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Hastanelerde Isıtma, Havalandırma ve İklimlendirme Uygulamalarının Enerji ve Ekserji Analizi

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Öz

Bu çalışmada, Irak, Süleymaniye'deki Qaladze hastanesinde kullanılan HVAC sistemlerinin enerji ve ekserji analizleri termodinamiğin birinci ve ikinci yasalarına göre 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. HVAC sistemlerinin genel olarak ısıl konforu hastanede sağladıkları tespit edilmiştir. Ancak hastanedeki iç hava kalitesini ve ısıl koşullarını iyileştirmek için HVAC sistemlerinin tüm bileşenlerinin sürekli kontrol edilmesi gerektiği görülmüştür.

Anahtar Kelimeler: Hastane, Enerji, Ekserji, İklimlendirme

Energy and Exergy Analysis of HVAC Applications in Hospitals

Abstract

In this study, energy and exergy analysis of HVAC systems used in Qaladze hospital in Sulaymaniyah, Iraq were done by using the first and second laws of thermodynamics. The average values of thermal energy and exergy efficiencies for the boiler and air handling units were found as 89%, 19.5% and 81.5%, 24%, respectively. The cooling coefficient of performance of the chiller group was calculated as 4.82 on average. It was determined that HVAC systems generally provide thermal comfort in the hospital. But it was concluded that all components of HVAC systems should be constantly checked to improve the thermal conditions and indoor air quality in the hospital.

Keywords: Hospital, Energy, Exergy, HVAC

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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 turn eyes on the 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 [1]. HVAC systems in the hospital are very demanding energy and play a determinant role in indoor environmental quality (IEQ). Energy efficiency in the HVAC system is also 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 energy and exergy analysis were evaluated of the actual energy consumption for thermal systems in the central heating systems of the hospital [2]. The exergy analysis is used to evaluate the performance of HVAC systems. The series of exergy analysis applications showed effectiveness in the HVAC system [3].

2. MATERIAL AND METHOD

Energy and exergy analysis of HVAC system application with all technologies are carried out for the Qaladze Hospital of Sulaymaniyah, Iraq. Since analysis of energy and exergy of the HVAC system in hospitals have a very desirable role in indoor 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 parameters related to the thermodynamic equations should be taken into account for energy and exergy analysis in the HVAC system. The applications of parameters are indicated for the heating and cooling process of air conditioning in the hospital.

2.1. Energy and Exergy Analysis (Thermodynamic Analysis)

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 in the HVAC system. The first and second laws of thermodynamics are also used to calculate energy and exergy efficiency and information about to work of the HVAC systems [4].

The amount of energy inlet and outlet should be equal according to the first law thermodynamic as known energy analysis [5]. It also are called energy conservation that are expressed as follows (Equation 1):

$$\Sigma E_i = \Sigma E_o \qquad (1)$$

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 losses.

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 equation (Equation 2):

$$\eta_I = \frac{E_o}{E_i} \qquad (2)$$

The exergy analysis is also expressed a percentage of exergy losses and second law efficiency of the thermodynamic analysis. Exergy analysis is an important device for evaluating and analyzing processes by identifying flaws due to thermodynamic irreversibility [6,7].

When the materials are under heating temperature T, pressure P, special enthalpy h, and entropy S reduced to T_o environmental temperature. The equation special of exergy can be calculated from the following equation [5] (Equation 3).

$$E_x=(h-h_0)-T_0(S-S_0) \quad (3)$$

The exergy difference between inlet and outlet of points for every device can be expressed irreversibility (I) as seen below (Equation 4):

$$I=\sum Ex_{inlet}-\sum Ex_{outlet} \quad (4)$$

The thermal efficiency is not an adequate criterion alone to evaluate energetic efficiency, irreversibility (second law efficiency) is required [8] (Equation 5).

$$\eta_{II}=\frac{\text{useful work output}}{\text{maximum possible (reversible)work output}} \quad (5)$$

The exergy ratio is expressed as follows [9] (Equation 6)

$$\eta_{II}=\frac{Ex_0}{Ex_i} \quad (6)$$

2.1.1. Energy and Exergy Analysis of the Boiler

Energy and exergy analysis are done for 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. The hot water in the boiler are distributed to the boiler line, air handling unit (AHU), and diffusers, as shown in Figure 1. The range of temperatures between 50 °C and 65 °C is produced from that of the boiler.

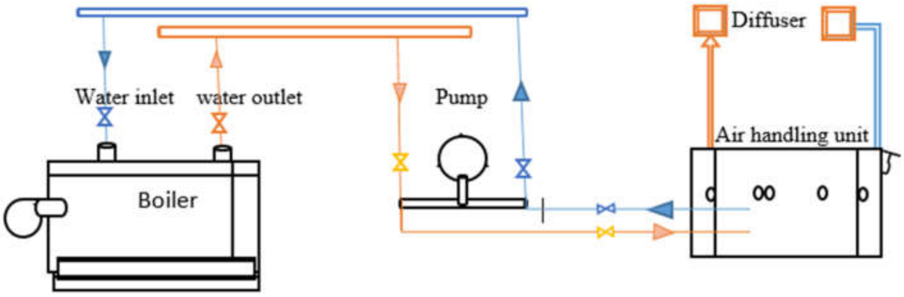

Figure 1. Schematic of a typical heating system with the boiler, AHU, and diffusers

Boiler inlet energy is the amount of fuel combustion ($Eb_i=\dot{E}_{bfuel}$), and it can be calculated as follows (Equation 7):

$$\dot{E}b_{fuel}=\dot{m}_{fuel} \text{ X } H_{net} \quad (7)$$

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 ($\dot{E}_{B_0}=\dot{E}_{bw}$) and it can be calculated as follows (Equation 8):

$$\dot{E}_{bw}=\dot{m}_{bw}[h_o-h_i] \quad (8)$$

Where, $\dot{E}_{bw}$ is energy boiler water, $\dot{m}_{bw}$ is the mass flow rate of water. Energy loss in the boiler can be acquired that from as follows (Equation 9):

$$\dot{E}_{b_L}=\dot{E}_{b_{fuel}}-\dot{E}_{bw} \quad (9)$$

Exergy analysis is used for the calculation of the second law efficiency of the boiler [10]. Inlet and outlet of total exergy in the boiler as seen in Figure 1.

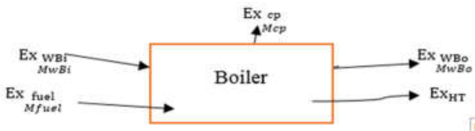

Figure 2. Exergy analysis for inlet and outlet of the boiler

As shown as in Figure 2, 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}) [11]. The following equation is given as a total of exergy losses, acquired by reformulating Equation 10, (5):

$$Ex_{b\ total}=Ex_{bfuel}+Ex_{bwi}-(Ex_{bwo}+Ex_{bHT}+Ex_{bCP}) \quad (10)$$

The exergy of burned fuel is indicated to work of the boiler, as diesel fuel when connected with oxygen and nitrogen during comprising of combustion natural gas fuel equation as seen the follows below [12] (Equation 11).

$$Ex_{bfuel}=\dot{m}_{fuel}*H_{net}*\varphi \quad (11)$$

Where Ex_{bfuel} is exergy boiler fuel, φ is chemical energy factor taken as (1.04) ([11,13] and H_{net} is the net calorific value of (diesel fuel) [14].

The exergy of boiler inlet and outlet of water calculated from the following Equations 12 and 13:

$$E_{Xb_{w_i}}=\dot{m}_{bw}\left[(h_{wi}-h_0)-T_0(S_{wi}-S_0)\right] \quad (12)$$

$$E_{Xb_{w_o}}=\dot{m}_{bw}\left[(h_{wo}-h_0)-T_0(S_{wo}-S_0)\right] \quad (13)$$

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.

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 (Equations 14 and 15):

$$\sum Ex_{HT}=\dot{Q}_L\left(1-\frac{T_0}{T_{BST}}\right) \quad (14)$$

$$\dot{Q}_L=\dot{m}_{fuel}\ x\ H_{net}-\left(\dot{E}x_B+\left(\dot{m}_{N_2}\cdot\Delta h_{N_2}+\dot{m}_{CO_2}\cdot\Delta h_{CO_2}+\dot{m}_{H_2O}\cdot\Delta h_{H_2O}\right)\right) \quad (15)$$

Where Ex_{HT} is the heat transfer exergy boiler kW, T_{BST} is the boiler surface temperature, So, QL acquired by subtraction of exergy by fuel combustion of value for exergy in the boiler, and Equation 16 calculated by [12].

The exergy of combustion products in the boiler calculated in the following Equation 16:

$$\sum Ex_{bcp}=\sum\dot{M}_i\ x\ Ex_i \quad (16)$$

Where $\sum Ex_{bcp}$ 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 combustion equation of diesel fuel is given the following Equation 17, [14].

$$C_{12}H_{23}+17.75(O_2+3.76N_2)\rightarrow 12CO_2+11.5H_2O+66.74\ N_2 \quad (17)$$

The percentage of total mass for each combustion product can be calculated as follow (Equation 18):

$$y_i=\frac{\dot{M}_i}{\dot{M}_{tot}} \quad (18)$$

$$\dot{M}_{tot}=(12*\dot{M}_{CO_2})+(11.5*\dot{M}_{H_2O})+(66.74*\dot{M}_{N_2}) \quad (19)$$

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 [15].

$$\dot{M}_{Cp}=(\dot{M}_{fuel}+\dot{M}_{air})\ x1* \quad (20)$$

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

$$\dot{M}_i=\dot{M}_{cp}\cdot y_i \quad (21)$$

The exergy of combustion products equals the addition of thermodynamic and chemical exergy. Total exergy value of flue gases are acquired from following Equation 22:

$$\sum Ex_{bcp}=\dot{M}_{N_2}xEx_{totN_2}+\dot{M}_{CO_2}xEx_{totCO_2}+\dot{M}_{H_2O}xEx_{totH_2O} \quad (22)$$

Table 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

2.1.2. Energy and Exergy Analysis of the Chiller

Chiller plants should be sized possible with current cooling loads when used for air-conditioning of the hospitals. The cooling system is used for the cooling process in the summer season in 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.

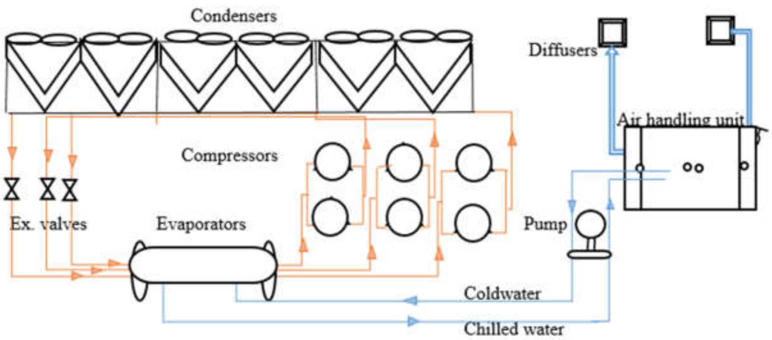

Figure 3. Schematic of a typical cooling system with the chiller, AHU, and diffusers

The cooling system is an air-cooled water chiller as shown in Figure 3. The energy and exergy analysis were done for components of the chiller: compressor, condenser, throttling device, and evaporator. The overall performance of the air-cooled water chiller is also calculated. The potential enhancement of performance of each component with the energy efficiency is investigating that analysis of the energy and exergy in the air-cooled water chiller [16]. In the chiller, energy and exergy analysis were done according to measured parameters for the components. All equations for the components are given in the Table 2, [17].

Table 2. Equations of energy and exergy analysis for chiller components

Components	Mass Balance	Energy analysis	Entropy	Exergy analysis
Compressor	$\dot{m}_2=\dot{m}_1$	$W_n=\dot{m}_1(h_2-h_1)$	$\phi_1-\phi_2=(h_2-h_1)-T_o(s_2-s_1)$	$\dot{E}x_{cp}=Wn-[\dot{m}_1(\phi_1-\phi_2)]$
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	$\dot{m}_4=\dot{m}_3$ $\dot{m}_{wi}=\dot{m}_{wo}=\dot{m}_w$	$Q_{ev}=\dot{m}_4(h_1-h_4)$ $=\dot{m}_a c_{p\omega}(T_{w0}-T_{wi})$	$\phi_1-\phi_4=(h_1-h_4)-T_o(s_1-s_4)$ $\phi_{wi}-\phi_{wo}=(h_{wi}-h_{wo})-T_o(s_{wi}-s_{wo})$	$\dot{E}x_{ev}=\dot{m}_4(\phi_1-\phi_4)+\dot{m}_w(\phi_{wi}-\phi_{wo})$

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.

The coefficient of performance (COP) used to evaluate overall performance in the air-cooled chiller. COP is calculated as seen from the equation below [18,19] (Equation 23).

$$COP=\frac{\dot{Q}_e}{\dot{W}_{c1}+\dot{W}_{c2}} \quad (23)$$

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

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

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. In addition, AHU is used for heating and cooling processes of air-conditioning in the hospital. The energy equation for AHU can be indicated from follows below [20] (Equations 24, 25 and 26).

$$\dot{E}_{AHU\ water}=\left[\dot{m}_{AHU_w}\ x\ \left(h_{wo}-h_{wi}\right)\right] \quad (24)$$

$$\dot{E}_{AHU\ air}=\left[\dot{m}_{AHU_a}\ x\ \left(h_{ao}-h_{ai}\right)\right] \quad (25)$$

$$\eta_{AHUI}=\frac{\dot{E}_{AHU\ o}}{\dot{E}_{AHU\ i}} \quad (26)$$

Exergy analysis in the AHU has excellent insulation, heat losses to the environment may be neglected that from elements as shown in Figure 4.

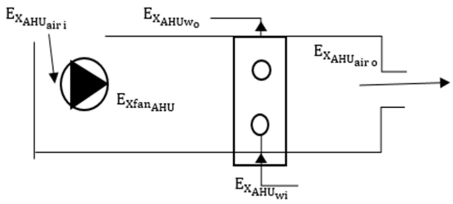

Figure 4. Exergy analysis for inlet and outlet of the AHU

Exergy value for inlet and outlet water in the AHUs can be calculated from the following equations (Equations 27 and 28);

$$Ex_{AHUw_i}=\dot{m}_{AHUw}\left[\left(h_{wi}-h_0\right)-T_0\left(S_{wi}-S_0\right)\right] \quad (27)$$

$$Ex_{AHUw_o}=\dot{m}_{AHUw}\left[\left(h_{wo}-h_0\right)-T_0\left(S_{wo}-S_0\right)\right] \quad (28)$$

When calculating the air part in AHU, exergy is assumed to be 0, because the air is drawn from the atmosphere [20]. Exergy for the outlet of AHU as shown in equations below (Equation 29):

$$Ex_{AHU_{air}}=\dot{m}_{AHUa}\left[\left(h_{ao}-h_0\right)-T_0\left(S_{ao}-S_0\right)\right] \quad (29)$$

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 of statements, the total exergy equation and exergy efficiency for AHUs have calculated from that the following Equations 30 and 31 [10].

$$Ex_{AHUt}=Ex_{AHU_{air_i}}+Ex_{AHU_{water_i}}+Ex_{AHU_{fan_i}} -(Ex_{AHU_{air_o}}+Ex_{AHU_{water_o}}) \quad (30)$$

$$\eta_{AHUII}=\frac{Ex_{AHU_o}}{Ex_{AHU_i}} \quad (31)$$

3. RESULT AND DISCUSSION

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 parameters. The parameters are measured during the operating of the HVAC system in the hospital.

3.1. Energy and Exergy Analysis of HVAC System

Energy and exergy analysis of the components of the 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.

3.1.1. Energy and Exergy Analysis of the Boiler

The boiler has a capacity values ranges between 250 kW to 600 kW. Analysis energy and exergy have consisted of temperature, mass flow (water/fuel), enthalpy, and entropy are measured for some days of month in the hospital. The total amount of analysis energy and exergy of the boiler are given in the Tables 3 and 4. The amount of energy and exergy of the boiler vary according to daily usage of the HVAC system as seen in Figure 3.

Table 3. 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. 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 h_i kJ/kg	Enthalpy h_o kJ/kg	Entropy S_i kJ/kg.K	Entropy S_o kJ/kg.K	Exergy boiler, 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

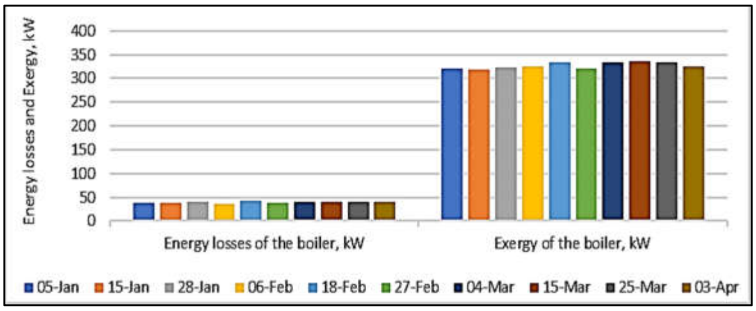

Figure 5. Energy and exergy analysis of the boiler

The terms of energy and exergy losses, of the HVAC systems have different values based on the temperature and mass flow. Figure 5 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 vary according to working days in the months. The value of energy and exergy of the boiler were 38.22 kW and 321.15 kW, on 05 January, as compared to another day were 39.89 kW and 335.52 kW on 15 March, respectively. The losses of energy and exergy in the boiler can be indicated the great difference among the values of energy and exergy.

3.1.1.1. 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. The thermal efficiency and exergy efficiency of the boiler should be calculated in order to understand how boiler works better. In the literature, thermal efficiency range between 80% and 90% and exergy efficiency range between 15% and 25%. The values of thermal efficiency and exergy efficiency for the boiler are 90% and 23% on 5 January, while they are 89% and 18% on 15 March, respectively. According to the results, the boiler has the optimum working for the heating process of the hospital as seen in Table 5.

Table 5. 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

The difference between thermal efficiency and exergy efficiency can be investigated that the work's boiler. The recommendation values of the boiler thermal efficiency above were 89%, and exergy efficiency under was 23%, which can be provided to a comfort air-conditioning in the hospital during the winter season.

3.1.2. Energy and Exergy Analysis of the Chiller

The chiller has a capacity value (180 tons of refrigeration and 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 given at working the devices of the HVAC system. The amount calculation of energy and exergy are given in the Tables 6 and 7 for air-cooled 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.

The energy analysis are given in the Table 6. The amount of energy of the air-cooled water chiller. varies with days for each month. The amount of energy of the chiller components such as the condenser, evaporator, and compressors were 751.43 kW, 631.63 kW and 119.799 kW on 20 June, while compared to another day were 766.51 kW, 630.68 kW and 135.828 kW on 30 July, respectively. According to the results, there are a great difference among the amounts energy of the chiller components of the days on monthly as seen from Figure 6.

Table 6. 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	h_1 kJ/kg	h_2 kJ/kg	$h_{3,4}$ kJ/kg	Q_{Cd} kW	Q_{ev} kW	W_{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

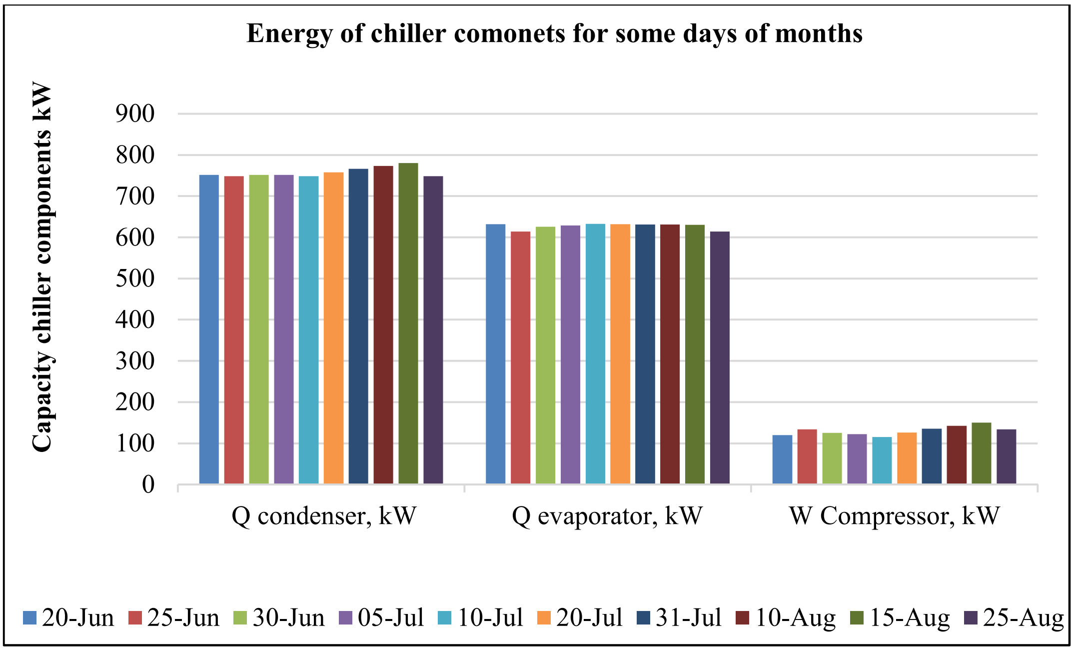

Figure 6. Energy analysis for chiller components

Figure 6 shows 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 the energy value among the components since the compressor is lower than both of them.

The Table 7 presents exergy analysis of the chiller. The amount of exergy components in the air-cooled water chiller are different for each day of month. The values of exergy for the components of chiller such as compressors, condenser, expansion valve, and evaporator were 88 kW, 48.9 kW, 23.9 kW, and 16.2 kW; on 20 June, while compared to another day were 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 are dependent on the temperature and mass flow, as seen from Figure 7.

Table 7. Exergy analysis of the chiller and values of parameters for some days of months

Some days of months	Te °C	Tc °C	m kg/s	h_1 kJ/kg	h_2 kJ/kg	$h_{3,4}$ kJ/kg	$s_{1,2}$ kJ/kg.K	s_3 kJ/kg.K	s_4 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

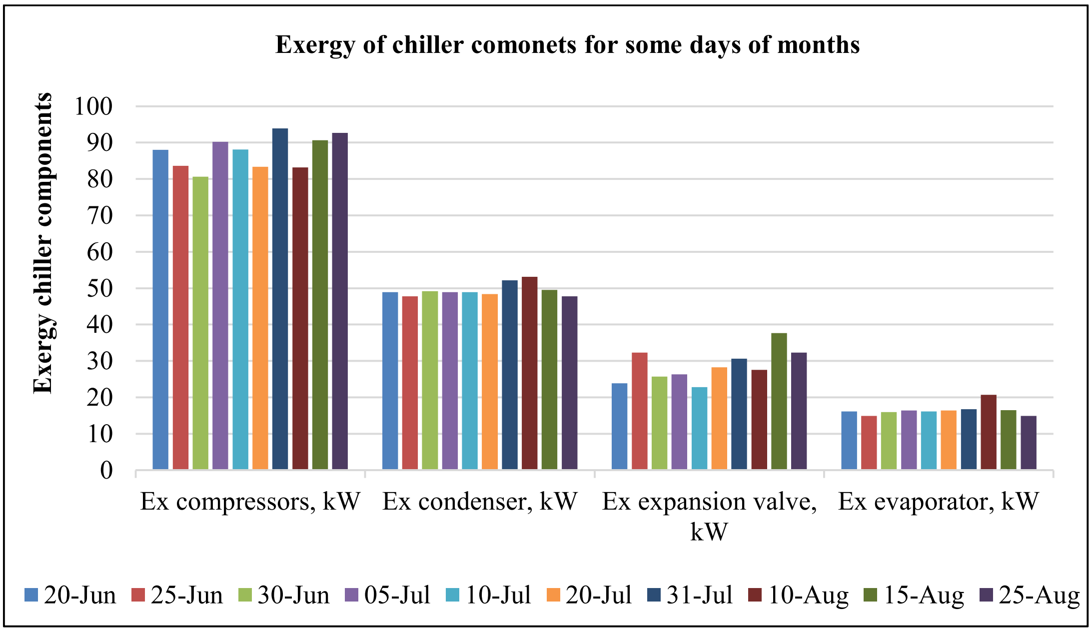

Figure 7. Exergy Analysis of the chiller components

Figure 7 shows that raising and lowering the amount of exergy of the chiller components for some days on monthly. In the figure above 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.

3.1.2.1. Coefficient of Performance (COP) of the Chiller

Table 8 gives that the amount coefficient of performance COP, and COP Carnot, for the air-cooled chiller. The values of COP actual and COP Carnot are 5.3 and 6.71 on 20 Jun, as compared to another day are 4.6 and 6.18 on 30 Jul, respectively. According to Figure 8, the amount of COP Carnot greater than COP actual. The overhead results are showed that changing the values among the chiller components.

Table 8. Coefficient of performance value of the chiller

Some days of months	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	5.0	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

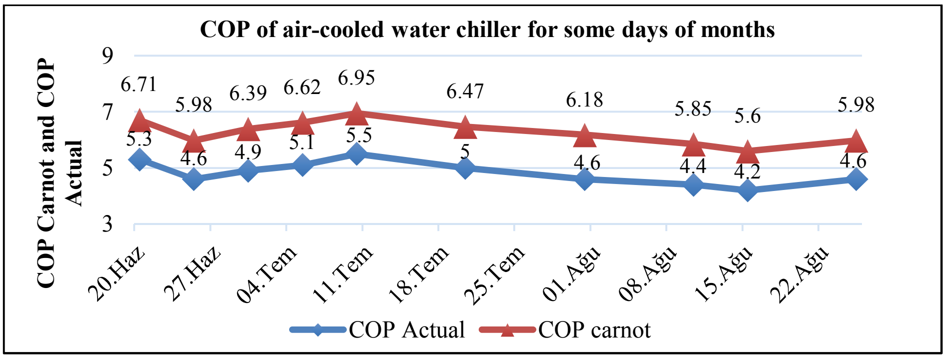

Figure 8. COP_{Actual} and COP_{Carnot} of the air-cooled water chiller

3.1.3. 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 9 and 10. 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. 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 8.

Table 9. Energy analysis of the AHU and values of parameters for some days of months

Some days of months	T_{in} °C	T_{out} °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 10. Exergy analysis of the AHU and values of parameters for some days of months

Some days of months	T_{in} °C	T_{out} °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

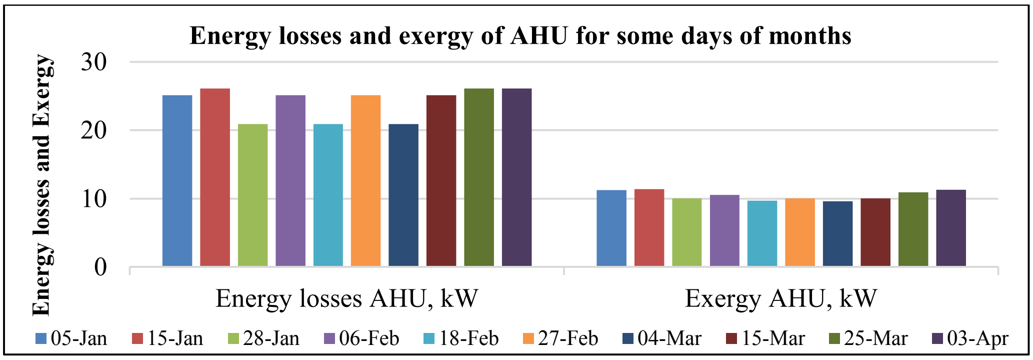

Figure 9. Energy and exergy analysis of the AHU

3.1.3.1. Energy and Exergy Efficiency of the AHU

The energy efficiency and exergy efficiency value of the AHUs are given in Table 11. 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 11. The values of energy and exergy efficiencies for the AHU were 83% and 33% on 5 January, while compared to another day were 83% and 23% on 15 March, respectively.

Table 11. 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

4. CONCLUSIONS AND RECOMMENDATIONS

The evaluation of HVAC systems used in the hospital Qaladeze in Sulaymaniyah, Iraq was done by using energy and exergy analysis in this study. 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.

There are general recommendations for energy and exergy of HVAC system applications in the hospital:

- 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.
- 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.
- 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 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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