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INVESTIGATION INTO ENERGY SAVINGS IN THE RENEWAL OF THE LIGHTING SYSTEM IN UNIVERSITY CAMPUS BUILDINGS

Summary

This study shows the amount of energy savings to be achieved in electricity consumption if the current lighting system in the buildings of the Cumhuriyet University campus in Turkey is replaced with efficient lighting systems. In addition, environmental effects of energy savings are determined by calculating the amounts of CO_2, SO_2, NO_X, CO emissions. The Life Cycle Cost (LCC) analysis is used to determine energy costs and payback periods. The calculations reveal that the use of three alternative lighting systems would lead to a substantial reduction in electricity consumption ranging between 16.5% and 40.5%, and that the payback periods of these alternative lighting systems vary between 1.9 and 5 years.

Key words: *lighting; life cycle cost analysis; emission reduction; energy efficiency*

1. Introduction

In addition to attempts made to meet energy needs of Turkey, the efficient use of current energy and attempts to save energy are also of great importance. The rapid increase in the consumption of electric energy versus the slow increase in the production of electric energy has put the issue of using electricity more efficiently on the agenda. To increase the efficient use of energy, to avoid waste, to ease the burden of energy costs on the economy, and to protect the environment, the Energy Efficiency Law (No. 5627) was enacted after it was published in the Official Gazette on May 2, 2007. Figure 1 shows electricity consumption estimated as a baseline scenario by the General Directorate of Turkish Electricity Transmission Corporation for a period of ten years. The electricity demand is estimated to be 376,785 GWh in 2023 [1]. By using a correct lighting system energy consumption costs can be reduced. In order to reduce electricity consumption for lighting purposes in public institutions, the use of energy-saving lamps has increased in Turkey in recent years as it has all over the world. The gap between electricity supply and demand in Turkey, the increase in expenditures on building power supplies and the perception of energy saving as a general policy constitute the main incentives for customers to choose these energy saving devices. Mahlia et al. investigated the amount of energy savings and payback periods that could be achieved by changing the lighting system at the University of Malaysia. The LCC decreased by 40% after all lamps were replaced with the T5 lighting system within 10 years [2]. In studies on efficient lighting conducted at the Stuttgart University [3], daylight measurements and simulations were performed for classrooms and computer labs, and electricity consumption was calculated. The analysis showed that the use of LED lamps reduced energy consumption by 34%.

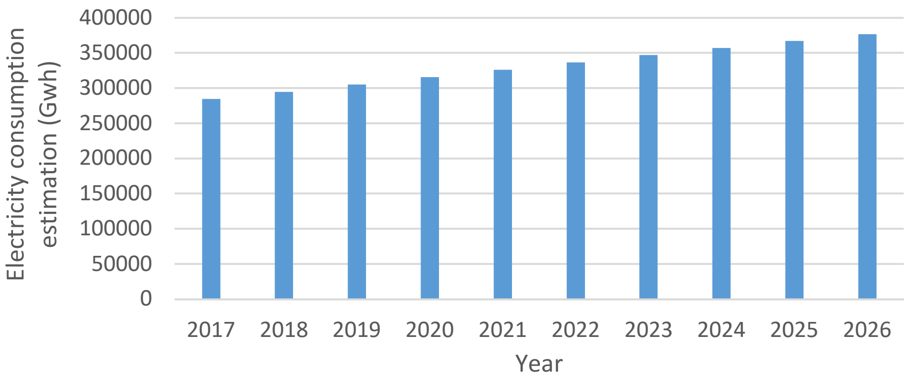

Fig. 1 Turkey's 2017-2026 gross electricity consumption estimation in the baseline scenario [1]

In a study conducted on another campus, energy gains and carbon dioxide emissions were calculated after 1.2 m-long fluorescent lamps installed in the buildings were replaced with four different lighting systems [4]. The results showed that there was a 13.9%, 20.5%, 24.4% and 64.9% decrease in energy consumption and a 10% decrease in CO_2 emissions. It was observed that the hours during which the lighting system was on, the electricity prices, and the prices of the lamps and equipment significantly influenced the results. Jamaludin et al. studied bioclimatic design strategies and the performance characteristics of the electricity use in college buildings. They used the Energy Efficiency Index to measure the performance of electricity usage. The simulation results indicate that, with efficient use of electricity the average electricity use can be reduced to 24 to 34 $kWh/m^2/year$ [5]. In 2011, Lam et al. used the life cycle cost method to analyze the replacement of general lighting lamps with energy saving light bulbs in two Honkong hotels. It was found that the payback period was about one year, and the obtained reduction in electricity consumption was 70%. The reduction in CO2 emissions was 420kg for the two hotels [6]. Preston et al. dealt with an economic analysis of the replacement by retrofitting three lighting systems commonly used in industrial applications. Recent pulse-start metal halide lamps and a range of T5 high output and T8 fluorescent lamp configurations were considered in the analysis. Savings, payback period, and net present value for many retrofit options, as well as the change in energy consumption, carbon footprint, and lumen output were calculated for each retrofit [7]. Soori et al. conducted a study on control strategy for energy efficient office lighting system design. They used a lighting control algorithm to increase energy efficiency [8]. Stansbury et al. investigated reduction in SO_2, NO_x, CO_2, and CO emissions and retrofitting the building with an energy-efficient lighting system. The results showed that significant reductions in utility bills as well as reductions in air emissions would result from a major conversion of a building if a more energy efficient lighting system were installed. Namely, the conversion of this large building would reduce SO_2 emissions by 14.6 tons/yr. and NO_x emissions by 6.3 tons/yr. [9].

In this study, decrease in electricity consumption, Life Cycle Cost (LCC) and payback period were calculated if different energy efficient lighting systems were installed in the buildings at the Cumhuriyet University.

2. Lighting System

Cumhuriyet University located on 11,000 decares (~2,718 acres) of land is a large higher education institution comprising 11 faculties, four institutes, one state conservatory, six colleges, 14 vocational schools and one research hospital (Figure 2). In all classrooms, corridors and offices of the university fluorescent lamps are installed. They have a wide range of power, color and lifespan. Visible light in fluorescent lamps is produced by a mixture of three different phosphors in the inner wall of the lamp.

No	Faculty	No	Faculty
1	Hospıtal	11	Refectory
2	Faculty of Dentıstry	12	Library
3	Faculty of Health Scıences	13	Faculty of Scıence
4	Faculty of Economıcs And Admınıstratıve Scıences	14	Faculty of Educatıon
		15	Lecture Hall
5	Faculty of Medıcıne	16	Sciences and CUSEM
6	Faculty of Letters	17	Faculty of Fıne Arts
7	Faculty of Technology	18	Physıcal Educatıon and Sports
8	Faculty of Engıneerıng	19	C. Gym
9	Faculty of Theology	20	School of Foreign Languages
10	Vocatıonal School		

Fig. 2 Map of the Cumhuriyet University

UV radiation generated by the collision of electrons detached due to the discharge between the electrodes to the mercury atoms in the discharge tube is converted into visible radiation by the fluorescent substance in the inner wall of the tube. The lamps in the university buildings are T12-40W, T12-20W, T8-36W and T8-18W fluorescent lamps 0.6 m and 1.2 m in length. All lighting systems have coil ballasts. To replace the current lighting system for the purpose of energy saving, three different lighting systems (T8 electronic ballast, T5 and T8 LED) were considered. The new lamps were chosen to have the same collective light intensity values as the existing lamps in offices and classrooms. The specifications of lamps are shown in Table 1 and Table 2.

2.1 Lighting Strategy 1

The first option is to replace all lamps with T8-36 W and T8-18 W lamps using electronic ballasts instead of coil ballasts as this is the case in the current lighting system. By using an electronic ballast, T8 fluorescent lamps will work faster, consume less energy, and will not produce the flickering-related buzzing or humming sound. In addition, T8 lamps have a life span of 20,000 hours and they lose 20% of their light output during their lifetime.

2.2 Lighting Strategy 2

The second alternative is to replace the current system with T5-14 W and T5-28 W lamps using T5 luminaires. In this process, the aim is to provide more efficient and economical lighting by replacing the current luminaires with T5 luminaires. Due to their high efficiency, the use of electronic ballasts in T5 lamps reduces energy consumption by about 50% if light output is the same as that of fluorescent lamps. T5 lamps are 16 mm in diameter. Although their light output is of the same lumen value as that of normal fluorescent lamps, they consume less energy. Their life span is 18,000 hours and they lose 5% of their light output during their life cycle.

Table 1 Comparison of lighting characteristics and price of T8, T5 and T8 LED lamps

Lamp type	Ballast	Ballast factor	Lumens (lm)	Lifetime (h)	Cost ($)
1.2 m					
Standard T8 36 W	Electronic	0.98	3350	20000	0.9
Ballast	--	-	-	-	8.7
T5 28 W (1149 mm)	Electronic	0.95	2900	18000	1.9
T5 conversion kits	-	-	-	-	30.6
T8 LED 18 W	-	-	1600	40000	8
Fixtures for T8 LED	-	-	-	-	4.2
0.6 m					
Standard T8 18 W	Electronic	0.98	1500	20000	0.8
Ballast	-	-	-	-	7.6
T5 14 W (549 mm)	Electronic	0.95	1350	18000	1.8
T5 conversion kits	-	-	-	-	27.8
T8 LED 9 W	-	-	800	40000	4.9
Fixtures for T8 LED	-	-	-	-	3.5

Table 2 Comparison of power characteristics of lamps

Lamps	Watt	System power (W)	
		Bobbin ballast (Number of lamps)	Electronic ballast (Number of lamps)
T12	20 W	28-(1)	-
		54-(2)	-
	40 W	48-(1)	-
		102-(2)	-
T8	18 W	24-(1)	18-(1)
		46-(2)	35-(2)
	36 W	43-(1)	35-(1)
		82-(2)	71-(2)
T5	14 W	-	14-(1)
		-	26-(2)
	28 W	-	25-(1)
		-	52-(2)
T8 LED	9 W	9-(1)	
		18-(2)	
	18 W	18-(1)	
		36-(2)	

2.3 Lighting Strategy 3

The third alternative is to replace all lamps with LED T8-9 W and LED T8-18 W lamps and increase the number of current luminaires. Because the lumen output of LED T8 lamps is lower, more lamps will be used for each room to produce the lumen value equal to that produced by current lamps. LED lamps consume approximately 50% less electricity compared to standard fluorescents. LED T8 lamps have a life span of about 40,000 hours, which is longer than that of standard fluorescent lamps. LED lamps do not emit ultraviolet or infrared rays as do fluorescent lamps and they are environmentally friendly because they do not contain harmful gases, such as mercury vapor. In addition, LED lamps emit stable light, do not flicker, can be directly connected to the mains electricity and do not need a starter and ballast like fluorescent lamps.

Table 3 Number of lamps collected

FACULTY	**T8 (0.6 m)**	**T8 (1.2 m)**	**T12 (0.6 m)**	**T12 (1.2 m)**
Letters	196	758	0	0
Scıence	106	448	24	1,058
Cumhuriyet Hıgher Vocatıonal	478	915	88	416
Health Scıences	561	928	2	0
Technology And Theology	296	929	4	76
Fıne Arts	166	806	0	0
Educatıon	157	13	197	944
Medıcıne	420	940	0	0
Economıcs And Admınıstratıve Scıences	1,160	312	0	28
Physıcal Educatıon And Sports	274	226	0	32
Gym	0	274	172	98
School Of Foreıgn Languages	840	408	60	778
Institutes And CUSEM	20	396	0	0
Pool	364	50	0	0
Library	10	28	60	606
Lecture Hall	236	0	136	60
Hospital	1,762	7,000	44	350
Engıneerıng	749	2,134	559	914
Dentıstry	104	616	0	0
Refectory	144	770	0	0
Total: 32,700	8,043	17,951	1,346	5,360

3. Study Data

To determine the number of lamps used at the Cumhuriyet University, current lamps were counted. After the counting, the number and types of the lamps, the number and types of the luminaires in each room and building were determined. As is seen in Table 3, the number of T8 and T12 lamps differs from one building to another. These are 18W and 36W lamps and their lengths are 0.6 m and 1.2 m, respectively. The number of all lamps in all buildings of the university was determined to be 32,700. If current lamps are replaced with T8 and T5 lamps, the number of lamps will remain the same, but if they are replaced with LED T8 lamps, the number of lamps is to be increased to produce the same light intensity. In case the LED T8 lighting system is used, the number of lamps and luminaires needed is shown in Table 4.

Energy saving provides also a significant reduction in common emissions such as CO_2, NO_X, SO_2, CO. Coal is used as the main fuel for power generation in Turkey. For emission calculations, the amount of CO_2, NO_X, SO_2, CO in the production of 1 kWh electricity is taken as 1.02 kg, 0.00211 kg, 0.00784 kg and 0.00067 kg, respectively [11].

Table 4 Total number of lamps and additıonal number of fixtures for T8 LED lamps

Watt	Number of lamps	Additional number of fixtures
9 W	15,844	3,228
18 W	48,807	12,748
Total	64,651	15,976

4. Life Cycle Cost Analysis

Total energy consumption in the lighting system (C_A) is calculated by using the following equation [4]:

$$C_A = (L \ x \ W \ x \ H)/1000 \tag{1}$$

L is the number of lamps, *W* is the power and *H* is the number of hours of use.

Energy saving (S_E) is the difference between energy consumption of the current system ($C_{A,\ Current}$) and the prospective lighting system ($C_{A,\ Prospective}$), and is shown in the following equation [2]:

$$S_E = C_{A,current} - C_{A,prospective} \tag{2}$$

Bill saving (S_B) is calculated by the following equation [2]. S_E is the energy saved and T_E is the electricity tariff. In the calculations, it was predicted that the electricity tariff would increase by about 8% each year.

$$S_B = T_E \ x \ S_E \tag{3}$$

Operating cost (C_O) is calculated by the following equation [2]:

$$C_o = L \ x \ W \ x \ H \ x \ T_E \tag{4}$$

Present worth factor (PW) is a method of determining the current value of future costs [10].

$$PW = \frac{(1+r)^N - 1}{r(1+r)^N} \tag{5}$$

where r is the inflation rate and *N* is the lifetime. Payback period (*PP*) is calculated by using the following equation [2]:

$$PP = -\frac{\Delta PC}{\Delta OC} \tag{6}$$

PC is the investment cost and *OC* is the yearly operation cost [2].

LCC is calculated by the following equation [2]:

$$LCC = C_P + (PW)(C_O) \tag{7}$$

C_p is the investment cost and C_O is the increased annual operating cost.

5. Results

In the calculations, the single rate electricity tariff of 0.117 $ / kWh for 2017 [12] was used as a base, and the electricity tariff was expected to increase by 8% per year. The rate of increase in electricity tariff was calculated based on the changes in electricity prices in the period of ten years [12].

To calculate energy savings as a result of reduction in energy consumption due to the use of efficient lighting systems in the buildings, the average daily working time was taken as 8 hours for 5 days a week. It is planned to replace 10% of lamps in the first year, and to complete the replacement of all old lamps with new lamps in 10 years. The current lighting system consumes 2,544,162 kW of energy per year. The total amount of energy consumed at the end of each year and the amount of savings after the current system is replaced with the energy efficient lighting system are shown in Table 5.

In the first option, energy consumption will be reduced by about 18.9% when the current system is replaced with the T8-18W and T8-36W lighting system with electronic ballasts. Of the three options, the second one, in which the T5 system is used, will yield the greatest decrease in energy consumption. Energy consumption is reduced by 40.5% compared to the current system because T5 lamps provide the same amount of light intensity as the existing lighting system but use less power (Figure 3).

Table 5 Energy consumption for existing and new lighting systems

Year	Energy consumption for lighting systems (kW)				Bill savings ($)		
	Existing System	T8 Electronic	T5	T8 LED	T8 Electronic	T5	T8 LED
2017	2,544,162	2,544,162	2,544,162	2,544,162	0	0	0
2018	2,544,162	2,496,051	2,441,200	2,502,140	6,062	12,973	5,295
2019	2,544,162	2,447,939	2,338,237	2,460,117	13,094	28,022	11,437
2020	2,544,162	2,399,827	2,235,275	2,418,094	21,213	45,396	18,528
2021	2,544,162	2,351,715	2,132,312	2,376,071	30,546	65,370	26,680
2022	2,544,162	2,303,603	2,029,350	2,334,048	41,237	88,250	36,018
2023	2,544,162	2,255,491	1,926,387	2,292,025	53,443	114,372	46,680
2024	2,544,162	2,207,379	1,823,425	2,250,002	67,339	144,109	58,816
2025	2,544,162	2,159,268	1,720,462	2,207,979	83,115	177,871	72,596
2026	2,544,162	2,111,156	1,617,500	2,165,957	100,985	216,114	88,204
2027	2,544,162	2,063,044	1,514,537	2,123,934	121,182	259,336	105,845
TOTAL	27,985,786	25,339,634	22,322,849	25,674,529	538,216	1,151,813	470,099

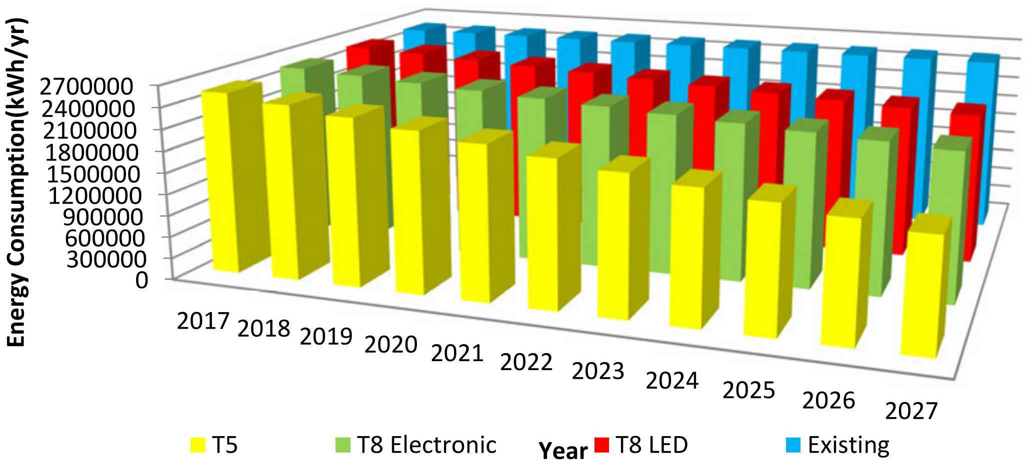

Fig. 3 Comparison of energy consumption of standard and new lighting systems

In the third option, in which T8 LED lamps are used, the power consumption is low, but because their lumen value is low, the number of lamps and luminaires in the system is high. Compared with the current system, energy consumption is reduced by 16.5 % in the third option. The comparison of the amount of savings in payments revealed that the T5 lighting system is the most economical lighting system with the cost of $ 1,151,813. Savings in the case of the T8 electronic and T8 LED systems are close to each other and estimated to be $538,216 and $470,009, respectively. Mahlia et al. carried out lighting retrofits of buildings and found that 12% and 45% less energy can be consumed by replacing the building lighting with a T5 fluorescent lighting system. The change in payback periods and LCC over time is shown in Figure 4, Figure 5 and Table 6.

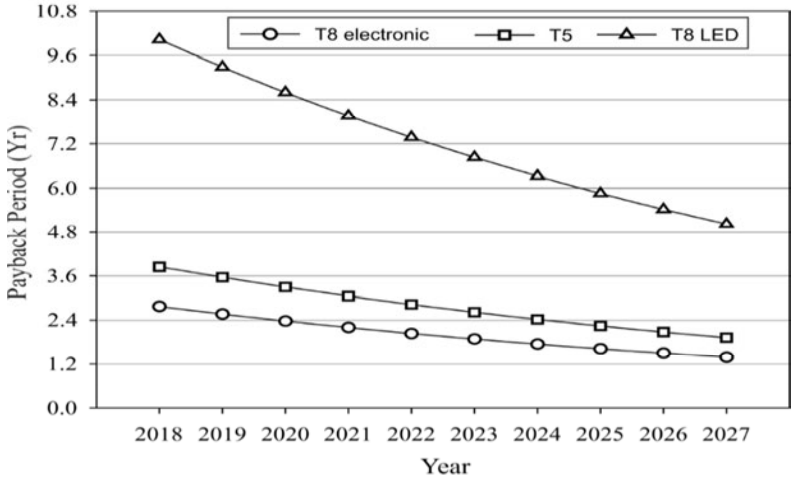

Fig. 4 Change in payback periods over time for different lighting systems

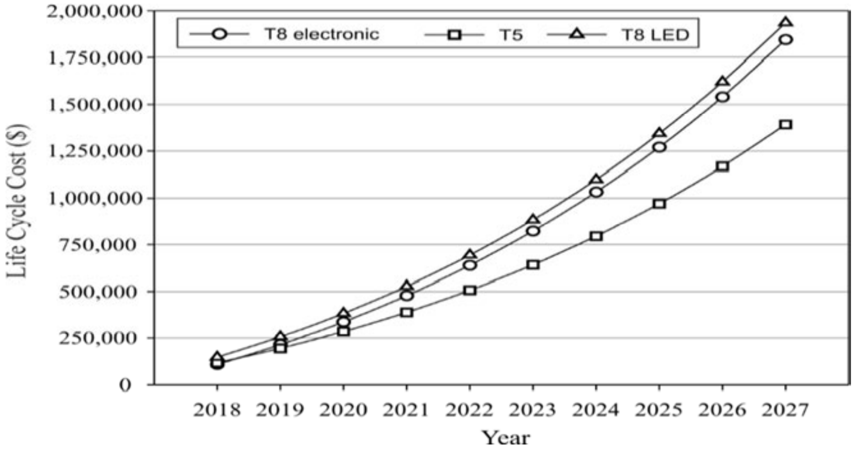

Fig. 5 Change in LCC over time for different lighting systems

Table 6 Change in payback period and LCC for different lighting systems

Year	T8		T5		T8 LED	
	Payback Period (year)	LCC ($)	Payback Period (year)	LCC ($)	Payback Period (year)	LCC ($)
2017	0	0	0	0	0	0
2018	2.77	108,256	3.85	117,022	10.03	147,259
2019	2.57	214,336	3.56	194,898	9.29	256,470
2020	2.38	336,803	3.30	284,804	8.60	382,552
2021	2.20	477,601	3.05	388,168	7.96	527,506
2022	2.04	638,879	2.83	506,566	7.37	693,543
2023	1.89	823,012	2.62	641,743	6.83	883,111
2024	1.75	1,032,625	2.42	795,626	6.32	1,098,911
2025	1.62	1,270,616	2.24	970,342	5.85	1,343,926
2026	1.50	1,540,185	2.08	1,168,240	5.42	1,621,451
2027	1.39	1,844,860	1.92	1,391,911	5.02	1,935,119

In all the three systems, while payback periods decrease over time, LCCs increase. After all lamps are replaced, the payback periods are 1.39 years in the case of the T8 electronic system, 1.92 years in the case of the T5 system and 5.02 years in the case of the T8 LED system. The Life Cycle Cost (LCC) includes operating, equipment and maintenance costs. The present worth (present value) factor used in the calculations was 3.518. The highest LCC in the current system is in the amount of $ 2,260,809. With the use of the T8 electronic lighting system, the LCC drops to $1,844,860, which corresponds to an 18.4 % decrease. If the current system is completely replaced with the T5 system, which is the second option, the LCC drops to $ 1,391,911, which corresponds to a 38.4% decrease. The life cycle cost for the T8 LED system is $ 1,935,119, which is about 14.4% less than that of the current system. As is seen in the LCC analysis, the lowest cost is achieved with the T5 lighting system.

The changes in CO_2, NO_X, SO_2, CO emission values over the years for the current lighting system in the buildings of the Cumhuriyet University and for all the proposed lighting systems are shown in Figure 6. As is seen in Figure 6, with the installation of all new lighting systems, all emissions will be reduced, and the emission values in the T8 electronic and T8 LED lighting systems are close to each other. With the installation of the T5 system, CO_2, NO_X, SO_2, and CO emissions will decrease by 1,050 tons, 2.17 tons, 8.07 tons and 690 kg, respectively by the end of 2027.

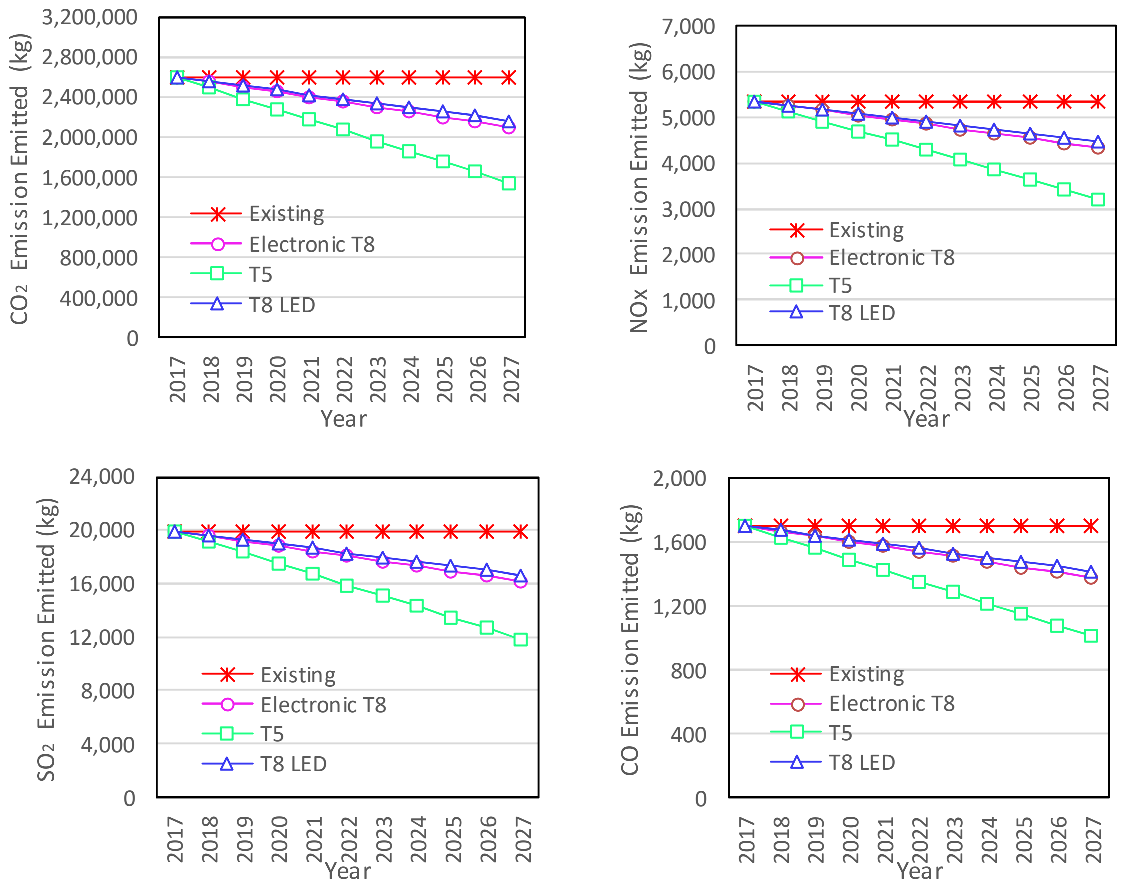

Fig. 6 Changes in CO_2, NO_X, SO_2, CO emission values over the years for different lighting systems

6. Conclusions

In the present study, the reduction in electricity consumption, the amount of savings, the payback period and the environmental impacts have been investigated in case the current lighting system at the Cumhuriyet University is replaced with different energy efficient lighting systems. T8 electronic, T5 and T8 LED lighting systems were considered as alternative efficient lighting systems. The result of the calculations revealed that the use of efficient lighting systems would reduce energy consumption by between 16.5% and 40.5%. The minimum energy consumption would be achieved with the installation of the T5 system. As seen in the LCC analysis, the lowest and maximum costs are achieved with the T5 and T8 LED lighting systems. The payback period of the T8 LED lighting system is four times the payback period of the T8 electronic and T5 systems. The comparison of the T8 electronic lighting system with the T5 lighting system showed that the LCC and the electricity consumption values were high and the payback period was low in the former system. The comparison of the T5 system with the T8 LED system indicated that in the T8 LED system, the initial investment costs would increase due to the use of additional lamps. Therefore, the T5 system is more advantageous due to its low electricity consumption resulting in the low LCC. The least amount of CO_2, NO_X, SO_2, CO emissions is achieved with the use of the T5 lighting system.

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