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The comparison of practical and economical aspects of utilization of various light sources

***Abstract**. The diversity of the properties of available light sources, such as: the energy consumption, expected lifetime and the price, can be a problem in terms of selection of the most suitable product. The long term tests allow to verify the reliability and observe the properties change in terms of the time of duty and number of power on/off cycles. In this work we present the results of the observation of the lifetime and its impact on the economical analysis of such light bulbs: LED – based, halogen, compact fluorescent lamp and incandescent (traditional) ones.*

Streszczenie.** Różnorodność parametrów dostępnych obecnie źródeł światła: zużycia energii, przewidywanego czasu pracy oraz ceny, może stanowić problem przy wyborze produktu. Wyniki długoterminowych testów weryfikujących poszczególne parametry w funkcji czasu pracy oraz cykli roboczych są źródłem informacji ułatwiających podjęcie takiej decyzji. W artykule przedstawiono rezultaty obserwacji czasu pracy oraz wynikającej z niej analizy ekonomicznej żarówek: o konstrukcjach bazujących na diodach LED, halogenowych, świetlówek kompaktowych oraz żarowych. **(Porównanie aspektów ekonomicznych i praktycznych stosowania różnego typu źródeł światła)

Keywords: light sources, lamps, reliability, economical analysis
Słowa kluczowe: źródła światła, żarówki, niezawodność, analiza ekonomiczna

Introduction

Lighting is one of the oldest inventions of human race. Once our ancestors learned to use the fire, we could exist independently from the sunlight. It had a major impact on our safety, productivity and the way we live. As a new achievements of technological development become available, we used to use the light sources commonly in indoor as well as in outdoor applications. Recently, approximately 19% of electrical energy is consumed by the light sources [1]. Also, the global energy production increases every year, as infrastructure in developing countries is expanding (fig. 1) and large fraction of the population has access to the electricity [2]. Therefore, the further increase of electrical energy consumption is expected.

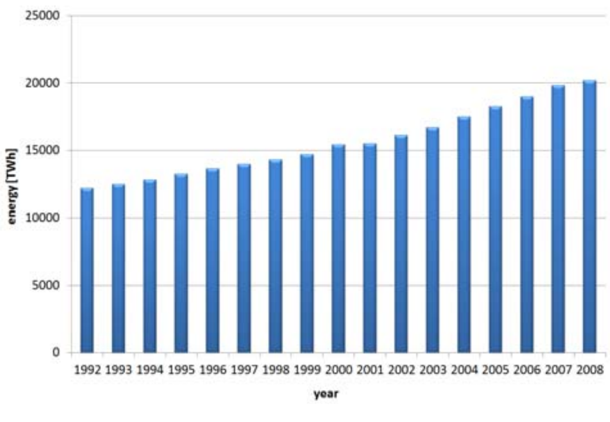

Fig.1. World power generation by energy resource in 1992-2008

As a protection of environment become a serious concern, the new ideas of energy saving methods have been developed. One of the most significant approaches is the utilization of high efficiency lamps allowing to reduce the energy consumption approximately by 40%. Among the most popular light sources used recently are: halogen, incandescent, compact fluorescent and LED-based lamps. The price, expected lifetime, energy consumption and other differences between those lamps are the subject of consideration if the purchase is planned. The reliability tests as well as application issues of certain lamp types, have been studied in several papers [3]-[5].

Additionally, according to the EU directives, incandescent lamps cannot be installed in household lighting systems anymore [6]-[8]. However, some objections according this document have been raised [9], [10].

It should be underlined, that the health issues related to utilization of certain light sources should be carefully investigated, as critical ones [11]-[13]. In this paper however, the basic reliability and economical aspects of selected lamps, have been studied.

The test procedure

Four types of light sources have been tested in order to verify the lifetime and the performance decrease: halogen, incandescent, compact fluorescent and LED-based lamps. As on/off cycles can have the influence on abovementioned factors, two major test groups were created: continuous and switched work. Switching was performed with the microprocessor controlled module, with 5 min on/ 5 min off cycle. Such approach allowed to generate reasonable amount of cycles within test period and to obtain thermal stability of the lamps in every cycle.

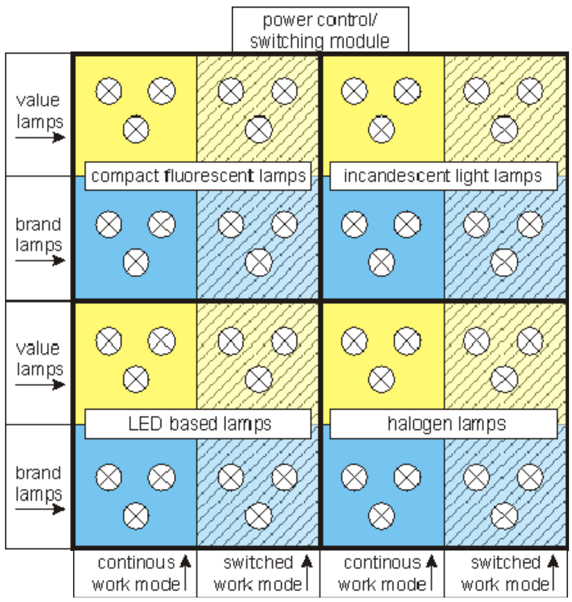

Fig.2. The diagram showing the arrangement of the test stand for lamps

As one can buy the lamps produced by worldwide known companies (brand) or cheaper ones, so called “value” lamps distributed by large selling networks, there is the price/performance factor consideration. In order to verify this issue for each type of lamp, two groups of products were taken into account: brand and value. The prices ratio for those two groups varied between 20% and 100%. It should be underlined, that for each subsection of tested lamps, three pieces have been analyzed, providing statistical information. The diagram showing the arrangement of the test is presented in figure 2.

In order to verify the performance decrease, each lamp was periodically tested using the luxmeter (fig. 3). As this device was not equipped with the digital interface, LabView 2012 [14]-[16] based software with advanced image processing algorithms was used in order to provide time-based data acquisition [17]. This feature allowed to measure the light emission change during first seconds after powering the lamps, revealing their performance degradation.

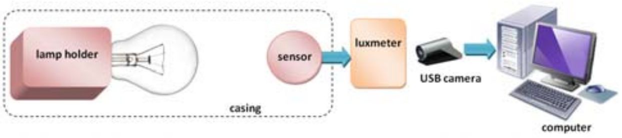

Fig.3. The diagram showing the test setup for lamps degradation observation

As the data was collected, the comparison of various groups of lamps was possible in order to verify the changes of the light generation effectiveness.

The experimental results

Obtained results allowed to observe decrease of the illuminance of tested lamps as the ageing proceeded.

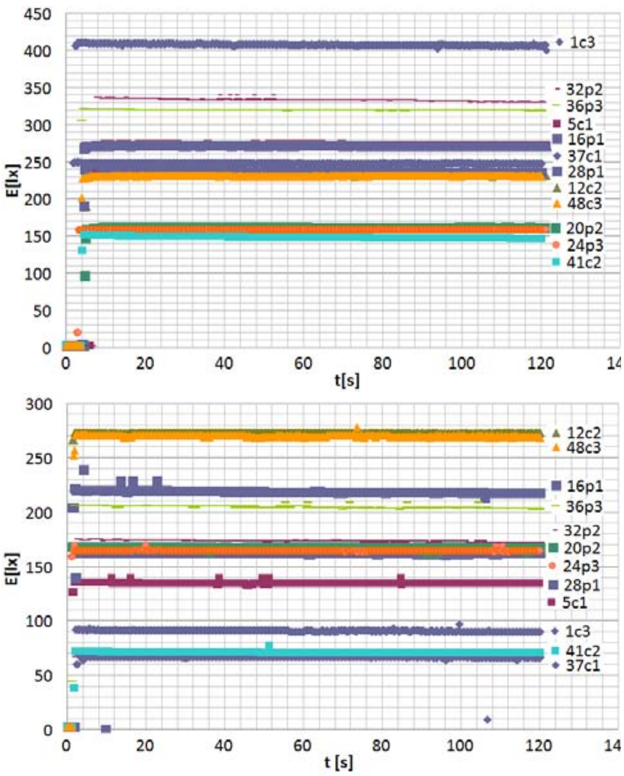

Fig.4. The time-based illuminance graphs of LED lamps acquired during first verification (top) and after 5256h (2628h for and 31356 cycles in switched mode) of work

Figure 4 shows the data acquired before the test procedure and after 5256h (2628h and 31356 cycles in switched mode) of work of LED lamps. One can observe the curve for each lamp separately. A significant degradation is visible. Additionally we could verify the repeatability of parameters within one lamp model and compare similar products from various producers. One can see, that LED products revealed significant distribution of the luminance. It indicates, that the production process still suffers some variations of parameters. During further analysis, averaging within subsections was performed in order to obtain statistical information.

Figure 5 presents the curves of the compact fluorescent lamps ignition. One can easily notice the 9%, 20% and 39% decrease after 360h, 1416h and 4272h respectively. Every single line was created by averaging the set of data for all compact lamps. Such approach allows to observe the performance decrease.

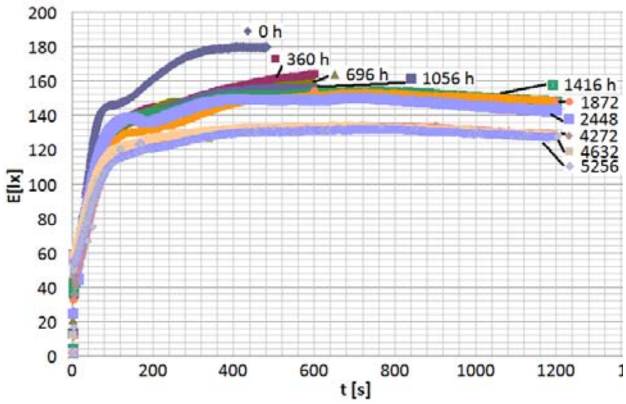

Fig.5. The time-based illuminance graphs of compact fluorescent lamps (averaged) acquired during several measurement sessions

Acquired data allowed to evaluate the lifetime of investigated lamps and verify if it meets expected values which were provided by producers (fig. 6) (the average value and the standard deviation of measured operation time were presented). Surprisingly, the value products worked longer than the brand ones. Even though there is a larger distribution of results, this indicates that the reliability of brand product may be not really as good as one would expect. One can argue if observed issue was due to development of reliability management in large companies.

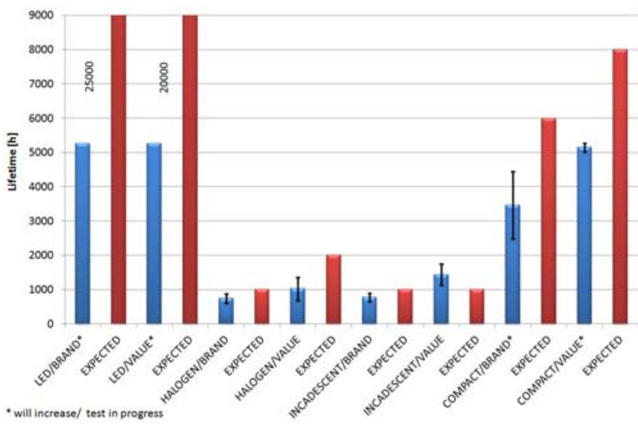

Fig.6. Measured and expected by producers lifetime of tested lamps. Please note, that in case of compact luminescence and LED lamps, there are not final results yet

As acquired data showed significant performance decrease of investigated lamps, the comparison presented in figure 7 allowed to summarize all results. The relative illuminance decrease was calculated by referring the last measurement result of certain subsection to the first one. One can see, that the highest performance decrease was in LED lamps case. Also compact luminescence lamps show significant degradation. It is however observed in few times longer time period than halogen or incandescent lamps.

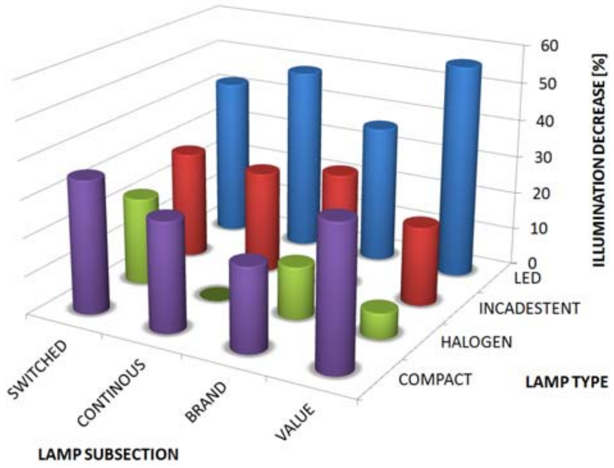

Fig.7. The performance decrease for specific subsections of tested lamps. Please note, that in case of compact luminescence and LED lamps, there are not final results yet

Basing on collected data, we've estimated the 2000 hours operation cost (*c*) for each group of products (fig. 8). The factor was calculated using formula 1.

$$c = P_{LS} \cdot \frac{2000}{L} + EC_{LS} \cdot 2000 \cdot P_E \quad (1)$$

where: P_{LS} – price of the light source, L – lifetime of the light source, EC_{LS} – energy consumption of the light source, P_E – price of the energy unit.

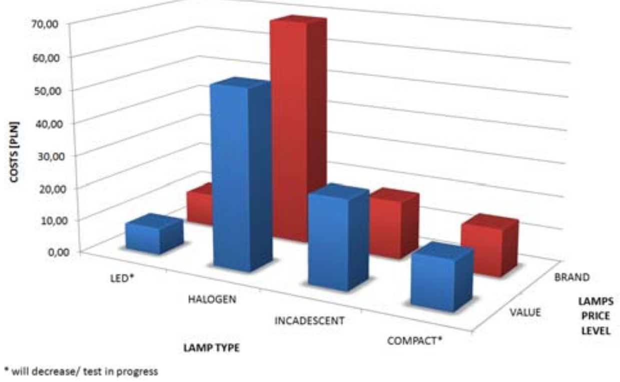

Fig.8. The operation costs calculated for 2000 hours of work of tested lamps. Please note, that in case of compact luminescence and LED lamps, there are not final results yet

One must be aware, that such analysis bases on the most obvious data. It should be noted, that the real cost of the light source recycling is very difficult to estimate as it is related to many factors, and except the additional charge included in the product price (Cost of Waste Management), it is not considered by the customer. In the wider view however, this factor is relevant. Also the consumption of the natural resources, which sometimes will not be recovered and used again, should be carefully taken into account.

Also, in the formula, the lifetime of the light source was used instead more sophisticated criteria related to the performance decrease, as there is very small group of applications where the replacement is triggered by the reduction of illuminance of the light source below required level. The majority of customers replaces the light source after its failure.

Due to very short lifetime and relatively high prices, halogen lamps turned out to be the most expensive solution. As this kind of light source is very sensitive to voltage increase, in some applications even shorter lifetime can be expected. Therefore it is the last cost-effective solution. As expected, LED and compact fluorescent lamps are the most promising products, in particular as the final results will be definitively better, however one must take into account long-term influence on the health condition [11],[12], which has to be carefully investigated.

Summary and outlook

In this paper we've presented the tests and analysis of basic application parameters of selected light sources. Performed experiment allowed to observe the performance changes and to estimate the lifetime of four types of lamps: halogen, incandescent, compact fluorescent and LED-based. By implementing both: continuous and switched operation modes, we could observe the impact of certain exploitation conditions. Additionally, we've tested brand and low-price products in order to verify the price/reliability correlation. Obtained data allowed us to conclude, that the most expensive in terms of both: purchase and energy consumption are halogen lamps, and LED lamps are expected to be the best solution in terms of being cost-effective ones. All types of lamps show decrease of the performance, so within long operation time one must take into account significant (more than 50%) illumination loss. More expensive, brand product don't provide longer lifetime, however, due to technological regime, may reveal less significant degradation. Often on/off switching of the light source have a significant impact in case of halogen and compact luminescence lamps.

This work was performed within frames of IEL statutory work.

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