A Pilot Study for the Determination of the Energy Saving Potential in a Typical School Building by Utilization of Daylighting

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Abstract: - This paper investigates the potential of the direct energy saving in the utilization of daylight for interior lighting in the schools of Greece. For this purpose a pilot application on a typical school building was carried out. That type of school has been designed by the National School Building Organization of Greece. This means that several such buildings are built all over the country. Therefore, the results from this pilot study may apply in many cases. The daylight potential is calculated by means of Adeline software package. The energy savings are estimated taking into consideration the determined daylight potential as supplementary to the artificial lighting. The daylight calculations cover a ten-month period and all the possible orientations of the school building are considered. The results of the performed feasibility study show that utilizing daylight the direct energy saving potential reaches 70%, when the windows of the schoolrooms include single-pane glazings and there is not any obstruction to prevent sunlight. The same calculation methodology is followed considering windows glazed with sheer curtains or an outdoor sizeable obstruction. In those cases the saving potential reached 55% or 48% respectively. Finally, the total achieved energy saving potential in this building is calculated and the results show that the energy saving in lighting by utilization of daylight is more than 30%.

Key-Words: - Daylight, day lighting, energy saving, school buildings

1 Introduction

In countries with plenty of sunshine it is definitely useful to take advantage of daylight [1, 2]. The majority of schools in Greece use artificial lighting to illuminate classrooms throughout the day. This results in a vast waste of electrical energy with obviously negative consequences regarding mainly the school operational costs and –not to forget- the pollution of the environment since it is well known that the electrical energy consumption is combined with the increase of carbon dioxide in atmosphere and the increase of the greenhouse effect. The basic aim of our study is to determine the extent of the exploitation of daylight that can be achieved in a common type of Greek school buildings named "Andreas Kalvos II" with the use of the appropriate electrical lighting control system [3, 4].

Three cases were considered: a) without curtains on the windows or an external obstruction impeding the suffusion of daylight b) with an outdoor obstruction reducing the external lighting in classrooms in a great percent and c) with sheer curtains in both previous cases. The curtains were found to be necessary only when the illuminance in some parts of any classroom exceeded the requirements for visual comfort. Such parts, as it is obvious, were always next to windows. The use of curtains result in the reduction of the daylight illuminance particularly in distant from the windows parts, where there is the need for one more row of lights to be switched on. Therefore, for the calculation of energy saving three scenarios are considered: a) no use of curtains, no outdoor obstruction b) no use of curtains but an obstacle impedes the daylight and c) use of curtains in order to reduce glaze, particularly in the places next to windows.

The outdoor obstruction was considered 15 m from the windows and its height was around 12 m. The geographical characteristics of the school under consideration are the following: altitude 107 m, geographical latitude 37 58' north, longitude 23 43' eastern. These data refer to the city of Athens.

The classrooms were considered completely empty assuming there are no obstacles, projected columns, large furniture etc. However, it is realized that if calculations were made with slightly corrected reflection factors, the results do not change considerably. The working plane is considered horizontal, to a height of 80 cm.

The results show that artificial lighting is not necessary for a lot of days, whereas in many others only a few lighting fixtures are necessary to achieve the appropriate illuminance everywhere in the classroom. Obviously, the use of artificial lighting depends on the time of the day. This study included all teaching classrooms and the teachers' classroom. Since all teaching classrooms as well as the teachers' office are of the same dimension, the calculations were carried out only once.

Finally, the study attempts to find out whether we have a particularly great energy saving with a specific orientation of the building, in order to propose it wherever possible, and thus make a better utilization of daylight. For this reason, the energy saving calculations are performed taking into consideration four different orientations: northern, southern, eastern and western. Significant conclusions are derived from this study, which show that the exploitation of day lighting is not another meaningless step towards energy saving but a necessity.

2 Methodology

The daylight calculations were performed by means of the Adeline 2.0 NT software package [5]. Adeline-Superlite 1.0 calculates the daylight distribution in a building taking into account a plenty of factors (geographical position, day and time, type of sky, meteorological data, room orientation, room dimensions etc.) [6]. Four cases of sky illuminance are used for the purposes of this study: a) clear sky with sun, b) clear sky without sun, c) uniform and d) overcast. The applied atmospheric conditions for each month are shown in Table 1. The hours of operation of the school are estimated considering a ten month period i.e. from September to June, from 8:00 until 14:00 (seven hours, one-day-course duration). The daylight distribution of the 15^{th} day of each month is considered to be the typical one of the respective month. The influence of the building orientation (north, east, south and west) was also examined.

The walls' reflectance factor (RF) is considered 50%, the ceilings RF 70% and the floors RF 30%. The building includes three floors: the basement, the first and second floor. In the basement there is the teachers' office. The teaching classrooms are at the first and second floor. The dimensions of the teaching classrooms, counts up to 7.0X7.6m, with three windows on the side of 7m. The total area inserted for calculations is 744.8 m^2 whereas the total area of the building is $1478.6m^2$.

The program calculated the level of illuminance in klux in 49 (7x7) points on the reference surface. For the window panes the following data are used in the 'no curtains' scenario: transmittance 90%, reflectance 5%, maintenance 100%, curtain transparency 100%. For the 'sheer curtains' scenario the following considerations are taken into account: transmittance 50%, reflectance 5%, maintenance 100%, curtain transparency 60%.

The days of school operation of each month are summarized in Table 2.

Table 1 Sky data

Month	Type of sky
September	Clear sky with sun
October	Clear sky without sun
November	Uniform
December	Overcast
January	Overcast
February	Uniform
March	Uniform
April	Clear sky without sun
May	Clear sky without sun
June	Clear sky with sun

3 Calculations

The energy saving is calculated with reference to a class without any control of light level and, therefore, with the lights switched on, all the working hours irrespective of the daylight in any month. First, the required total luminous flux is calculated for the lighting of the classrooms without the utilization of daylight. The power consumption is also calculated. Thus, results 3 rows of 3 fluorescent luminaires (2X36 W) in each teaching classroom. The energy saving scenario considers 3 lighting zones, parallel to the windows that can operate separately by means of a photo sensor. When illuminance in every part of the reference surface is below 500 lux, all three zones are programmed to switch on. If daylight is sufficient in the area next to the windows, the two most distant rows of lights are switched on or even one, provided that lighting is not below a level of illuminance of 500 lux in every part of the class under examination [7]. All those calculations are performed comparing the results from Adeline and Calculux and considering that the number of switched on rows of luminaires are a) one, b) two or c) three (all). Thus, when the illuminance in some parts is less than 500 Lux using daylight only, it is checked how many and which rows of luminaires should be switched on, so as to achieve this illuminance level. Through this way, sufficient lighting is achieved, while on the other hand the calculation of the required electrical energy is easier.

Table 2 Days of school operation per month

Month	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Total
Classrooms	22	22	22	18	18	19	21	12	22	22	198

It is well known that the illuminance obtained in practice will never be completely uniform over the entire reference surface. In this study it was checked that the average illuminance on the working surfaces does not exceed the threefold of the illuminance on the general areas of a working interior in the class.

For the calculation of the energy saving in each classroom it is crucial to estimate how many hours throughout the year each row of luminaires is switched on. This gives the number of luminaire-hours i.e. the number of switched on luminaires multiplied by the time (hours) that they are switched on. Further, it is easy to determine the percentage of saving, for the specific classroom, throughout the year. The estimation of the required lighting is based on the following steps if daylight is not utilized: in the teaching classroom there are three rows of lights, each row includes three luminaires, each one has two fluorescent lamps of 36W (2 lamps and ballast, total 88W). Therefore, without the implementation of the energy saving program, the total power consumption throughout the year (198 days) in every classroom will reach 1098 kWh.

Implementing the energy saving program the consumption is reduced. In this case the orientation of the classroom affects slightly the needs for artificial light. However, the achieved energy saving is remarkable in any case. The respective results for the case of the obstruction existence are obtained following the same procedure. Table 3 presents the energy saving in both cases.

Summarizing the results from that table we take noticeable information about the energy saving when an external obstruction exists. We see that the saving drops about 20%.

The total annual electrical energy saving for all classrooms and for every orientation is presented in Table 4 taking into account that the power consumption without the utilization of daylight in the 14 classrooms of the school 15372 kWh. As mentioned earlier, this typical school building has a certain structure, which is always taken into account in every orientation, i.e. when the eight classrooms face south and six face north.

All these results concern the annual energy saving without the use of curtains. Curtains are used if the illuminance at one part of the classroom exceeds the upper allowed value for visual comfort. In that case, the results change somehow because in other parts of the classroom the illuminance is below 500 Lux. Obviously this will happen in those parts that are far from the windows, where lighting was already less intense. Thus, using curtains the annual energy saving for each orientation and for all classrooms is calculated and the results are presented in Table 5.

The Adeline calculations show that the energy saving in the specific school is reduced up to 15% and thus, about 2000 kWh/y when using curtains when the existence of an outdoor obstruction is not considered. In case that an obstruction is opposite the windows it is not necessary the most times to use the curtains, so there is not remarkable reduction of energy saving.

In some areas of the classrooms the daylight is not enough to maintain the required illuminance level of 500 lux. In these cases additional lighting is needed. The needs for artificial lighting are calculated, by means of Calculux. The Calculux results are combined with the respective Adeline results for the determination of the number of luminaires that are needed to switch on in order to maintain the required illuminance level. The energy saving was found to be negligible in areas with low daylight levels, such as corridors or rooms with few and small windows. This means that there is no need to include them in a daylight utilization policy. On the other hand, small rooms with low consumption such as the director's office, the computer room, toilettes etc. are not recommended for an energy saving investment since the benefits are limited compared to the initial cost of the investment. All these areas sum up to 733.8 m^2 and their estimated consumption comes up to 9000 kWh/y, so the total consumption for the interior lighting of the whole building reaches 24372 kWh/y, if added the consumption of the classrooms (15372 kWh). The annual total saving is approximately (without outdoor obstruction) 10700 kWh thus 44% of the total consumption. In case of the obstruction existence the annual energy saving is about 7400 kWh and the respective percentage saving is 30%. Table 6 presents these results for all the orientations.

Another interesting table (Table 7) shows the percentage energy saving for all the building per month per orientation.

Table 3 – Energy demand and saving without curtains

Month	Orientation	Demand without daylighting (kWh)	Demand with daylighting without obstruction (kWh)	Energy saving without obstruction (kWh)	Energy saving without obstruction (%)	Demand with daylighting with obstruction (kWh)	Energy saving with obstruction (kWh)	Energy saving with obstruction (%)
Sept	South	122	0	122	100	29	93	76
	East	122	0	122	100	29	93	76
	North	122	0	122	100	41	81	67
	West	122	0	122	100	46	76	62
Oct	South	122	0	116	95	46	76	62
	East	122	0	110	90	58	64	52
	North	122	0	82	67	81	41	33
	West	122	0	88	72	70	52	43
Nov	South	122	0	70	57	81	41	34
	East	122	0	70	57	81	41	34
	North	122	0	70	57	81	41	34
	West	122	0	70	57	81	41	34
Dec	South	100	71	29	29	71	29	29
	East	100	71	29	29	71	29	29
	North	100	71	29	29	71	29	29
	West	100	71	29	29	71	29	29
Jan	South	100	71	29	29	71	29	29
	East	100	71	29	29	71	29	29
	North	100	71	29	29	71	29	29
	West	100	71	29	29	71	29	29
Febr	South	105	45	60	57	70	35	33
	East	105	45	60	57	70	35	33
	North	105	45	60	57	70	35	33
	West	105	45	60	57	70	35	33
Mar	South	116	44	72	62	55	61	52
	East	116	44	72	62	55	61	52
	North	116	44	72	62	55	61	52
	West	116	44	72	62	55	61	52
Apr	South	67	6	61	91	25	42	62
	East	67	9	58	86	29	38	57
	North	67	22	45	67	44	23	34
	West	67	16	51	76	38	29	43
May	South	122	6	116	95	46	76	62
	East	122	6	116	95	46	76	62
	North	122	17	105	86	46	76	62
	West	122	17	105	86	58	64	52
June	South	122	0	122	100	46	76	62
	East	122	0	122	100	17	105	86
	North	122	0	122	100	41	81	67
	West	122	0	122	100	41	81	67
Total (10 months)	South	1098	301	797	72.6	540	558	50.8
	East	1098	310	788	71.8	527	571	52.0
	North	1098	362	736	67.0	601	497	45.3
	West	1098	350	748	68.0	601	497	45.3

Table 4 Total annual energy saving in all classrooms without curtains.

Energy saving	South		East		North		West	
	kWh	%	kWh	%	kWh	%	kWh	%
Without obstruction	10792	70.2	10792	70.2	10670	69.4	10712	69.7
With obstruction	7446	48.4	7550	49.1	7324	47.6	7402	48.2

Table 5 Total annual energy savings in all classrooms (with sheer curtains) (%).

Energy savings	South	East	North	West
Without obstruction	56.1	56.3	54.9	56.1
With obstruction	47.9	48.6	47.2	47.8

Table 6 Total annual energy savings in the building (%).

Energy savings	South	East	North	West
Without obstruction	44.3	44.3	43.8	44.0
With obstruction	30.6	31.0	30.0	30.4

Table 7 Total monthly energy savings in the building (%).

		Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Without obstruction	South	63.1	52.0	36.2	18.3	18.3	35.9	39.0	51.3	57.5	63.1
	East	63.1	52.0	36.2	18.3	18.3	35.9	39.0	52.1	57.5	63.1
	North	63.1	50.0	36.2	18.3	18.3	35.9	39.0	49.2	56.7	63.1
	West	63.1	50.0	36.2	18.3	18.3	35.9	39.0	51.2	56.7	63.1
With obstruction	South	48.1	34.0	21.2	18.3	18.3	21.0	33.0	32.1	39.3	40.4
	East	48.1	30.0	21.2	18.3	18.3	21.0	33.0	32.4	36.6	49.0
	North	41.9	25.0	21.2	18.3	18.3	21.0	33.0	29.5	39.3	40.8
	West	39.3	30.0	21.2	18.3	18.3	21.0	33.0	31.2	35.8	47.2

Table 8 Modified annual energy saving per classroom, without curtains

Energy savings	South	East	North	West
Without obstruction (kWh)	552	543	489	503
Without obstruction (%)	64.6	63.6	57.3	58.9
With obstruction (kWh)	389	373	335	340
With obstruction (%)	41.9	41.4	35.8	36.1

4 Estimation of the actual energy saving

The calculations presented in the following Tables show that there is no need for artificial lighting, or the needs are few, in the teaching classrooms during September and June. Assuming that there is a provision to keep the lights off during these months, the results will change. That means that the annual consumption of 1098 kWh per classroom without the utilization of daylight that was the base of the above calculations should be modified. Deducting the 44 days of the school operation in September and June, the annual consumption per classroom becomes 854 kWh. Taking all these into consideration the final results of Table 3 are modified as it is shown in Table 8 for one room.

Finally, the total energy saving, which has been presented in Table 4, is modified giving the results of Table 9. It should be noticed that these figures concern rooms without curtains.

It has been observed during the energy audits that classrooms with curtains need artificial light during September, October, April, May and June. Therefore, for the estimation of the current situation, without daylight utilization, the lights should be considered switched on regularly during that period. This means that the calculated energy savings of Table 6 are valid without any modification in case that curtains are used.

5 Conclusion

It is worth noticing the fact that the building's orientation is not of great importance. This can be explained considering that for every orientation, the classrooms are split: almost half of them on the one side and the rest on the opposite. Usually, if one orientation offers a considerable amount of saving, the opposite does not. Another important conclusion which is gathered from the Tables is that the percentage results are not influenced too much when the lightening administrator is a prudent and a thrifty one. In that case the energy saving from about 70% (without obstruction), falls to 60% (Tables 4 and 9 respectively), so the reduction of saving is 14%. On the other hand it is noticeable that the net annual energy saving falls from 10700 kWh to 7300 kWh (Tables 4 and 9 respectively), which shows a 32% reduction, more than double from the former case. How this difference will be appreciated depends on the head of the school building.

Table 9 Modified total annual energy saving, without curtains

Energy saving	South		East		North		West	
	kWh	%	kWh	%	kWh	%	kWh	%
Without Obstruction	7350	61.5	7362	61.6	7224	60.4	7282	60.9
With Obstruction	5122	39.3	5024	39.2	5014	38.4	4958	38.3

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