First and Second Law Analysis of Central Cooling System of a Multipurpose Buildings

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Abstract

The energy is an important parameter for all countries and usage of it needs to be planned carefully. In the world, energy consumption of HVAC equipments in residential buildings corresponds to the 16% -50% of the total energy consumed, varying from country to country. For this reason, design of Central Cooling System (CCS) of a building is very important in terms of rational usage of energy. In this study, energy and exergy analyses of a cooling system are conducted using the actual data obtained from a multipurpose building (a shopping center) located in Ankara, Turkey. The building needs cooling in an area of 80.000 m^2 . CCS has a 496 kW air-cooled chiller. Inlet, outlet temperatures and mass flow rate of the chilled water are 7, 12°C and 13.01 kg/s, respectively. From the calculations, total exergy loses and efficiency have been calculated 1607.08kW and % 22.4, respectively.

Key words: Energy analysis, exergy analysis, multipurpose building, central cooling system.

1. Introduction

Today, rational use of energy in buildings is one of the most significant methods of energy saving. Especially, for commercial buildings such as shopping malls which are in service during the day, a small saving accomplished will contribute to the country and the world economy consequently. In the world, energy consumption of HVAC equipment in residential buildings ranges between 16% and 50% of the total energy consumption countries [1]. In Turkey energy consumption of residential buildings is 30 % of the total consumption and 80% of this consumption is related to the heating-cooling systems [2]. For these reasons, energy analysis of the heating and cooling systems in buildings will contribute to the country and the world economy.

A great number of studies have been carried out on the energy-exergy analysis in buildings. In Hepbaşlı and Özgener's study, exergy analysis of a university campus which have water-cooled chiller unit has been carried out and they have calculated exergy efficiency of cooling system and overall efficiency of the system as 33.6% and 27.2%, respectively [3]. According to Söğüt's study, some analyses are performed on exergy and energy in a campus featuring accommodation that has fuel oil consumption in a heat exchanger connected to heat exchanger house. In case of system preference with different assessments, changes on exergy efficiency and environmental effects because of CO_2 emission are analyzed. At the end of the study, 77.26% energy efficiency and 27.67 exergy efficiency are obtained. In addition, regional solutions can be more suitable

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than local solutions by increasing the usage of natural gas for heating system in the country. Besides, exergy efficiency will be better when it is supported by renewable energy resources [4].A study by Hepbaşlı and Özgener indicate that today the percentage of heating, cooling and air conditioning (HVAC) system energy consumption is concluded as approximately 20% in total energy consumption. It is also revealed that effective and efficient use of wasted energy has great importance. For the performance evaluation of heating, cooling and ventilation systems, the first law of thermodynamics is used. However, required energy for these systems is available energy in order to have effective work. [5]. Yıldız and Güngör studies are implemented in an office building that has 240 m^2 area of usage and volume of 720 m^2. The project, based on preliminary design of data, is studied in terms of exergy and energy through air to air heat pump and condensing boiler. In this study, values of energy efficiency are determined as 63.6% for natural gas condensing boiler, 53.9% for conventional boiler and 80.9% for air to air heat pump. Besides, values of exergy efficiency are determined as 8.68% for natural gas condensing boiler, 8.68% for conventional boiler and 6.66% for air to air heat pump [6].

2. Central Cooling System

Application has been made in a shopping mall (hereinafter, it will be referred to as the building) in Ankara, Turkey. The building has an approximately 80 000 m^2 - usage area. An air-cooled chiller compressor with power of 496 kW has been used in cooling system. Working parameters of chiller are given in Table 1. Energy-exergy analyses have been carried out by modeling of these parameters in SOLKANE software.

Table 1. Working parameters of chiller

Compressor efficiency, η_{comp}	0.95
Evaporator pressure drop, P_{ed} (bar)	0.669
Condenser pressure drop, P_{cd} (bar)	0.2
Evaporating temperature, T_{evap} (C°)	0.13
Condensing temperature, T_{con} (C°)	60.32
Ambiant temperature, T_o (C°)	25
Evaporator entering temperature, T_5 (C°)	12
Evaporator leaving temperature, T_6 (C°)	7
Total evaporator water mass flow (kg/s)	57.125
Total refrigerant mass flow (kg/s)	13.01

3. First and Second Law Analysis

The flow diagram of chiller is shown in Fig. 1. First and second law analysis have been carried out according to the points in Fig 1.

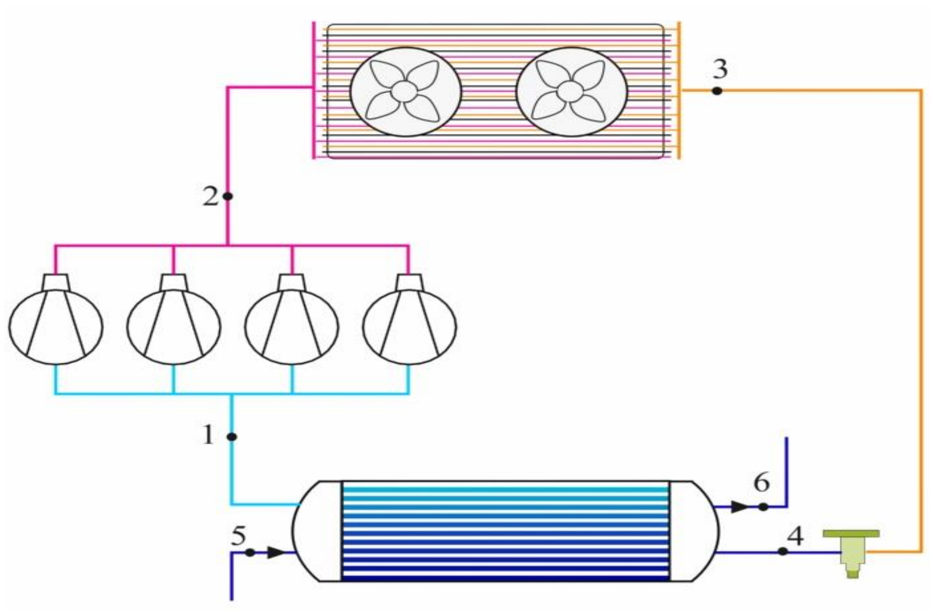

Figure 1. Flow diagram of chiller unit

First law of thermodynamic, known as energy balance calculation, is taken into consideration for system design, capacity account of devices in the system and efficiency account of system for each devices. Exergy calculation -second law- which is actually an indication of what proportion used is also taken into account after gaining the importance of the energy today. CCS's energy and exergy analyses belong to shopping center were performed. For this reason, thermal and exergetic analyses are done for system components that are the chillers. According to results of the analyses, first and second laws efficiencies for CCS are compared with each other, and it is determined that which of the devices in the system has the most missing and needed to be improved.

3.1. First Law Analysis

According to this cycle, compressor work, condenser load, evaporator load has been calculated. Because of no enthalpy change in the expansion valve, there is no any energy transfer. If friction in the cooling system, pressure losses in fittings and heat transfer from the pipes are being ignored, the equation for conservation of energy principle can be expressed as following;

$$W_{comp} + Q_{evap} = Q_{con} \tag{1}$$

Compressor work;

$$W_{comp} = \dot{m}\left(h_2 - h_1\right) \tag{2}$$

Condenser load;

$$Q_{con} = \dot{m}\left(h_2 - h_3\right) \tag{3}$$

Evaporator load;

$$Q_{evap} = \dot{m}\left(h_1 - h_4\right) \tag{4}$$

Eq. 1, Eq. 2, Eq. 3 and Eq. 4 are for the first law of thermodynamic. However, the coefficient of performance (COP) should be calculated for determination of the performance of the system. This value is a percentage of evaporator load to compressor work.

$$COP = \frac{\dot{Q}_{evap}}{\dot{W}_{comp}} \tag{6}$$

3.2. Second Law Analysis

First law of thermodynamics is related to conversation of energy and energy balance in system, and it is not sufficient to evaluate of actual energy performance of thermal systems of CCS and so [5]. It provides to be expressed numerically of the quality of thermodynamics' second law or the potential doing business. These functions led to the identification of a feature called exergy. Exergy is defined as potential reversibility of energy to work, and it represents the maximum work obtained from a source [8,9].

When a substance is under heating T and pressure P, having special entropy s and special enthalpy h, reduced to T_0 environmental temperature, special exergy owned or availability, it can be calculated as follows [10];

$$E_x = \left(h - h_0\right) - T_0\left(s - s_0\right) \tag{7}$$

By calculating the exergy values of inlet and outlet points for every device shown in the Fig. 1, the difference between exergy inlet and outlet, and irreversibility (*I)* can be calculated as follows:

$$I = (\sum Ex_{inlet} - \sum Ex_{outlet}) \tag{8}$$

Energy efficiency (COP) shown on Eq. 6 is not an adequate criteria alone to evaluate CCS, so exergetic efficiency, an indicator of irreversibility (second law efficiency), is required [11]. Second law efficiency is as general;

$$\eta_{II} = \frac{\text{Useful work output}}{\text{Maximum possible (reversible) work output}} \tag{9}$$

Eq. 9 is expressed as follows for exergy at inlet and outlet of all device [12].

$$\eta_{II} = \frac{Ex_o}{Ex_i} \tag{10}$$

Exergy losses in evaporator, compressor, condenser and expansion valve in chiller unit can be calculated following equations;
Exergy destruction in compressor;

$$E\dot{D}_{comp} = \dot{E}_{X2'} - \dot{E}_{X1} + \dot{W}_{comp,el} \tag{11}$$

$$\dot{W}_{comp,el} = \frac{W_{comp}}{\eta_{el*}\eta_{mec}} \tag{12}$$

Exergy destruction in condenser;

$$E\dot{D}_{con} = \dot{E}_{X3} - \dot{E}_{X2} + Q_{cond}\left(1 - \frac{T_o}{T_{cond}}\right) \tag{13}$$

Exergy destruction in expension valve;

$$E\dot{D}_{ev} = \dot{E}_{X4'} - \dot{E}_{X3} \tag{14}$$

Exergy destruction in evaporator;

$$E\dot{D}_{evap} = \dot{E}_{X4} - \dot{E}_{X1} + \dot{E}_{X5} - \dot{E}_{X6} \tag{15}$$

Exergy efficiency is also calculated by the following Eq.;

Exergy efficiency of compressor;

$$\dot{\eta}_{ex,comp} = \frac{Ex_2 - Ex_1}{\dot{W}_{comp,el}} \tag{16}$$

Exergy efficiency of condenser;

$$\eta_{ex,cond} = \frac{\dot{Q}_{cond}\left(1-\frac{T_o}{T_{cond}}\right)}{Ex_3 - Ex_2} \tag{17}$$

Exergy efficiency of expansion Valve;

$$\eta_{ex,\exp} = \frac{\dot{E}x_4}{Ex_3} \tag{18}$$

Exergy efficiency of evaporator;

$$\eta_{ex,cond} = \frac{\dot{E}x_6 - Ex_5}{Ex_1 - Ex_4} \tag{19}$$

Exergetic efficiency of chiller unit;

$$\eta_{II} = \frac{\dot{Q}_{evap}\left(1-\frac{T_o}{T_{evap}}\right)}{W_{comp,el}} \tag{20}$$

4. Results and Discussions

The results consist of two parts, for the first law and the second law. According to inlet and outlet temperatures of each device, enthalpy and entropy values has been obtained from the thermodynamics tables of r-134a and water.. Mass flow rates circulating in system and amount of energy-exergy on inlet and outlet of devices are given in Table 2.

Table 2. Energy and exergy values of components of chiller

Components	**Fluid**	**Temp.** *(°C)*	**Enthalpy** *(kj/kg)*	**Entropy** *(kj/kg)*	**Mass flow rate** *kg/s*	**Energy Value** *(kW)*	**Exergy Value** *(kW)*
Compressor inlet	R134a	0.13	398.57	1.7267	13.01	5185.79	1184.350
Compressor outlet	R134a	68.11	436.86	1.7223	13.01	5683.98	1699.601
Condenser inlet	R134a	68.11	436.86	1.7223	13.01	5683.98	1699.601
Condenser outlet	R134a	59.83	287.05	1.2837	13.01	3734.80	1450.998
Exp. valve inlet	R134a	59.83	287.05	1.2837	13.01	3734.80	1450.998
Exp. valve outlet	R134a	5.94	287.05	1.3119	13.01	3734.80	1341.658
Evaporator inlet	R134a	5.94	287.05	1.3119	13.01	3734.80	1341.658

Evaporator outlet	R134a	0.13	398.57	1.7267	13.01	5185.79	1184.350
Evaporator inlet	Water	12	50.406	0.18046	57.13	2879.44	11633.070
Evaporator outlet	Water	7	29.4208	0.10622	57.13	1680.66	11698.096

Obtained values depending on first law are given in Table 3 after calculation of energy and exergy values for each point in Figure 1

Table 3. Capacities of components of chiller (only cooling cycle) obtained from first law analysis

Components	**Values**
Compressor Work (kW)	496
Evaporator Load (kW)	1451.98
Condenser Load (kW)	1949.17
COP	2.91

When values are taken into consideration in Table 3, it can be seen that Eq. 1 is provided. COP is determined as 2.91 by using equation 2, 4 and 6. After first law analysis, second law analysis has been made. The second law analysis results and values of exergy destruction and efficiency are given in Table 4 in order to determine better system performance.

Table 4. Obtained values from second law analysis

Components	**Exergy Destruction (kW)**	**Exergy Efficieny (%)**
Compressor	1011.25	86.5
Condenser	264.162	62.7
Expansion Valve	109.339	92.4
Evaporator	222.334	41.3
System	1607.08	22.4

The biggest exergy destruction is observed in compressor as shown in Table 4. Then the condenser, evaporator and expansion follow it, respectively. The expansion valve has the highest efficiency in terms of device efficiency. Then compressor, condenser and evaporator follow it, respectively. Overall efficiency of the system is determined as 22.4% by using Eq. 20. Second law efficiencies of components of system in Table 2 are shown as in Fig 2.

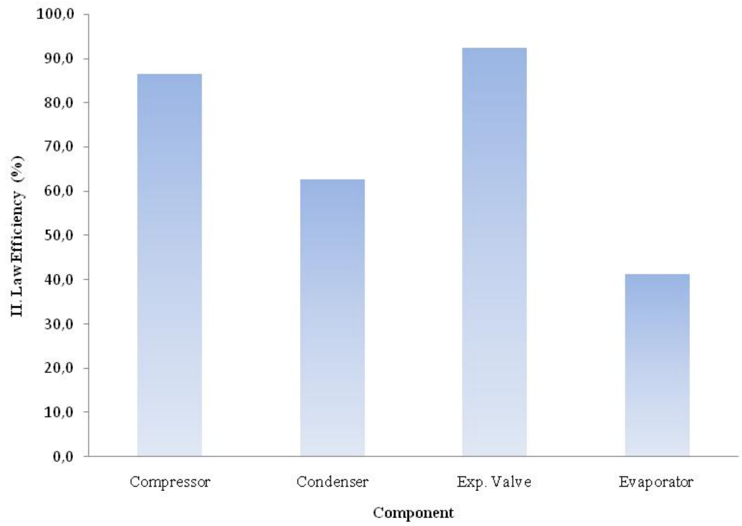

Figure 2. II. Law efficiency of component of the system

In order to understand exergy analysis better in CCS, grassman diagram (Fig.3) -generally used at literature- [13,14] are drawn for exergy destruction and exergy efficiency are given in Table 4.

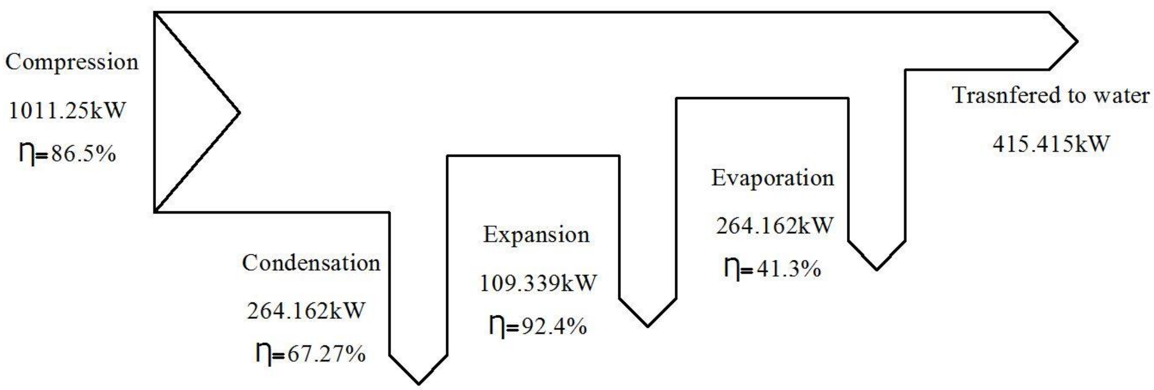

Figure 3. Grassman diagram of CCS

5. Conclusion

In this research, first and second law analyses of central cooling system in multi-purpose buildings are studied. It is obtained that only first law analysis is not adequate for system performance according to these results. Second law analysis needed to have an accurate and realistic analysis.

Evaluations below can be carried out according to results of the study.

- COP of the system is determined as 2.91. It is a satisfied value for like this big system.
- The highest destruction is in the compressor, so compressor of system must be evaluated again.

- It is a positive result that although system efficiency is low, compressor efficiency is high
- Apporiximately found as 22.4 % systems exergetic efficieny is suitable for this kind of thermal systems

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