ENERGY AND EXERGY ANALYSES OF THE HEATING SYSTEM IN A MULTIPURPOSE BUILDING

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ABSTRACT

The energy is an important parameter for all countries and the usage of it needs to be planned carefully. In the world, energy consumption HVAC equipment in residential buildings ranges between 16% and 50% of total energy consumption, depending on the countries. This energy is mostly used by central heating systems (CHS) for heating. Design of CHS in buildings is very important in terms of rational energy usage. CHS's are generally designed using energy analysis (First Law). However this analysis is not adequate itself, so second law analysis is also required for evaluation of system performance. In this study, energy and exergy analyses of a heating system are performed using the data and experiments of 3 years in a multipurpose building (a shopping center) which needs heating in an area of 80.000 m^2 in Ankara, Turkey. As a result of the energy analysis, it is shown that the lowest efficiency is in the heating exchanger, and the highest efficiency is in the boiler. On the other hand, there is an opposite situation for exergy analysis. These results indicate that exergy analysis is more realistic than energy analysis, and system performance can be increased by improving the boiler.

Key words: HVAC, Energy analysis, Exergy Analysis, Energy Efficiency, heating systems.

BİR ALIŞ VERİŞ MERKEZİNE AİT ISITMA SİSTEMİNİN ENERJİ VE EKSERJİ ANALİZİ

ÖZET

Enerji bütün ülkeler için önemli bir parametredir ve dikkatlice planlanması gerekir. Dünyada ülkelere bağlı olarak, konut amaçlı binalardaki HVAC donanımları tarafından tüketilen enerji toplam enerji tüketiminin % 16 ila % 50'si aralığındadır. Bu enerji çoğunlukla merkezi ısıtma tesisatlarında (MIT) ısıtma için kullanılır. Binaların MIT tasarımı enerjin rasyonel kullanımı açısından çok önemlidir. MIT'ların tasarımları genellikle enerji dengesine (I. Kanun) yapılmaktadır. Ancak sistem performansının değerlendirilmesinde, sadece I. Kanun yeterli olmayıp, II. Kanun analizinin de yapılması gerekmektedir. Bu çalışmada Türkiye, Ankara'da 80.000 m2'lik bölümünde ısıtma ihtiyacı olan bir alışveriş merkezinin ısıtma sistemi üzerinde yaklaşık 3 yıl süren deney ve verilerinden faydalanarak enerji ve ekserji analizi yapılmıştır. Analizler sonucunda, ısıtma sistemi için yapılan enerji analizinde; en düşük verimin eşanjörde, en yüksek verimin kazanda, ekserji analizinde ise bunun tersi bir durum görülmüştür. Bu sonuçlar neticesinde; bu tür çok amaçlı yapılarda enerji performansının değerlendirilmesinde, ekserji analizinin, enerji analizine göre daha gerçekçi olduğu ve kazanda yapılacak iyileştirmenin sistem performansının arttıracağı belirlenmiştir.

Anahtar Kelimeler: HVAC, enerji analizi, ekserji analizi, ısıtma sistemleri.

Nomenclature	
HVAC	heating ventilating air conditioning
CHS	central heating system
CCS	central cooling system
SC	shopping center
AHU	air heating unit
FC	fan coil
HE	heat exchanger
HEHL	heat exchanger heating line
DHW	domestic hot water
W_{Bi}	boiler inlet water
W_{Bo}	boiler outlet water
HT	heat transfer (from boiler surface)
CP	combustion products
BST	boiler surface temperature
m	mass flow rate
M	molar mass flow rate
h	enthalpy
s	entropy
TM	thermo mechanic
T	temperature

1. INTRODUCTION

In recent years, construction sector has been fast developing all around the world. All constructed buildings need to be heated and cooled. These needs have been satisfied by central heating systems and cooling systems (CHS and CCS). A large part of the energy consumption in buildings (80-85%) is done for heating purposes. When we take into account that a large amount of energy is used for domestic applicants today, choosing the right CHS and conducting the necessary analysis before usage gains importance [1].

Yumrutaş et al. states that energy analysis is a commonly used method in a thermal system, however, it does not provide any information about how, where and when the performance of the system decreases. On the other hand, exergy analysis is a more beneficial method for determining the performance and design of the system [2]. In Söğüt's research, exergy and energy analyses are carried out in a campus style accommodation that has a fuel oil operated boiler and exchanger. At the end of the study, it is revealed that the system energy efficiency is % 77,26, and exergy efficiency is % 27,67. [3]. Yıldız and Güngör implemented a study of an office building that has 240 m^2 area of usage and volume of 720 $m^{3.}$ The project, based on preliminary design of data, is analyzed in terms of exergy and energy through air to air heat pump and condensing boiler. Energy efficiencies are found as 63.6% for natural gas condensing boiler, 53.9% for conventional boiler and 80.9% for air to air heat pump, where values of exergy efficiency are found to be 8.68% for natural gas condensing boiler, 8.68% for conventional boiler and 6.66% for air to air heat pump [4]. A study by Hepbaşlı and Özgener indicate that heating, cooling and air conditioning (HVAC) systems' energy consumption is approximately 20% of total energy consumption. Consequently effective and efficient use of energy, and even the waste energy has great importance. They also state that for the performance evaluation of heating, cooling and ventilation systems, the first law of thermodynamics has been used, however the required energy for these systems is usable energy in order to have effective work. [5]. Özkaymak conducted energy and exergy analyses using operational data from the cogeneration facility of BOSEN, a power plant founded in Bursa. Energy and exergy input and output values for of each unit of the facility were calculated. Depending on these values, the loss of energy and exergy values are revealed, and it is stated that the heat flow and transfers caused the the loss of exergy. Energy and exergy losses are then compared with each other. The total energy loss of plant is calculated as 3974, 34 kW. The total exergy loss of plant is calculated as 18758, 03 kW. As a result of energy and exergy analyses in plant, the largest energy loss (2781.4 kW) and exergy loss (9034.87 kW) were found in steam turbine. According to these results, it is stated that the the efforts should be focused on turbines to improve efficiency [6]. In the study of Şahin et al., the analyses of first and second law of thermodynamics are carried out using operational data of sugar production process belonging to 2002-2003 in Kayseri Sugar Factory. In the end some recommendations to improve first and second law efficiencies were made [7]. It is stated that in industrial facilities, energy and exergy analyses have great importance in terms of thermodynamics and these analyses will help increasing energy efficiency and recycling of waste energy. Today, energy is one of the most significant issues. Depending on the countries energy consumption by HVAC equipment in residential buildings ranges between 16% and 50% of total energy consumption (Fig. 1), which is mostly done for heating in CHS [8].

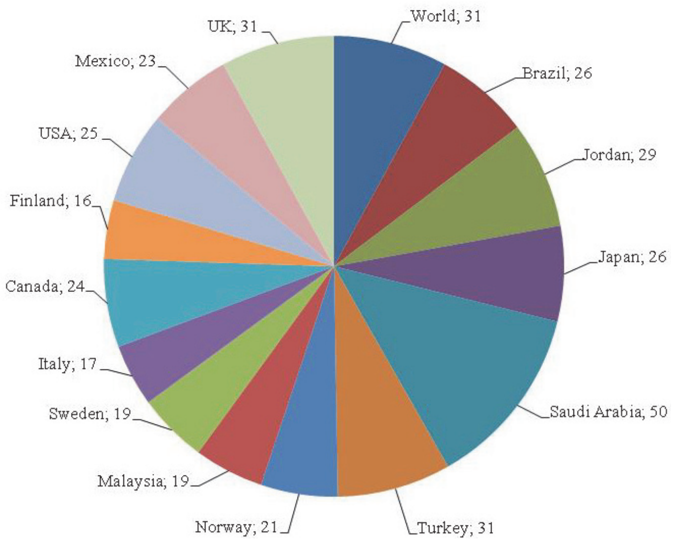

Figure 1 – World wide residential energy consumption[8]

In Turkey approximately 36% of the energy consumption is done in buildings in which people live, shop etc. [9], in which designs of CHS are very important for rational use of energy. The rational use of energy is an important parameter that should be taken into account for not only in the operation of the system but also in process of system design. Thermodynamic analysis is significant especially at CHS's design stage, for the system and selection of the devices which constitute the system. This analysis is generally performed by energy analysis which is also known as first law analysis. However only energy analysis is not enough. To achieve minimum energy and maximum work II. Law also need to be taken into account. The right design and performance evaluation for these type of buildings will provide correct and efficient usage. In this study, energy and exergy analyses of CHS's are conducted in a multipurpose building in Ankara, Turkey (a shopping center) (SC) that needs heating in area of 80.000 $m^{2.}$ Thanks to obtained results, weak points of system in terms of energy efficiency are determined, and some suggestions have been made to reduce energy costs and increase efficiency.

2. PROPERTIES OF CHS

The devices used for CHS are Scotch-type-counter-pressure boiler for meeting the usage of hot water; air heating units (AHU) for heating large space; fan-coil (FC) for heating small spaces; and heat exchanger (HE) for preparation of domestic hot water (DHW). Water temperature at point of inlets and outlets of the system and each system elements with circulation of the fluid mass flow rates are given in Table 1 while the system is working in balance. The hot water coming from boiler is distributed to air heating unit, fan coil and heat exchanger by supply collector. The pipes on this line are insulated, and heat losses are ignored. CHS flow chart showing the connections of devices is given in Figure 2.

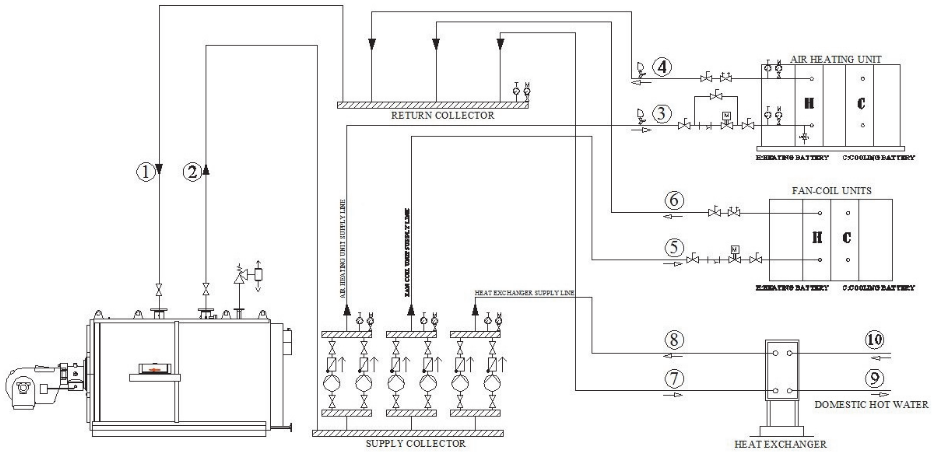

Figure 2 – CHS's flow chart

No	Device input/output	Fluid Type	Temperature (°C)	Mass Flow Rate (kg/s)
1	Boiler input	Water	65	122,2
2	Boiler output	Water	85	122,2
3	AHU input	Water	85	98,55
4	AHU output	Water	65	98,55
5	FC input	Water	75	13,88
6	FC output	Water	55	13,88
7	HE heating line input	Water	85	11,944
8	HE heating line output	Water	65	11,944
9	HE DHW line input	Water	5	11,944
10	HE DHW line output	Water	60	11,944

Table 1 – Inputs and outputs in the fluid temperature and flow rates in CHS

The analyses consist of first and second laws assessments of CHS. The spot features as enthalpy and entropy used in analyses are determined according to the temperature values given Table 1. The values given in Table 1 are obtained by measurements that were collected during three years process after CHS was taken into circuit [1].

3. THERMODYNAMIC ANALYSES

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. CHS'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 boiler, air conditioning unit, heat exchanger and fan coil. According to results of the analyses, first and second laws efficiencies for CHS 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. ENERGY ANALYSIS (FIRST LAW ANALYSIS)

The first law of thermodynamics known as energy analysis should be equal to the amount of energy inlet and outlet in control volume [7]. This is also named as conservation of energy. The conservation of energy is expressed as follows:

$$\sum E_i = \sum E_o \tag{1}$$

The left side of equation expresses total energy input while the right side of equation represents total energy output. The difference between inlet and outlet of energy gives the total amount of energy loss. In this term, Eq.1 shown as follows:

$$\sum E_i - \sum E_o = \sum E_L \tag{2}$$

Efficiency of systems or devices is equal to energy ratio of inlet and outlet of system and devices. Efficiency of first law for system and devices is determined by the following equation:

$$\eta_I = \frac{E_i}{E_o} \tag{3}$$

All of the elements used in CHS are accepted as continuous open flow system, and analyses are made according to it. According to Figure 1, values of E_o and E_i are calculated separately as Eq. 2 for CHS:

Boiler;

Boiler inlet energy is amount of energy which is obtained by fuel combustion ($\dot{E}_{B_i} = \dot{E}_{fuel}$), and it can be calculated as follows:

$$\dot{E}_{fuel} = \dot{m}_{fuel} \times H_{net} \tag{4}$$

Boiler output energy is energy amount of water that is diverging by heating from the boiler ($\dot{E}_{B_o} = \dot{E}_W$) and it can be calculated as follows:

$$\dot{E}_W = \dot{m}_{W_B} (h_2 - h_1) \tag{5}$$

Eq. 2 is reformulated according to Eq. 4 and Eq. 5, equation of energy loss in boiler can be acquired as follows:

$$\dot{E}_{B_L} = \dot{E}_{fuel} - \dot{E}_W \tag{6}$$

Air Heating Unit ($\dot{E}_{AHU}$):

AHU is a device that transforms heat of fluid to air through serpentine and transmits to area through air ducts. Energy value belongs to fluid at air conditioning center is calculated as follows:

$$\dot{E}_{AHU} = \left[\dot{m}_{W_{AHU}} \times (h_3 - h_4) \right] \tag{7}$$

Fan-coil unit ($\dot{E}_{FC}$):

Fan coil units are devices that pass the temperature of fluid through the air. These devices are used for small locations in SC. The energy value of fan coil units is calculated by:

$$\dot{E}_{FC} = \left[\dot{m}_{W_{FC}} \times (h_5 - h_6) \right] \tag{8}$$

Heat Exchanger ($\dot{E}_{HE}$):

A heat exchanger in a shopping center meets needs of hot water in areas by transferring temperature of hot water from boiler to water network. There are two lines in heat exchanger: Heating (HE_{HL}) and domestic hot water (HE_{DHWL}).The energy value of energy exchanger is calculated by:

$$\dot{E}_{HE} = \left[\dot{m}_{HE_{HL}} \times (h_7 - h_8) \right] + \left[\dot{m}_{HE_{DHWL}} \times (h_9 - h_{10}) \right] \quad (9)$$

3.2. EXERGY ANALYSIS (SECOND LAW ANALYSIS)

Thermodynamics' first law 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 CHS 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 [10,11].

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 [7];

$$E_x = (h - h_0) - T_0 (s - s_0) \quad (10)$$

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

$$I = \sum Ex_{inlet} - \sum Ex_{outlet} \quad (11)$$

Thermal efficiency shown on Eq. 3 is not an adequate criteria alone to evaluate CHS, so exergetic efficiency, an indicator of irreversibility (second law efficiency), is required [12]. Second law efficiency is as general;

$$\eta_{II} = \frac{\text{Useful work output}}{\text{Maximum possible (reversible) work output}} \tag{12}$$

Eq. 12 is expressed as follows for exergy at inlet and outlet of any device [13].

$$\eta_{II} = \frac{Ex_o}{Ex_i} \tag{13}$$

Exergy irreversibility, methods and equations used for calculation of second law efficiency are shown below for CHS that composed of boiler, air heating unit, fan-coil and heat exchanger [1];

Boiler;

Inlet and outlet of exergy in the boiler is shown in Figure 3.

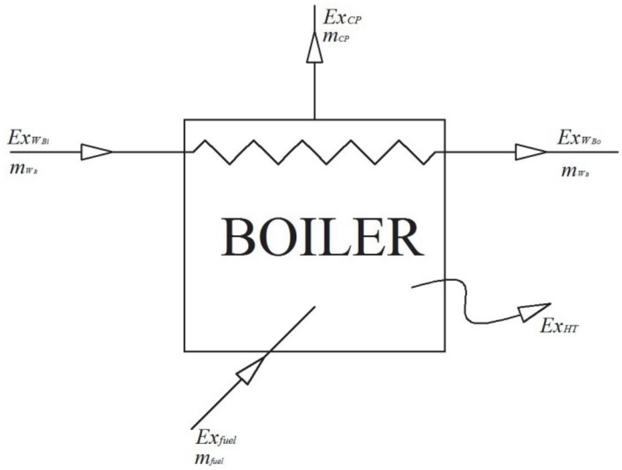

Figure 3 – Exergy inlet and outlet from to boiler

According to Figure above, inlet exergy are energy that composes of fuel combustion (Ex_{fuel}) and the exergy of inlet fluid to boiler ($Ex_{W_{Bi}}$). On the other hand, outlet exergy are the energy of combustion products (Ex_{CP}), exergy of outlet fluid to boiler ($Ex_{W_{Bo}}$) and heat transfer from the boiler surface to environment (Ex_{HT}) [14]. According to these expressions, following equation which gives total irreversibility can be acquired by reformulate Eq.11:

$$I_B = Ex_{fuel} + Ex_{w_{Bi}} - Ex_{W_{Bo}} + Ex_{HT} + Ex_{CP} \quad (14)$$

The exergy of burned fuel (Ex_{fuel});

As methane (CH_4) is the main component of the natural gas, it is accepted that all fuel is made of methane during comprising of combustion of natural gas fuel equation. Exergy of fuel for each unit of mass is found as follows [15]:

$$\varepsilon_{fuel} = H_{net} \times \varphi \quad (15)$$

Here, φ chemical energy factor is taken as 1, 04 [14, 16] and H_{net} is net calorific value of CH_4 [17].

The exergy of boiler inlet water (Ex_{w_i});

$$Ex_{w_i} = \dot{m}_{W_B}[(h_1 - h_O) - T_O(s_1 - s_O)] \quad (16)$$

The exergy of heat transfer from boiler surface to environment (Ex_{HT});

There is a heat transfer from the boiler surface to the environment, this transition is called as exergy losses on the surface of boiler, and is calculated as follows:

$$\sum Ex_{HT} = \dot{Q}_L (1 - \frac{T_o}{T_{BST}}) \quad (17)$$

The value of $\dot{Q}_L$ is acquiered by subtraction of exergy obtained by fuel combustion from value of exergy in boiler house, and equation is calculated by [15]:

$$\dot{Q}_L = \dot{m}_{fuel} \times H_{net} - [\dot{Q}_B + (\dot{m}_{N_2}\Delta h_{N_2} + \dot{m}_{CO_2}\Delta h_{CO_2} + \dot{m}_{H_2O}\Delta h_{H_2O})] \quad (18)$$

Besides T_{BST} is boiler surface temperature.

Exergy of Combustion Products (Ex_{CP});

Exergy of combustion products is calculated in following equation

$$\sum Ex_{CP} = \sum \dot{M}_i \times Ex_i \qquad (19)$$

Actual combustion equation must be known in order to calculate exergy value of the combustion product. When it is accepted that fuel completely composes of CH_4, the fuel equation of actual combustion can be used as combustion equation of CH_4.

$$CH_4 + 2\left(O_2 + 3,76N_2\right) \rightarrow CO_2 + 2H_2O + 7,52N_2 \qquad (20)$$

After calculation of total mass of combustion products are found, percentage of total mass for each combustion product can be calculated by following equation:

$$y_i = \frac{\dot{M}_i}{\dot{M}_{top}} \qquad (21)$$

As the average yield is 92% for natural gas combustion, the mass of combustion products will have 8% loss during the combustion process.

$$\dot{M}_{CP} = (\dot{M}_{fuel} + \dot{M}_{air}) \times 0.92 \quad ^{1)} \qquad (22)$$

After calculation of mass flow rate of combustion products are found, the value of combustion products within this mass are calculated thanks to percentage values.

$$\dot{M}_i = \dot{M}_{CP} \times y_i \qquad (23)$$

[1)] In this equation, reacting of M_{air} with fuel was ignored.

Transactions and their results for combustion product are given in Table 2

Table 2 – Mass flow rate and percentages of combustion products

CP	M_i (g)	M_{tot} (g)	$y_i = M_i / M_{tot}$ (%)	$\dot{M}_{CP}$ (kg/s)	$\dot{M}_i = y_i \times \dot{M}_{CP}$ (kg/s)
N_2	210,56	290,59	73,4	0,052	0,0382
H_2O	36	290,59	12,3	0,052	0,0064
CO_2	44	290,59	15,2	0,052	0,0079

In order to calculate exergy of combustion products, it is necessary to find essential values and exergy values of thermo-mechanic and chemical for each combustion products. Then total energy loss of the combustion product (irreversibility) can be calculated. Temperature of combustion products is taken as 185 °C during the three years period [18].

In Table 3, combustion products (CP) and thermodynamics features depend on these combustion products are given.

Table 3 – Thermodynamic properties of combustion products (CP)

CP	h *(kj/kmol)*	s *(kj/kmol)*	h_0 *(kj/kmol)*	s_0 *(kj/kmol)*
N_2	1334,2	204,0406	8669	191,502
H_2O	15358,4	203,3444	9904	188,720
CO_2	15829,4	230,854	9364	213,685

Exergy of combustion products equals to addition of thermodynamic and chemical exergy. Combustion products' thermodynamic and chemical exergy are given in Table 4.

Table 4 – Thermo-mechanic, chemical and total exergy of combustion products

CP	$Ex_{TM} = (h - h_0) - T_o (s -$ *(kJ/kmol)*	$Ex_{CH} = \bar{R}T_0 \ln - 1/y_i^e$ *(kJ/kmol)*	$Ex_{tot} = Ex_{TM} + Ex_{C}$ *(kJ/kmol)*	Ex_{tot} *(kJ/kg)*
N_2	934,69	691	1625,69	58,064
H_2O	1096,33	8663,09	8769,42	487,19
CO_2	1319,24	19752	21071,24	478,89

The $y_{E_i}^{e}$ value in the table is an existence percentage of flue gases in environment. These values are given in Table 5.

Table 5 – Definition of the environment (Moran & Shapiro 2000).

Reference Component	Mol fraction (%)
N_2	75.67
CO_2	0.034
H_2O	3.03

Ex$_{tot}$ values can be obtained in Table 4 and Table 2. When each of the gas mass flow rate is placed on Eq.24, total exergy value of flue gases is acquired.

$$\sum Ex_{CP} = \dot{M}_{N_2} \times Ex_{tot_{N_2}} + \dot{M}_{N_{CO_2}} \times Ex_{tot_{CO_2}} + \dot{M}_{H_2O} \times Ex_{tot_{H_2O}} \qquad (24)$$

Exergy of boiler outlet water in boiler (Ex_{W_o});

$$Ex_{w_o} = \dot{m}_{w_B} [(h_2 - h_O) - T_O (s_2 - s_O)] \qquad (25)$$

The value of T_o is dead state temperature, and it is 25 °C.

Inlet and outlet exergy in air heating unit (Ex_{AHU_i}, Ex_{AHU_o}):

Air heating unit has been considered to have an excellent insulation, heat losses to environment is neglected.

$$Ex_{AHU_i} = \dot{m}_{w_{AHU}}[(h_3 - h_0) - T_O(s_3 - s_0)] \quad (26)$$

$$Ex_{AHU_o} = \dot{m}_{w_{AHU}}[(h_4 - h_0) - T_O(s_4 - s_0)] \quad (27)$$

$$I_{AHU} = Ex_{AHU_i} - \sum Ex_{AHU_o} \quad (28)$$

Inlet and outlet exergy in Fan-coil unit (Ex_{FC_i}, Ex_{FC_o}):

Fan-coil units is considered to have an excellent insulation, heat losses to environment is ignored.

$$Ex_{FC} = \dot{m}_{FC}[(h_5 - h_0) - T_O(s_5 - s_0)] \quad (29)$$

$$Ex_{FC} = \dot{m}_{FC}[(h_6 - h_0) - T_O(s_6 - s_0)] \quad (30)$$

$$I_{FC} = Ex_{FC_i} - \sum Ex_{FC_o} \quad (31)$$

Inlet and outlet exergy in Heat Exchanger (Ex_{HE_i} , Ex_{HE_o}):

Heat exchanger is considered to have an excellent insulation, and heat losses to environment are ignored. In this situation, inlet and outlet of heat exchanger and irreversibility in heat exchanger can be calculated by the following equations:

$$Ex_{HE_i} = \dot{m}_{HE_H}[(h_7 - h_8) - T_O(s_7 - s_8)] \quad (32)$$

$$Ex_{HE_o} = \dot{m}_{HE_{DHW}}[(h_9 - h_{10}) - T_O(s_9 - s_{10})] \quad (33)$$

$$I_{HE} = Ex_{HE_i} - \sum Ex_{HE_o} \quad (34)$$

4. RESULTS AND DISCUSSION

The results consist of two parts for the first law and for the second law. For these analyses, some data which is acquired from working conditions of full load is used. Inlet and outlet temperatures of each device, enthalpy values obtained from the chart depending on these temperatures, fluid flow rates circulating in devices and energy amount on inlet and outlet of devices are given in Table 6.

Table 6 – Inlet and outlet energy from/to devices by fluid

No	Device input/output	Fluid	Temperature *(°C)*	Enthalpy *(kj/kg)*	Mass Flow Rate $\dot{m}$ *(kg/s)*	Energy *(kW)*
1	Boiler input	Water	65	272,12	122,2	33253,06
2	Boiler output	Water	85	355,96	122,2	43689,62
3	AHU input	Water	85	355,96	98,55	35079,85
4	AHU output	Water	65	272,12	98,55	26817,42
5	FC input	Water	75	313,99	13,88	4358,18
6	FC output	Water	55	230,26	13,88	3196
7	HE heating line input	Water	85	355,96	11,94	4251,58
8	HE heating line output	Water	65	272,12	11,94	3250,20
9	HE DHW line input	Water	5	21,02	11,94	251,062
10	HE DHW line output	Water	60	167,53	11,94	2000,97

In Table 6, only energy value of fluid inlet and outlet to devices are taken into consideration. According to the results, the most energy interaction occurs at inlet and outlet of the boiler. In this situation, the factor is mass flow of fluid rather than difference between inlet and outlet of the fluid because all heat need of system is provided by the boiler. Total amount of water, circulated in the system, is also heated by the boiler.

Performance of devices is determined by thermal efficiency. Especially, heat proficiency is the one of the most important parameter in order to choose devices during design process. Thermal efficiency of devices is given Table 7.

Table 7 – Thermal efficiency of devices

No	Device	$\sum EQ_{Inlet}$ (kW)	$\sum EQ_{Outlet}$ (kW)	$\sum EQ_{Losses}$ (kW)	Thermal Efficiency (η)
1	Boiler	11330,76 [1]	10245,24 [2]	1085,51	0,90
2	AHU	35079,85	26817,42	8262,43	0,76
3	FC	4358,18	3196	1162,18	0,73
4	HE	6251,58	3501,262	2750,31 [3]	0,56

In terms of thermal efficiencies in the system, boiler has the highest efficiency and heat exchanger has the lowest efficiency. Another way of expressing the heat flow of thermal system is Sankey Diagrams(Fig.4). The Sankey Diagram ideally expresses which amount of energy at system is given to which devices, and which efficiency is used for them. The Sankey Diagrams for CHS which is done thermal analyses are demonstrated in Table 4.

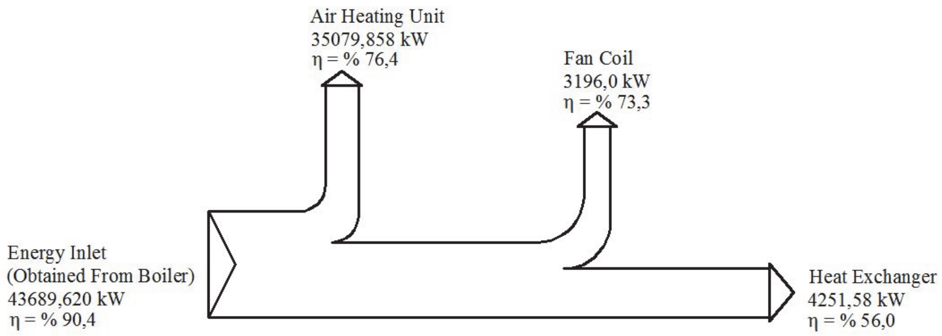

Figure 4 –Sankey diagram for CHS

[1] Energy values are handled by fuel
[2] Energy values are handled by inlet and outlet of water in Boilers
[3] The Amount can not be transmitted to usage water in Boilers

After exergy analyses for CHS are implemented, the obtained results are given Table 8.

Table 8 – Exergy at inlet and outlet of device

No	Device input/output	Fluid	Temp. *(°C)*	Enthalpy *(kj/kg)*	Entropy *(kj/kgK)*	Mass Flow Rate *(kg/s)*	Exergy *(kj/kg)*	Total Exergy *(kW)*
1	Boiler inlet	Water	65	272,12	0,8937	122,2	10,393	317,50
2	Boiler outlet	Water	85	355,96	1,1346	122,2	22,445	685,69
3	AHU inlet	Water	85	355,96	1,1346	98,55	22,445	2211,96
4	AHU outlet	Water	65	272,12	0,8937	98,55	10,393	1024,23
5	FC inlet	Water	75	313,99	1,0158	13,88	15,877	220,37
6	FC outlet	Water	55	230,26	0,768	13,88	5,992	83,16
7	HE HL inlet	Water	85	355,96	1,1346	11,944	24,445	291,97
8	HE HL outlet	Water	65	272,12	0,8937	11,944	10,393	124,13
9	HE DHW inlet	Water	5	21,02	0,0763	11,944	1,55	18,51
10	HE DHW outlet	Water	60	167,53	0,5724	11,944	2,878	34,374

Irreversibility and exergetic efficiency are given Table 9.

Table 9 – Exergetic efficiency of devices

No	Device	$\sum Ex_{Inlet}$ *(kW)*	$\sum Ex_{Outlet}$ *(kW)*	I *(kW)*	Exergy Efficiency (η)
1	Boiler	13026,52	2958,28	10062,24	0,23
2	AHU	2150,90	995,96	1154,964	0,46
3	FC	220,37	83,16	137,21	0,38
4	HE	310,48	158,504	151,976	0,51

In order to understand exergy analysis better in CHS, grassman diagram (Fig.5) -generally used at literature- are drawn for inlet and outlet of exergy and irreversibility are given in Table 9.

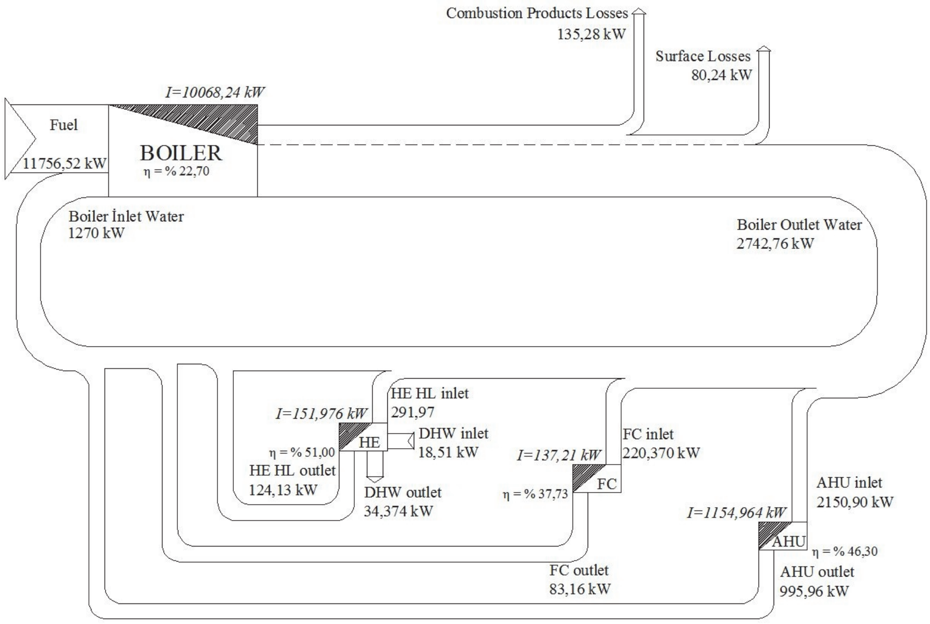

Figure 5 –Grassman diagram of CHS

In order to understand better which amount of energy in this type of building with high heating needs is used efficiently, energy and exergy losses for devices in CHS and first and second law efficiency are given respectively in Figure 6 and Figure 7.

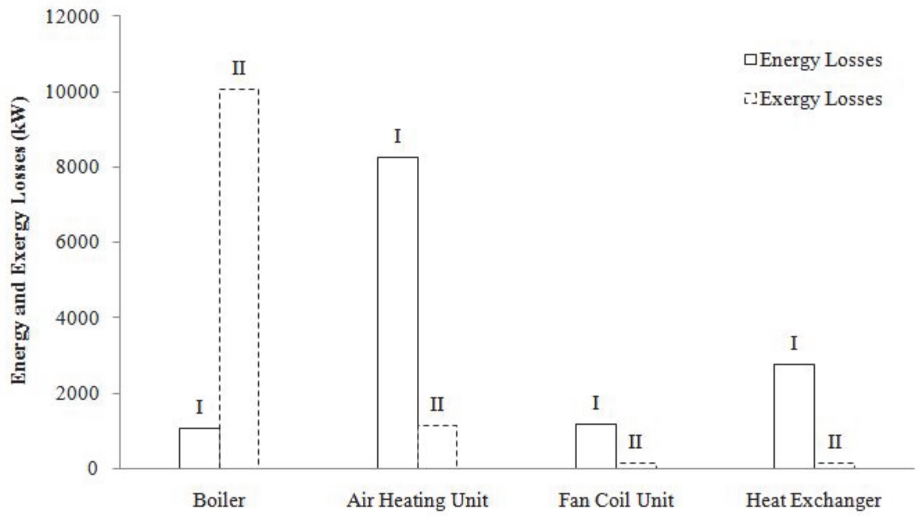

Figure 6 – Exergy and energy losses of devices at CHS

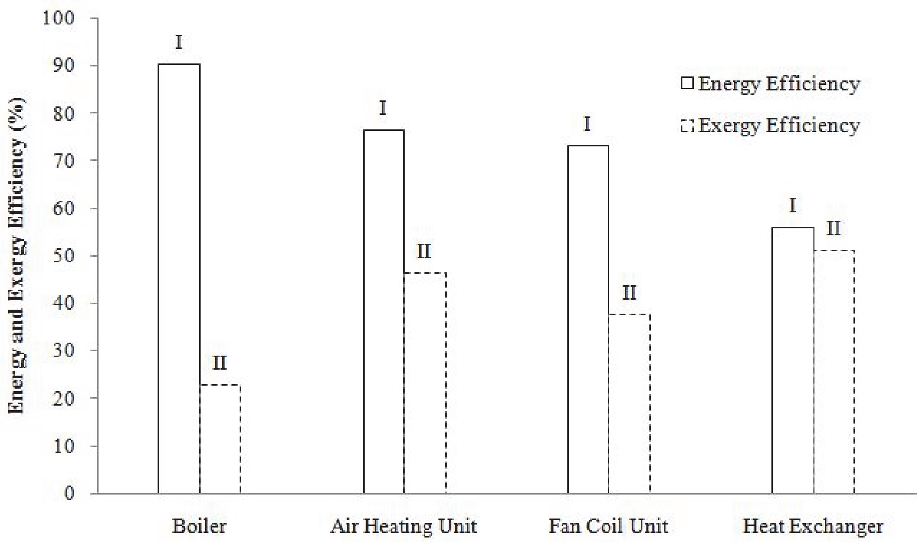

Figure 7 – First and second law efficiency of devices at CHS

When Table 5 and 6 are are evaluated together to make results more understandable, it is seen that boiler has the lowest energy loss and the highest thermal efficiency. In contrast, boiler has the highest exergy loss and the lowest exergitic efficiency. Boiler's energy loss is 1085. 51´kW and thermal efficiency is 90 % while exergy loss is 10062. 24 kW and exergetic efficiency is 23%. In terms of energy and exergy losses, other system devices have different situations. Energy losses of air heating unit, fan coil and heat exchanger are more than exergy losses. However, boiler and other elements have shown similar results in terms of efficiency. When energy loss and efficiency for the air heating unit are respectively 8262,43 kW and % 76, exergy loss and efficiency are 1154,96 kW and % 46. The energy loss and efficiency for the fan coil are respectively 1162,18 kW and % 73, when exergy loss and efficiency are 137,21 kW and % 38. The energy loss and efficiency in heat exchanger are 2750,31 kW and % 56, but exergy loss and efficiency are 151,97 kW and % 51.

All devices in the system have remarkable differences between first and second law analyses. The differences of boiler, air heating unit, fan coil and heat exchanger respectively are % 67, % 30, % 35 and % 0, 5. The highest loss is in the boiler, and the lowest loss is in the heat exchanger. Heat losses are ignored in air heating unit, fan coil and heat exchanger to the environment, so differences between efficiency of thermal and exergetic are not so much alike in boiler.

5. CONCLUSIONS

In this study, energy and exergy analyses are carried out for a shopping center which has 80.000 m^2 heated areas in Ankara, Turkey. Results indicate that exergy losses are higher than the energy losses, thus only thermal (first law) analysis is not adequate, exergy analyses should also be taken into consideration.

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