Energy Saving by Compensation of Daylight Deficiencies in Buildings

Maciej Piotrowicz, and Witold Marańda

***Abstract*—The exploitation of the daylight in the illumination of the offices is one of the possibilities of the electrical energy saving for lighting. The paper presents the calculations performed in order to estimate the possible savings in Polish climate. The amount of energy consumed by artificial light sources for an exemplary office is taken as a reference. Power demands together with energy consumption for the daylight deficiencies compensation are calculated using the solar radiation measurements from September 2011 in Łódź, Poland.**

***Index Terms*—energy saving, lighting techniques, solar radiation**

I. INTRODUCTION

LIGHTING of the rooms is a common and necessary element of everyday life. It is seen as one of the determinants of the civilization progress. The development of the lighting techniques caused that the rooms are often illuminated more than necessary. This phenomenon, among others, is called light pollution and can be observed especially at the offices, where the light is turned on regardless of the daylight illuminance. But the continuous growth of energy cost motivates the research for energy savings in this application too.

It is worth to notice, that there is no real alternative for the electrical lighting. Thus one of possible ways of energy saving is the usage of more efficient light sources. Fluorescent lamps and – in last years – light emitting diode (LED) technology become popular. The lightness of the latter can be easily controlled, thus giving the user the ability of artificial lighting intensity adjustment.

The exploitation of the natural lighting can be another source of energy savings. The rooms may be illuminated using as much daylight as possible, and any deficiency is compensated with artificial light. This idea is especially applicable to the offices and other workplaces, as the demand for the light meets the availability of the solar radiation.

The research performed by the authors gives the estimation of potential energy saving with the usage of the natural light for the illumination of the room.

II. ROOM MODEL

A. Model Configuration

The idea of saving energy in buildings is becoming very popular. The designers often take into account the minimization of energy waste. The amount of energy saved for lighting depends on many factors; location of the building, its orientation, size and location of the windows are the most important. Thus a large number of modern buildings with large windows either in the southern and western walls or in the roof can be seen.

The authors have studied the possibilities of energy saving for climate in Poland, with average insolation of 128 W/m^2 (day and night). For the purposes of calculation, a rectangular room with a single roof window has been chosen, as shown in Fig. 1. The similar room is located in the Department of Microelectronics and Computer Science building in Łódź, Poland (N: 51° 44' 46" E: 19° 27' 20").

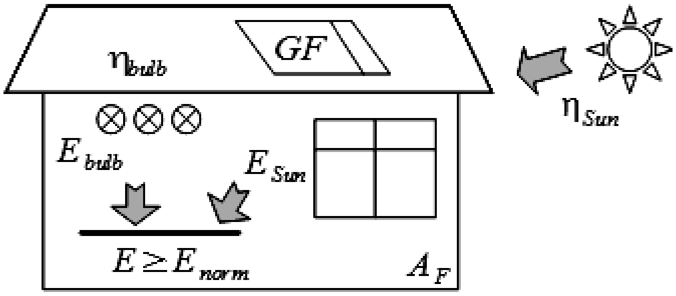

Fig. 1. The room model used for calculations; A_F – the area of the room floor.

B. Calculations

Energy savings are calculated as the difference between the maximum energy consumption (when the natural light is not taken into account) and the energy which is needed only for the compensation of daylight deficiencies. Thus the illuminance demands has to be known in order to provide the comfortable level of illumination. According to the Polish Norm [1], the illuminance should be in range of 200 to 500 lx.

Another important parameter is the luminous efficacy of the light sources used in the room. This factor gives the relation between the electric power used by lamp and the luminous flux produced. The more efficient lamp, the higher is the value of this factor. For typical incandescent bulb, the efficacy is in

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range of 10-20 lm/W; the fluorescent lamps are more effective (35-75 lm/W) [2,3]. It is worth to notice, that the natural sunlight gives 93 lumen from each Watt of radiation.

The luminous flux F, that is necessary to provide the requested illumination E, can be calculated as:

$$F = E \cdot A_F\,, \tag{1}$$

where A_F is the area of the room floor.

On the other hand, this flux is produced by the installed lamps, according to:

$$F = P \cdot \eta_b\,, \tag{2}$$

where P is the power consumed by the lamps and η_b – luminous efficacy of the lamps.

Power consumed by the bulbs can be derived from (1) and (2) as follows:

$$P = \frac{E \cdot A_F}{\eta_b}\,. \tag{3}$$

The illuminance E in (3) is the requested illuminance for the room (without taking the natural light into account) and the power calculated is the maximum power needed. In the case of daylight deficiencies compensation, the value of illuminance produced by bulbs can be lowered because of the light provided by the Sun. To calculate the illuminance provided by the natural light E_{sun}, the insolation values ought to be known. As the level of radiation varies in time, it is necessary to calculate the values for each radiation sample separately as follows:

$$E_{sun} = \eta_{sun} \cdot R \cdot GF\,, \tag{4}$$

where R is the solar radiation power, η_{sun} is the luminous efficacy of sunlight and GF is glazing factor, which represents glazed-to-floor area proportion and configuration [4].

Introducing the E_{sun} into (3), the formula for calculating the power consumption changes to:

$$P = \frac{\left(E - E_{sun}\right) \cdot A_F}{\eta_b}\,,$$

and finally

$$P = \frac{\left(E - \eta_{sun} \cdot R \cdot GF\right) \cdot A_F}{\eta_b}\,. \tag{5}$$

All the necessary calculations were performed with the usage of GNU Octave software. All the graphs presented in the paper, were made with the Gnuplot tool.

III. CASE STUDY

As it was stated in the previous section, the rectangular room was chosen as the exemplary room for calculations. Its dimensions are: $L_1 = 20$ m, $L_2 = 10$ m; thus the area of the floor A_F=200m^2. There is a roof window with the surface of 2 m^2 (approximated by the rectangular 1x2 m), made of clear glass. Assuming that the room is located in the middle of building, there are no wall windows. For such case, glazing factor value GF is equal 0,875%.

The room is illuminated by means of the set of fluorescent lamps with the luminous efficacy η_b of 60 lm/W. Assuming, that the required illuminance should be at least 400 lx, the maximum power needed can be calculated from (3) as:

$$P = \frac{400lx \cdot 200m^2}{60lm/W} = 1333W\,.$$

The energy consumption is the product of the power and the operation time of the lights. The authors assumed, that the room is the typical office, exploited from 8:00 to 16:00, therefore, during one day, the illumination consumes up to:

$$E = 8h \cdot 1333W = 10664Wh\,.$$

Also solar radiation data are necessary for the calculations of energy saving. The photovoltaic installation used at the Department of Microelectronics and Computer Science is now connected to the electronic monitoring system, that performs the measurement and analysis of the work parameters. Apart from the electrical parameters of the installation, the data from two weather stations are collected (i.e. atmospheric pressure, humidity, air temperature, strength and direction of wind and solar radiation) for the purpose of linking electrical data with the weather conditions [5]. This system has been chosen as a source of the radiation intensity data for the calculations described in the paper.

The measurements have been read every 5 seconds from the radiation sensor and organized in one day radiation patterns. Three different patterns were used in the calculations, representing the data collected on September the 9th (Fig. 2), September the 19th (Fig. 3) and September the 21st (Fig. 4) of 2011.

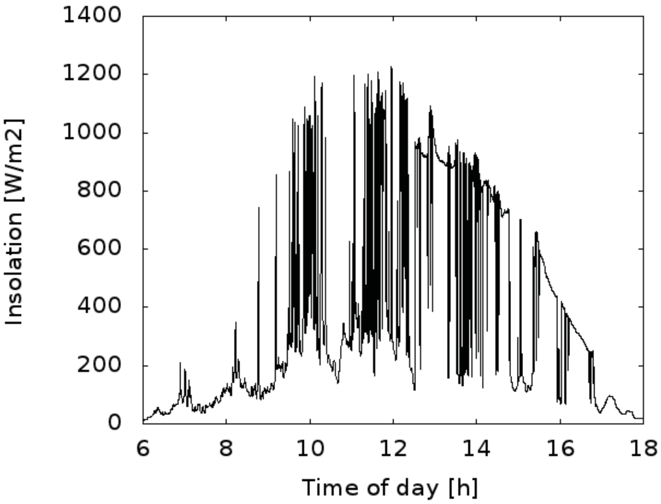

Fig. 2. Radiation pattern on September the 9th.

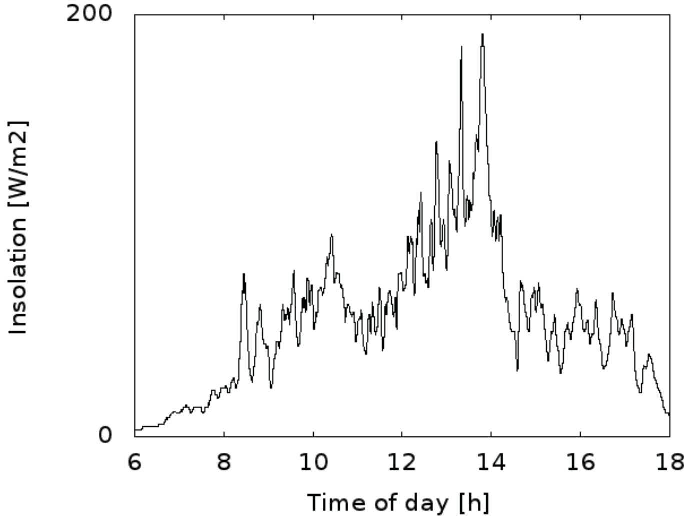

Fig. 3. Radiation pattern on September the 19th.

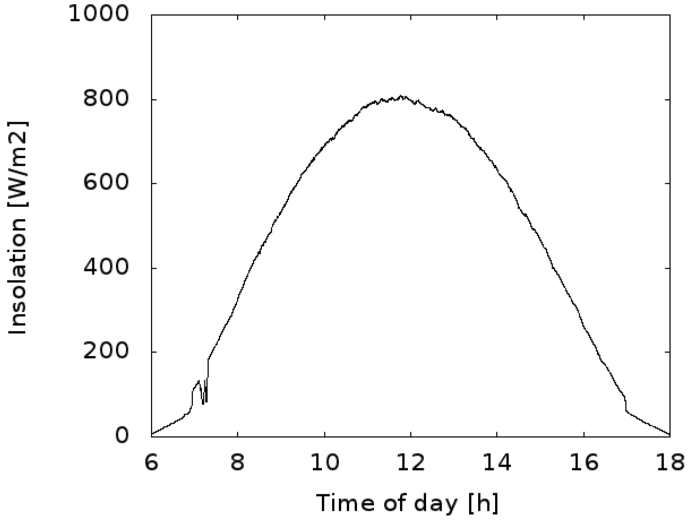

Fig. 4. Radiation pattern on September the 21st.

IV. RESULTS

The power consumed by the lamps used for the compensation of energy deficiencies has been calculated from (5), using the solar radiation data described in the previous section. The results are presented in Fig. 5 (the power pattern for September the 9th), Fig. 6 (September the 19th) and Fig. 7 (September the 21st).

It is worth to notice, that for any of the presented graph, the maximum value of the power never reaches the power required in case of illuminating the room with artificial light only (1333 W). Moreover, for September the 21st small artificial illumination is needed only from 8:00 to 9:00 and from 15:00 to 16:00 – during most of the working time the office can use only natural lighting, without the reduction of the illumination level requirements.

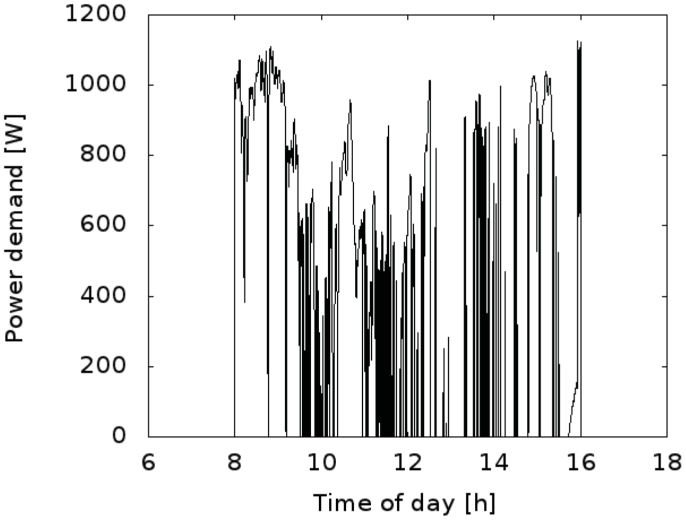

Fig. 5. Power demand for daylight deficiencies compensation on September the 9th.

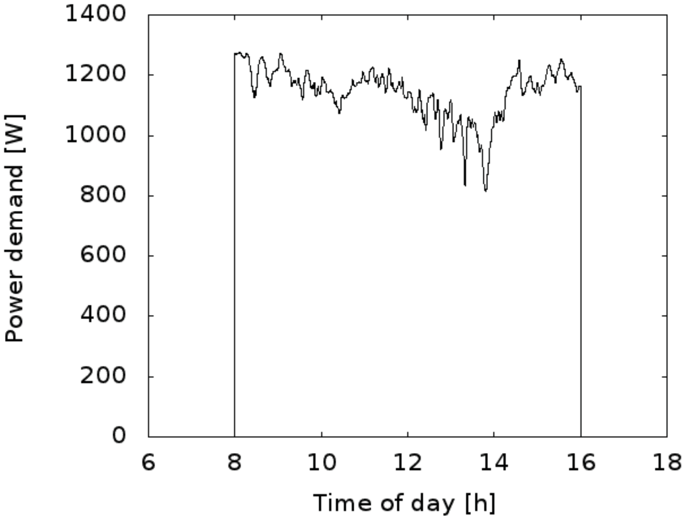

Fig. 6. Power demand for daylight deficiencies compensation on September the 19th.

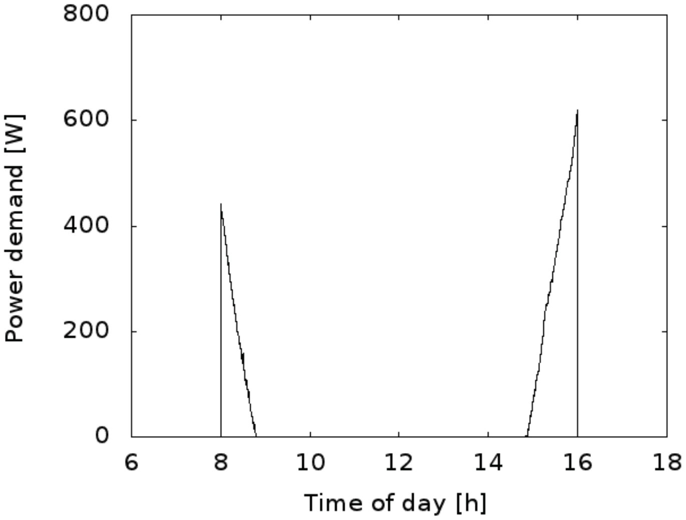

Fig. 7. Power demand for daylight deficiencies compensation on September the 21st.

The presented power patterns have been also integrated in order to obtain the amount of energy that is necessary for artificial illumination. The results of these calculations, compared to the maximum energy demand, are presented in the Table I.

TABLE I
Results of the simulations

Energy consumption by lamps	**Data for 3 different days**		
	9 Sept. 2011	***19 Sept. 2011***	***21 Sept. 2011***
without daylight usage	10664 Wh		
with daylight usage	3561.6 Wh	9143.4 Wh	501.8 Wh
energy savings	7102.4 Wh	1520.6 Wh	10162.2 Wh
percentage	66.60%	14.26%	95.29%

It should be noticed, that the calculations presented in the previous sections do not take into account the materials the room is composed of. Especially, the reflection coefficient for the walls and the floor should be taken into consideration. Also the transparency of the window glass can change the luminous efficacy of the daylight illuminance inside the room. However, in spite of the simplification of the calculations, they are good argument for further research in this field.

V. CONCLUSIONS

As it was shown, the usage of the natural lighting can become the efficient source of the electrical energy saving. Even for a cloudy day (as on September the 19th), about 15% of energy can be saved in the office with relatively small roof window – the area of the window is only 1% of the area of the room. For sunny days – as on September the 21st – the saving can exceed 90%.

The idea presented in the paper can be easy implemented into the existing installations. Only two elements are necessary to introduce the daylight compensation – the device for measuring the intensity of natural light and the controller of artificial light sources (a dimmer). Due to many potential applications, this solution can be important answer to the energy saving demands.

The further research is being carried out at the Department of Microelectronics and Computer Science. Various sets of both natural illuminance and architectural parameters (e.g. size of the room, size and localization of the windows, the transparency of glass) should be studied. The authors are planning to perform the experiment with a prototype lighting system in order to confirm the simulation results.

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