4 of hygiene needs of the surgical site. Class I, is used to high or very high levels of hygiene, and Class II, is also used to normal levels of hygiene in the OP rooms. Also, Class I, has two Classes, Class Ia, and Class Ib, were divided according to the use of levels hygiene needs and air distribution in the room (DIFN, 1999). According to ASHRAE and AIA, ORs are divided into three groups as Class A, B, and C (AIA, 2006; ASHRAE, 2003). Brazilian standard NBR specified a general determination and cesarean for the OP rooms (Melhado et al., 2005). Consequently, Australian Standards and Guidelines are similarly classified as of DIN 1946-4, where Option 1 is equal to Class Ia, and Option 2 is also equal to Class Ib (Queensland Health Communicable Diseases Unit and Capital Works Branch, 2002). Sometimes, standards and guidelines are used (N/A, N/D) for the parameters as seen from Tables below.

According to all standards and guidelines, the room temperature ranges between 18-26 ºC, most of the publications are agreed on the range desire, as seen from the table (3.6) PHG is recommended to a lower value 16ºC in the OP room.

Also, according to most of standards and guidelines in the OP room ranges of relative humidity between 30-60% were accepted of the word, but in some standard or guidelines were recommended different value for RH for example, PHG recommended a range of 40%-%70, and ICG proposes a decreased range of 50-55%.

Most standards and guidelines are specified to the filtration stage with number and type filter when used to remove the concentration of the particles in the room air distribution. AIA was lack information about filtration where opposition to specify and description of the filtration stage. For example, designers of DIN 1946-4 for cleaned air supply must be used of at least three stages of filtration set as F5/F7-H13, in the OP rooms. PHG has used a HEPA filter because it has a maximum of efficiency 99%, and NBR was used to F2-G2-A3, of the filter stages. Information all types and number of filters as seen in Table (3.3). Also, information all parameters are indicated in Table (3.6) and (3.6.1 cont).

Air velocity is an important factor in room air distribution therefore, air distribution depended on air velocity in the room. The disturbance is created by the airflow and must be minimized in the ORs therefore, the air velocity for the comfort conditions of the room should be lower than 0.2 m/s, this value was accepted most of the publications in the world. Laminar flow has a low air velocity and high level of hygiene in rooms therefore all standards of the word are suggested to use from the OP room. Also, for turbulent flow DIN 1946-4 and ICG were used to a permit of Class Ib (or Option 2) of the OP room. The ranges of air velocity of the OP room can be specified around as 0.1-0.5 m/s according to most standards and guidelines. For example, supply velocity according to ASHRAE standard is recommended as 0.25-0.45 m/s, while VDI is recommended 0.2 m/s (VDI, 2004), and CDC is also recommended 0.3 m/s (Melhado et al., 2005).

According to standards and guidelines, the pressure difference must be required constant values for maintaining positive pressure in an operating room. All references agree to pressurization of the OR a positive pressure room recommended and airflow of the OP room should be lower than other spaces in the hospital. For example, ASHRAE and AIA are agreed to a constant pressure difference between the OP room and neighboring spaces. ASHRAE and ICG are defined for both pressure difference and flow rate between the supply air and exhaust air.

The references are recommended to different values about the fresh air change rate of the OP rooms. For example, DIN standard is suggested 20 m^3/h to air supply with an additional every meter joint length of the room. The length of the joint is subtracted off the operable door and windows therefore it is suggested 1200 m^3/h flow air for fresh air and 2400 m^3/h for total supply air rate in the rooms. Subsequently, recommendation value according to ICG total air supply is submitted as 6120 m^3/h for general surgery, and 7200 m^3/h for orthopedic surgeries and PHG for orthopedic surgeries is submitted as 55 air changes per hour (ACH) as compared to them.

Table 3.6 Recommended values for HVAC design parameters of the operating rooms according to standards and guidelines.

References	Operation of room type	Temperature ºC	Relative Humidity %	Filtration	Air velocity m/s	Air distribution	Pressure	Pressure difference	Out door ACH	Total ACH
ASHRAE	Class A Class B Class C	18-26	30-60	MERV 7/8/14/15-17 MERV 7/8/14/15-17 MERV 7/8/14/15-17	0.25-0.45	Laminar	P	2.5-7.5 Pa/ 35-45 L/s excess supply	5*/15**/ 15(lt/s)/ person	25*/15**
AIA	Class A Class B Class C	20-23	30-60	N/D	N/D	Laminar	p	2.5 pa	3	15
DIN	Class Ia Class Ib	19-26	30-60	F5-F7-H13 F5-F7-H13	N/D	Lamina/ Turbulent	P	20 m³/h excess supply	1200 m³/h	2400 m³/h
CBZ	N/D	18-24	N/D	F5-F7-F9-H13	N/D	Laminar	P	N/D	N/D	N/D
VDI	N/D	18-24	30-50	F5/F6/F7-F9-H13	0.20	Laminar	P	N/D	N/D	N/D
NBR	General Cesarean	19-24 22-26	45-60	G2-F2-A3 N/A	N/A	N/A	P	N/A	N/A	N/A

* Recommended of outdoor and Total ACH values for return air system.

** Recommended total ACH for 100% fresh air systems.

ASHRAE: ASHRAE Standard, 2003

AIA: ASHRAE Guideline, 2006

DIN: Germany Standard, 1999

CBZ: Netherlands Guideline (Melhado, et al., 2005)

VDI: Germany Guideline, 2004

NBR: Brazilian Standard (Melhado, et al., 2005)

Table 3.6.1. (Cont) Recommended values for HVAC design parameters of the operating rooms according to standards and guidelines.

References	Operation of room type	Temperature ºC	Relative humidity %	Filtration	Air velocity m/s	Air Distribution	Pressure	Pressure difference	Outdoor ACH	Total ACH
CDC	N/A	N/A	30-60	%30-%90-%99.97	0.3-0.5	N/A	P	N/A	3/20%	15
NF S90	N/A	N/A	40-60	F6/F7-H13	N/A	Laminar	P	N/A	N/A	N/A
UNE 100713	N/A	N/A	N/A	F6-F9-H13/H14	N/A	Laminar	P	N/A	N/A	N/A
PHG	General	16-24	40-70	See Text	N/D	Laminar	P	N/D	30%	20
	orthopedic			See Text	0.1-0.25				6	55
ICG	Option 1	18-24	50-55	Two-stage (AHU and Terminal)	0.2 m/s	Laminar	P	15 Pa/150-200 lt less exhaust	350 l/s or 8	1700 l/s-2000 l/s if orthopedic
	Option 2	18-24	50-55	Two-stage (AHU & Terminal)	0.2 m/s	Laminar/ Turbulent	P	15 Pa/150-200 lt less exhaust	350 l/s or 8	20

N/A: Not Available.

N/D: Not Defined

CDC: Guideline (Melhado, et al., 2005)

NF S90: French Standard (Melhado, et al., 2005 and Dorchies, 2005)

UNE 100713: Spanish Standard (Melhado, et al., 2005)

PHG: Australian Guideline, 1999

ICG: Queensland Guideline, 2002.

Recommended values for HVAC parameters for different room types and comparisons between references are seen in Table (3.6). The limit of references is indicated and require to airflow rate in the term of an air change per hour (ACH), depend on the room volume, generally, it is meaning (how many times of the room air chanced in an hour). Generally, the recommendation value of airflow of the room for fresh air set as 3 ACH, and 15 ACH for total air supply in the rooms. Therefore, the room air is mining that room air supply should be 15 times changed in an hour, and so 3 of the 15 should be changed to fresh air. For example, when are calculation to the room flow rate should be given a room volume such as room flow rate have 6m long x 5.5m width with 3m high, this room having 99m^3 volume, the room should be supplied air at least 1485m^3/h, and at least 297 m^3/h of 1485 should be fresh outdoor air. Also, ASHRAE standard is mentioned to use 25 times to returning air, while 15 ACH is suggested for 100% fresh air system. Therefore, fresh air according to ASHRAE have a significant point, because the minimum amount of fresh air must not be lower than 15 l/s per person of the room, and so it suggested two different values for ventilation rate according to use of the room.

The particle contaminations are very complex in the OR, since they could not level that of the criterion for microbiological pollution when reported in some studies of the literature. The maximum acceptable levels for the clean area set as 10 cfu/m^3 during the work of the OP room. Also, the maximum allowable limits at rest time for the clean area set as 20 cfu/m^3 of the OP room (Dharan and Pittet, 2002; Chow and Yang, 2005). In addition, in the study, Dharan and Pittet recommended value for bacterial levels set up 20 ACH and obtained 50-150 cfu/m^3 predictably in the OP room air ventilation (Dharan and Pittet, 2002).

3.4.3. Pre-OP and Post-OP Rooms

The information about the design parameters of the HVAC system for the pre and post OP room can be seen from Table (3.7). Also, the recommended value for all parameters can be found during the work HVAC system for the pre and post OP room. A comparison among the standards can reveal the work of all parameters of the HVAC system in the buildings.

According to ASHRAE and AIA, were recommended ambient temperature for the pre and post OP room ranges between 21-24 ºC, and DIN 1946-4 is suggested of ambient temperature for the pre and post OP room ranges between 22-26 ºC. Consequently, the reference value for the relative humidity ratio has accepted the range between 30-60% of the pre and post OP room.

Pre and post OP rooms according to ASHRAE and DIN are suggested to the filtration stages the same as operating rooms. But, PHG is recommended differ value for filter supply air of the pre/post-op rooms, the filters must be haven minimum dust arresting of efficiencies, while used for air conditioning. Therefore, HEPA filter should be used from any spaces of the hospital. Only AIA guideline showed that lack of information about filtration, information all filters Table (3.3).

ASHRAE is suggested a turbulent airflow for the air distribution of the pre and post OP room, but other references have no mention about air distribution of the pre and post OP room. Therefore, DIN 1946-4 and ASHRAE's are agreed to positive pressurization in the pre and post OP rooms.

A comparison between the standards have revealed the values to the airflow of the pre and post OP rooms as given in Table (3.7). ASHRAE and AIA are suggested to the airflow rate should be air changed to fresh and total supplied in the rooms. Also, Australian PHG is suggested for air supplying should be fresh according to number occupancy in the rooms, and DIN standard is mentioned to a sure amount of fresh air per unit area in the rooms.

Table 3.7. Recommended values for design parameters of HVAC system of the pre-OP and post-OP rooms according to standards and guidelines.

References	Temperature ºC	Relative humidity %	Pressure	Pressure difference	Filtration	Air velocity m/s	Air distribution	Outdoor ACH	Total ACH
ASHRAE	21-24	30-60	P	N/D	Same with OP	N/D	Turbulent	2	6
AIA	21-24	30-60	N/D	N/D	N/D	N/D	N/D	2	6
DIN	22-26	N/D	N/D	N/D	F5-F7-H13	N/D	N/D	30 $m^3/m^2.h$	N/D
PHG	N/D	N/D	N/D	N/D	See Text	N/D	N/D	20 L/s/person or 2	10

N/D: Not Defined.

ASHRAE: ASHRAE Standard, 2003
AIA: ASHRAE Guideline, 2006
DIN: Germany Standard, 1999
PHG: Australian Guideline, 1999

3.4.4. Delivery Room

Design criteria for the delivery room should a confirm condition, therefore it required high-level hygiene as an operating room. Since the recommended value for design parameters of HVAC system should be indicated briefly of the delivery room accordance with the standards and guidelines. The comparison between Table (3.6) and (3.8) are revealed the room temperatures higher than the delivery rooms.

Recommendation value for all parameters of the delivery room should be the same as operation room such as the range levels of room temperature are between 20-24 ºC, and the range levels of relative humidity are between 30-60 %, according to ASHRAE and AIA, but other standards are recommended differ value for the parameters, as seen from Table (3.8).

DIN is the first standard mentioned that to specify the hygienic condition of the delivery room as compared to other standards. Therefore DIN standard is specified as a Class II for the delivery room, thus meaning this room is needed normal levels of hygiene. So, PHG standard is suggested low levels of hygiene of the delivery room.

All references suggested to a filtration stage set as Pre-filter and HEPA filter should be used in the delivery room. Therefore, in the delivery room have a waste of anesthetic gases must be removed properly by usage ULPA filter. In addition, air distribution has a very important duo to dilution chemical gases and particles in the rate of fresh air change should be removed off the air. Therefore, the references had no information about the air distribution and air velocity of the delivery room.

Table 3.8. Recommended values for HVAC design parameters of the delivery rooms according to standards and guidelines.

References	Temperature ºC	Relative humidity %	Pressure	Pressure difference	Filtration	Air velocity m/s	Air distribution	Outdoor ACH	Total ACH
ASHRAE	20-24	30-60	P	N/D	N/D	N/D	N/D	5*/15**	25*/15**
AIA	20-23	30-60	P	N/D	N/D	N/D	N/D	3	15
DIN	min 24	N/D	N/D	N/D	F5-F7-H13	N/D	N/D	15 $m^3/m^2.h$	N/D
PHG	N/D	N/D	N/D	N/D	See Text	N/D	N/D	20 L/s/person or 2	10
NBR	22-26	45-60	P	N/A	N/A	N/A	N/A	N/A	N/A

N/A: Not Available

N/D: Not Defined

ASHRAE: ASHRAE Standard, 2003

AIA: ASHRAE Guideline, 2006

DIN: Germany Standard, 1999

PHG: Australian Guideline, 1999

NBR: Brazilian Standard (Melhado, et al., 2005)

3.4.5. Intensive Care Unit (ICU) Room

Design criteria for the ICU room are very important because the patient may stay 24 h in the hospital. The hospitals have more different types of ICU room therefore design parameters may be taken different values as presents in accordance with the different aims of the references.

Intensive care units showed to available data of HVAC design of parameters as given in Table (3.9). Besides, standards have not information about the levels of hygiene for the ICU rooms, except DIN standard 1946-4. According to DIN standard, ICU rooms are classified as two types such as regular patient ICU rooms should be using a high level of hygiene, and infection risk ICU rooms should be using a very high level of hygiene. In addition, ASHRAE and DIN standards recommend a high level of temperature for the newborn ICU rooms as compare to the other standards.

According to all references recommendation value of design, parameters can differ in the ICU room compare to other room types of the hospital. Also, recommendation value of parameters have a different value such as the levels of room temperature are 21-26^{o}C, levels of relative humidity are 30-60%, and specify a positive pressure for all types ICU room according to more standards and guidelines. Besides, the burn ICU room should be used a high level of relative humidity to prevent air drying on the skin patients, such as ASHRAE suggested a relative humidity up 95%, of the burn ICU room (ASHRAE, 2011). Also, the pressurization room of the ICU room must be a positive and the filtration stage must be used as a HEPA and Pre-filtering. Consequently, according to references are suggested of the most publication permits for air change rates when to use return air, as seen from the Table (3.9).

For improving the positive pressure room must be the room of supply air greater than the room of exhaust air thus to ensure that comfort condition into rooms under the references.

Table 3.9. Recommended values for HVAC design parameters of the intensive care unit (ICU) room according to standards and gudelines.

References	Operation of room type	Temperature ºC	Relative humidity %	Pressure	Pressure difference	Filtration	Air velocity m/s	Air distribution	Out door ACH	Total ACH
ASHRAE	General	21-24	30-60	N/D	N/D	N/D	N/D	Laminar	2	6
	Newborn	22-26	30-60	N/D	N/D	N/D	<0.25 m/s @ isolate level		2	6
	Burn	N/D	40-60	P	N/D	HEPA	0.25 m/s @ Bed level		2	6
AIA	General	21-24	30-60	N/D	N/D	N/D	N/D	N/D	2	6
	Newborn	22-26	30-60	N/D	N/D	N/D	N/D	N/D	2	6
DIN	Infection	24-26	N/D	P	N/D	F5/F7-H13	N/D	N/D	30 $m^3/m^2.h$	N/D
VID	General	N/D	N/D	P	N/D	F9	N/D	N/D	100 m^3/h/ person	N/D

N/D: Not Defined.

ASHRAE: ASHRAE Standard, 2003
AIA: ASHRAE Guideline, 2006
DIN: Germany Standard, 1999
VDI: Germany Guideline, 2004

3.4.6. Central Sterile Services Department (CSSD)

The central sterile service department is a very important part of the health care places of the hospital. Therefore, the health care facilities are needed a high level of hygiene, because the sterilization rooms have to do all procedure cleaning such as medical devices and medical garments must be kept levels of hygiene in the CSSD room. Also, the levels of hygiene of the sterilization area and sterile equipment store should be equal or higher than the OP rooms. DIN and PHG are declared to specify the central sterile service department and sterile equipment should not need a high level of hygiene as compared to the operating rooms. Therefore, DIN standard suggested specifying of the sterile equipment in the operation site should be use Class I for levels hygiene and any areas outside of the operation site should be used to a Class II from all the hospital buildings.

Recommendation value for all parameters should be desired according to standards and guidelines of the CSSD rooms. According to references, of the sterilization and soiled equipment area, the levels of room temperature are between 20-26^{o}C, and AIA guideline is recommended 20^{o}C a minimum value for a room temperature of the sterilization and equipment rooms. Consequently, the recommended value for relative humidity ranged between 30% to 60%, and AIA, this value was raising to max 70%, when of the sterile room haven a work, as seen from the Table (3.10).

All references have declared no comment about the information of the filter stage for supplied air, except VDI, DIN, and ASHRAE standards which of them are suggested to the requirement a high-efficiency for the filtration stage when used in that rooms. Also, the differential pressure of the room should be positive pressure of the sterilization of equipment areas according to all references. Besides, the differential pressure of the soiled equipment room should be maintained a negative pressure according to more standards and guidelines.

Table 3.10. Recommended values for design parameters of HVAC system of the central sterile service and sterile equipment store.

References	Room Type	Temperature ºC	Relative humidity %	Pressure	Pressure difference	Filtration	Air velocity m/s	Air distribution	Out door ACH	Total ACH
ASHRAE	Soiled Eqpt Room	22-25	30-60	N	N/D	N/D	N/D	N/D	2	6
	Sterile Eqpt Room			P		MERV 8-15			2	4
	Sterile Work Room			P		MERV 8-15			2	4
AIA	Soiled Eqpt Room	20-23	N/D	N	N/D	N/D	N/D	N/D	N/D	6
	Sterile Eqpt Room	24	30-60	P						4
	Sterile Work Room	N/D	max 70	P						4
DIN	Sterile Eqpt Room	22-26	N/D	P	N/D	F5-F7-H13	N/D	N/D	15 $m^3/m^2.h$	N/D
PHG	N/D	N/D	N/D	P	N/D	See Text	N/D	N/D	N/D	10
VDI	N/D	N/D	N/D	P	N/D	F7-F9-H10/H11	N/D	N/D	N/D	N/D

N/D: Not Defined.

ASHRAE: ASHRAE Standard, 2003
AIA: ASHRAE Guideline, 2006
DIN: Germany Standard, 1999
PHG: Australian Guideline, 1999
VDI: Germany Guideline, 2004

3.5. HVAC Applications in the Hospital

Every HVAC system may have many problems related to the design parameters in the area of hospitals. In this chapter, brief information about all problems is indicated and Some solutions are determined for the types of equipment of HVAC systems in the hospital. The equipment used to the design parameters of HVAC system should be under the rules of standards in the world.

3.5.1. Continuity of Service and Energy Concepts

Energy conservation must be measured under the code of standards because it has influenced applications on the HVAC design and performance. In this chapter can be a focus on HVAC applications and the latest technologies when related to the subject of the hospital. HVAC system applications may take advantage and disadvantage of the hybrid system especially for providing ventilation. Ventilation has a very important role in the buildings such as mechanical ventilation can take advantage of outdoor air by using an economizer cycle and reduce heating and cooling loads. Therefore, energy-conserving is used to reduce utility costs such as recovery devices, variable air volume, load shedding, and devices to shut down or reduce ventilation of certain areas when unoccupied in the room. Also, these designs needed into separate systems can reduce the overall exhaust air volume and resulting energy consumption in hospitals. The subsection on Continuity of Service and Energy Concepts in hospital facilities included information about equipment, zoning, and insulation that applied to the outpatient facilities (ASHRAE, 2011).

3.5.1.1. Equipment

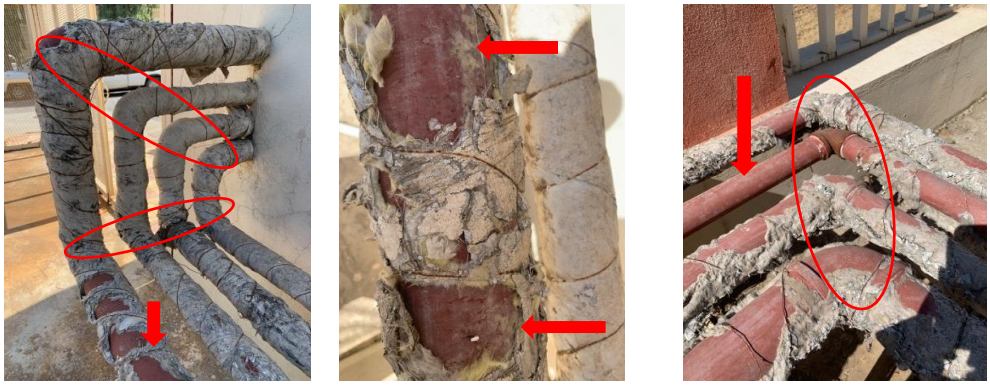
Equipment with HVAC system and high number occupants are caused by the uncomforting condition of areas in the hospital. The design of equipment systems is very important in the areas, therefore, it should be regulated and maintenance of the HVAC systems. In this section, information about equipment applications may be a haven in any space or situation in the hospital (ASHRAE, 2011).

3.5.1.2. Zoning

Zoning is used to separate air systems for different departments of the hospital. Zoning and zone are used to control the temperature in two ways from the central areas of HVAC systems. Typically, the first way all forced-air systems there have only one thermostat to control heating and cooling, and the second-way thermostat can not control the temperature virtually in each room, therefore manually closing off the outlets in each room. Also, zoning solved problems by allowing de-centralized control and allowing each zones thermostat to make the demand instead of what's good for one has to be good for everyone. In addition, zoning improved the overall comfort by allowing the zone thermostats to react to change in the temperature in each zone. For example, the supply airflow may stop in areas else maintained to a positive or neutral pressure relative to the spaces the exhaust should stop. Similarly, supply air may disable when the exhaust airflow stopped the spaces may maintain a negative pressure (ASHRAE, 2011).

3.5.1.3. Insulation

All the HVAC systems have insulation such as pipes, ducts, and equipment therefore insulation influences energy and exergy efficiencies of HVAC systems. To prevent condensation of ducts, casings, piping, and equipment on the outside surface temperature below ambient dew point must be covered for all external vapor barriers. Insulation is an appearance on the exterior surfaces of ducts, pipes, and equipment and solved under NFPA Standard-255 (NFPA, 2009). According to DHHS insulation of pipes are not exceed 150 because of acted to the energy efficiency (DHHS, 1984). Subsequently, linings in air ducts and equipment should meet the erosion test method when consist of coatings, adhesives, and insulation on exterior surfaces of pipes and ducts in building spaces used as air supply plenums. For improvement, energy saving should be controlled duct external insulation since cause to energy destruction of the HVAC systems (ASHRAE, 2011) as seen in Figure (3.16).



✘ Insulation elbow and cover pipe. ✘ Insulation cover pipe. ✘ Insulation elbow and cover pipe.

Figure 3.16. Insulation of the pipes (Qaladze Hospital, 2010).

3.5.1.4. Space Layout

Space layout planning is the assignment of discrete space elements to their corresponding locations while the space elements have relationships among each other. The relationships include topology and geometry and distinguish space layout planning from the classical linear assignment problem. Also, relationships make the design process complicated and difficult by increasing the computational cost. The optimal plan is determined by interactions and the travel cost between the space elements in the plan. The space of elements may closely interrelated and tend to the located near each other in the plan as seen in Figure (3.17).



✘ Outward of air sometimes may close. ✓ Outward of air which of them are opened.

Figure 3.17. Space layout of HVAC system (Qaladze Hospital, 2010).

3.5.1.5. Maintenance

Maintenance of HVAC equipment must ensure that operating conditions and suitable HVAC system design for the reduced energy consumption of the hospital. Regular and maintenance for all system components were possible to maintain good working conditions of the HVAC systems. The regular maintenance of the HVAC system can be detected to potential problems and easy to solutions as shown in Figure (3.18). Also, the performance can be detected to optimum working conditions after long operation hours of the HVAC system. Sometimes, without routine care, the devices can be intended to problems, such as AHU, ductwork, and other equipment, therefore HVAC system must be available to inspection at periodic cleaning manually. All files, equipment, and systems must be readily available to record and report of implemented, operating data, and energy consumption during operating of HVAC system (ASHRAE, 2011). Also, the competent technical personnel and the understaffed technical were common problems in practice that should be inspected of the hospitals.



✗ Bad condition since the design of the pipe is wrong.

✓ Good conditions and design of the pipes are right.

Figure 3.18. Good and bad maintenance of the pipes (Qaladze Hospital, 2010).

3.5.1.6. Control Systems

HVAC equipment needs a control system to regulate the operation of the heating and cooling of air conditioning in the hospital building. The operating control system usually available on the HVAC system should be satisfactory. Control systems are important to optimally indoor desirable conditions in the hospital. Each AHU serves of the surgical suite of the hospital should be provided that a thermostat and humidistat for temperature and humidity regulation. Also, various regulations of HVAC system techniques can be used as a different complication and effectiveness. Good control systems and schemes can not improve indoor conditions but can improve the energy efficiency of the HVAC system as seen in Figure (3.19).

The Building Management System (BMS) provided the most comprehensive means to control the OR conditions and properly qualified, personnel needed to take benefit such elaborate control systems. Since more elaborate, systems are acceptable for large size facilities, especially when combined with additional hospitals to controls.



Typical wall mounted of space thermostat.



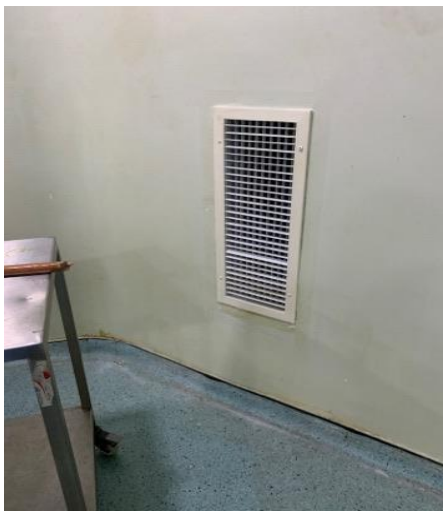
Main control panel, including thermostat, light switches, and air supply controls.

Figure 3.19. Types of control systems (Qaladze Hospital, 2010).

3.5.2. Indoor Air Quality

Outdoor pollutants can be transferred indoors through the outdoor air intake for the rooms. Outdoor air inlets and exhaust outlets must properly be placed to minimize the possibility of mixing the fresh and contaminated air. Also, outdoor air intakes must be placed away from the systems exhaust air or other emission sources. The air exhaust outlet should also be located a minimum of 3 m above ground level and away from doors, occupied areas and operable windows (ASHRAE 1999a).

Some national regulations allowed to limit recirculation under favorable outdoor conditions and for sure types of the hospitals. In addition, Hellenic hospitals, the number of air changes per hour (ACH) must be at least 20 ACH to maintain the OR at a positive pressure, while the outdoor air requirements for acceptable indoor air quality must be at least 51 m^3/hr, person according to ASHRAE Standard-62 (ASHRAE, 1999b). Therefore, the specific indoor air must be required higher than the air-change rates. So, AHU does not provide necessary air changes due to the futility of unit to improper sizing or poor maintenance occupants, poor indoor air quality, and medical gases when used to different ventilation systems (Memarzadeh, 2002).



✓ Wall-mounted rectangular opening used to exhaust the air from the surgical suite to the adjacent auxiliary space.



✘ Exhaust rectangular wall mounted grille, near floor level, blocked with medical supplies or equipment.

Figure 3.20. Air exhaust outlets of the OP room (Qaladze Hospital, 2010).

3.5.3. Ventilation

A ventilation system is operated continuously therefore the air must be aseptic of the indoor conditions in the hospital. Natural ventilation is not acceptable for the hospital, because the air must be fresh a 100% in the hospitals. However, the problems of air are dependent on the air ventilating to apply the proper control approach during the off-use hours can be reduced the total air change rate of the room. According to Hellenic regulations, airflow can be reduced down 30% at full load conditions during off-use hours (Ministry, 1997). In addition, indoor airflow patterns in the hospital must ensure that the air directed from the clean to less clean zones, and there are no takes where the air can be trapped. Airflow patterns should not encounter any problems, especially in the direction towards the main pollution sources around the operating systems. Also, pressurization introduced a specific zone control requirements for accomplished by different methodologies flow tracking of diffusers and differential spaces of the hospitals (Anderson, 1987).

3.5.3.1. Temperature

The indoor air temperature must maintain stability with desired ranges that could be recommended under standards to ensure acceptable conditions of the hospital. Also, the indoor air temperature must be a constant within the spaces and desirable value is usually 18-26 °C, according to the international standards, depending on the types of surgery suite in the hospital. Higher indoor air temperature may cause to discomfort condition of the surgical suite in the summer season, but lowering indoor air temperature was offers more hopeful to growing moisture and bacteria in the winter season. Also, staff hospitals, patients, visitors, and equipments may be to raising room temperature, especially in the surgical suite because the staff hospital stayed along time periodically in the room. The indoor air temperature must be stayed constant and controlled allow for regulation of HVAC systems (ASHRAE, 2011).

3.5.3.2. Humidity

The ventilated air may have to phenomenon such as decreasing (dehumidification) or increasing (humidification) based on the water content in the seasons. Humidification must be careful about transferring bacteria of the hospital and through the ventilation system since humidifiers provided a favorable environment to bacteria growth and the best talent to supply dry steam. However, moisture can be absorbed within the duct lining and building materials where it may support microbial evolution and some gases hazard in the environment. Also, humidification may be necessary to increase low humidity levels in the summer, commonly encountered during the winter. Although, air humidity must be a constant within the spaces and desirable value is usually 30-60 %, according to the international standards, depending on the types of surgery suite in the hospital. Besides, high humidity levels caused to grow bacteria that can easily become airborne of the water molecules, while low humidity levels caused to blood clotting, which of them can be felt discomfort condition, therefore undesirable during surgery of the hospital. So, when used a heavy of electric equipment in the hospital can be lowering humidity levels due to static electricity medical equipment and staff hospital (Lew, 2001)

3.5.3.3. Air Velocity in the Room

Air velocity must be maintained at low levels to avoid drafts and turbulence that can be caused by air mixing by diffusion bacteria and airborne particles. Also, air velocity must be a constant within the spaces and desirable value is usually 0.25-0.45 m/s, according to the international standards, depending on the supply airflow and activity load in the hospital. Also, airflow always focused on the most demanding zones to the less demanding zones in terms of air quality. Some standards recommended to the direction of airflow from the top downwards to maintain laminar flow and minimize strong draft, but some reference this value is lowering that 0.2 m/s for comfort conditions from over the patients. The airflow patterns are determined to the placement of the air supply and exhaust vents of effectively collect to control eliminate zones with trapped air or strong swirls and provided the desirable indoor conditions throughout the conditioned spaces (ASHRAE, 2012).

Generally, outlets of air supply should be located on the ceiling, with outside or several exhaust inlets near the floor (ASHRAE, 1999a). Therefore, the arrangement provided to the downward movement of clean air through the activity zone (i.e. around the operating table) of the unclean floor area to exhaust. The bottoms of return or exhaust vents should be at least 75 mm above floor level. Laminar airflow can be directed vertically or horizontally, without fixed or movable walls around the operating table (ASHRAE, 1999a). Air diffusers must have a good throw performance over a wide range of discharge velocities depending on the geometry of space to appropriate indoor air mixing of supply and indoor air, and eliminate air drafts. Also, the air supply diffusers are varied with sized and geometry depending on the detailed design of HVAC systems. The location and number of diffusers depended on the air volume to supply into space, the space layout and load distribution, and temperature differential between the indoor and supply air as seen in the Figure (3.21).

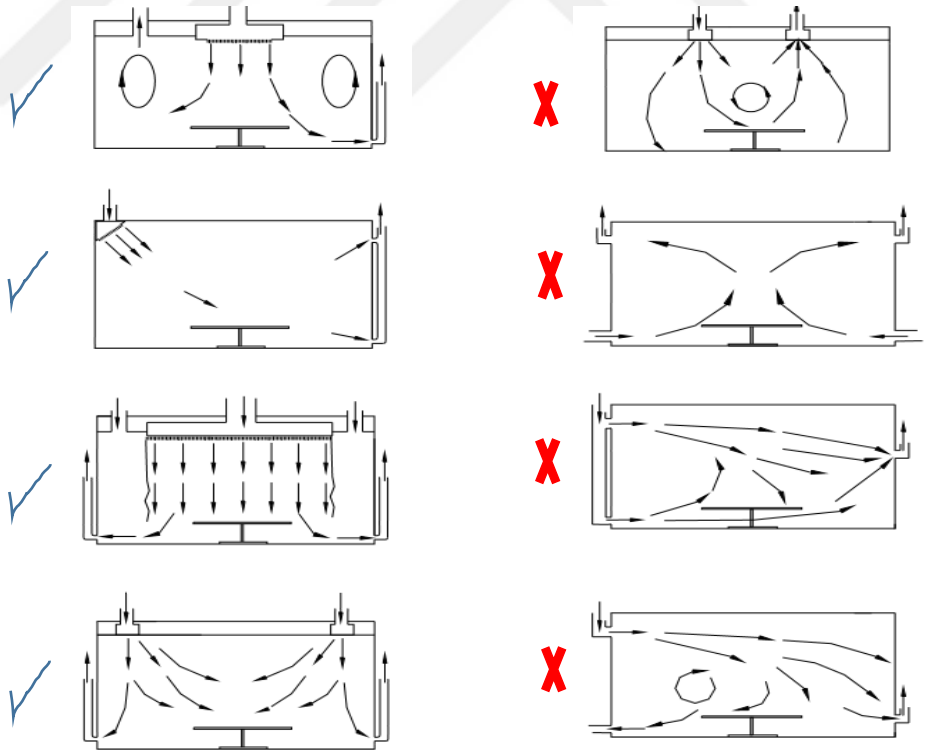


Figure 3.21. Good and bad location diffusers in the surgical site (Balaras et al., 2002).

3.5.4. The Situation of the Air Handling Unit (AHU)

The situation of AHUs can be supplied in a range of sizes, and with a variety of capabilities, typically AHUs comprises an insulated box that forms the housing for filter racks or chambers, fan (or blower), heating elements, cooling elements, sound attenuators, and dampers that can be operated manually or automatically to regulate or prevent specific airflows. Also, AHU is used to the foremost component of the HVAC system. Each component design (i.e. filters, coils, fans, and humidifier) must be perfect to proper on the design HVAC systems. Type and number of filters used in (AHUs), filters must preserve the high air quality required and optimum performance when used in the hospital spaces. Therefore, dirty filters created problems in AHU homeowners due to neglect to clean or replace them during maintenance periodically. Besides, low flow rates of the room may create problems in ice on the cooling coil and even on refrigerant piping; when the ice ultimately melts, water cannot enter places that should stay dry. Sometimes air cleanliness has a problem when airflow enough to raise fan power cause to cooling coils is freeze up, as seen in Figure (3.22).



✘ The problem in Fan due to the cooling coil is freezing up.

✘ Problem in HEPA filter due to neglect maintenance periodically.

✘ The problem in the cooling coil due to freezing.

Figure 3.22. AHU component applications (Qaladze Hospital, 2010).

3.5.5. The Situation of Duct Applications

The ducts are used to transport heating and cooling air for the rooms due to the fans. Duct systems should be careful to design made by skim rules under code standards. Small ducts created a high resistance airflow that can be caused by excessive power consumption, high pressures, and low flow rates when joined with an oversized system. Also, long ducts were run to outside walls not only increase resistance, sometimes run through unconditioned space where they can expose to dangerous temperatures. In addition, high pressures can be increased to the noise of airflow and fan, since difficult to balanced the system for suitable distribution air for all rooms. Sometimes ducts have air leakage due to more problems such as properly all openings in an air-handling cabinet, joints in the duct system, joints where ducts meet register flares, and openings are penetrated the room. One of the most common problems is an oversized cooling system that does not need to run very long cool air, so that can not remove much moisture, and periodic cleaning should necessary in the ducts (ASHRA, 2011). When two surgical suites worked by a common AHU, they must operate with the same diary to minimize energy losses as seen in Figure (3.23). Practically in AHUs used for sterile applications called as hygienic air handling units for supplies air of the sterile spaces in the hospital.



✘ Indirectly supply air from duct to duct, not direct AHU.

✘ AHU, supply air duct indirect to air distribution for the rooms.

✘AHU has two supply air ducts and one return duct.

Figure 3.23. Duct applications (Qaladze Hospital, 2010).

4. RESULTS AND DISCUSSIONS

The results consist of two parts: the first part analysis energy and exergy of HVAC systems, and the second part IAQ and ventilation in the hospital. This study deals with the energy and exergy analysis of HVAC systems in the hospital of Qaladze in Sulaymaniyah from Iraq. The general information and some applications are discussed where that relates to the subject. Analysis of energy and exergy for HVAC systems based on the parameters which were measured during the operation of HVAC systems in the hospital.

4.1. Energy and Exergy Analysis of HVAC System

Energy and exergy analysis of the components of HVAC system are based on the first and second laws of thermodynamics. Some data are acquired from the working conditions of the component at full load. Inlet and outlet temperature for each device are measured and recorded. Enthalpy and entropy values are taken from the thermodynamic tables. Water flow rate and energy consumption are read on the label of devices.

4.1.1. Energy and Exergy Analysis of the Boiler

The boiler has a capacity values ranges between 250 kW to 600 kW. For energy and exergy analysis, temperature, mass flow (water/fuel), enthalpy, and entropy are measured for some days on monthly in the hospital. The total amount of analysis energy and exergy of the boiler are given in the Tables (4.1) and (4.2), and Figure (4.1). It is seen that the amount of energy and exergy of the boiler vary according to usage on daily of the HVAC system.

Table 4.1. Energy analysis of the boiler and values of parameters for some days of months.

Some Days of months	T in °C	T out °C	$\dot{m}_{water}$ kg/s	$\dot{m}_{fuel}$ kg/s	Enthalpy hi kJ/kg	Enthalpy ho kJ/kg	Energy $\dot{E}b_{fuel}$ kW	Energy $\dot{E}b_{water}$ kW	Energy boiler losses kW
05-Jan	55	65	7.78	0.0085	230.26	272.12	363.8	325.6	38.22
15-Jan	54	64	7.78	0.0085	230.16	272.08	363.8	326	37.76
28-Jan	52	62	7.5	0.0083	209.54	251.38	353.7	313.8	39.89
06-Feb	53	65	7.78	0.0085	230.06	272.12	363.8	327.1	36.67
18-Feb	52	60	7.5	0.0083	209.54	251.18	353.7	312.3	41.39
27-Feb	54	64	7.78	0.0085	230.16	272.08	363.8	326	37.76
04-Mar	51	60	7.5	0.0083	209.44	251.18	353.7	313.1	40.64
15-Mar	52	62	7.5	0.0083	209.54	251.38	353.7	313.8	39.89
25-Mar	51	60	7.5	0.0083	209.44	251.18	353.7	313.1	40.64
03-Apr	50	60	7.5	0.0083	209.34	251.18	353.7	313.8	39.89

Table 4.2. Exergy analysis of the boiler and values of parameters for some days of months.

Some Days of months	T in °C	T out °C	$\dot{m}_{water}$ kg/s	$\dot{m}_{fuel}$ kg/s	Enthalpy hi kJ/kg	Enthalpy ho kJ/kg	Entropy Si kJ/kg.K	Entropy So kJ/kg.K	Total Exergy boiler Ex_{Bt} kW
05-Jan	55	65	7.78	0.0085	230.26	272.12	0.768	0.8937	321.15
15-Jan	54	64	7.78	0.0085	230.16	272.08	0.7585	0.8834	317.37
28-Jan	52	62	7.5	0.0083	209.54	251.38	0.7286	0.8496	322.75
06-Feb	53	65	7.78	0.0085	230.06	272.12	0.7524	0.8937	324.98
18-Feb	52	60	7.5	0.0083	209.54	251.18	0.7286	0.8313	333.7
27-Feb	54	64	7.78	0.0085	230.16	272.08	0.7585	0.8834	320.25
04-Mar	51	60	7.5	0.0083	209.44	251.18	0.7146	0.8313	333.74
15-Mar	52	62	7.5	0.0083	209.54	251.38	0.7286	0.8496	335.52
25-Mar	51	60	7.5	0.0083	209.44	251.18	0.7146	0.8313	333.74
03-Apr	50	60	7.5	0.0083	209.34	251.18	0.7038	0.8313	325.97

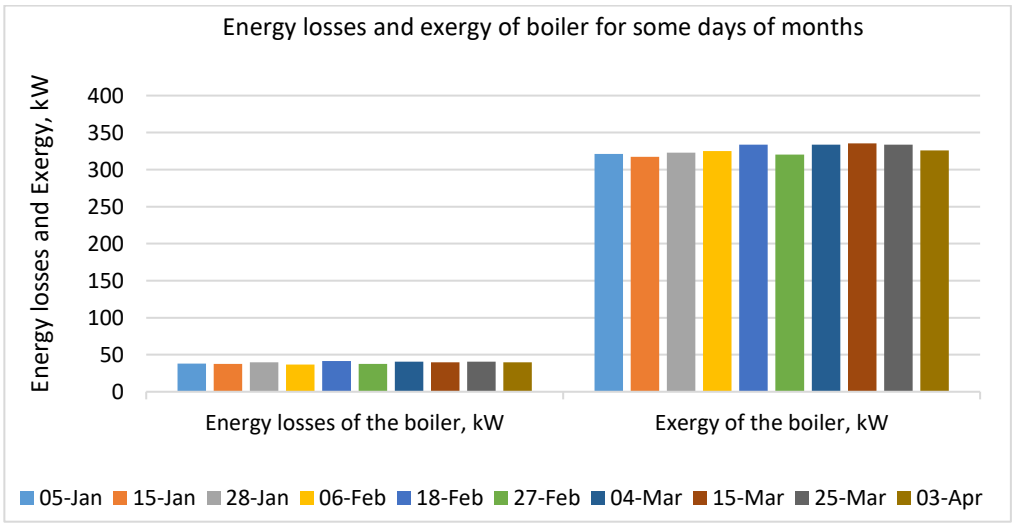


Figure 4.1. Energy and exergy analysis of the boiler.

The terms of energy and exergy losses, of the HVAC systems have different values based on the temperature and mass flow. In the Figure (4.1) have more understandable to the amount of energy and exergy losses of the boiler. The boiler has the lowest energy loss and the highest exergy. The amount of energy and exergy from the boiler may vary according to working days monthly. The value of energy and exergy of the boiler were 38.22 kW and 321.15 kW, on 05 January months, as compared to another day were 39.89 kW and 335.52 kW on 15 March months, respectively. The losses of energy and exergy in the boiler can be indicated the grate difference among the values of energy and exergy as seen in Figure (4.1)

4.1.1.1. Thermal Efficiency and Exergy Efficiency of the Boiler

The thermal efficiency and exergy efficiency are dependent on the values of the fluid inlet and the outlet boiler can be taken consideration. To understand the better workings of the boiler should be calculated as thermal efficiency and exergy efficiency. If thermal efficiency had a high taken range as (80%-90%), and exergy efficiency had taken below under range (25%-15%), thus boiler can be operated that an optimum properly according to first and second laws. Also, the first and second laws have used the analysis of thermal and exergy efficiency. The values of thermal efficiency and exergy efficiency for the boiler are 90 % and 23 % on 5 January months, when as compared to another day are 89 % and 18 % on 15 March months, respectively. According to the results, the boiler has the optimum working for the heating process of the hospital as seen in Table (4.3) and Figure (4.2).

Table 4.3. Thermal efficiency and exergy efficiency of the boiler.

Some days of months	Thermal efficiency boiler, ηb (%)	Exergy efficiency boiler, ξb (%)
05-Jan	90	23
15-Jan	90	23
28-Jan	89	20
06-Feb	90	22
18-Feb	88	17
27-Feb	90	22
04-Mar	89	17
15-Mar	89	18
25-Mar	89	17
03-Apr	89	16

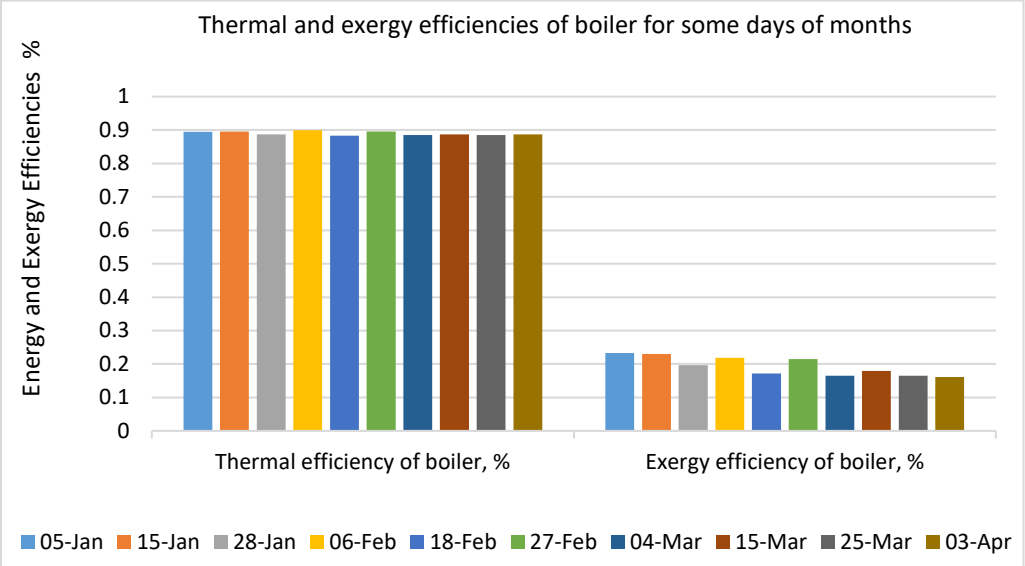


Figure 4.2. Energy efficiency and Exergy efficiency in the boiler.

As seen in Figure (4.2) that the difference between thermal efficiency and exergy efficiency is high. The values of the boiler thermal efficiency are around 89 %, and exergy efficiency is under 23%.

The amount of analysis energy, exergy, thermal efficiency, and exergy efficiency of the boiler considered and the instrument precision requirement reference (Ergün, 2015). These data used to verify the accuracy of the simulation results with a comparison between the values of the boiler. Comparison among the energy, exergy, thermal efficiency, and exergy efficiency data of the actual boilers and predicted values obtain to the simulation. The total amount of energy input of the boiler was 363.8 kW, the energy output of the boiler was 325.6 kW, the energy loss of the boiler was 38.22 kW, and the total exergy of the boiler was 321.57 kW. When compared to a simulation of another study, the energy input of the boiler was 11330.76 kW, the energy output of the boiler was 10245.24 kW, the energy loss of the boiler was 1085.51 kW, and total exergy of the boiler was 10062.24 kW. The total amount of thermal and exergy efficiency of the boiler was 90 %, and 23 %, as opposed to the simulated amount was 90 %, and 23 %, respectively. These results verified the suitability of the theoretical simulation method used for the boiler.

4.1.2. Energy and Exergy Analysis of the Chiller

The chiller has a capacity value of 180 tons of refrigeration (633 kW) that was used for air-cooling in the hospital. The air-cooled water chiller at the actual operation was investigated to determine the power consumption of the compressors, the heat capacity of the evaporators and condensers, and the COP of the chiller. The determination data used to verify the accuracy of the simulation results that are given at working the devices of the HVAC system. The amount calculation of energy and exergy are given in the Tables (4.4) and (4.5) for air-cooled water chiller. Consequently, the amount of energy and exergy can be varied according to the temperature given on the daily working of devices, as seen from the tables and figures below.

Table 4.4. Energy analysis of the chiller and values of parameters for some days of months.

Some days of months	Te ˚C	Tc ˚C	m kg/s	h1 kJ/kg	h2 kJ/kg	h3,4 kJ/kg	Q_{Cd} kW	Q_{ev} kW	Q_{Cpt} kW
20-Jun	2	43	4.59	398.44	424.54	260.83	751.43	631.63	119.799
25-Jun	2	48	4.72	398.44	426.85	268.36	748.07	613.98	134.095
30-Jun	2	45	4.64	398.44	425.48	263.57	751.26	625.8	125.466
05-Jul	5	47	4.71	400.15	426.16	266.65	751.29	628.79	122.507
10-Jul	5	45	4.62	400.49	425.48	263.57	748.02	632.57	115.454
20-Jul	5	48	4.78	400.49	426.85	268.36	757.58	631.58	126.001
30-Jul	5	50	4.9	400.15	427.87	271.44	766.51	630.68	135.828
08-Aug	2	49	4.9	398.44	427.53	269.73	773.22	630.68	142.541
14-Aug	2	51	5	398.78	428.9	272.8	780.5	629.9	150.6
25-Aug	2	48	4.72	398.44	426.85	268.36	748.07	613.98	134.095

In the Table (4.4) amount of energy can be changed among days on monthly of the air-cooled water chiller. The amount of energy of the chiller components such as condenser, evaporator, and compressors were 751.43 kW, 631.63 kW and 119.799 kW on 20 Jun, while compared to another day were 766.51 kW, 630.68 kW, and 135.828 kW on 30 Juley, respectively. According to the results are investigated a grate difference among the amounts energy of the chiller components of the days on monthly as seen in Figure (4.3).

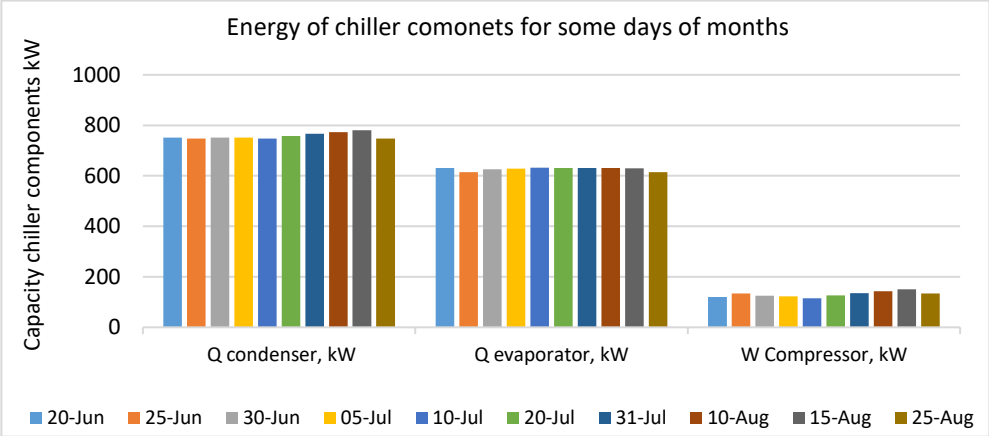


Figure 4.3. Energy analysis for chiller components.

From the Figure (4.3) investigated that increase or decrease the energy value for the chiller components among days on monthly. The parameters can be raising and lowering of the chiller components depended on the temperature value and mass flow on the daily working chiller. The figure above is indicated that the energy value of the compressor is the lowest among the components.

The amount of exergy for each component of the air-cooled water chiller varies with the days as shown in Table (4.5). The values of exergy for the components of chiller-compressors, condenser, expansion valve, and evaporator- are 88 kW, 48.9 kW, 23.9 kW, and 16.2 kW on 20 June, while compared to another day they are 93.9 kW, 53.1 kW, 27.5 kW, and 20.7 kW on 8 August, respectively. According to the results, raising and lowering of the parameter values were dependent on the temperature and mass flow, as seen from Figure (4.4).

Table 4.5. Exergy analysis of the chiller and values of parameters for some days of months.

Some days on monthly	Te °C	Tc °C	m kg/s	h1 kJ/kg	h2 kJ/kg	h3,4 kJ/kg	S1,2 kJ/kg.K	s3 kJ/kg.K	s4 kJ/kg.K	$\dot{E}x_{cp}$ kW	$\dot{E}x_{cd}$ kW	$\dot{E}x_{ex.v}$ KW	$\dot{E}x_{ev}$ kW
20-Jun	2	43	4.6	398.4	424.5	260.8	1.72	1.204	1.22	88	48.9	23.9	16.2
25-Jun	2	48	4.7	398.4	426.9	268.4	1.72	1.227	1.25	83.6	47.8	32.3	14.9
30-Jun	2	45	4.6	398.4	425.5	263.6	1.72	1.213	1.23	80.6	49.2	25.7	16
05-Jul	5	47	4.7	400.2	426.2	266.7	1.72	1.222	1.24	90.2	48.9	26.3	16.4
10-Jul	5	45	4.6	400.5	425.5	263.6	1.72	1.213	1.25	88.1	48.9	22.8	16.1
20-Jul	5	48	4.8	400.5	426.9	268.4	1.72	1.227	1.25	83.4	48.4	28.2	16.4
30-Jul	5	50	4.9	400.2	427.9	271.4	1.72	1.237	1.26	93.9	52.2	30.7	16.8
08-Aug	2	49	4.9	398.4	427.5	269.7	1.72	1.232	1.25	83.2	53.1	27.5	20.7
14-Aug	2	51	5	398.8	428.9	272.8	1.72	1.241	1.27	90.7	49.5	37.7	16.5
25-Aug	2	48	4.7	398.4	426.9	268.4	1.72	1.227	1.25	92.7	47.8	32.3	14.9

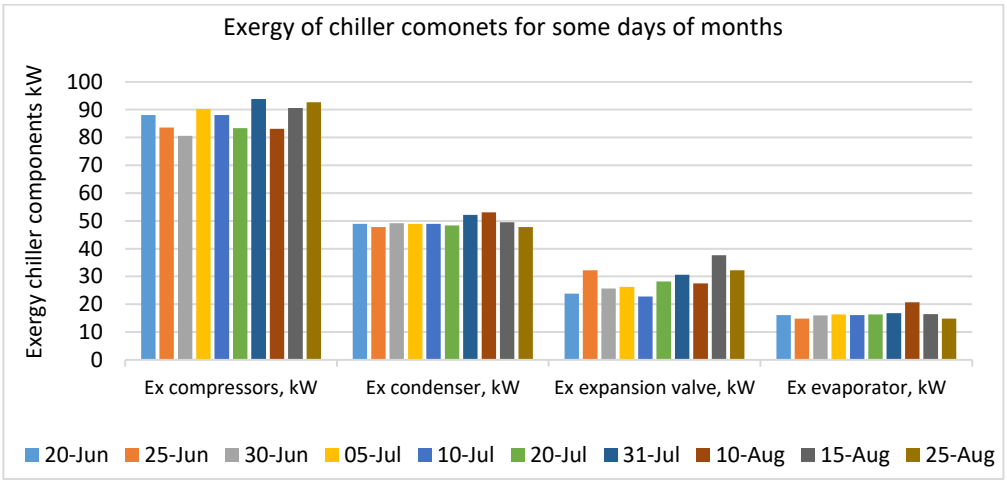


Figure 4.4. Exergy Analysis of the chiller components.

Figure (4.4) indicates that there are raising and lowering the amount of exergy of the chiller components for some days on monthly. As seen from the figure, the amount of exergy in the evaporator is lower than all components, but exergy compressors are higher than all components of the air-cooled water chillers.

4.1.2.1. Coefficient Of Performance (COP) of the Chiller

Table (4.6) showed that the amount coefficient of performance COP, and COP Carnot, for the air-cooled water chiller. The values of COP actual and COP Carnot were 5.3 and 6.71 on 20 Jun, as compared to another day was 4.6 and 6.18 on 30 Jul, respectively. According to Figure (4.5), the amount of COP Carnot is greater than COP actual. This result is expected.

Table 4.6. Coefficient of performance value of the chiller.

Some days on monthly	Te °C	Tc °C	COP Actual	COP Carnot
20-Jun	2	43	5.3	6.71
25-Jun	2	48	4.6	5.98
30-Jun	2	45	4.9	6.39
05-Jul	5	47	5.1	6.62
10-Jul	5	45	5.5	6.95
20-Jul	5	48	5	6.47
30-Jul	5	50	4.6	6.18
08-Aug	2	49	4.4	5.85
14-Aug	2	51	4.2	5.6
25-Aug	2	48	4.6	5.98

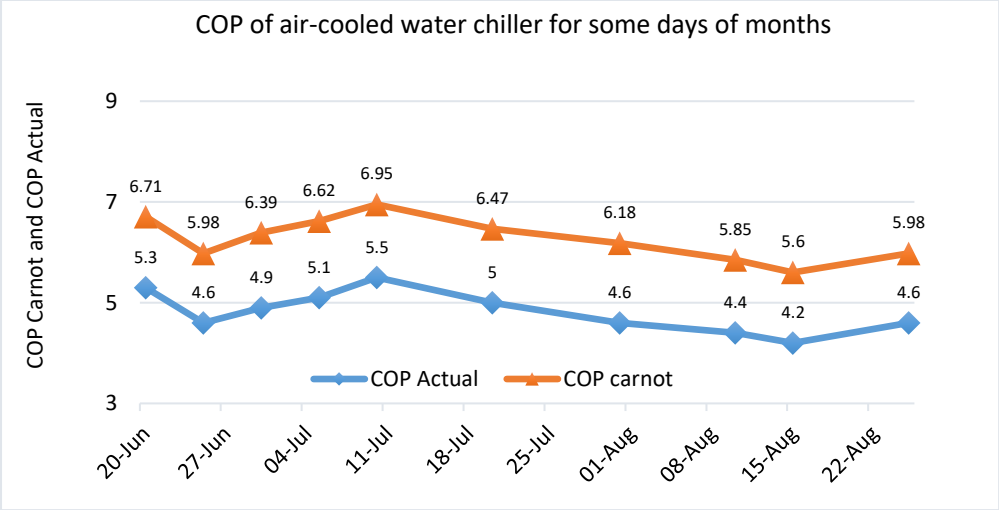


Figure 4.5. COPactual and COPcarnot of the air-cooled water chillers.

Under thermodynamic analysis, the energy and exergy analysis for components in the air-cooled water chiller are done. The overhead results are showed that changing the values among the chiller components.

The amount of analysis energy, exergy, and COP of the air-cooled water chiller are considered and the instrument precision requirement reference (Wu et al., 2012). These data were used to verify the accuracy of the simulation results with a comparison between chiller components. Comparison among the energy, exergy, and COP data of the actual chillers with the predicted values of obtaining simulation. The total amount of energy and exergy of the condenser were 751.43 kW, and 48.9 kW, as compared to the simulation data were 579.5 kW and 20.3 kW. The total amount of energy and exergy of the evaporator were 631.63 kW, and 16.2 kW, as compared to the simulation data were 439.5 kW and 6.5 kW. The power consumption and exergy compressors with simulation data were 119.8 kW, and 88 kW, with 140 kW, and 40.6 kW, respectively. Finally, the amount exergy of the throttling valve was 23.9 kW, as compared to simulation data was 17.4 kW, and the amount COP was (5.3) and simulated by (2.93). These results verified the suitability of the theoretical simulation method used to an air-cooled water chiller.

4.1.3. Energy and Exergy Analysis of the AHU

The energy and exergy values for fluid/air inlet and outlet of AHU are given that considered from the Tables (4.7) and (4.8). The values of energy and exergy are indicated from the results, and the most exergy interaction occurs at inlet and outlet in the AHUs. Energy and exergy losses of the AHUs have different values on the days of months in the hospital.

Table 4.7. Energy analysis of the AHU and values of parameters for some days of months.

Some days of months	Tin °C	Tout °C	$\dot{m}_{wAHU}$ kg/s	$\dot{m}_{air\ AHU}$ kg/s	Enthalpy h_i kJ/kg	Enthalpy h_o kJ/kg	Energy $\dot{E}_{AHU\ water}$ kW	Energy $\dot{E}_{AHU\ Air}$ kW	Energy E_{AHUL} kW
05-Jan	60	50	0.6	0.999	251.18	209.34	150.71	125.6	25.1
15-Jan	60	49	0.5	0.999	251.18	198.89	125.59	99.45	26.1
28-Jan	59	48	0.5	0.999	240.72	198.89	120.36	99.45	20.9
06-Feb	58	48	0.6	0.999	240.72	198.89	144.43	119.3	25.1
18-Feb	55	45	0.5	0.999	230.26	188.44	115.13	94.22	20.9
27-Feb	57	49	0.6	0.999	240.72	198.89	144.43	119.3	25.1
04-Mar	55	45	0.5	0.999	230.26	188.44	115.13	94.22	20.9
15-Mar	59	47	0.6	0.999	240.72	198.89	144.43	119.3	25.1
25-Mar	58	45	0.5	0.999	240.72	188.44	120.36	94.22	26.1
03-Apr	60	48	0.5	0.999	251.18	198.89	125.59	99.45	26.1

Table 4.8. Exergy analysis of the AHU and values of parameters for some days of months.

Some days of months	Ti °C	To °C	$\dot{m}_{wAHU}$ kg/s	$\dot{m}_{air\ AHU}$ kg/s	Enthalpy h_i kJ/kg	Enthalpy h_o kJ/kg	Entropy S_i kJ/kg.K	Entropy S_o kJ/kg.K	Exergy fan kW	Exergy Ex_{AHUt} kW
05-Jan	60	50	0.6	0.999	251.18	209.34	0.8313	0.7038	5.5	11.24
15-Jan	60	49	0.5	0.999	251.18	198.89	0.8313	0.6712	5.5	11.41
28-Jan	59	48	0.5	0.999	240.72	198.89	0.7997	0.6712	5.5	10.03
06-Feb	58	48	0.6	0.999	240.72	198.89	0.7997	0.6712	5.5	10.54
18-Feb	55	45	0.5	0.999	230.26	188.44	0.768	0.6386	5.5	9.707
27-Feb	57	49	0.6	0.999	240.72	198.89	0.7997	0.6712	5.5	10.03
04-Mar	55	45	0.5	0.999	230.26	188.44	0.768	0.6386	5.5	9.61
15-Mar	59	47	0.6	0.999	240.72	198.89	0.7997	0.6712	5.5	10.03
25-Mar	58	45	0.5	0.999	240.72	188.44	0.7997	0.6386	5.5	10.94
03-Apr	60	48	0.5	0.999	251.18	198.89	0.8313	0.6712	5.5	11.29

The AHU has the highest energy loss and the lowest exergy losses. The amount of energy and exergy losses of the AHU were 25.1 kW and 11.24 kW, on 05 January month, as compared to another day were 26.1 kW and 10.94 kW on 25 March month respectively. The AHU has a grate differentiable between the amount of energy and exergy as seen in Figure (4.6).

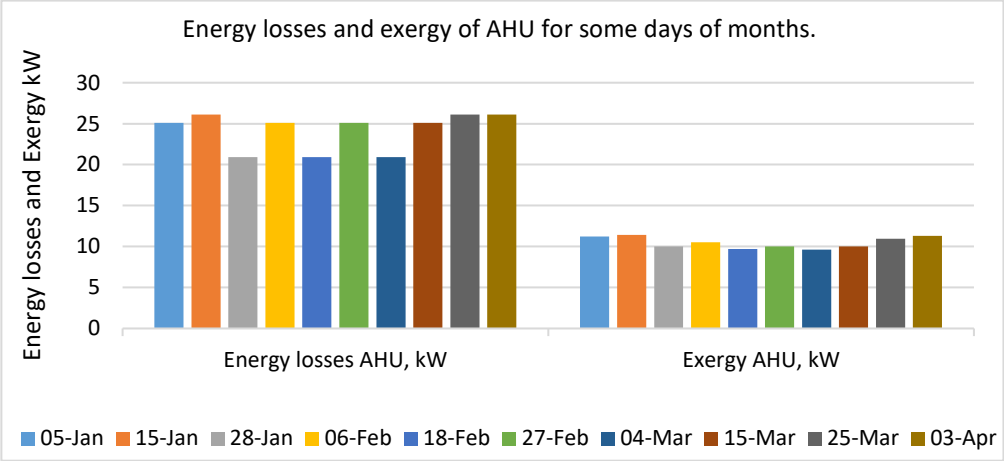


Figure 4.6. Energy and exergy analysis of the AHU.

4.1.3.1. Energy and Exergy Efficiency of the AHU

The energy efficiency and exergy efficiency value of the AHUs is given in Table (4.9). To understand better that the amount of energy efficiency and exergy efficiency are used to specify the work of the AHU according to first and second laws of thermodynamics. Besides, the first and second laws are used to calculating energy efficiency and exergy efficiency as shown in Table (4.9), and Figure (4.7). The values of energy and exergy efficiencies for the AHU were 83 % and 33 % on 5 January months, while compared to another day were 83 % and 23 % on 15 March months, respectively. As seen the results from that the Table (4.9) and Figure (4.7) can be investigative all differences of working AHU among the days on the monthly.

Table 4.9. Energy efficiency and exergy efficiency values of the AHU.

Some days of months	Energy efficiency AHU, η_{AHUI} (%)	Exergy efficiency AHU, η_{AHUII} (%)
05-Jan	83	33
15-Jan	79	23
28-Jan	83	26
06-Feb	83	28
18-Feb	82	22
27-Feb	83	23
04-Mar	82	21
15-Mar	83	23
25-Mar	78	19
03-Apr	79	22

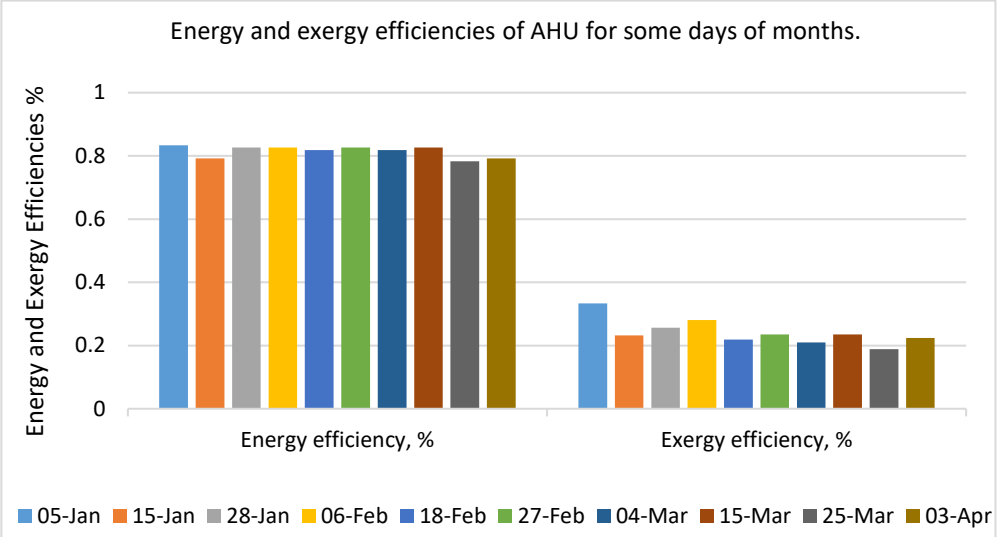


Figure 4.7. Energy efficiency and exergy efficiency of the AHU.

The amount of analysis energy, exergy, energy efficiency, and exergy efficiency of the AHU was considered and the instrument precision requirement reference (Ergün, 2015). These data used to verify the accuracy of the simulation results with comparison among the values of AHU. Comparison among the energy, exergy, thermal efficiency, and exergy efficiency data of the AHUs with the predicted values obtained of the simulation data. The total amount energy input of the AHU was 150.71 kW, energy output of the AHU was 125.6 kW, and energy losses of the AHU was 25.1 kW, as simulated to another study, energy input of the AHU was 35079.85 kW, energy output of the AHU was 26817.42 kW, and energy losses of the AHU was 8262.43 kW. Also, the amount of total exergy of the AHU was 11.24 kW, as simulated data was 1154.96 kW. The total amount of energy efficiency and exergy efficiency of the AHU were 83 %, and 33 %, as simulated data were 73%, and 46%, respectively. These results verified the suitability of the theoretical simulation method used for the AHUs.

4.2. Indoor Air Quality and Ventilation in the Hospital

Knowing that working from all the hospitals in the world are maintained 24 hours periodically. In the hospital, haven an activity load of occupancy (i.e. employed, patients, and visitors). The occupancy has a different time for the starting and ending of work from each part in the hospital. For example, in the operation room surgery was started at 09:00, and continued up to 17:00, and it was “at rest” from 17:00 to 08:00, during work for all days in the hospital. Besides, the operating room does not use two days of the weekend, but the first day on weekly was a busy day for the operating room of the hospital. So, all types of surgery can be doing that from one day in OR of all the hospitals in Iraq. Generally, surgery is performed time between 09:00 to 13:00, therefore that has more loads during working from this period. Also, the number of team surgery for all types of surgeries, medical staff should be 7 persons occupied in the operating room. Some locations of the hospital are measured on the days that can be indicated below:

4.2.1. Variation of Air Temperature and RH in OP-Room on 1/7/2019

The room temperature was desired 18-26 ºC during from seasons of the operating room according to standards and guidelines. On this day, room temperature at 8:00 can be decreased down to 24ºC during starting of the operation room, while increased gradually around 8:30 to17:00 during the work of the operation. The levels of room temperature can be changed from 24 hours period except at ‘’rest’’ time. Because of ‘’at rest’’ time from 17:00 to 8:00, the room temperature and relative humidity are not varied can be stayed a constant at 24ºC and 42% respectively. The room temperature and relative humidity levels can be stayed a constant at ‘’rest’’ time since there was nobody and have not activity load in the operating room. Sometimes the parameters such as room temperature, supply temperature, relative humidity, and air velocity, in the rooms ‘’at rest’’ time may be changed when the outdoor condition had application. The OP room had more loads due to maintaining medical staff, therefore the levels of room temperature can be varied during the time working in the OP rooms as shown in Table (4.10). Also, the supply air temperature almost lower than the room temperature during the summer season but varies adverse during winter as seen in Figure (4.8).

Table 4.10. T-Room and T-Supply values of the OP-Room on 1/7/2019

Time on daily	T-Room °C	T-Supply °C
0	24	22
8:00	24	22
9:15	24.5	22.3
10:25	24.2	22.5
11:30	24.6	22.8
12:15	24.8	23.1
13:45	24.5	22.7
14:40	25.2	23.2
15:30	26.1	23.7
16:20	26.3	23.9
17:00	26.2	23.8
20:10	25.4	23
22:00	24.4	22.2
23:30	24	22

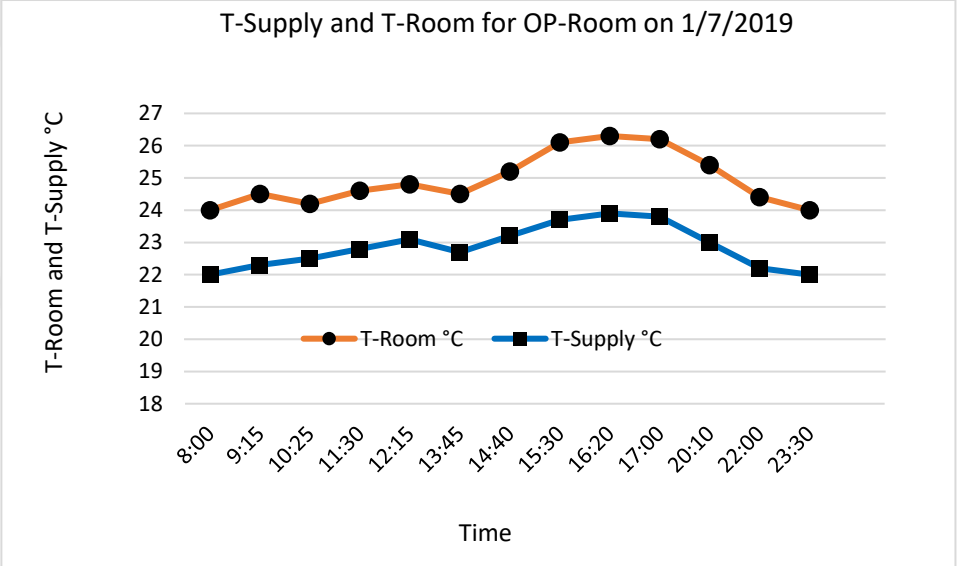


Figure 4.8. Variation air temperature in the OP room.

According to ASHRAE, desired temperature levels range between 18-26 ºC for the operating room of the hospital. On this day, the room temperature of the operation room is increased gradually at around 16:20 to 26.3 ºC upper than the limits of ASHRAE during working in the OP room of the hospital as seen in Figure (4.9). Also, the levels of room temperature can be varied from 24 hours period except at rest time.

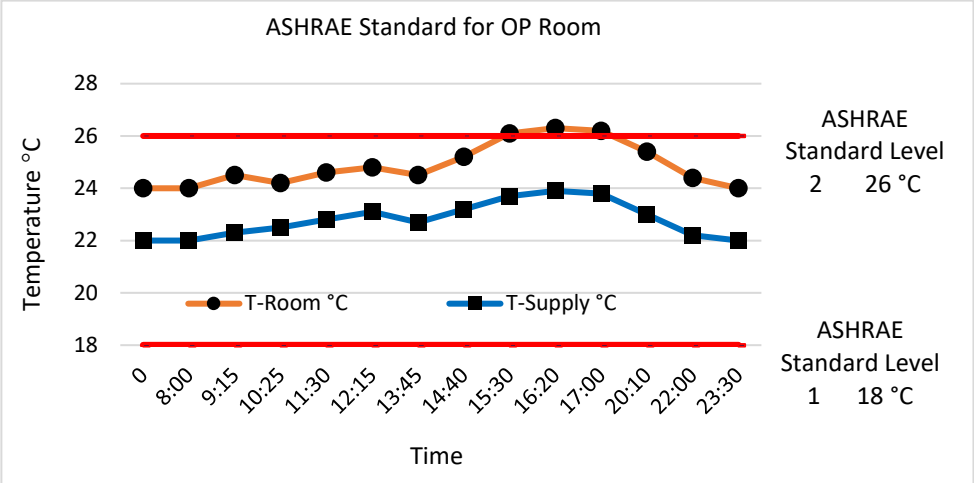


Figure 4.9. Variation of air temperature in the OP room according to ASHRAE standard

Also, relative humidity in the operating room is kept at around 42% at night and the room temperature is around 24ºC ‘’at rest’’ time on this day of the summer season. The levels of room temperature and relative humidity can stay constant because there was no activity load at rest time in the OP rooms. The levels of relative humidity are increased up to 48%, at the begun of the work and the levels of room temperature are also increased into the OP room. In addition, the levels of relative humidity may be lowering to nearly 28% due to maintaining the staff of surgery in the OP room as seen in Table (4.11) and Figure (4.10).

Table 4.11. Relative Humidity and T-Room values of the OP-Room on 1/7/2019

Time on daily	RH %	T-Room °C
0	42	24
8:00	42	24
9:15	48	24.5
10:25	40	24.2
11:30	37	24.6
12:15	35	24.8
13:45	32	24.5
14:40	30	25.2
15:30	28	26.1
16:20	29	26.3
17:00	32	26.2
20:10	38	25.4
22:00	41	24.4
23:30	42	24

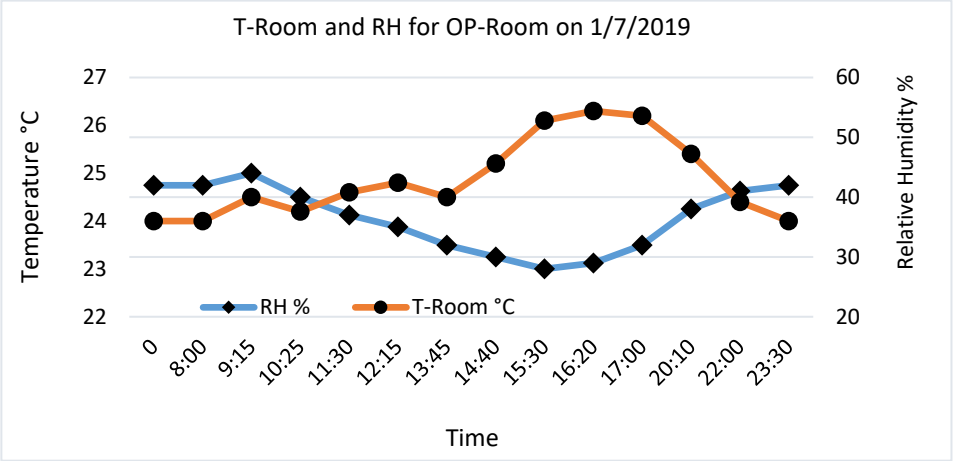


Figure 4.10. Variation Relative humidity and room temperature in the OP room.

Relative humidity according to ASHRAE levels were desired value between 30-60% for the operating room of the hospital. On this day, the levels of RH are decreased to nearly 28% at around 15:30 due to more have activity load during work of the OP room as shown in Figure (4.11). The levels of RH can be varied from 24 hours period except at rest time based on the activity load of the operating room.

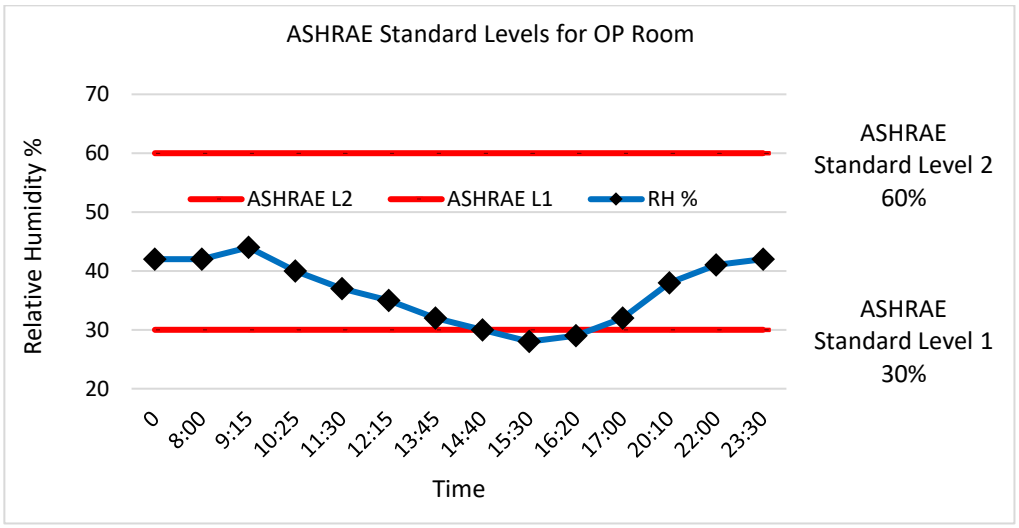


Figure 4.11. Variation of relative humidity in the OP room according to ASHRAE standard.

The levels each of room temperature and relative humidity can be raising and lowering to the limits of ASHRAE standard in the summer season but vice versa in the winter season.

4.2.2. Variation of Air Temperature and RH in the (ICU) room on 3/7/2019

In the ICU room, patients stayed that from 24h, since temperature and RH can be varied during 24 hours period in the room. Consequently, room temperature, RH, and air velocity values for the ICU room were 21-26 ºC, 30-60%, and <0.25 m/s, which are accepted that according to standards and guidelines. In the ICU room, the levels of room temperature are kept at around 24ºC, and the relative humidity is around 42% at night ‘’at rest’’ time in the summer season as shown in the Table (4.12). Also, the levels of room temperature were increased with the activity load began to work, and supply air temperature is commonly varied according to room temperature in the ICU room as seen in Figure (4.12). The levels of room temperature can be raising and lowering also based on the activity load of this room.

Table 4.12. T-Room and T-Supply values of the ICU Room on 3/7/2019

Time on daily	T-Room °C	T-Supply °C
0	24	22
8:00	24	22
9:20	24.4	22.1
10:30	24.3	22.4
11:35	24.5	22.7
12:15	24.6	22.9
13:40	24.2	22.8
14:25	24.8	23.2
15:35	25.7	23.3
16:20	26.2	23.6
17:00	25.9	23.4
20:05	24.8	22.9
22:25	24.4	22.2
23:40	24	22

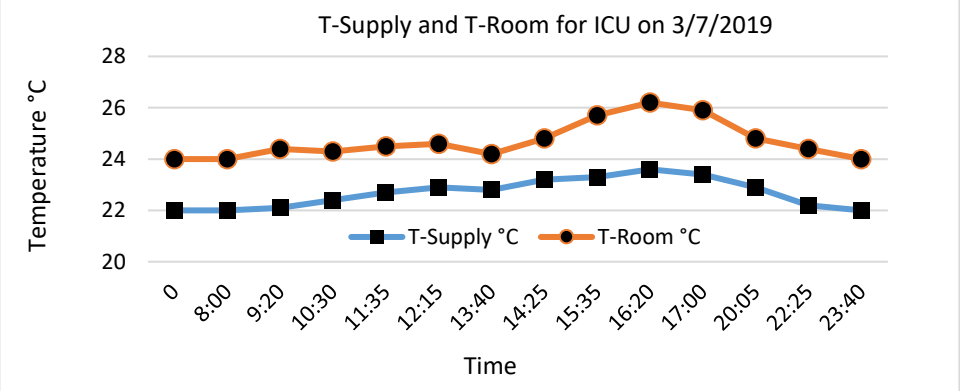


Figure 4.12. Variation of room and supply air temperature in the ICU room.

According to ASHRAE, temperature levels are desired to be between 21and 26 ºC for the ICU room in the hospital. Also, the levels of room temperature of the ICU room can be increased gradually at around 16:20 to 26.2 from upper the limits of ASHRAE due to having activity load at this time in the ICU room as seen in Figure (4.13). Besides, room temperature varies in 24 hours period except at rest time.

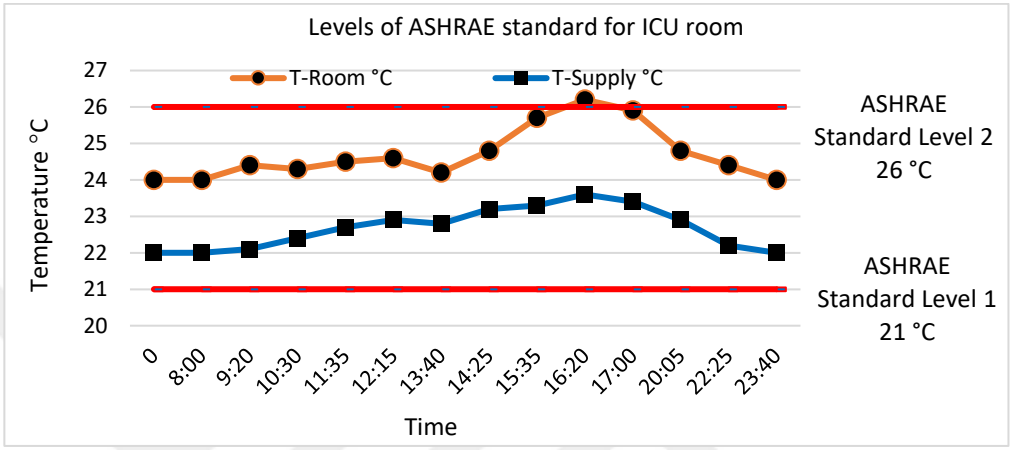


Figure 4.13. Variation of air temperature in the ICU room according to ASHRAE standard.

The levels of relative humidity may be raised in the ICU room due to influence by devices, visitors, hospital staff, etc. Sometimes, the levels of RH can be decreased by nearly 29%, due to more have activity load in the ICU room as seen in the Table (4.13) and Figure (4.14). Also, the levels of RH are decreased when the levels of room temperature increased in the summer season but vice versa in the winter.

Table 4.13. Relative Humidity and T-Room values of the ICU Room on 3/7/2019

Time on daily	RH %	T-Room °C
0	24	42
8:00	24	42
9:20	24.4	47
10:30	24.3	41
11:35	24.5	42
12:15	24.6	40
13:40	24.2	39
14:25	24.8	35
15:35	25.7	31
16:20	26.2	29
17:00	25.9	32
20:05	24.8	38
22:25	24.4	40
23:40	24	42

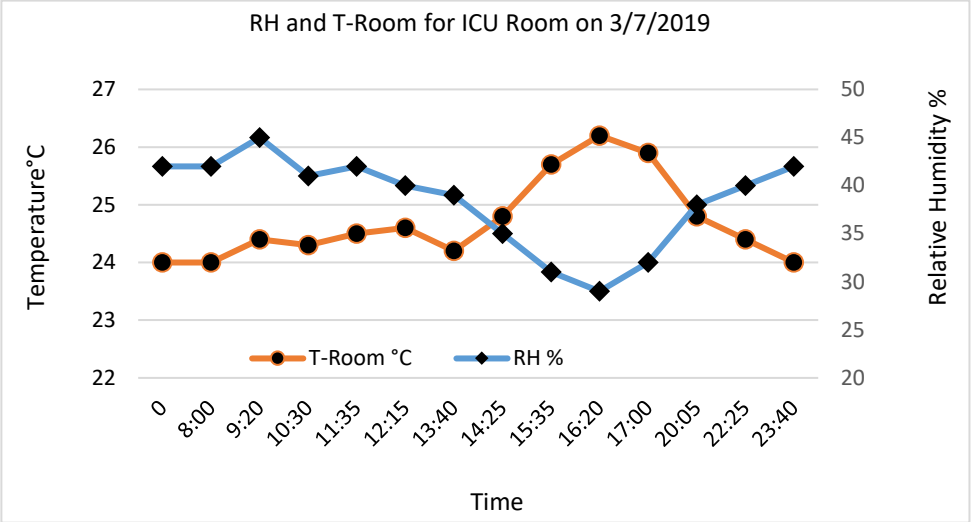


Figure 4.14. Variation of relative humidity and room temperature with time in ICU room.

Relative humidity according to ASHRAE levels were desired value between 30-60% for the ICU room of the hospital. Also, the levels of RH can be decreased to lower than the limits of ASHRAE such as at around 16:20 can be down to 29% due to more have activity load during work of the ICU room as seen in Figure (4.15). Besides, the levels of RH can be raising and lowering depend on activity load.

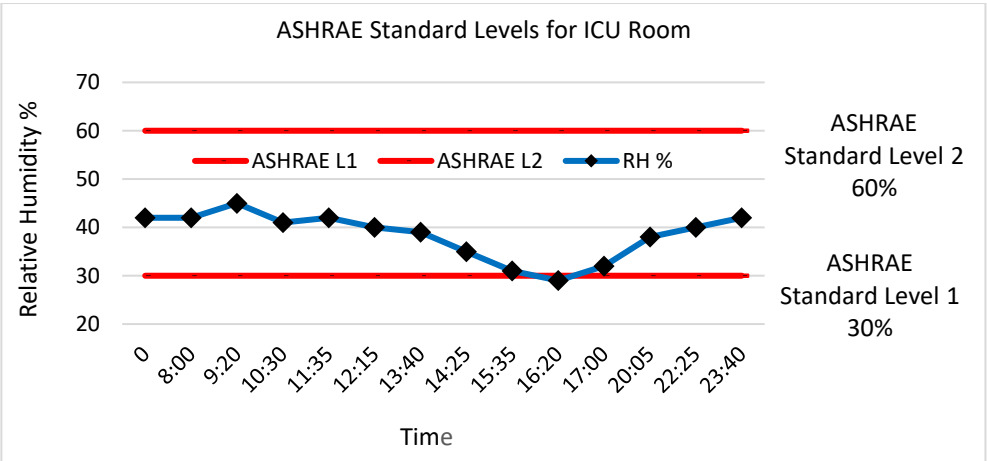


Figure 4.15. Variation of RH according to the ASHRAE standard in the ICU room.

The levels of RH and room temperature can be also raising and lowering to the limits of ASHRAE standard due to more have activity load at this time in the rooms of the hospital.

4.2.3. Variation of Air Temperature in Different Room Types on 15/7/2019

The measurement results for more room types in the hospital are indicated in Table (4.14). The room types have a different time for started and ended staff of workers during the experimental period from each part of the hospital. The levels of the parameter of the room types can be changed during 24 hours working period in the hospital. Also, the measurement of parameters of the room types can vary with time off periodically. From Figure (4.16) the levels of room temperature are higher than the levels of supply temperature on this day of the summer season.

Table 4.14. T-Room and T-Supply values for the Room Types on 15/7/2019.

Room Types	T-Room °C	T-Supply °C
OP-Room	26.3	22.9
Delivery Room	26.2	22.8
Recovery Room	26.1	22.8
ICU Room	26.1	22.7
X-ray Room	25.6	22.4
Laboratory Room	24.8	22.4
Pharmacy Room	24.5	22.4
sterilizer equipment Room	25.8	22.5
Medical/anesthesia gas storage	25.4	22.6
Treatment room	24.6	22.4
CCU-Room	25.4	22.7
Corridor	26.3	22.9

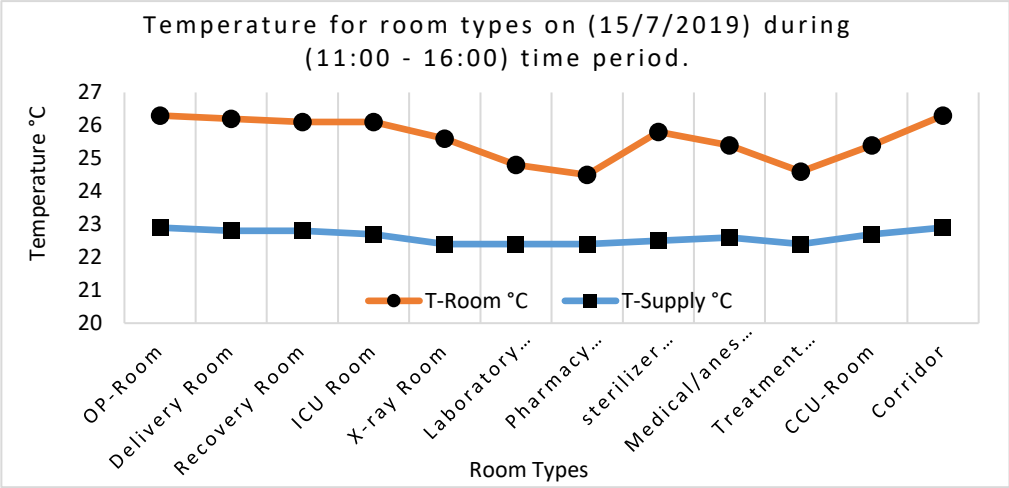


Figure 4.16. Variation of indoor and supply air temperature for Room Types.

The levels of relative humidity and room temperature for the room types of the hospital can be indicated in Figure (4.17). The levels of relative humidity in the OP-room, delivery room, and recovery room are lower than the levels of standards and guidelines, therefore conditions uncomforted in the room types of the hospital as seen in the Table (4.15).

Table 4.15. Relative Humidity and T-Room for the Room Types on 15/7/2019.

Room Types	T-Room °C	RH %
OP-Room	26.3	28
Delivery Room	26.2	29
Recovery Room	26.1	29
ICU Room	26.1	34
X-Ray Room	25.6	35
Laboratory Room	24.8	35
Pharmacy Room	24.5	36
sterilizer equipment Room	25.8	32
Medical/anesthesia gas	25.4	33
Treatment room	24.6	36
CCU-Room	25.4	35
Corridor	26.3	31

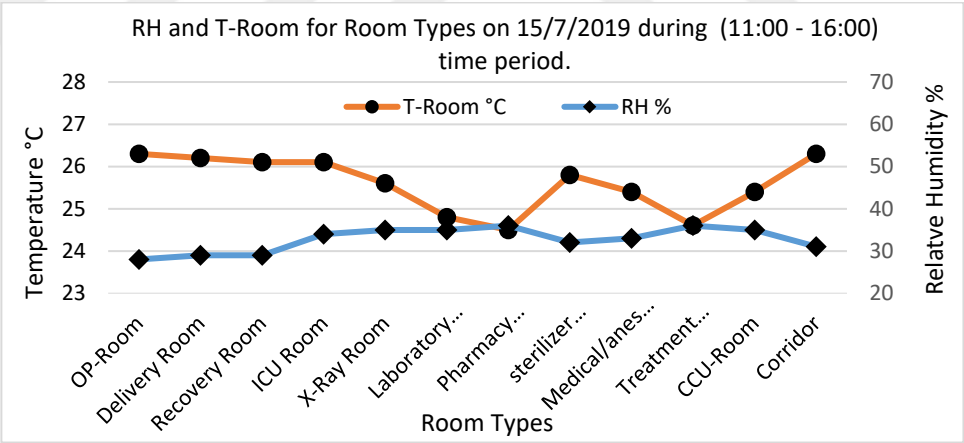


Figure 4.17.Variation of RH and room temperature for Room Types.

The levels each of relative humidity and the room temperature must be inside between the limits of standards and guidelines to comfort conditions in the room types of the hospital. Sometimes the levels of RH and room temperature may be raising or lowering to the limits of standards and guidelines, therefore the area has an uncomforted condition of the hospital.

4.2.4. Variation of Air Temperature and RH in Different Room Types on 19/8/2019

Supply air temperature, indoor air temperature, and relative humidity are measured in Different Room Types of the hospital on 19/8/2019. On this day, a variation of RH and room temperature are seen in Figures (4.18) and (4.19). The comparison of supply and indoor air temperature are given in Table (4.16). The relative humidity and indoor air temperature are also presented in Table (4.17). The levels of RH and room temperature vary according to different room types depend on activity load and time measurement of parameters in the areas of the hospital.

Table 4.16. T-Room and T-Supply for Different the Room Types on 19/8/2019

Room Types	T-Room °C	T-Supply °C
OP-Room	25.8	22.8
Delivery Room	25.6	22.7
Recovery Room	25.7	22.6
ICU Room	24.9	22.7
X-ray Room	24.6	22.3
Laboratory Room	24.2	22.4
Pharmacy Room	24.1	22.2
Sterilizer Equipment Room	24.5	22.3
Medical/anesthesia gas storage	24.6	22.4
Treatment room	24.4	22.2
CCU-Room	24.7	22.5
Corridor	25.6	22.6

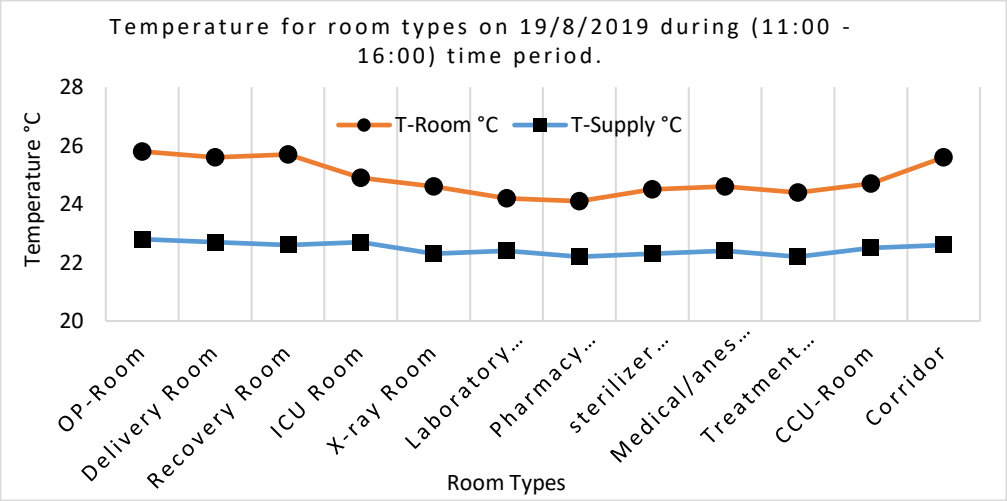


Figure 4.18. Variation of air temperature for different Room Types.

The levels of relative humidity and room temperature are raising in all the room types of the hospital as compared to the other day of last month as shown in the Table (4.17). The levels of relative humidity and room temperature change in room types of the hospital as seen in Figure (4.19).

Table 4.17. Relative Humidity and T-Room of the Room Types on 19/8/2019

Room Types	T-Room °C	RH %
OP-Room	25.8	32
Delivery Room	25.6	33
Recovery Room	25.7	33
ICU Room	24.9	36
X-Ray Room	24.6	37
Laboratory Room	24.2	38
Pharmacy Room	24.1	38
sterilizer equipment Room	24.5	36
Medical/anesthesia gas storage	24.6	35
Treatment room	24.4	38
CCU-Room	24.7	36
Corridor	25.6	34

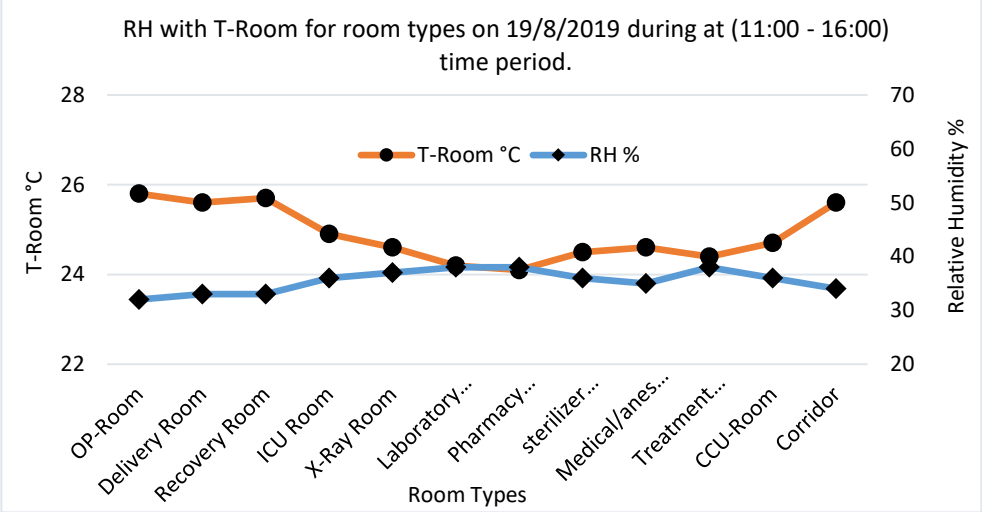


Figure 4.19.Variation of RH and room temperature for Different Room Types

The maximum and minimum levels of the parameter must between to inside the limits of standards and guidelines for improving conditions in different room types of the hospital.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The evaluation of HVAC systems used in the hospital was done by using energy and exergy analysis and thermal condition analysis in this study. The results are given in two parts: indoor air quality and energy and exergy analysis of the HVAC system of the hospital Qaladeze in Sulaymaniyah, Iraq. The first and second laws of thermodynamics are used in energy and exergy analysis of HVAC systems. Energy and exergy analysis were done in the boiler, chiller, and AHU as components of the HVAC system in the hospital. The maximum value of energy efficiency and exergy efficiency of the boiler are 90% and 23%, respectively. The maximum COP of the chiller is calculated as 5.5. The maximum energy efficiency and exergy efficiency of AHU are 83% and 33%, respectively. The results showed the working conditions of each component of the HVAC system have a significant effect on the analysis of energy and exergy.

The second part analysis of energy and exergy are mentioned to the good design of parameters and good operation of the HVAC system serving to sterile spaces in the hospital according to standards and guidelines. Most standards and guidelines were provided to the satisfactory information about the design of parameters in the hospitals and concrete to distinguish according to their needs of hygiene for the spaces were performed by DIN 1946-4 as Class I and II spaces. Generally, in the global world was accepted three standards and guidelines (DIN 1946-4, ASHRAE, and VDI 2167) while comparison among the references revealed in the results. Standards and guidelines are given general information about the design parameters of the HVAC system applications. The design of the HVAC system must be perfected for all parameters since that can be avoided to the problems during an operation period of experimental study. The experimental study continued to the measurement of the operation room, intensive care unit ICU, and room types on daily in the hospital were revealed in the results. Also, understanding the installation of the HVAC system must be measured of each parameter during the ‘’in operation’’ condition of the hospital. The results are indicated to the raising or

lowering the levels of parameters than the levels desired of the references due to activity load from the spaces of the hospital. The maximum and minimum levels of the parameters must between to inside the limits of standards and guidelines, for improving conditions into room types of the hospital. Therefore, lowering or raising of the levels of relative humidity and room temperature are acted to the health of patients and occupants in the hospitals. According to standard and guideline levels are mentioned to the requirement of room condition depended on time measured of parameters, and activity load in the hospitals. When the parameters are calculated to design room temperature can be serving conditions for all types of room in the hospital according to references. The measurement levels of the parameter can be indicated that relative humidity is around 42% and room temperature is around 24ºC, during rest time are stayed a constant in the summer but varies versa in the winter season. Therefore, the levels of parameters can vary with had activity load on each of the spaces of the hospital. All standards and guidelines are declared to specify low levels of air velocity in the room hospitals, especially in the OP room. Activity and movement of personnel in the clean area are greatly increasing particle concentrations and air velocity into the room air. This study shows information about the applications in the design parameters of HVAC systems to serving sterile areas in hospitals according to the limit of standards and guidelines. Also, in most reviewed references airflow between sterile spaces can found important factors to keep the directions of the sterile rooms to require hygiene levels and no fixed relative pressure value to providing pressure difference between the spaces. During the experimental study according to most references cannot find information about the filtration stages for sterile environments, and the parameters to measuring hygiene levels in the room hospitals.

5.2. Recommendations

Energy and exergy analysis are commonly influenced by the air conditioning processes of the HVAC systems. To understand that the negative effects on the efficiency of large exergy destructions, which are relational to entropy generations due to energetic in the HVAC systems and the conforming durable environmental degradation. Besides, the replacement to be possible of environmental costs on the exergy destruction must be factored into controls and should be compatible with HVAC systems to avoid the temperature peaking or equipment oversizing. In this regard, energy and exergy analysis helps the information and improvement of the optimum work of the HVAC system of the hospital. In this study, we can see the factors are affected by the HVAC systems. Also, the HVAC system has applications maybe avoid the parameters since they should be tested that manually. Application and renovation of the HVAC system should be according to national and international regulations and standards, where using suitable materials and equipment. Sometimes, replace and resize of the equipment HVAC system is required to improve their operating conditions. To serve and improve the performance of AHU must be the spaces appropriate and installations backup number and type filters of the AHUs. When the AHU is operated throughout 24-hours of year, necessary in order to ensure in indoor conditions. Check and replace or install, were direct to applications of HVAC system controls for adjusting physical parameters according to the desired levels for surgical operations and proper conditions in the hospital. To reduce the concentration of anesthetic gases and other gas pollutants must be install scavenging equipment in the hospital especially in the operation rooms.

There are general recommendations for HVAC system applications in the hospital:

- The maximum and minimum levels of the parameter must between to inside the limits of standards and guidelines, for improving conditions into room types of the hospital.

- While above-mentioned standards involve many of the subjects regarding the design, application, planning, production, maintenance, and operation of the hygienic HVAC system in the hospitals.

- Design criteria for the manufacture of products, especially where materials and products exposed to the environment should be a suitable level of cleanliness of the room hospitals.

- The level of air cleanliness for different areas in the hospital should be determined according to the standards and guidelines.

- Appropriate design and controls for the locations and HVAC systems should be in place to achieve containment, cleanliness and suitable levels of safety such as the product, personnel, and environment.

- Design criteria for recommendation value of parameters such as temperature, relative humidity, and air velocity should be maintained under codes according to standards and guidelines in the world.

- Personnel and materials did not move from a higher cleanliness zone to a lower cleanliness zone and back to a higher cleanliness zone. Where this is unavoidable risks should be recognized, and controlled in the hospitals.

- HVAC systems should be ensure attended that to specify room conditions for example through heating, cooling, air filtration, air distribution, airflow rates, and air exchange rates in the room of hospitals.

- Air-handling units (AHUs) should be provided to sufficiently designed drains to remove any condensate that may be formed in them.

- Where possible, ducting, piping, fittings, sensors and other components should be marked or labeled for ease of documentation, indicating location, and direction of flow must be suitable.

- Return and exhaust filters, and grilles are selected and installed that should be a suitable design for cleaning and maintenance in the rooms.

- The air in the rooms was polluted that with organic solvents or highly hazardous materials should normally not be recirculated.

- HEPA filters may be installed (in the supply air stream or return air stream) to remove pollutants and thus prevent cross pollution. The filter selection should be suitable for their intended use and classified according to the modern international classification system.

- The Air should not flow through the dust extraction ducting or return air ducting from the room with higher pressure to the room with lower pressure.

- Pressurization in the room of hospital should normally be maintained positive pressure relative to the outside, to prevent the entrance of pollutants. Where it was being maintained negative pressures in the different spaces should be taken to lessen any risks.

- For suitability temperature and relative humidity should be controlled, tested and recorded to ensure that the conditions and maintained stability along period time require products a comfortable condition in the rooms.

- Operation and maintenance manuals of the HVAC system should be available to procedures and kept up to date with details of any system made revisions.

- Each equipment of AHU (i.e. fan, coil, filter, and humidifier) should be checked that problems at working periodically.

- Consequently, all ducts and pipes should be checked that of surface coating damage caused by insulation, corrosion, and scratching.

- Sometimes ducts have air leakage due to more problems such as properly all openings in an air-handling cabinet, joints in the duct system, joints where ducts meet register flares, and openings are penetrated the room.

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CURRICULUM VITAE

Name and Surename : **Kale Mawlood Mina**

Nationality : **Iraq**

Place and Date of Birth : **Pshdar-Sulaymaniyah 5/12/1985**

Phone No : **07504442309**

e-mail : **kale.mina12@gmail.com**

EDUCATION

Degree	**Name, District, Province**	**Completion Year**
High School	: Amaday Sangasar High School Sulaymaniyah	2006
University	: Salahaddin University – College of Engineering	
	Dept. General Mechanical Engineering – Hawler	2010
Master	: Harran University Institute of Science	
	Mechanical Engineering Department	2020

FOREIGN LANGUAGES : **English, Turkish**