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Energy saving potential and energy audit of a faculty building at Marmara University in Türkiye

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ABSTRACT

According to the Council of Higher Education's records in 2022, one hundred thirty-one public universities operate in Turkiye. If the energy efficiency in faculty buildings is improved by 20%, 1.458 million U.S. dollars savings per year would be possible. This paper presents the energy profile and energy audit of the Faculty of Technology at Marmara University, in Istanbul Türkiye. The energy efficiency opportunities for faculty building are investigated depending on the energy audit results. The fact that the faculty building is uninsulated therefore this situation causes severe energy losses. The annual heating energy requirement of this university building, which has an average construction area of 15,000 m², is 297,728 kWh. Only an average of 56,987 kWh in fuel consumption and up to 20% energy savings can be achieved with thermal insulation. However, when the existing lighting fixtures are replaced with Light Emitting Diode (LED) fixtures, the annual savings amount is $6,198. The results of this study enable search of sustainable solutions for reducing energy consumption and improving energy audits for faculty buildings.

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1. INTRODUCTION

With the population rising in the world, the need for energy is also increasing, continuously. We have been facing a time when global warming is on the agenda, and natural energy resources are rapidly consumed. The most important question to ask is whether we need new energy sources or we need to use existing energy sources more efficiently. The answer to this problem is critical regarding the sustainability of energy. Türkiye's Energy Efficiency Strategy Plan for 2012-2023 aims to reduce the amount of energy consumed per unit of Gross Domestic Product (GDP) in Türkiye by at least 20% compared to 2011 levels [1, 2]. Türkiye's energy import dependency, mainly on oil and natural gas, is increasing due to this growing energy demand. The installed power generation, gross generation, and net electricity consumption in Türkiye are shown in Figure 1(a). Electricity generation and distribution accounted for 42.4%, the manufacturing industry 38.4%, transportation and storage sector 9.5%. The share of the industry in GDP in 2016 was 19.7% value of approximately 511 billion Turkish Liras (TL). In Türkiye, the percentage of industry in final energy consumption was 32.5%, with 8% - 44% saving potential in 2015 [3]. Annual average earnings are ~ 20 Million tons of oil equivalent (TOE) (~ 7 Billion USD).

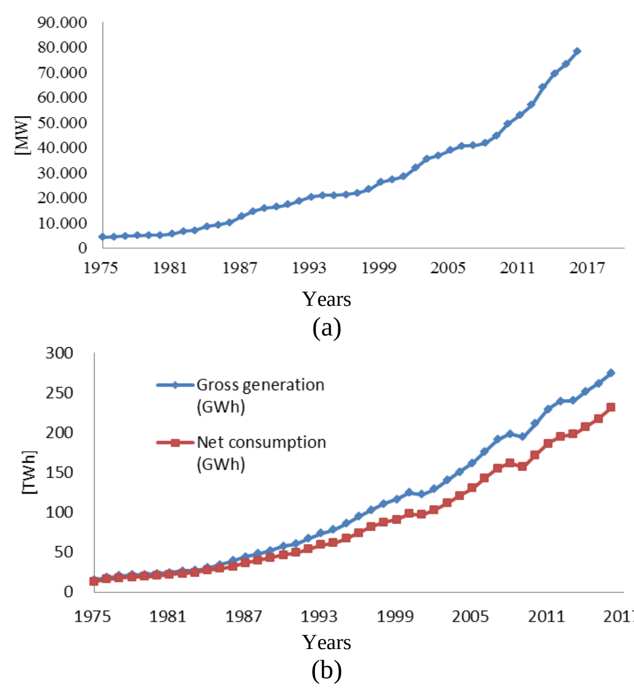

Fig.1. (a) The installed power generation, (b) gross generation, and net consumption of electricity in Türkiye [4].

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As of 2016, the total number of buildings in Türkiye is 9.1 million [3]. Residential buildings in Türkiye constitute 86.8% of the total building.

Türkiye's total annual natural gas consumption is around 48.7 million cubic meters. 19.1% of this is consumed in residential buildings [6, 7]. Energy efficiency in buildings is the reduction of energy consumption per unit of service or product without lowering living standards and service quality in buildings [8]. Energy saving and energy efficiency are different concepts. Reducing energy consumption can be saved, but maintaining or increasing product and service quality while reducing energy consumption is energy efficiency. In Türkiye, thermal insulation requirements for buildings with TS 825 standard is predicated by the Institute of Turkish Standards [9]. Furthermore, BS EN ISO 6946:2017 standard is utilized for buildings located in Europe.

Furthermore, energy efficiency does not necessarily have to be achieved through technological transformations [10, 11]. There is also a need for legal regulations that promote energy efficiency and accelerate sectoral change. Using energy efficiently is the fastest and lowest-cost solution for reducing greenhouse gas emissions. The energy audit is designed to identify energy-saving potentials, energy wastes, and greenhouse gas emissions, as well as technical and economic aspects of their associated rehabilitative or preventive measures [12]. As shown in Table 1, net electrical energy consumption has been increasing for years [4, 5].

Table 1. Distribution (%) of net electricity consumption by sectors in Türkiye [5].

Year	*Total (GWh)*	*Household*	*Commercial*	*Government*	*Industrial*	*Illumination*	*Other(1)*
2012	194,923	23.3	16.3	4.5	47.4	2.0	6.5
2013	198,045	22.7	18.9	4.1	47.1	1.9	5.3
2014	207,375	22.3	19.2	3.9	47.2	1.9	5.5
2015	217,312	22.0	19.1	3.7	47.6	1.9	5.7
2016	231,204	22.2	18.8	3.9	46.9	1.8	6.4

(1) It includes consumption in agriculture, livestock, fishery sector, municipal water abstraction pumping facilities, other public services, etc.

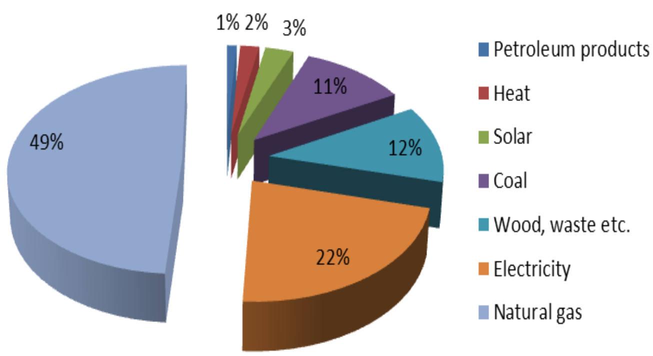


Fig.2. Distribution of energy consumption in buildings by fuel type in Türkiye, 2016 [4].

Energy consumed in the buildings in 2016 increased by 36.8% compared to 2000 and reached 19.7 million TOE as shown in Figure 2. When the energy consumed in buildings is examined according to their usage areas, consumed energy for space heating seems to have a significant share. The energy used for space heating in 2000 corresponds to 68.7% of the total energy consumed in houses, but in 2016 this proportion has decreased to 59.9%. According to the European Union countries in 2015 energy consumption in residential areas was 67% of the energy consumed, 13% in water heating, 15% in electrical appliances & lighting, and 5% in cooking [13]. The ever-increasing energy consumption in public offices indicates that the current energy needs to be used more efficiently.

On the other hand, a simulation has been performed to investigate the annual electrical energy consumption for this faculty building and the calculations reflect that the annual savings value of faculty buildings' electrical consumption is approximately 90,298 kWh of energy [14]. Similarly, to balance the rate of energy demand, energy consumption efficiency is crucial and necessary for an energy audit, which is analyzed for calculating the level of energy consumption of a building at Diponegoro University Campus [15].

In public buildings in 2015, the number of schools providing preschool education in Türkiye was 26,972. The number of primary schools is 27,544, the number of secondary schools is 16,969, the number of high schools is 3,955, the number of vocational high schools is 5,106, and the number of faculties is 2,748. The total number of schools is around 83,294 [3]. The university buildings show dynamic properties in terms of energy consumption because of the number of students, laboratories, classes, offices, and 7/24 life. Therefore, they have enormous energy-saving potential. According to a study supported by the general directorate of renewable energy of the Republic of Türkiye Ministry of Energy and Natural Resources, the annual electricity savings of four different universities in Türkiye was 792.33 Tons of Oil Equivalent (TOE) between 2014 and 2015.

Energy-efficient buildings need to be passed down without sacrificing the quality of education. Therefore, effective use of energy in university buildings is essential in terms of sustainable energy and continuing this culture and education in the future professions of the students who are studying in these buildings [16]. Similarly, sizing and technical study analysis for a specific area have been performed by a solar photovoltaic-thermal system to pay attention to students' awareness in this field [17].

In this context, we have only calculated to clarify researchers' awareness of improving energy audits and consumption by evaluating the faculty building. We have determined the situation of heating energy requirements. Thus, we have emphasized the energy audit and insolation requirements for a faculty building by calculating energy audits based on the TS 825 standard.

This paper is organized as follows. The energy profile of the Marmara University Faculty of Technology is shown in Section 2 of this paper. Then, in Section 3, the annual heating energy required by the faculty building is calculated within the framework of the national standard TS 825 and international standard ISO 10456. Finally, the results of the lighting audit of the faculty building are shown in Section 4. Lastly, the concluding remarks are given in Section 5.

2. ENERGY PROFILE OF MARMARA UNIVERSITY

Marmara University has 14 campuses scattered on the Asia and European sides of Istanbul. It is one of the most prominent universities in Türkiye, regarding the number of students and academic personnel. Göztepe Campus is the second largest campus of Marmara University. Marmara University Göztepe Campus has six faculties, four colleges, and five institutes with an area of 153.394 m² [18]. Göztepe campus is located in the Kadıköy district of Istanbul. Geographical coordinates are 40 ° 59 'North latitude, 29 ° 3' East longitude, 40 m above sea level, UT +2 hours. The Göztepe Campus layout plan is shown in Figure 3. The Faculty of Technology, where we conduct the energy audit that is the subject of this study, is shown in Figure 3.

Fig.3. Faculty buildings of Göztepe Campus [18].

A total of 28 feeders and five transformers provide electrical energy within the university's campus. The electricity consumption of Marmara University between 2012 to 2014 is shown in Figure 4.

A total of four electricity meters measure the energy consumption of the Göztepe Campus. Two meters are in the rector shipbuilding, one in the Atatürk Faculty of Education and the other in the Faculty of Technology. The energy measurements of these electricity meters and the yearly average electricity bills are shown in Table 2 below.

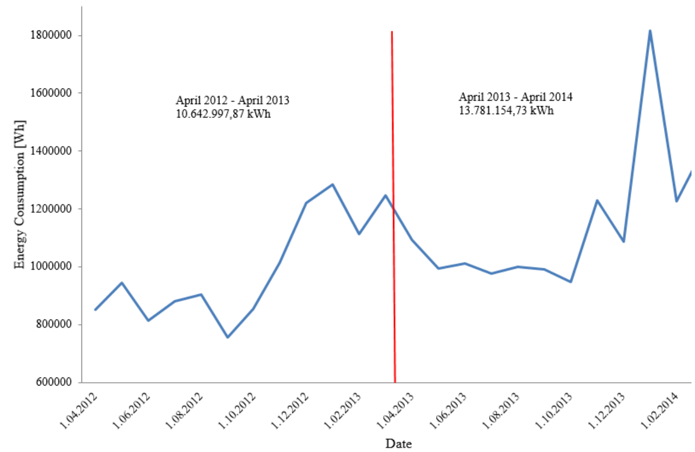


Fig.4. Electricity consumption of Marmara University between 2012 to 2014.

Table 2. Electrical energy profile of Göztepe Campus.

Location of Electricity Meter	*Installed Power (kW)*	*Annual Average Energy Consumption (MWh)*	*Annual Average Electricity Bill (U.S. Dollars)*
Rectorship Building	1000	2428.848	192849.731
Rectorship Building	116.66	332.925	2643.41
Atatürk Faculty of Education	833.33	430.864	34210.532
Faculty of Technology	1260	683.948	54305.23
Total	3209.99	3876.586	284008.90

2.1. Energy Profile of Faculty of Technology

Within the Faculty of Technology, there are six departments for education and training activities, including electrical & electronics engineering, mechanical engineering, textile engineering, mechatronics engineering, computer engineering, metallurgical, and materials engineering. The Faculty of Technology's building is shown in Figure 5.

The building was constructed in 1976 that has a footprint of 14,733.02 m^2. Detailed information about the faculty building is shown in Table 3.

Table 3. General information about the faculty building [14].

Info	*Unit*
Construction date	1976
Enclosed volume	44123.47 m^3
Total area	14733.03 m^2
Number of classrooms	18
Number of laboratories	65
Laboratory area	4937 m^2
Number workshops	14
Number of employees	144
Number of students	1590
Heating system	Central
Cooling system	Air Condition
Annual electricity consumption	683,948.20 kWh
Annual water consumption	7500 m^3

(a) (b)

Fig.5. (a) Overview of Göztepe Campus, Marmara University, (b) Faculty of Technology's building.

3. THE CALCULATION OF THE ANNUAL HEATING ENERGY REQUIREMENT OF THE FACULTY BUILDING

As is the case in all buildings, when energy audits are being carried out in buildings used for educational purposes, it is necessary to calculate the heating energy needed and determine whether this requirement is met. When calculating the heating energy requirement of the building, it is needed to consider some factors [19]. These factors are building characteristics, heating system features, inner climatic conditions, external climate conditions, internal heat gain sources, and solar energy. Building characteristics are consisting of heat losses via conduction, convection and ventilation, and thermal capacity [20]. Especially the control system and heating system response time to the changes in the heating energy requirement [21]. The temperature values required by the building users are changed in inner climatic conditions at different parts of the building and at different times of the day [22]. External climate conditions are outside temperature, direction, and wind intensity [23]. Internal and external climatic conditions and weather conditions for the Faculty of Technology at Marmara University are given in Tables 4-5, respectively. Apart from the heating system, various devices and people are used for purposes such as internal heat sources, which contribute to heating, food cooking, hot water acquisition, and lighting [24]. The quantity of solar energy directly reaches the space heated by transparent building elements such as windows [25]. In the calculation method specified in this International Standard ISO 10456 and TS 825, heat losses through conduction, convection, and ventilation, internal heat gains, and solar energy gains are taken into account [26, 27].

Table 4. Climatic conditions for the Faculty of Technology at Marmara University.

Measurement dates	*Interior temperature-Ti (°C)*	*Exterior temperature-Te (°C)*	*Average sunshine duration (hours)*	*The average number of rain days*	*Mean monthly rainfall (mm)*	*Ti-Te*
01-Jun-17	23.8	21.4	10.4	6.1	35.9	2.4
01-Jul-17	22.8	23.8	11.3	4.2	32.5	-1
01-Aug-17	22.8	23.8	10.4	4.9	40.1	-1
01-Sep-17	20.9	20.1	8.2	7.4	60	0.8
01-Oct-17	21.8	15.7	5.4	11.2	87.8	6.1
01-Nov-17	24.1	11.7	4	13	122.7	12.4
01-Dec-17	28.7	8.2	2.5	17.2	815.2	20.5
01-Jan-18	22.8	7.5	2.9	17.3	106	15.3
01-Feb-18	22.5	8.5	3.6	15.2	77.7	14
01-Mar-18	21.5	10.8	4.6	13.8	71.4	10.7
01-Apr-18	18.3	14.3	6.5	10.3	45.9	4
01-May-18	18.8	17.7	8.8	8	34.4	1.1

Table 5. Weather conditions for the Faculty of Technology at Marmara University.

Month	*Air temperature (°C)*	*Relative humidity (%)*	*Precipitation (mm)*	*Daily solar radiation-horizontal (kWh/m2/day)*	*Atmospheric pressure (kPa)*	*Wind speed (m/s)*	*Heating degree days-18°C (°C-d)*	*Cooling degree days-10°C (°C-d)*
January	6	78.20%	119.07	1.68	98.4	4.9	372	0
February	5.6	76.20%	113.34	2.45	98.3	4.9	347	0
March	7.5	74.50%	95.03	3.65	98.1	4.7	326	0
April	12	71.60%	68.88	4.82	97.9	4.1	180	60
May	16.8	70.50%	45.07	6.27	97.9	4.2	37	211
June	21.6	67.30%	34.84	7.21	97.8	4.1	0	348
July	24.3	66.40%	20.97	7.30	97.8	5	0	443
August	24.3	68.30%	31.68	6.41	97.8	5.1	0	443
September	20.8	69.40%	59.73	5.01	98.1	4.4	0	324
October	16.2	75.20%	101.48	3.14	98.4	4.5	56	192
November	11.3	76.90%	111.04	1.91	98.4	4.5	201	39
December	7.8	78.50%	154.69	1.38	98.4	5.1	316	0
Annual	14.6	72.70%	955.82	4.28	98.1	4.6	1.835	2061

$$Hi = \sum AU + 1U1 \quad (1)$$

$$\sum AU = U_D A_D + U_p A_p + 0.8U_T A_T + 0.5U_t A_t + U_d A_d + 0.5U_{dsic} A_{dsic} \quad (2)$$

$$Hh = p.c.V' \quad (3)$$

$$H = Hi + Hh \quad (4)$$

$$V_x = \frac{V_h n_{50} e}{1+\frac{f}{e}\left[\frac{V_S - V_E}{V_h n_{50}}\right]^2} \quad (5)$$

$$V' = V_0(1-\beta) + (V_f + V_x)\beta \quad (6)$$

$$\Phi g.ay = \sum ri.month.gi.month.Ii.month.Ai \quad (7)$$

Where, the abbreviations used for Equations 1-7, the values used in this study. All of the variables and equations are taken by the TSE 825 standard, as also can be seen in Table 6. Furthermore, the solar heat parameters are shown in Table 7 in terms of average solar radiation for different directions, window areas for different directions and solar heat gain through the windows.

Table 6. The acronym of the parameters and variables.

	Parameters	*Unit*		*Parameters*	*Unit*
Hi	Heat loss through conduction	10986.67 W/K	H_h	Ventilation heat loss	447843.5026 W/K
U_D	Heat transfer coefficient of exterior wall	0.53 W/m^{2}K	ρ	Air density	1.184 kg/m^3
A_D	Exterior wall area	6337.54 m^2	c	Specific heat capacities of air	1006 J/kgK
U_P	Heat transfer coefficient of window	1.80 W/m^{2}K	V'	Volume airflow rate	375.99 m^3/h
A_P	Window area	531.57 m^2	V_h	Ventilated volume	44123.47 m^3
U_T	Heat transfer coefficient of ceiling	1.30 W/m^{2}K	n50	Air change rate	4
A_T	Ceiling area	m^2	f	Open surface coefficient	20
U_t	Heat transfer coefficient of floor	W/m^{2}K	e	Building class	0.04
A_t	Floor area	m^2	V_S	Air intake	0.33 m^3/h
U_d	Heat transfer coefficient of floor	W/m^{2}K	V_X	Additional volumetric air change due to wind effect	7059.76 m^3/h
A_d	Floor area in contact with outside air	m^2	V_O	Volumetric air change when the ventilation are not working	23.95 m^3/h
U_{dsic}	Heat transfer coefficient of building Structures in contact with indoor Environments at low temperatures	W/m^{2}K	β	Fans running time rate	0.05
A_{dsic}	Area of building structures in contact with indoor environments at low temperatures	m^2	V_f	Volumetric air change when the ventilation is working	5 m^3/h

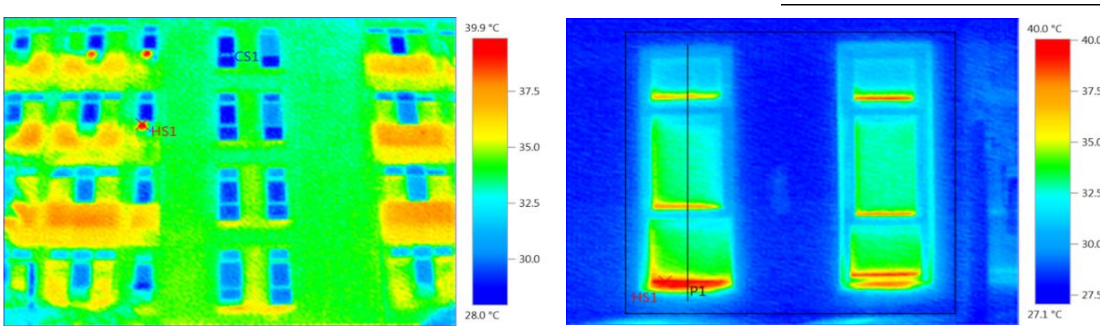
Table 7. Solar heat gains.

Months	*Average Solar Radiation at Different Directions (W/m²)*			*Window Areas at Different Directions (m²)*				*Solar Heat Gain Through The Windows (W)*
	I (South)	*I (North)*	*I (West/East)*	*A (West)*	*A (North)*	*A (East)*	*A (West)*	*Φg.ay*
01-Jun-17	94.88	83.44	121.19	1962.84	1961.98	1372.7	1373	245769.5712
01-Jul-17	93.29	81.17	117.28	1962.84	1961.98	1372.7	1373	239177.8642
01-Aug-17	94.6	72.58	105.22	1962.84	1961.98	1372.7	1373	222115.5815
01-Sep-17	90.47	56.29	80.59	1962.84	1961.98	1372.7	1373	183345.8227
01-Oct-17	83.38	39.02	58.61	1962.84	1961.98	1372.7	1373	144411.6729
01-Nov-17	66.8	25.58	40.39	1962.84	1961.98	1372.7	1373	105193.4349
01-Dec-17	63.57	21.22	35.83	1962.84	1961.98	1372.7	1373	95324.17874
01-Jan-18	71.87	24.56	41.46	1962.84	1961.98	1372.7	1373	109113.2142
01-Feb-18	85.09	35.42	55.75	1962.84	1961.98	1372.7	1373	140250.2984
01-Mar-18	96.61	51.3	76.88	1962.84	1961.98	1372.7	1373	180492.8265
01-Apr-18	84.24	65.33	89.18	1962.84	1961.98	1372.7	1373	193819.4356
01-May-18	93.29	79.12	113.96	1962.84	1961.98	1372.7	1373	234448.2624

*ri.month=gi.month=0.6

Table 8. Calculation of heating energy for the faculty building.

Dates	*Heat Loss*			*Heat Gains*			*Gain/Loss Ratio*	*Gain Usage Factor*	
	Specific Heat Loss	*Temperature Difference*	*Total*	*Interior Hea Gains*	*Solar Heat Gains*	*Total*			
	H (W/K)	*Ti-Td (K,C)*	*H(Ti-Td) (W)*	*Φi (W)*	*Φg (W)*	*T=Φi+Φg (W)*	*y*	η_{month}	*Heating Energy (MJ)*
01-Jun-17		2.40	1101192.42		245769.57	270245.82	0.25	0.98	2165718.846
01-Jul-17		-1.00	-458830.17		239177.86	263654.11	-0.57	-4.70	2021900.213
01-Aug-17		-1.00	-458830.17		222115.58	246591.83	-0.54	-5.43	2280201.458
01-Sep-17		0.80	367064.14		183345.82	207822.07	0,57	0.83	504854.957
01-Oct-17		6.10	2798864.06		144411.67	168887.92	0.06	1.00	6816898.172
01-Nov-17	458830,17	12.40	5689494.15	24476.25	105193.43	129669.68	0,02	1.00	14411065.022
01-Dec-17		20.50	9406018.56		95324.18	119800.43	0.01	1.00	24069877.392
01-Jan-18		15.30	7020101.66		109113.21	133589.46	0.02	1.00	17849839.601
01-Feb-18		14.00	6423622.43		140250.30	164726.55	0.03	1.00	16223058.125
01-Mar-18		10.70	4909482.86		180492.83	204969.08	0.04	1.00	12194099.720
01-Apr-18		4.00	1835320.69		193819.44	218295.69	0.12	1.00	4191455.107
01-May-18		1.10	504713.19		234448.26	258924.51	0.51	0.86	732638.933
								Total	***103461607.550***



(a) (b)

Fig.6. (a) Thermograph of the building facade, (b) Heat losses through windows on July 05. 2018. 15:11 pm.

The amount of annual heating energy of the building is 103,461,607.550 MJ. as seen in Table 8. According to the meteorological characteristics of Istanbul. there is no heating needed for the faculty building from June to October. The heating system also operates to meet the need for hot water due to the infrastructure problem of the building. Therefore. 13,789,573 MJ of excess heating energy is used. One of the biggest reasons for this is the central heating system inside the campus. There is no external insulation in the building. The annual heating energy of the faculty building is 25.6 TOE. If insulation is needed. the required value is 20.7 TOE. An average energy saving is 4.9 TOE per year with the insulation of the building. The investment cost of the insulation is $ 61,361,804. The amount of savings made with insulation is $ 9,037.56 per year. The heat losses resulting from some insulation problems are shown in Figure 6. The most significant heat losses in the building are through infiltration and ventilation not through transmission.

4. LIGHTING ENERGY AUDIT FOR THE FACULTY BUILDING

Energy saving in lighting is achieved by ensuring the required lighting intensity without sacrificing visual conventions. For this high-efficiency light sources should be used instead of low-efficiency light sources [28. 29]. Despite the rapidly developing LED Technology. fluorescent lamps are the most used and indispensable light sources in commercial and public buildings. Whether it is a fluorescent lamp or an LED lamp. almost all the lighting elements produce harmonics [30]. Furthermore, presents a novel fully controlled LED lighting system supported PV-Battery powered scheme [31].

Harmonics; voltage, current, or power are periodic distortions in the sine wave. The waveform can be interpreted as a combination of various sinusoidal waves of different frequencies and magnitudes. The contribution of each of these components to the full signal is measured. The values can be given as a percentage of the base value. as a percentage of the sum of all harmonics. or as an RMS value. The total harmonic distortion is expressed as the ratio of the current harmonics in the signal to the RMS value of the fundamental signal or as a percentage of the fundamental frequency signal value (f %) [32].

The fluorescent lamps used in the lighting of public buildings include a very high rate of 85% of the general lighting in Türkiye. These lamps are devices that work with the discharging principle. Conventional ballasts consist of a transformer with an iron core and a capacitor. The efficiency is low with heat losses for the fundamental frequency working [33]. Electronic ballasts include a switch-mode power supply system. Thus, a small core is sufficient for the arc current, and at the same time, it prevents flicker at 100-120 Hz. The load must be distributed equally to the phases to eliminate the harmonics generated by the fluorescent lamps [34]. Electronic ballasts without filters and compact fluorescent lamps generate high harmonic currents (typically around 150-170%). This is particularly the case for additional harmonic loads to the low-voltage networks. Therefore, it is critical to conduct accurate harmonic measurement modeling, and analysis so that adequate measures can be taken and predictions can be made according to the energy audit results.

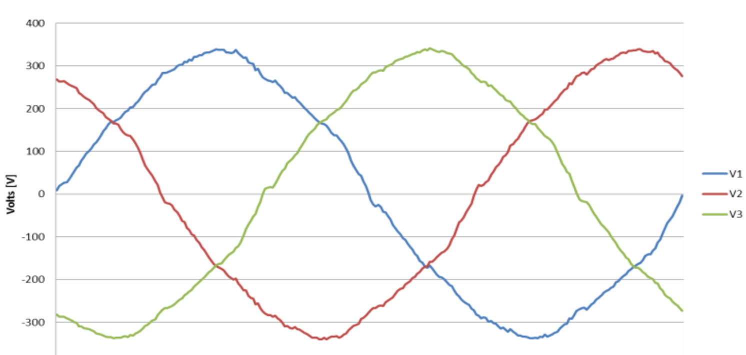
As a result of the measurements made harmonics do not exceed voltage harmonic limits specified in IEC 61000-2-2 standard in Figure 7. However, it can be seen that in some offices and classrooms there are not enough light levels. This situation has negative consequences regarding light comfort as seen in Table 9.

The share of the lighting for the faculty building is around 25% of total electricity consumption. The interior lighting of the faculty was mostly fluorescent lighting. If LED bulbs are used instead of fluorescent lamps, the initial investment cost is about $12,511. The payback period is one year and 11 months. The annual savings amount is $6,198. The yearly operations and maintenance (O&M) fee are $4,504.

5. CONCLUSION

Today, university education has to be continuous and innovative. For this reason, university buildings are dynamic structures that operate independently from the concept of time. In these buildings. energy should be used efficiently as well as energy must be continuous and of high quality. When the fuel consumption distribution of this university building with an average construction area of 15.000 m² is examined. it is seen that the most significant part of usage is for heating purposes. Energy efficiency studies can save up to 20% on fuel consumption. Improvement of the circulation pumps, building automation systems, lighting system modernization, and external heat insulation are essential as energy-saving opportunities. According to the energy audit, the annual heating energy requirement of the faculty building is 297,728 kWh. If insulation is needed. the required value is 240,741 kWh. With the insulation of the building, an average of 56,987 kWh energy savings per year can be made. The current lighting in the buildings used old technology such as fluorescent or discharge lighting. The lighting systems of the faculty building are the places where the electricity consumption is the greatest, according to the result of the energy audit. Air conditioning systems and office equipment follow lighting systems. The initial investment cost of LED luminaires is about $12,511. The payback period is one year and 11 months. The annual savings amount is $6,198. The annual O&M cost is $4,504. With the use of LED luminaires, both less energy consumption and less harmonic distortion will occur.

It is seen that there are many heat energy losses. especially in old buildings where there is no or lack of thermal insulation. This study will be a reference for people/institutions and researchers who will conduct energy audits for faculty buildings.



(a)

Odd harmonics		Even harmonics	
n	%Vn	n	%Vn
5	6	2	2
7	5	4	1
11	3,5	6	0,5
13	3	8	0,5
17	2	10	0,5
19	1,5	> 12	0,2
23	1,5		
25	1,5		
> 29	k	k= (0,2 + 12,5/n)	

(b)

Fig.7. (a) Lighting harmonic voltage profiles of the building (b) Standard IEC 61000-2-2 voltage harmonic limits.

Appendix

Table 9. The energy audit report of lighting systems for some offices in the faculty building.

Office Number	Number of Fluorescent Lamp	Power of Lamp (W)	Number of Broken Lamps	Daily Working Time (Hours)	Consumed Electrical Energy per day (Wh)	Light Levels (Lux)	Recommended Light Levels (Lux)	Result
D501	6.00	36.00	1.00	10.00	1800	120.00	200.00	Good
D502	4.00	36.00	1.00	10.00	1080	150.00	220.00	Good
D503	16.00	36.00	0.00	10.00	5760	300.00	450.00	Good
D504	8.00	36.00	2.00	10.00	2160	230.00	480.00	Bad
D505	24.00	36.00	0.00	10.00	8640	300.00	500.00	Good
D506	6.00	36.00	0.00	10.00	2160	150.00	200.00	Bad
D507	12.00	36.00	1.00	10.00	3960	280.00	400.00	Bad
D508	8.00	36.00	0.00	10.00	2880	240.00	390.00	Bad
D509	8.00	36.00	0.00	10.00	2880	310.00	490.00	Good
D514	2.00	36.00	0.00	10.00	720	150.00	170.00	Bad
D515	12.00	36.00	3.00	10.00	3240	220.00	480.00	Bad
D516	12.00	36.00	0.00	10.00	4320	310.00	510.00	Good
D517	12.00	36.00	0.00	10.00	4320	300.00	300.00	Good
D518	12.00	36.00	2.00	10.00	3600	220.00	360.00	Bad
D519	12.00	36.00	0.00	10.00	4320	300.00	450.00	Good
Office Number	Number of Fluorescent Lamp	Power of Lamp (W)	Number of Broken Lamps	Daily Working Time (Hours)	Consumed Electrical Energy per day (Wh)	Light Levels (Lux)	Recommended Light Levels (Lux)	Result
Entrance	4.00	36.00	1.00	12.00	1296	300.00	520.00	Good
E Hall	42.00	36.00	12.00	12.00	12960	200.00	400.00	Good
E1	48.00	37.00	3.00	8.00	13320	280.00	300.00	Good
E2	48.00	38.00	0.00	9.00	16416	270.00	310.00	Good
E3	48.00	39.00	2.00	10.00	17940	300.00	310.00	Good
E4	48.00	40.00	3.00	11.00	19800	290.00	310.00	Good
E5	48.00	41.00	5.00	12.00	21156	310.00	310.00	Good
E6	48.00	42.00	6.00	13.00	22932	320.00	300.00	Good
E7	48.00	43.00	2.00	14.00	27692	270.00	285.00	Good
Office Number	Number of Fluorescent Lamp	Power of Lamp (W)	Number of Broken Lamps	Daily Working Time (Hours)	Consumed Electrical Energy per day (Wh)	Light Levels (Lux)	Recommended Light Levels (Lux)	Result
A1 Hall	24.00	36.00	10.00	10.00	5040	110.00	120.00	Good
A 101	16.00	36.00	1.00	8.00	4320	300.00	330.00	Good
A 102	16.00	36.00	1.00	8.00	4320	290.00	320.00	Good
A 103	16.00	36.00	0.00	8.00	4608	400.00	500.00	Good
A 104	16.00	36.00	2.00	8.00	4032	310.00	340.00	Good
A 105	16.00	36.00	8.00	8.00	2304	290.00	330.00	Good
A 106	8.00	36.00	2.00	8.00	1728	300.00	330.00	Good
A 107	4.00	36.00	1.00	8.00	864	200.00	330.00	Bad
A 108	8.00	36.00	3.00	8.00	1440	271.00	291.00	Bad
A 109	8.00	36.00	2.00	8.00	1728	312.00	330.00	Good
A 110	16.00	36.00	10.00	8.00	1728	100.00	200.00	Bad
A 111	10.00	36.00	2.00	8.00	2304	150.00	250.00	Bad
A 112	32.00	36.00	10.00	8.00	6336	160.00	240.00	Bad
A2 Hall	24.00	36.00	12.00	10.00	4320.00	200.00	230.00	Good
A 201	16.00	36.00	2.00	8.00	4032	300.00	400.00	Good
A 202	16.00	36.00	4.00	8.00	3456	170.00	330.00	Bad
A 203	16.00	36.00	4.00	8.00	3456	360.00	420.00	Good
A 204	16.00	36.00	5.00	8.00	3168	280.00	360.00	Good
A 205	16.00	36.00	5.00	8.00	3168	271.00	291.00	Good
A 206	8.00	36.00	3.00	8.00	1440	261.00	291.00	Good
A 208	8.00	36.00	2.00	8.00	1728	300.00	330.00	Good
A 209	16.00	36.00	3.00	8.00	3744.00	250.00	330.00	Good
A 210	32.00	36.00	6.00	8.00	7488.00	300.00	330.00	Good
A 211	16.00	36.00	2.00	8.00	4032.00	320.00	380.00	Good
A 212	32.00	36.00	4.00	8.00	8064.00	290.00	330.00	Good
A3 Hall	24.00	36.00	11.00	10.00	4680.00	120.00	130.00	Good
A 301	16.00	36.00	0.00	8.00	4608.00	200.00	300.00	Bad
A 302	12.00	36.00	0.00	8.00	3456.00	210.00	240.00	Bad
A 303	2.00	36.00	0.00	8.00	576.00	230.00	260.00	Bad
A 304	4.00	36.00	0.00	8.00	1152.00	240.00	270.00	Bad
A 305	4.00	36.00	0.00	8.00	1152.00	210.00	240.00	Bad
A 306	4.00	36.00	0.00	8.00	1152.00	221.00	251.00	Bad
A 307	4.00	36.00	0.00	8.00	1152.00	232.00	262.00	Bad
A 308	4.00	36.00	0.00	8.00	1152.00	231.00	261.00	Bad
A 309	4.00	36.00	2.00	8.00	576.00	234.00	264.00	Bad
A 310	4.00	36.00	0.00	8.00	1152.00	211.00	241.00	Bad
A 311	4.00	36.00	0.00	8.00	1152.00	209.00	239.00	Bad
A 312	4.00	36.00	0.00	8.00	1152.00	207.00	237.00	Bad
A 313	4.00	36.00	0.00	8.00	1152.00	204.00	234.00	Bad
A 314	4.00	36.00	0.00	8.00	1152.00	204.00	234.00	Bad
A 315	4.00	36.00	0.00	8.00	1152.00	287.00	317.00	Bad
A 316	4.00	36.00	0.00	8.00	1152.00	263.00	293.00	Bad
A 317	4.00	36.00	0.00	8.00	1152.00	282.00	312.00	Bad
A 318	4.00	36.00	0.00	8.00	1152.00	248.00	278.00	Bad
A 319	4.00	36.00	0.00	8.00	1152.00	242.00	272.00	Bad
A 320	4.00	36.00	0.00	8.00	1152.00	234.00	264.00	Bad
A 321	4.00	36.00	0.00	8.00	1152.00	241.00	271.00	Bad

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