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DEVELOPMENT OF SCENARIOS FOR INCREASING THE EFFECT OF INTERIOR LIGHTING AUTOMATION TO ENERGY EFFICIENCY

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ABSTRACT

Today, global warming and the consequent decline of energy reserves, together with the increasing population of the world, have led to the necessity of taking energy saving measures by the European Union and various countries. As a result, the 'Energy Performance of Buildings Directive' (2002/91 / EC) was prepared by the European Union countries and the CEN (European Committee for Standardization) was tasked with the necessity of establishing a standard and formula for energy performance. The EN 15232 standard from these standards was prepared for a guide and resource on "Energy performance of Buildings, Impact of Building Automation, Controls and Building Management ". The other standard EN 15193 "Energy performance of buildings - Energy requirements for lighting" is a standard prepared for the realization of saving measures for lighting energy in buildings. In this study, it will be determined which automation system is more efficient and economical by calculating the annual energy amount consumed in an office building according to various scenarios based on these two standards and a proposal for the automation system will be determined and it will be found out which energy efficiency class these automation systems are in.

KEYWORDS: Energy Performance in Buildings, Impact of Building Automation Systems on Energy Efficiency, Lighting Energy Requirements, EN 15193 standard, EN 15232 standard

INTRODUCTION

Energy efficiency can be defined as the ratio of the amount of energy used to the amount of energy needed. With the developing technology, the energy consumption rates are also increasing. Following these increases, efficient use of energy along with developing technology has come to the agenda. As a result, the 'Energy Performance of Buildings Directive' (2002/91 / EC) was published in Europe[1]. This directive aims at establishing a common method for determining the energy performance of the buildings. Following this directive, various standards have been established by CEN (European Committee for Standardization) for effective use of energy performance in various systems such as heating, cooling, ventilation and air conditioning (HVAC), lighting[2]. One of these standards is EN 15193, "Energy performance of buildings - Energy requirements for lighting" standard, which is designed to analyze the energy efficiency impact of control systems used in lighting systems[3]. The other is EN 15232, "Energy performance of Buildings, Impact of Building Automation, Controls and Building Management" standard.

The buildings are at the beginning of structures where energy is consumed most with 40% energy consumption when a comparison is made according to the amount of energy consumed from the energy reserves[4]. It is also the leading cause of greenhouse gas emissions and global warming. For these reasons, ensuring energy efficiency in the buildings is a very important issue in terms of environmental cleanliness and energy saving.

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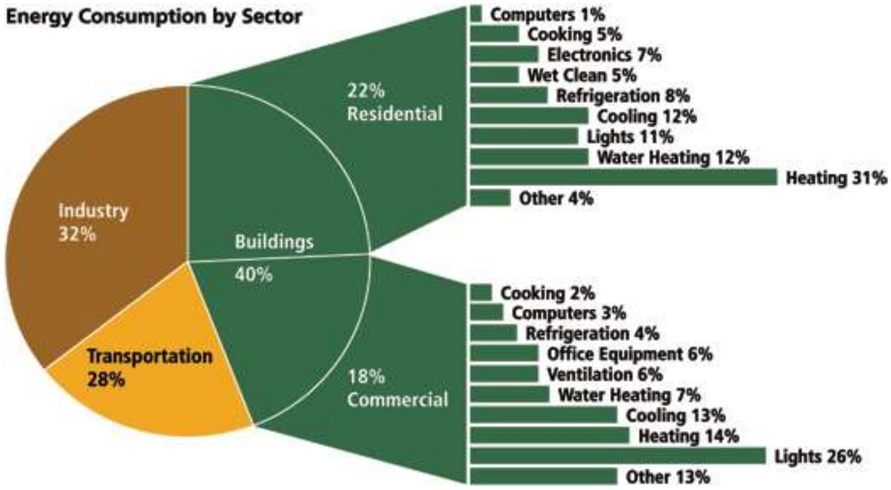

Figure 1. Energy Consumption Systems for Buildings and Residences[4]

As can be seen from Figure 1, heating, ventilation and air conditioning systems (HVAC) are the most energy consumed systems, followed by lighting systems[5]. Because of this, it is necessary to increase the energy efficiency class by improving the control systems. Because HVAC systems are mechanical systems, the effect of lighting control systems on energy efficiency will be analyzed in this study and it will be found which control system is more efficient.

According to EN 15232 standard, the savings obtained for thermal energy when the energy efficiency class is increased in various building constructions are as follows.

Table 1. Thermal Energy for Non-residential Buildings Energy Efficiency Factor[6]

Non-residential building types	**BAC efficiency factor (for thermal energy)**			
	D	**C**	**B**	**A**
	Non energy efficient	Standard (Reference)	Advanced	High energy performance
Offices	1.51	1	0.80	0.70
Lecture hall	1.24	1	0.75	0.5
Education Buildings (Schools)	1.20	1	0.88	0.80
Hospitals	1.31	1	0.91	0.86
Hotels	1.31	1	0.85	0.68
Restaurants	1.23	1	0.77	0.68
Wholesale and retail trade service buildings	1.56	1	0.73	0.6

As can be seen from the above, when an automation system is upgraded from energy efficiency class C to class A, the most energy saving is achieved in Lecture hall and wholesale and retail trade service buildings. The least savings are realized in hospitals. This is due to the fact that the number of people in hospitals and the working hours are higher.

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Table 2. Thermal Energy for Residential Buildings Energy Efficiency Factor[6]

Residential building types	**BAC efficiency factor (for thermal energy)**			
	D	**C**	**B**	**A**
	Non-energy efficient	Standard (Reference)	Advanced	High energy performance
Single family houses Apartment block Other residential buildings or similar residential buildings	1.10	1	0.88	0.81

As seen in Table 2, when we look at the heat energy saving rate for residential buildings, when the system is upgraded from Class C to Class A, an energy saving of 19% is achieved. When we look at it there is more energy savings compared to hospitals, but compared to the efficiency factors in other buildings, there is not a high energy saving in the house in the heat energy. The reason for this is the fact that the number of users in the day does not change much in the day.

Another energy efficiency factor comparison is made for electricity. This comparison is as follows.

Table 3. Electric Energy for Non-residential Buildings Energy Efficiency Factor[6]

Non-residential building types	**BAC efficiency factor (for electric energy)**			
	D	**C**	**B**	**A**
	Non-energy efficient	Standard (Reference)	Advanced	High energy performance
Offices	1.10	1	0.93	0.87
Lecture hall	1.06	1	0.94	0.89
Education Buildings (Schools)	1.07	1	0.93	0.86
Hospitals	1.05	1	0.98	0.96
Hotels	1.07	1	0.95	0.90
Restaurants	1.04	1	0.96	0.92
Wholesale and retail trade service	1.08	1	0.95	0.91

Looking at the efficiency factors in Table 3 and Table 4, the most savings for electricity is achieved in schools. The least saving is realized in hospitals as it is in the case of heat energy saving. This is due to the fact that the number of users is not changed much daily, and in some cases the electricity energy is necessary for comfort and safety. There is an energy saving potential of 8% in residential buildings. Furthermore, when we look at saving rates from heat and electrical energy, we save a lot more in heat energy. The reason is that it is more difficult protect the heat energy compared to the electric energy and the electric energy is more important than the heat energy in terms of comfort and safety.

Table 4. Electric Energy for Residential Buildings Energy Efficiency Factor[6]

Residential building types	**BAC efficiency factor (for electric energy)**			
	D	**C**	**B**	**A**
	Non-energy efficient	Standard (Reference)	Advanced	High energy performance
Single family houses Apartment block Other residential buildings or similar residential buildings	1.08	1	0.93	0.92

When we examine this data, we save energy by 30% in offices, 20% in schools, 14% in hospitals, 32% in hotels and restaurants and 19% in residential areas for thermal energy. For electric energy, there is an energy saving potential of 13% in offices, 14% in schools, 4% in hospitals, 10% in hotels, 8% in restaurants and 8% in residential buildings. In this study, the annual energy consumption of an office building is calculated on the basis of EN 15193 standard. It will be decided which automation system is more efficient, and the amount of savings provided when the system is developed will be evaluated and a proposal will be made.

MATERIALS AND METHODS

Data and Formula in EN 15193 Standard

The following formulas are used according to EN 15193 standard to calculate the total amount of lighting energy consumed annually.

$$W_t = W_{L,t} + W_{P,t}\ (kWh) \qquad (1)$$

W_t : Total energy used for lighting
$W_{L,t}$: Energy consumption used for illumination
$W_{P,t}$: Luminaire parasitic energy consumption

$$W_{L,t} = \{(P_n\, x\, F_c)\, x\, [(t_D\, x\, F_o\, x\, F_D) + (t_N\, x\, F_o)]\} / 1000\ (kWh) \qquad (2)$$

P_n: Total installed lighting power in the room or zone (W)

The total installed lighting must be determined together with all the lamps, numbers and forces used to calculate the power.

F_c: Constant illuminance factor
t_D: Daylight time usage (h)
F_o: Occupancy dependency factor
F_D: Daylight dependency factor
t_N: Usage outside of day hours (h)[7]

According to this standard, the total luminaire parasitic energy consumption $W_{P,t}$ is taken as a constant of 5 kWh/m^2. In the case of control systems, the value is added to the total energy consumption used for illumination[8].

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Impact Factor: 4.116
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Daylight dependency factor (F_D)

The daylight supply factor ($F_{D,S}$) is calculated by the following equation depending on the latitude:

$$F_{D,S} = a_{fds} + b_{fds}\gamma_{latitude} \quad (3)$$

a_{fds} , b_{fds} : Coefficients for determining the daylight supply factor $F_{D,S}$

$\gamma_{latitude}$: The latitude of the place where the zone is located

Table 5. $F_{D,S}$ values calculated according to maintained illuminance and daylight penetration[9]

Maintained illuminance (lx)	Daylight penetration	a_{fds}	b_{fds}	$F_{D,S}$ values based on latitude					
				36	37	38	39	40	41
300	Weak	1,2425	-0,0117	0,8213	0,8096	0,7979	0,7862	0,7745	0,7628
	Medium	1,3097	-0,0106	0,9281	0,9175	0,9069	0,8963	0,8857	0,8751
	Strong	1,2904	-0,0088	0,9736	0,9648	0,956	0,9472	0,9384	0,9296
500	Weak	0,9432	-0,0094	0,6048	0,5954	0,586	0,5766	0,5672	0,5578
	Medium	1,2425	-0,0117	0,8213	0,8096	0,7979	0,7862	0,7745	0,7628
	Strong	1,322	-0,011	0,926	0,915	0,904	0,893	0,882	0,871
750	Weak	0,6692	-0,0067	0,428	0,4213	0,4146	0,4079	0,4012	0,3945
	Medium	1,0054	-0,0098	0,6526	0,6428	0,633	0,6232	0,6134	0,6036
	Strong	1,2812	-0,0121	0,8456	0,8335	0,8214	0,8093	0,7972	0,7851

These latitude values are the latitude values within the boundaries of Turkey. According to this figure, as the latitude value increases, the value of daylight dependency factor decreases. In order to calculate the value of the daylight dependency factor, it is necessary to know the daylight supply factor as well as daylight dependent artificial lighting control. The daylight effect of this factor and the values of the control system used are shown in Table 6 [10].

Table 6. Values for the Artificial Lighting System[8]

Control of Artificial Lighting System	$F_{D,C}$ as function of daylight pentration		
	Weak	Middle	Strong
Manual	0.2	0.3	0.4
Automatic, daylight dependent	0.75	0.77	0.85

The daylight factor (F_D) value can be calculated according to the values in Table 5 and Table 6. $F_D = 1 - (F_{D,S}\ x\ F_{D,C})$ Daylight factor values are given in the table below using the formula .

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

Table 7. Variable F_D values according to maintained illuminance, daylight penetration, latitude and artificial lighting control

Maintained illuminance (lx)	Daylight penetration	$F_D = 1 - (F_{D,S} * F_{D,C})$											
		Manual						**Automatic**					
		36	**37**	**38**	**39**	**40**	**41**	**36**	**37**	**38**	**39**	**40**	**41**
300	Weak	0,83574	0,83808	0,84042	0,84276	0,8451	0,84744	0,384025	0,3928	0,401575	0,41035	0,419125	0,4279
	Medium	0,72157	0,72475	0,72793	0,73111	0,73429	0,73747	0,285363	0,293525	0,301687	0,309849	0,318011	0,326173
	Strong	0,61056	0,61408	0,6176	0,62112	0,62464	0,62816	0,17244	0,17992	0,1874	0,19488	0,20236	0,20984
500	Weak	0,87904	0,88092	0,8828	0,88468	0,88656	0,88844	0,5464	0,55345	0,5605	0,56755	0,5746	0,58165
	Medium	0,75361	0,75712	0,76063	0,76414	0,76765	0,77116	0,367599	0,376608	0,385617	0,394626	0,403635	0,412644
	Strong	0,6296	0,634	0,6384	0,6428	0,6472	0,6516	0,2129	0,22225	0,2316	0,24095	0,2503	0,25965
750	Weak	0,9144	0,91574	0,91708	0,91842	0,91976	0,9211	0,679	0,684025	0,68905	0,694075	0,6991	0,704125
	Medium	0,80422	0,80716	0,8101	0,81304	0,81598	0,81892	0,497498	0,505044	0,51259	0,520136	0,527682	0,535228
	Strong	0,66176	0,6666	0,67144	0,67628	0,68112	0,68596	0,28124	0,291525	0,30181	0,312095	0,32238	0,332665

According to the values given in Table 7, the daylight dependency factor (F_D) value increases when the brightness level increases, the F_D value decreases when the daylight effect increases, the F_D value increases when the latitude increases, and the F_D value increases when the lighting control is manual. That is, when this situation is evaluated, the value of the F_D and the total amount of energy consumed by the control systems are reduced. As a result, when the brightness level and the latitude grade increase, the F_D value and thus the total amount of energy consumed increases, whereas when the daylight effect increases, the F_D value decreases and accordingly the total energy consumed decreases. These assessments will be examined in detail in the following sections.

Occupancy Dependency Factor (F_o)
In the cases described below, $F_o = 1$ is taken:

- If the lighting is turned on and off as a center, In the case of a complete floor or a plurality of volumes connected to a single key,

- If an area larger than 30 m^2 is connected to a single key, or if there is a central opening and closing system,

In the cases described below, $F_o < 1$ and F_o value is calculated:

- If the lighting is not centrally controlled in the volumes,

- If the lighting elements used in a volume smaller than 30 m^2 are switched together or if the area generated by the automatic movement sensor is equal or close to the illuminated area[9].

The F_o value is calculated by the following relation.

$$F_O = [7 - (10\, x\, F_{OC})]\, x\, (F_A - 1)\ (if\ 0.9 \leq F_A \leq 1) \quad (4)$$
$$F_O = 1 - [\,(1 - F_{OC})\, x\, F_A \,/\, 0.2\,]\ (if\ 0 \leq F_A < 0.2) \quad (5)$$
$$F_O = F_{OC} + 0.2 - F_A\ (if\ 0.2 \leq F_A < 0.9) \quad (6)$$

F_o values according to the lighting control dependent factor (F_{OC}) and F_A value are given in Table 8. The F_A value is defined as the absence factor and varies according to various building and space properties. As the volume of the space and the number of the personnel in it increases, the F_A value decreases. As the volume becomes smaller and the number of personnel decreases, F_A value also increases accordingly.

Table 8. Occupancy Dependency Factor (F_O) values varying according to F_A and F_{OC} values

Areas without automatic motion sensor	**F_{OC}**	F_O			
		$0{,}9 \leq F_A \leq 1$ (F_A=0,9)	$0 \leq F_A < 0{,}2$ (F_A=0,1)	$0{,}2 \leq F_A \leq 0{,}9$ (F_A=0.5)	F_A=0.2
Manual on / off switch	1	0,3	1	0,7	1
Manual on / off switch - additional automatic sweeping extinction signal	0,95	0,25	0,975	0,65	0,95
Locations with automatic motion sensor	**F_{OC}**				
Auto On / Dimmed	0,95	0,25	0,975	0,65	0,95
Auto On / Auto Off	0,9	0,2	0,95	0,6	0,9
Manual On / Dimmed	0,9	0,2	0,95	0,6	0,9
Manual On / Auto Off	0,8	0,1	0,9	0,5	0,8

Auto On / Dimmed:
When a motion is detected in the volume, the lamps are automatically activated by the lighting control system and are set to a lower light output automatically adjusted within 5 minutes at no more than 20% of normal operating conditions. In addition, if no movement is detected within 15 minutes of detection of the last movement in the volume, the lamps are completely switched off by the lighting control system.

Auto On / Auto Off:
When a motion is detected in the volume, the lamps are automatically switched on by the lighting control system and are automatically switched off after 15 minutes of detection of the last movement.

Manual On / Dimmed:
The lamps are manually opened by a switch located close to the area to be illuminated. If they are not turned off by hand, they are automatically set to a lower light output that is set to no less than 20% of normal operating conditions within 15 minutes at the latest. In addition, if no movement is detected within 15 minutes of detection of the last presence in the room, the lamps are completely switched off by the lighting control system.

Manual On / Auto Off:
The lamps are manually opened by a switch located close to the area to be illuminated. If they are not turned off by hand, they are turned off by the lighting control system no later than 15 minutes after the last movement is detected in the room.

Calculation of t_D and t_N Values
In order to calculate the t_D and t_N values depending on the building usage hours, it is necessary to calculate the day time separately for the cities in Turkey. The day lengths are calculated as average values using the value of day 15 of each month. At the calculations need to take into account the conversion of the country clock and summer time applications[9].

07:05 - 17:07 (January day times for Antalya)
09:00-18:00 (Working hours for all months)

$DC1 = 08{:}00$
$DC2 = 17{:}00$
$WH1 = 09{:}00$
$WH2 = 18{:}00$

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

$WH1 \geq DC1 \rightarrow WH1\,(for\ the\ beginning) = t_{D1}\ is\ to\ be\ taken$
$WH2 \leq DC2 \rightarrow WH2\,(for\ the\ end) = t_{D2}\ is\ to\ be\ taken$
$WH1 < DC1 \rightarrow DC1\,(for\ the\ beginning) = t_{D1}\ is\ to\ be\ taken$
$WH2 > DC2 \rightarrow DC2\,(for\ the\ end) = t_{D2}\ is\ to\ be\ taken$

Calculation of t_D:
$t_D = t_{D2} - t_{D1}$ (7)

Calculation of t_N:
$t_N = WH - t_D$ (8)

t_D and t_N are calculated and accumulated for each month according to their working days. For the monthly value, t_D and t_N are multiplied by the number of working days. The yearly value is obtained as the sum of monthly values.

Table 9. Periods of utilization and non-availability of annual daylight for Antalya

Antalya		Day clocks		Working hours						Number of working days	Monthly (hour)	
		DC1	DC2	WH1	WH2	t_{D1}	t_{D2}	t_D	t_N		t_D	t_N
MONTHS	1	07:05	17:07	09:00	18:00	09:00	17:07	08:07	00:53	22	177,54	11,66
	2	06:43	17:41			09:00	17:41	08:41	00:19	20	168,20	3,8
	3	06:04	18:09			09:00	18:00	09:00	00:00	22	198,00	0
	4	06:19	19:36			09:00	18:00	09:00	00:00	22	198,00	0
	5	05:45	20:02			09:00	18:00	09:00	00:00	22	198,00	0
	6	05:33	20:22			09:00	18:00	09:00	00:00	22	198,00	0
	7	05:46	20:20			09:00	18:00	09:00	00:00	22	198,00	0
	8	06:10	19:52			09:00	18:00	09:00	00:00	22	198,00	0
	9	06:35	19:08			09:00	18:00	09:00	00:00	22	198,00	0
	10	07:01	18:24			09:00	18:00	09:00	00:00	22	198,00	0
	11	06:32	16:52			09:00	16:52	07:52	01:08	22	165,44	23,76
	12	06:39	16:46			09:00	16:46	07:46	01:14	22	164,12	25,08
ANNUAL TOTAL											2259,30	64,3

Based on the values calculated and introduced in this section, the total amount of illumination energy consumed in the next section will be calculated. The daylight factor, utilization factor and daylight utilization times are calculated for this. Total lighting energy consumption value will be calculated for Antalya city located at 36º latitude. For this, the values related to Antalya should be added to the account and the total value of the interference power should be added in addition to this calculated value. The calculation will be performed for an office building and the total installed lighting power value (P_n) for this office building must be calculated according to the number of luminaires used and for various lighting levels.

RESULTS AND DISCUSSION

Total Energy Used for Lighting

$W_t = W_{L,t} + W_{P,t}\,(kWh)$ (9)
$W_{L,t} = \{(P_n\, x\, F_c)\, x\, [(t_D\, x\, F_o\, x\, F_D) + (t_N\, x\, F_o)]\} / 1000\,(kWh)$ (10)
$W_{P,t} = 5\, kWh/m^2$ (11)

The above formulas are used to find the total amount of lighting energy consumed annually. According to these formulas, P_n and F_c values are not calculated in the previous section. When calculating the P_n value, the total installed lighting power is reached by determining armature of the numbers and type of luminaires used according to the luminous level and the volume surface area used. Since the F_C value is only used for systems with dimming, will not participate in this calculation in order to make a correct comparison.

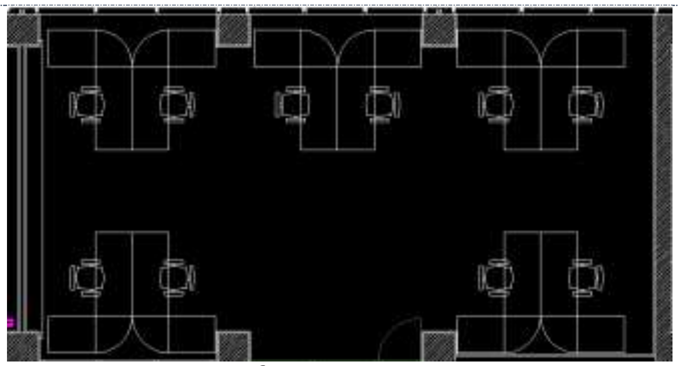

Figure 2. 80 m^2 open plan office for 10 people

The number of luminaires to be used according to the various lighting levels of 80 m^2 office building for 10 persons and the total installed lighting power should be calculated as shown in Fig 2. This calculation was carried out according to the formulas in the illumination calculation as in Table 10.

Table 10. Number of luminaires to be used according to their brightness levels

TYPE OF SPACE	**OFFICE**		
Brightness Level (lx)	300	500	750
Span of Space	6,6	6,6	6,6
Length of the space	12	12	12
Venue Area	79,2	79,2	79,2
Armature Height	2,9	2,9	2,9
Location Index (k)	1,47	1,47	1,47
Location Lighting Efficiency (n)	0,46	0,46	0,46
Selected Armature Type	LED	LED	LED
Selected Armature Power	40	40	40
Selected Armature Light Flow	4200	4200	4200
Calculated Number of Armatures	15,37	25,62	38,43
Number of Fixtures to be used	20	30	40
Total Installed Power (W)	800	1200	1600

The total amount of energy consumed for office lighting in Antalya, located at 36°, depending on the total installed lighting power, usage factor, daylight factor, daylight effect and total lighting level calculated above is calculated in Table 11. The F_A value should normally be taken as '0' for an office that is larger than 10 m^2 and 30 m^2. However, in this case, since the effect of the control systems can not be analyzed, the annual energy consumption is calculated while the absence factor is taken as F_A 0,2.

ISSN: 2277-9655
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CODEN: IJESS7

Table 11. Annual lighting energy for an office building in Antalya

Brightness Level (lx)	Daylight Effect	P_n	$W_{L,t}$ values for Antalya (kWh)											
			According to Manual and F_O values						According to Auto and F_O values					
			1	0,95	0,95	0,9	0,9	0,8	1	0,95	0,95	0,9	0,9	0,8
300	Weak	800	1561,99	1483,89	1483,89	1405,791	1405,791	1249,592	745,5421	708,265	708,265	670,9879	670,9879	596,4337
	Middle		1355,634	1287,853	1287,853	1220,071	1220,071	1084,508	567,2165	538,8557	538,8557	510,4949	510,4949	453,7732
	Strong		1154,991	1097,241	1097,241	1039,492	1039,492	923,9925	363,115	344,9592	344,9592	326,8035	326,8035	290,492
500	Weak	1200	2460,378	2337,359	2337,359	2214,34	2214,34	1968,302	1558,538	1480,611	1480,611	1402,684	1402,684	1246,83
	Middle		2120,317	2014,301	2014,301	1908,286	1908,286	1696,254	1073,78	1020,091	1020,091	966,4017	966,4017	859,0238
	Strong		1784,106	1694,901	1694,901	1605,696	1605,696	1427,285	654,366	621,6477	621,6477	588,9294	588,9294	523,4928
750	Weak	1600	3408,326	3237,91	3237,91	3067,494	3067,494	2726,661	2557,384	2429,514	2429,514	2301,645	2301,645	2045,907
	Middle		3010,039	2859,537	2859,537	2709,035	2709,035	2408,031	1798,396	1806,212	1806,212	1711,148	1711,148	1521,02
	Strong		2495,063	2370,31	2370,31	2245,557	2245,557	1996,05	1119,529	1063,552	1063,552	1007,576	1007,576	895,6231

The values calculated in Table 11 are values that are not noise power. If automation systems are used, annual consumption of parasitic power is also required. Annual power consumption is assumed to be 5 kWh / m^2. For an 80 m^2 office the total noise energy is 400 kWh. If this value is added to the account, the total lighting energy consumed per year is found.

Table 12. Total lighting energy consumed per year for an office building in Antalya

Brightness Level (lx)	Daylight Effect	P_n	$W_{p,t}$(kWh)	W_t values for Antalya (kWh)									
				According to Manual and F_O values					According to Auto and F_O values				
				1	0,95	0,9	0,9	0,8	1	0,95	0,9	0,9	0,8
300	Weak	800	400	1961,99	1883,89	1805,791	1805,791	1649,592	1145,542	1108,265	1070,988	1070,988	996,4337
	Middle			1755,634	1687,853	1620,071	1620,071	1484,508	967,2165	938,8557	910,4949	910,4949	853,7732
	Strong			1554,991	1497,241	1439,492	1439,492	1323,992	763,115	744,9592	726,8035	726,8035	690,492
500	Weak	1200		2860,378	2737,359	2614,34	2614,34	2368,302	1958,538	1880,611	1802,684	1802,684	1646,83
	Middle			2520,317	2414,301	2308,286	2308,286	2096,254	1473,78	1420,091	1366,402	1366,402	1259,024
	Strong			2184,106	2094,901	2005,696	2005,696	1827,285	1054,366	1021,648	988,9294	988,9294	923,4928
750	Weak	1600		3808,326	3637,91	3467,494	3467,494	3126,661	2957,384	2829,514	2701,645	2701,645	2445,907
	Middle			3410,039	3259,537	3109,035	3109,035	2808,031	2198,396	2206,212	2111,148	2111,148	1921,02
	Strong			2895,063	2770,31	2645,557	2645,557	2396,05	1519,529	1463,552	1407,576	1407,576	1295,623

In the case of manual control of artificial lighting according to the values in Table 12, energy is consumed in the amount of 1961 kWh per year in the office compared with 300 lx illumination level and weak daylight effect, if the control system is in the manual on / off scenario. According to the same situation, the energy consumption is 1883 kWh per year in the control system auto on /dimmed scenario. In the same way, in the case of the control system in the auto on/auto off scenario, the annual amount of energy consumed is 1805 kWh, in the manual on/dimmed scenario, 1805 kWh, in the manual on /auto off scenario, 1649 kWh energy consumption is taking place. This can be seen in Table 13.

When the daylight-dependent artificial lighting control is automatic, a considerably higher energy efficiency than the manual control is achieved. However, when daylight effect increases, there is a large decrease in annual energy consumption. On the contrary, when the brightness level increases, the annual energy consumption increases. In addition, when the latitude increases, there is a large increase in annual energy consumption.

Table 13. Amount of energy consumed by scenario

Scenario of control system	Annual amounts of energy consumed Daylight effect is weak and Illumination level is 300 lx
Manual on/off	1961,99 kWh/year
Auto on/dimmed	1883,89 kWh/year
Auto on/off	1805,791 kWh/year
Manual on/dimmed	1805,791 kWh/year
Manuel on/Auto off	1649,592 kWh/year

When comparison of control systems is made, the manual on / auto off control system is seen as the most energy-saving control system. The most inefficient system among the systems that have automatic control is the system with auto on / dimmed scenario. When this situation is interpreted, the system consumes more energy if there is a dimming condition in the system, and more energy is saved if the first switching of the system is done manually instead of automatic control. As shown in Figure 3, the control system's manual on / off status (F_O = 0.8) is the control scenario where the most energy is saved.

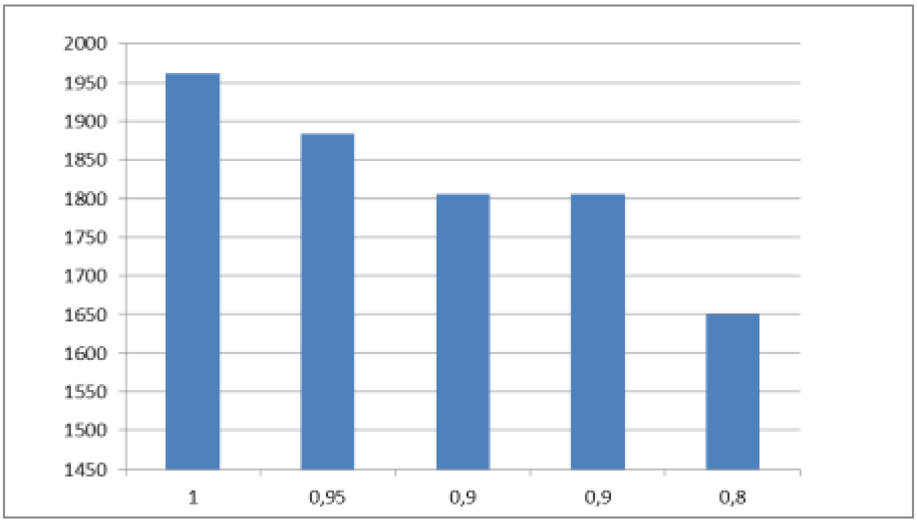

Figure 3. Amount of energy consumed annually according to automation scenarios

The analysis of the effect of daylight on energy consumption in the case of manual on / off scenario and automatic control of daylight-dependent artificial lighting is as shown in Fig 4.

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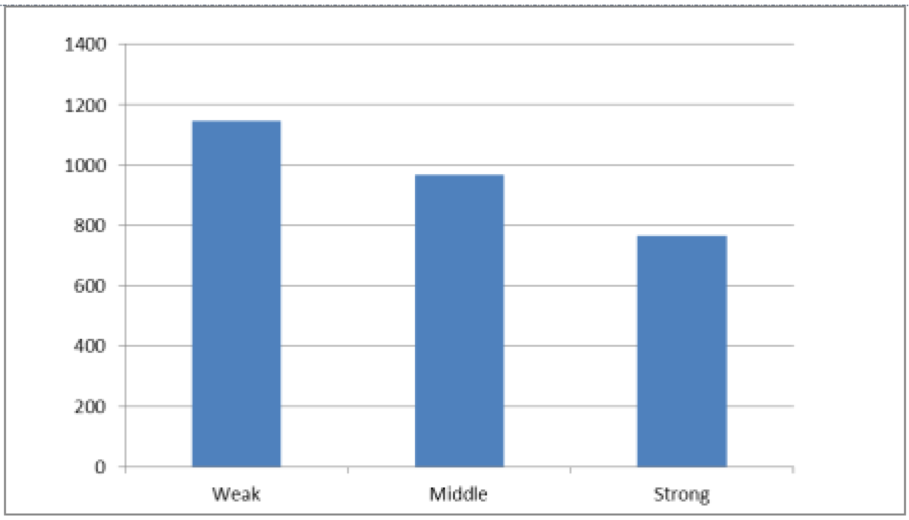

Figure 4. Effect of sunlight

As seen in Figure 4, the amount of energy consumed per year decreases as the daylight effect increases.

Figure 5 shows the effect of light intensity required per year on the amount of energy consumed per year in the case of manual on / off scenario and daylight dependent artificial lighting control being automatic and daylight effect being weak.

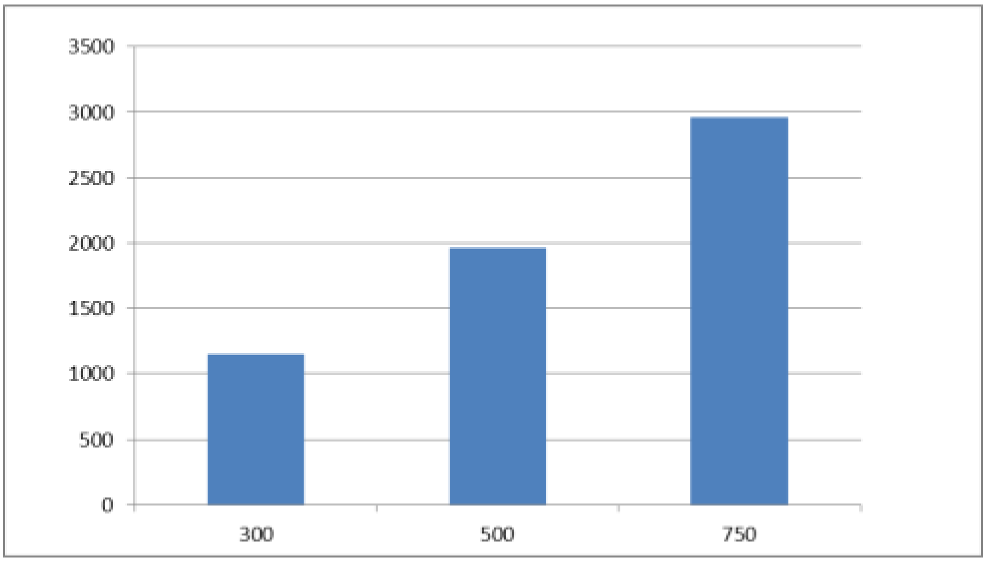

Figure 5. Amount of energy consumed annually by the level of brightness

As can be seen from Figure 5, the amount of energy consumed per year increases considerably when the amount of light level increases.

After calculating the amount of energy consumed annually, the value of LENI (Lighting Energy Numeric Indicator) must be calculated. This value is calculated by dividing the amount of energy consumed per year by the total volume surface area.

The energy efficiency class is considered to be class B if the daylight control system is manually controlled if the light level is 750 lx and the daylight effect is weak and if the control system scenario is manual on/off. Because in this case the LENI value is 47,6 kWh / m^2 from 3808 kWh / 80 m^2. If the daylight-dependent artificial lighting control is automatic and the usage-based control system scenario is manual on / auto off, then the LENI value is 30.56 kWh / m^2. In this case the control system increases from energy class B to class A energy [10].

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Table 14. LENI values by energy classes

Energy Classes	**LENI values**
A	0-39
B	40-79
C	80-99
D	100-119
E	120-139
F	140-174
G	175-…

CONCLUSION

In the previous section, the automatic control system which provides the most savings according to the calculated value is the control system with manual on / auto off scenario. According to this scenario, the system works as follows: The lamps are manually opened by a switch located close to the illuminating zone. If they are not turned off by hand, they are turned off by the lighting control system no later than 15 minutes after the last movement is detected in the room. According to this scenario, if the lighting system is manually controlled instead of the automatic control when it is first switched on, more savings are achieved. In addition, if the lamps are turned off automatically after 15 minutes, without dimming after detection of the last movement, more savings are achieved compared to the dimming and manual closing automatic control system. In other words, the manual on / auto off scenario for the office building is more efficient than the other control systems, and this control system should be used in office buildings as a priority over other systems.

In addition, as a result of the increase in daylight effect, a large amount of energy is saved in the annual amount of energy consumed. This means that when the building is being designed, attention must be paid to the position of the building.

If the brightness level needs to increase and if the latitude is in the up position, the total amount of energy consumed per year is increasing accordingly.

In summary, the most efficient in terms of the amount of energy consumed per year for an office building is the automatic operation of daylight-dependent artificial lighting control, the manual on / auto off of the control system, the daylight effect is strongest, the lightest level is lowest and the latitude is geographically lowest situation. As the most efficient control system to be used for an office building is analyzed, it is a system with a manual on / auto off scenario.

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