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Examination of Electrical Energy Usage in Terms of Thermodynamic Efficiency and Sustainability in the Residential and Commercial Sector

Zafer Utlu[1]

Abstract - Energy usage is vital for social life and sustainability in the residential sector. This study examines the electrical energy utilization and efficiency of the Turkish residential and commercial sector in terms of sustainable energy and efficiency in 2013 by using energy and exergy analyses. The total energy input that was produced as 27.55% while the rest was obtained by imports in 2013. In this year, 35.02% of Turkey's total end-use energy was consumed by the residential - commercial sector. Annual fuel consumptions in space heating, water heating and cooking activities as well as electrical energy used by appliances are determined for 2013. It is clear from this figure that the energy efficiencies in the year studied range from 56.60 to 86.15%, while the exergy efficiencies vary from 5.05 to 24.76%. Additionally, researches on electrical household appliances efficiency indicated an efficiency of 86.15% for the first law of thermodynamic and 24.76% for the second law of thermodynamics.

Keywords - *Analysis, efficiency, electrical usage, thermodynamic, sustainability, residential-commercial sector*

1. Introduction

Energy is an important factor, in terms of social, economic and technological development of countries and the protection of the environment. The basic ways to increase energy efficiency is to reduce energy consumption. Approximately 35% of the energy consumption in our country and the world are used in the building. In about 80% of the energy used in buildings is spent for heating, cooling, air conditioning and hot water supply. The average residential energy consumption in Europe is 100 kWh /m^2 in Turkey is found normally 200 kWh/m^2. The average energy consumption in passive house building design is criteria consumed under of 15 kWh / m^2 [1]. Values are investigated when energy consumption in homes nationwide, and it reached twice the amount of energy consumed is compared with households in Europe. This energy consumption gives that short and outstanding information about our buildings sector.

The residential and commercial sector (RCS) used about 38-40% of primary energy consumption in the developed countries. However, in this sector, share of the electricity use is 68-70%, and of atmospheric emissions are 40% in these countries [1]. Total amount of energy usage in RCS is 20-30% of primary energy usage and emissions all over the world.

Sustainable energy can be defined as energy which provides affordable, accessible and reliable energy services that meet economic, social and environmental needs within the overall developmental context of society, while recognising equitable distribution in meeting those needs [2]. In practice, sustainable energy has different meanings to people. Some consider it as the energy related to renewable energy and energy efficiency. Some include natural gas under the heading of sustainable energy because of its more favourable environmental quality. Whatever approach is used, sustainable energy always implies a broad context covering resource endowment, existing energy infrastructure, and development needs.

In this study; electrical energy usage in terms of thermodynamic efficiency and sustainability will be analysed in the residential and commercial sector. Firstly, general evaluation will be done with regard to energy usage and sustainability. Secondly, the perspective of energy usage of Turkey will be presented, and energy utilization in the

[1] *İstanbul Aydın University, Engineering Faculty, Mechanical Engineering Department, Istanbul, Turkey*
zaferutlu@aydin.edu.tr

RCS will be explained followingly. Efficiency values of electric usage will be calculated. Finally, progression of efficiency in the RCS will be discussed in both findings and discussion sections.

2. The Perspective of Energy Usage in Turkey

Energy production and consumption values of Turkey is increasing constantly over the last thirteen years. The value of energy consumption in 2000 which was 3527.2 PJ has dramatically raised to 5077.16 PJ in 2013. When this increase is examined through electric consumption depending on technological development and economic growth, the total electric consumption measured as 128.29GWh in 2000 increased to 229.39GWh in 2013 [3,4]. The rate of meeting consumption through production is 27.20%, thus rest of the consumption which is 72.80% is met through imports in 2013.

Furthermore, whilst total greenhouse gas emission of Turkey was 298 million tons in 2000, it reached out 422.41 million tons in 2013 by increasing 5.9% annually. While 71% of the total emission in 2013 stemmed from energy sector, the rates of other sectors given as: 9% from waste product, 13% from industrial and 7% from agriculture sectors. Greenhouse gas emission potential shall be reduced with activities carried out within the scope of the energy efficiency studies. Particularly efficiency of the second law is considered as a cornerstone in efficiency thus efficiency is low and research projects increasing efficiency should be carried out. Considering aforementioned particularities, Researches and Development projects and projects increasing the efficiency of EHA which are recommended within the scope of the project are compulsory and should be seen as an opportunity.

Table 1. Values of energy and exergy inputs Turkey and RCS during 2013

			TRCS			Turkey	
Types of energy	toe/q*		Input (PJ)	Sector (%)	Turkey (%)	(PJ)	(%)
Hard coal	0.61	Energy	172.70	13.88	3.55	668.76	13.76
	1.03	Exergy	177.88	14.94	3.77	688.82	14.64
Lignite	0.21	Energy	61.23	4.92	1.26	648.98	13.36
	1.04	Exergy	63.68	5.35	1.35	674.94	14.35
Asphaltite	1.03	Energy	6.56	0.53	0.14	15.54	0.32
	0.97	Exergy	6.76	0.57	0.14	15.07	0.32
Petroleum	1.05	Energy	52.01	4.18	1.07	1274.17	26.22
	0.99	Exergy	51.49	4.32	1.09	1261.43	26.81
Natural gas	0.91	Energy	446.18	34.26	8.77	1870.68	35.00
	0.92	Exergy	412.08	32.92	8.30	1710.63	33.26
Wood	0.30	Energy	102.06	8.21	2.10	102.25	2.10
	1.05	Exergy	107.17	9.00	2.27	107.36	2.28
Bio – Mass	0.23	Energy	42.89	3.45	0.88	45.61	0.94
	1.05	Exergy	45.03	3.78	0.95	47.89	1.02
Hydro-power	0.09	Energy	316.54	25.45	6.51	188.14	3.87
	1.00	Exergy	316.54	26.58	6.70	188.14	4.00
Geothermal	0.86	Energy	45.19	3.63	0.93	86.09	1.77
	0.29	Exergy	13.10	1.10	0.28	24.97	0.53
Solar	0.86	Energy	18.43	1.48	0.38	26.33	0.54
	0.93	Exergy	17.14	1.44	0.36	24.49	0.52
Wind	0.09	Energy	0.00	0.00	0.00	16.98	0.35
	1.00	Exergy	0.00	0.00	0.00	16.98	0.36
Coke	0.70	Energy	0.00	0.00	0.00	68.99	1.42
	1.05	Exergy	0.00	0.00	0.00	72.44	1.54
Petrocoke	0.77	Energy	0.00	0.00	0.00	16.64	0.34
	1.04	Exergy	0.00	0.00	0.00	17.31	0.37
Total		**Energy**	**1298.65**	**100.00**	**26.40**	**5077.16**	**100**
		Exergy	**1243.45**	**100.00**	**26.20**	**4937.79**	**100**

* (toe/q)(tons oil of equivalent/ quality factor)

The values of energy and exergy inputs for 2013 according to energy carriers are indicated in Table 1. As can be shown in this table, total energy and exergy inputs of the Turkish sector were 5077.16 and 4937.79PJ, respectively, whilst RCS was determined as 1298.65PJ and 1243.45 PJ in 2013, respectively. In 2013, 34.47% of total ultimate energy usage of Turkey was used up by the RSC. The other sectors were calculated as; the industrial, with 36.25%; the transportation, with 19.15%; the agricultural, with 6.2% and out of energy, with 5.3%. In the analysed year, in terms of consumption of the thirteen energy sources, natural gas had the largest share, with 35.02%, followed by petroleum, with 26.20%.

2.1 Energy utilization in the Turkish residential commercial sector

The RCS includes space heating, water heating, cooking and electrical appliances for energy consumption. In the following subsections, the utilization of energy and exergy in the RCS in the year of 2013 was analysed. The specific electrical applications for energy and exergy consumptions were determined for 2013. Table 1 illustrates the use of energy and exergy as well as the shares of the resources in this sector for the year of 2013. Share of the energy utilization in the residential commercial modes are: space heating with 45%, water heating with 25%, cooking with 12% and electrical appliances with 18% in studied year. Table 1 shows energy and exergy utilization values for the year studied in the RCS. The highest contributions came from renewable resources (includes wood) with 41.50 %, fuel with 38.70 and electric with 19.80 in this year. Natural gas constituted 446.18 PJ of used energy in RCS in 2013. Moreover, usage of renewable energy became widespread in TRCS.

2.2. Estimation of overall efficiency values for electric utilization

Growth in living standards has been influencing the usage of electrical appliances; thus there is an emerging considerable increase in electricity demand day by day. According to a survey conducted by Turkish Statistical Institute in Turkey on 2013, there were 19,681,255 residences in Turkey. The average household appliances in a residence are refrigerator, air conditioning (AC), washing machine, dishwasher, television (TV), iron, vacuum cleaner, computer, oven, microwave oven; which means electrical energy is used for various purposes in this sector. Energy utilization and the saturation values of electrical appliances for the RCS are indicated in Table 2. Refrigeration had the largest ratio of electricity consumption as 29.4% in the analysed year, followed by lighting with 28.4%.

Table 2. Energy utilization and saturation values of components in Turkey in 2013

Components	Consumption (kW/year)	Electrical (%)	Fuels (%)	Renewables* (%)	Saturation values
Lighting	936	28.4			100
Refrigerator	917.28	29.4			99
Water heating		*	30	54	100
Cooking	272.48	8.3	18		100
Space heating	*	*	50	46	100
Washing machine	187.2	5.7			95
Vacuum Cleaner	78	2.4			93
Dishwasher	171.6	5.2			76
AC		4			14.50
TV	498,8	14.8			99
Iron	130	4			98
Computer	109.2	15			45
Total	**3290,56**	100	100	100	

2.3. Examining of electrical appliances and lighting efficiency

In Turkey, the average household appliances and lighting energy consumption by class of energy are given in the Table 3[4].

Table 3. Energy consumption values of some household appliances in housing sector

Type of appliances	Class B consumption of device	Class A consumption of device
Fridge	917.28 kW	733.82 kW
Washing machine	187.2 kW	149.76 kW
Dishwasher	171.6 kW	137.28 kW
TV	296.4 kW	237.12 kW
Lighting	936 kW	748.8 kW

2.4. Energy class labelling of household electrical appliances

Energy efficiency classification are grouped in seven categories; A, B, C, D, E, F and G is composed of these groups. Class-A shows the lowest energy consumption. Values of energy efficiency index (Z) are stated depend on the energy efficiency class values, and are shown in Table 4 [4].

Table 4. Energy efficiency index values in connection with energy efficiency class

(Z)	**Class**
$Z < 55$	A
$55 \leq Z < 75$	B
$75 \leq Z < 90$	C
$90 \leq Z < 100$	D
$100 \leq Z < 110$	E
$110 \leq Z < 125$	F
$125 \leq Z$	G

Energy Efficiency Index (Z) is estimated as follows as stated in percent (%).

$$Z=E/E\ ST \quad (1)$$

E: Annual energy consumption of the device in accordance with the standards specified kWh / year terms (24 hours consumption x 365) will be provided and it will be measured according to Turkish Standard (TS-EN 153).

Est: The standard annual energy consumption of device as expressed in kWh / year

$$Est = M \times DH + N \quad (2)$$

DH = Adjusted net volume (liter)

M and N values are taken from Table 5.

Table 5. Values of M and N according to class of devices [4]

Electrical Appliances	M	N
Refrigerator	0.233	245
Fridge-chiller	0.233	245
Starless fridge	0.233	245
One star refrigerator *	0.643	191
Double stars fridge **	0.450	245
Three stars fridge ***	0.657	235
Deep-freezer *(***)	0.777	303
Vertical-freezer	0.472	286
Horizontal-freezer	0.446	181
Other refrigerating appliances	(1)	(1)

M and N values for these electrical appliances are calculated by considering the low-temperature chamber and the number of stars as given Table 5. The differences between the classes of A, A+ and A++ is because of energy consumption hence class A++ is more efficient in terms of energy consumption. In Table 6 it is compared to the energy consumption of this class. Class A+ + Energy level is consumed energy of 0.5 kWh in a day. Thus consumption is equivalent to 0.5kWh is equivalent 40W lighting lamp 12.5 hours a day.

Table 6. Electricity consumption of electrical appliances depend on energy class for per day

Class	Consumption (kWh/24hour)
B	1.70
A	1.23
A+	1.07
A++	0.50

2.5. Evaluation of electrical appliances terms of efficiencies

Lighting; Lighting used approximately 35-38% of all electrical usage [8]. Annual electricity consumption of dwelling unit for lighting is assumed to change linearly from 138 kWh in 1990, 180 kWh in 2001 and 235 kWh in 2013 [9,10]. Lighting is assumed to be 60% incandescent and 40% fluorescent with first and second law efficiencies of about 5 and 4.5%, and 20 and 18.5% in 2013, respectively [9,10]. Combining the relevant first and second law efficiencies for lighting, we calculated η =9.5-15.5% and ϵ=8.70-14.3% for the year considered, as mentioned in Table 7.

Refrigerator; Refrigerators consume big share of electricity. Usage of electricity for refrigeration was 30-35% out of all electrical use in TBS [4,6]. Electricity consumption is projected to decrease by using new technologies for refrigerators. Average annual consumption was determined to be 346 kWh in 1990, 328 kWh in 1995 and 300 kWh in 2001, and 285 kWh in 2013 [9-10].

The second law efficiency of refrigeration was estimated from;

$$\epsilon = \eta [(T_0/ T_3) -1] \quad (3)$$

It is presumed that the temperatures inside the freezers and the refrigerators are approximately 8^{o}C, the coefficient of performance (COP) is 1.0, and the room temperature near the refrigerator coil is 20^{o}C. Using Eq. (3), these assumptions yield ϵ = 11.60% in 2013, while exergy efficiencies are mentioned in Table 7 for 2013.

Water heating; In 2013, usage of electricity purposes of water heating was 4% out of all electrical use in TBS. Energy efficiencies of electrical use for water heating are assumed to be 90% [4]. The assumed-temperatures of hot

water and ambient are 60°C and 20 °C, whilst quality factor (q_{fuel}) is 1.0 for electrical use. The exergy efficiency for water heating was calculated from Eq. (3) and was found to be 10.8%, as demonstrated in Table 6.

Cooking; in 2013, usage of electricity purposes of cooking appliances (electric oven, hob, cooker, kettle etc.) was 3-4% out of all electrical use in RCS. It is presumed that energy efficiency of electrical use is 80%, and the cooking and ambient temperatures are 120°C and 20°C, respectively [5]. Using Eq. (3), these assumptions yield Є= 17.2% for cooking.

Table 7. Energy and exergy efficiency values of electrical components

Components	2013	
	η	ε
Lighting	15.5	14.3
(Incandescent)	5	45
(Fluorescent)	20	18.5
Refrigerator	150	15.7
Water heating	90	10.8
Cooking (electric oven, hob, cooker, kettle etc.)	80	17.2
Space heating	98	8.22
Washing machine	90	90
Vacuum-cleaner	80	80
AC	200	14
TV	85	85
Iron	98	30
Others	90	70
Total	**86.15**	**24.76**

Space heating; Usage of direct electrical purposes of space heating was 2-3% out of all electrical use in this Turkish building sector. It is determined that, energy efficiency is 98%, the supply temperature for the space heating equipment is 50°C and the ambient temperature is 20°C [6,10] using Eq. (3), the numerical values and the first law efficiencies estimated, it is calculated exergy efficiency 8.22% for space heating.

Air conditioning; Considering the COP value of the AC unit is 2, the unit extracts heat from air at 14°C and the outside temperature is 35°C and using Eq. (3) in a similar manner, it is calculated Є = 14% in the year studied.

Television; Usage of electric for TV and computer was *6,* 7% out of all electrical use in this sector. Electricity consumption of TV per year has increased compared to previous years; since the number and the usage of television and TV channels as well as computers and computer appliances have been increased over the last decade. Energy and exergy efficiencies are estimated to be 85%.

Others; Other electrical appliances are washing-machine, dishwasher, iron, computer and vacuum-cleaner and electricity consumption values of these appliances are given in Table 3. Whilst the energy and exergy efficiencies of these appliances are stated in Table 7. Substituting the relevant numerical values into Eqs. (4)-(5), it is found **η** = 86.15% and Є= 24.76% for electrical use in 2013.

Total energy and exergy efficiencies ($\boldsymbol{\eta}_{,orc}$ and $Є_{,orc}$) for the entire TRCS were calculated by collecting used electrical energy (e_{rc}), direct fuel (f_{rc}), and renewable energy (r_{ec}) use as follows:

$$\eta_{,orc} = [(\eta_{oe} * e_{rc}) + (\eta_{of} * f_{rc}) + (\eta_{r} * r_{rc})] / (e_{rc} + f_{rc} + r_{rc}) \quad (4)$$

$$Є_{,orc} = [(Є_{oe} * e_{rc}) + (Є_{of} * f_{rc}) + (Є_{r} * r_{rc})] / (e_{rc} + f_{rc} + r_{rc}) \quad (5)$$

The weighted mean of overall energy and exergy efficiencies for TRCS were calculated to be η_{orc}=67.35%, and $Є_{orc}$ =11.05 % in 2013 by using the numerical data given in Table 7. The overall calculated efficiency values of RCS in 2013 is shown in Table 8.

Table 8. Energy and exergy efficiency values of RCS in 2013 (%)

Sub-sectors	η	Є
Space heating	62.15	5.05
Water heating	63.65	7.60
Cooking	56.60	11.80
Fuel use of all sub-sectors	61.02	7.05
Electrical energy use of all sub-sectors	86.15	24.76
Total	**67.35**	**11.05**

3. Results and Discussion

Energy and exergy utilization efficiencies of electrical appliances in RCS in 2013 were analysed. Energy and exegy consumption values of RCS and Turkey in total were calculated. Consumption and saturation values and efficiency indexes of electrical appliances used in RCS were examined. Energy and exergy efficiency of electrical appliances were investigated by utilizing from the obtained data. Finally, the energy and exergy inputs were compared by identifying losses and efficiencies of electrical appliances.

3.1. Development of energy and exergy efficiencies in the RCS

Energy and exergy efficiency values for the RCS is compared in this study. It can be understood through the values that the energy efficiencies in the year studied range from 56.60 to 86.15%, while the exergy efficiencies vary from 5.05 to 24.76%. This sector shows considerably important and comparable losses of energy and exergy. In terms of exergy loses, this sector ranks rather differently, accounting for about 75.24% of all exergy loses.

The study stated that exergy utilization in Turkey was even worse than energy utilization. As a result of this, there is big potential for increasing the exergy efficiency in this sector. It can be seen that a conscious and planned effort is needed to improve exergy utilization.

Electric energy saving shall be increased in RCS thus electric energy consumption and greenhouse gas emissions shall be reduced by transforming the market towards EEA with high energy efficiency and accelerating the replacement of old and non-efficient products with highly energy-efficient products. In the other hand, main approach in National Climate Change Strategy Document states that Turkey aims to extend energy efficiency, increase use of clean and renewable energy resources and integrate climate change policies with development policies in order to become a country offering high quality of life and wealth to all citizens with low carbon emissions.

4. Conclusion

It is essential to use exergy analysis along with the energy analysis for determination of the efficiency of the system. Exergy analysis is considerable significant in terms of detecting irrevibilities occurring in the system. Also, exergy is a suitable and necessary concept in the development of a sustainable energy and efficiency, and future research of exergy and its applications must be further directed towards the development of a sustainable society [9]. The obtained results in this study are summarized below;

- There are big potential for development of energy and exergy efficiency in Turkey. This potential can be used to eliminate environmental emissions.
- A common language shall be created with the purpose of improving effective energy use, energy efficiency in this sector and greenhouse gas emissions shall be reduced in Turkey by providing trainings and courses at every stage of education corporate capacity shall be improved towards developing and implementing energy policies.
- To reduce electrical energy consumption in RCS and greenhouse gas emissions caused by this consumption by accelerating market circulation towards electrical household appliances with high energy efficiency and replacement of old and non-efficient products with highly efficient products.
- Awareness of end users and members of the supply chain shall be raised by improving capacity of producers in developing and implementing special promotional activities in education and course environments with the purpose of increasing sales of products with high-energy efficiency.
- The energy efficiency labelling for electrical appliances such as air-conditioning either does not exist or is now under development.
- Led and compact fluorescent lights are efficient types of lighting. The lights spread more widely. Efficient lighting practices should be applied.

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