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Influence of ambient temperature on electrical and photometric parameters of fluorescent lamps

Abstract. *The article presents results of laboratory measurements of photometric parameters of various fluorescent lamps of different powers in ambient temperature ranging from* $+25^0$*C to* -25^0*C in steps of* 5^0*C. Intensity of current, real, reactive and apparent powers as well as power factor and relative changes of luminous flux have been registered. Straight fluorescent lamps of 8 W, 18 W and 36 W powers have undergone the measurement. Additionally, one straight frost-proof fluorescent lamp and one 18 W compact fluorescent lamp integrated with a conventional magnetic choke have been measured. In terms of straight fluorescent lamps, measurements of electrical parameters were conducted on the terminals and the lamp itself. For the 18 W straight fluorescent lamp, measurements have been repeated replacing the conventional magnetic choke with an electronic ballast. The measurements were additionally accompanied by registration of voltage and current timing as well as harmonic spectrum. In parallel to measurements of electrical parameters, relative changes of luminous flux for individual light sources in terms of alternating ambient temperature have been measured. The influence of changes in particular parameters of researched lamps on the energy class has also been analyzed.*

Streszczenie. *W artykule przedstawiono wyniki pomiarów laboratoryjnych parametrów elektrycznych i fotometrycznych świetlówek różnych mocy w funkcji temperatury otoczenia od* $+25^0$*C do* -25^0*C z krokiem co* 5^0*C. Zarejestrowano natężenie prądu, moc czynną, bierną, pozorną, współczynnik mocy oraz względne zmiany strumienia świetlnego. Przedmiotem badań były świetlówki liniowe o mocach: 8 W, 18 W i 36 W. Oprócz tego pomiarom poddano jedną liniową świetlówkę mrozoodporną oraz jedną świetlówkę kompaktową zintegrowaną o mocy 18 W, współpracującą z konwencjonalnym dławikiem magnetycznym. W odniesieniu do świetlówek liniowych rejestracje parametrów elektrycznych przeprowadzono na zaciskach układu zasilającego lampę oraz bezpośrednio na lampie. Dla świetlówki liniowej o mocy 18 W pomiary powtórzono przy zastąpieniu konwencjonalnego dławika statecznikiem elektronicznym. Pomiary uzupełniono rejestracją przebiegów czasowych napięć i prądów oraz widmem wyższych harmonicznych. Równolegle z pomiarami parametrów elektrycznych zmierzono względne zmiany strumienia świetlnego dla poszczególnych źródeł światła przy zmianie temperatury otoczenia. Przeanalizowano także wpływ zmian poszczególnych parametrów badanych lamp na klasę energetyczną (****Wpływ temperatury otoczenia na parametry elektryczne i fotometryczne niskoprężnych lamp rtęciowych****).*

Key words: low-pressure fluorescent lamp, ambient temperature, electrical parameters, photometric parameters
Słowa kluczowe: niskoprężna lampa fluorescencyjna, temperatura otoczenia, parametry elektryczne, parametry fotometryczne

Introduction

The usage of electrical power for lightening purposes has been systematically growing over the last decades. Therefore, currently manufactured light sources must meet not only the requirements of proper luminous flux, its reproducitibility during operation, its proper light color etc., but also in terms of light sources, the economical factor has became significant. Such terms as energy efficiency of lightning, energy-efficient lightning or effectiveness of lightning have become evident in literature. The subject is widely discussed in publications i.e. [1, 4, 5, 6].

The primary factor in the implementation of energy-efficient lightning is the use of light sources of high luminous efficacy. One of the most popular and relatively cheap light sources are mercury vapor lamps known as fluorescent lamps. Their power ranges from 4 W to 80 W, and their luminous efficacy ranges from a few dozens to more than 100lm/W.

Due to the fact that fluorescent lamps are not only used as interior lighting but also as pedestrian lighting (e.g. in underground passages), parking lot lightning, public transport stops' lightning, bus and railway platform's lightning, signboards' lightning, billboards' and advertising coffers' lightning, thus the publication focuses on the influence of ambient temperature on selected electrical and photometric parameters of those lamps. The influence of changes in particular parameters of researched lamps on the energy class of mercury vapor lamps has also been analyzed.

Subject and scope of study

A few straight fluorescent lamps of 8 W, 18 W and 36 W powers as well as one integrated compact fluorescent lamp of 18 W power have undergone the measurement. In case of straight fluorescent lamps of 18 W power, different colors have been taken into consideration. All the lamps (including the compact lamp) were coordinated with a conventional magnetic choke. In case of one lamp, the measurements have been repeated after replacing the conventional choke with an electronic ballast. One straight frost-proof fluorescent lamp of 18 W power has additionally undergone measurements. General information on the researched light sources are presented in table 1. For the purpose of this study, the researched light sources have been given symbols from 1 to 7.

Table 1. General information on the researched mercury vapor lamps

lamp	power	color	tube's diameter	tube's length	symbol
straight	8 W	840	16 mm	288 mm	*1*
straight	18 W	827	26 mm	590 mm	*2*
straight	18 W	640	26 mm	590 mm	*3 a,b*
frost-proof	18 W	840	26/38 mm*	590 mm	*4*
Compact	18 W	Warm white	-	-	*5*
staight	18 W	Daylight	26 mm	590 mm	*6*
straight	36 W	840	26 mm	1200 mm	*7*

* lamp's tube of 26 mm diameter additionally protected with a 38-mm glass cover
a – conventional choke, *b* – electronic choke

In terms of particular lamps, in ambient temperature ranging from +25 ^{0}C to −25 ^{0}C in steps of approximately 5^0C, relative changes of electrical parameters (current intensity I, real power P, reactive power Q, apparent power S, power factor cosφ) as well as photometric parameters (luminous flux Φ, which facilitated to mark the luminous efficacy η) have been registered.

Measurements of electrical parameters for straight fluorescent lamps integrated with a magnetic choke have been conducted in two places – on the terminals of the power-supply system and directly on the lamp itself. In terms of a compact fluorescent lamp and a straight fluorescent lamp coordinated with an electronic ballast, registration of electric parameters was conducted on the "input" terminals of the power-supply system.

Measuring system

Laboratory measurements which measured the influence of ambient temperature on electrical and photometric parameters of fluorescent lamps have been conducted on a system whose structure is presented in fig. 1.

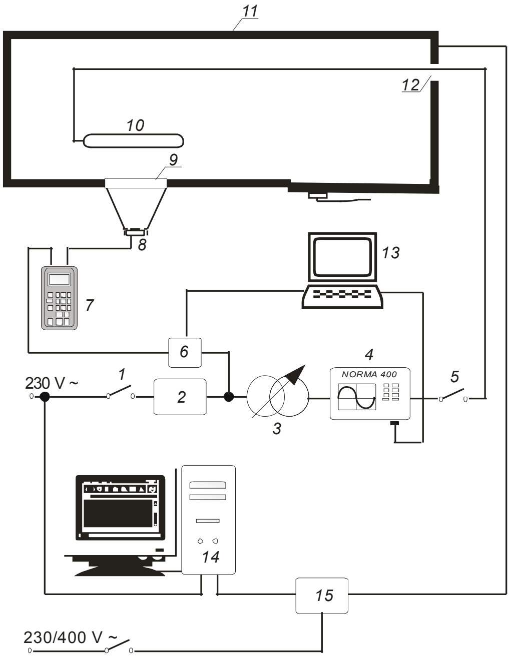

Fig. 1. Schematic diagram of a measuring system designed to determine electrical and light characteristics of low-pressure fluorescent lamps in the function of temperature: *1, 5* – power switches, *2* – voltage stabilizer, *3* – autotransformer, *4* – power analyzer, *6* – external power supply integrated with an illumination meter, *7* – control unit of an illumination meter, *8* – photometer head, *9* – circular glass unit enabling observation, *10* – researched light source with necessary power supply unit, *11* – environmental test chamber made of sandwich panels, *12* – culvert enabling introduction of power supply cables into the chamber, *13* – PC registering electrical and photometric parameters, *14* – computer controlling the chamber, *15* – chamber control unit

Circuits of individual lamps (a fluorescent lamp with the necessary choke) were fed on voltage stabilizer *(2)* which provided constant rms voltage with an accuracy of 0.1%. By means of the autotransformer *(3)* the value of 230 V was set, which was checked by the power analyzer *(4).*

Photometer head *(8)* permanently fixed to the apex of the cone, which was mounted to the external side of the circular glass (the one from the thermal chamber) measures luminous intensity in a selected direction. If one assumes that the shapes of photometric masses of the researched lamps do not change along with the temperature function, the results of laboratory measurements might be treated as values which represent relative changes of luminous flux. Room temperature of 25^{0}C was taken as a reference temperature. The temperature inside the research area was stabilized and varied ±1 ^{0}C. In order to maintain homogeneous temperature, the chamber was equipped with a fan, which created air movement. The whole process of temperature regulation was controlled by the PC (14) and operated by a PLC driver.

Visualization of measurement results

Relative changes of electrical and photometric parameters of the researched fluorescent lamps of various powers and color codes, in the function of ambient temperature, are graphically presented in figures 2÷10. The researched light sources had been aged prior to measurements and, additionally, the temperature inside the lamps had been stabilized – approximately 20 min. of glowing after switching it on. All the researched lamps, during measurements, were placed in a horizontal position, their longitudinal axis was parallel to the direction of the air flow.

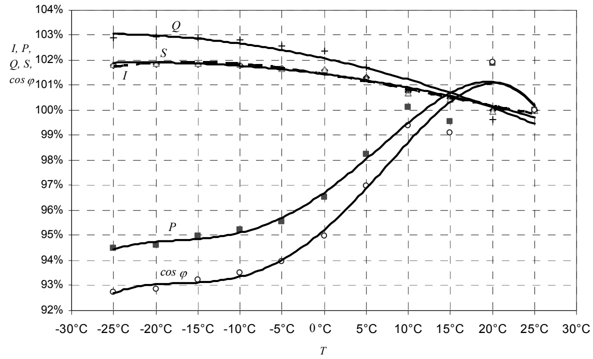

Fig. 2. Relative changes of electrical parameters on the power terminals feeding the system containing an 8 W lamp (source *1*)

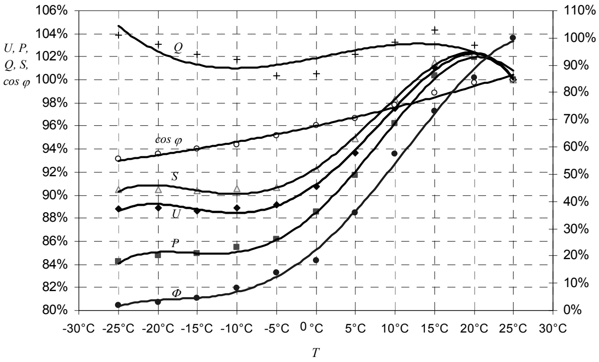

Fig. 3. Relative changes of electrical and photometric parameters of an 8 W fluorescent lamp directly registered on the lamp (source *1*)

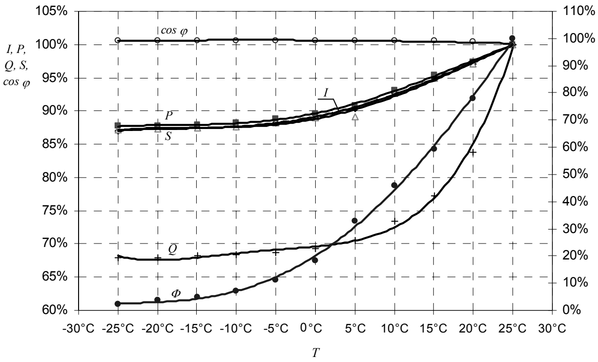

Fig. 4. Relative changes of electrical parameters of an 18 W compact fluorescent lamp with an electronic choke (source *3*)

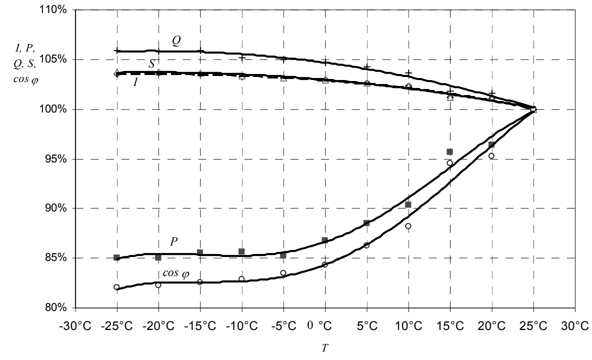

Fig. 5. Relative changes of electrical parameters of an 18 W compact fluorescent lamp with a conventional choke (source *3*)

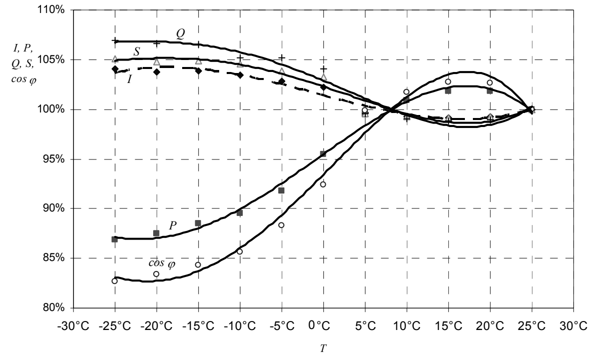

Fig. 6. Relative changes of electrical parameters on the power terminals feeding the system containing an 18 W frost-proof fluorescent lamp (source *4*)

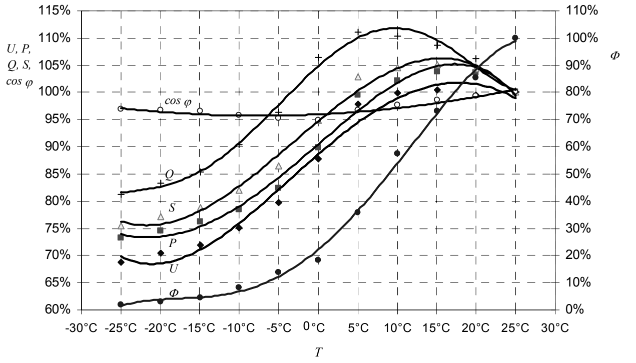

Fig. 7. Relative changes of electrical and photometric parameters directly on the 18 W frost-proof fluorescent lamp (source *4*)

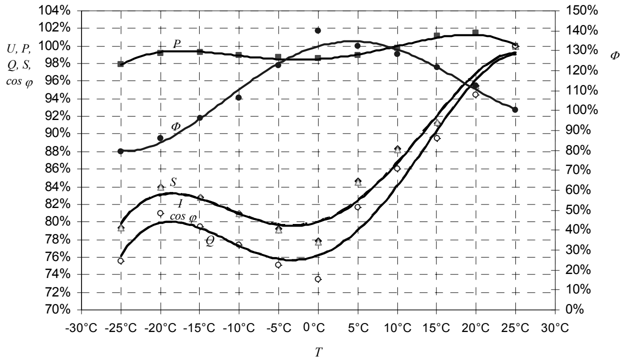

Fig. 8. Relative changes of electrical and photometric parameters of an 18 W integrated compact fluorescent lamp (source *5*)

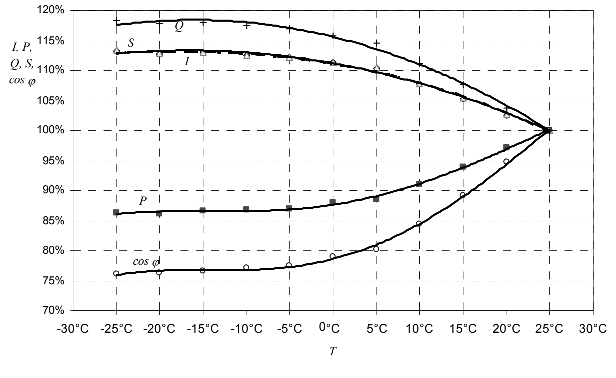

Fig. 9. Relative changes of electrical parameters of a 38 W fluorescent lamp on the input (source *7*)

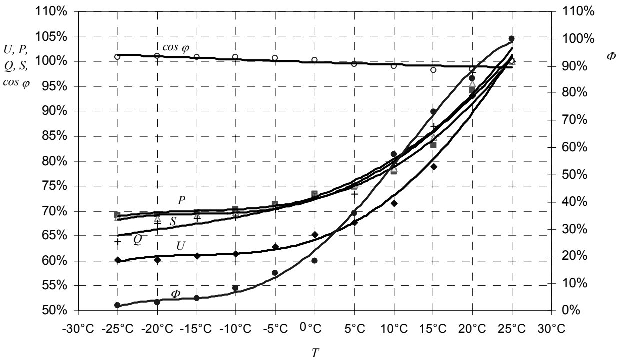

Fig. 10. Relative changes of electrical parameters of a 36 W fluorescent lamps on the lamp itself (source *7*)

Energy efficiency of researched fluorescent lamps

In lighting technology, luminous efficacy is a parameter which provides information on the fraction of electromagnetic power which is useful and generates light. It is calculated (1) as the ratio of luminous flux Φ emitted by the light source and the real power charged P. The highest the luminous efficacy, the more energy-efficient the light source is.

$$\eta = \frac{\Phi}{P} \tag{1}$$

In case of circuits with gas-discharge lamps integrated with a ballast, when ones wants to estimate luminous efficacy, the power losses at the choke ΔP should be taken into account, relationship (2)

$$\eta = \frac{\Phi}{P + \Delta P} \tag{2}$$

Luminous efficacy of a light source with a choke is lesser.

Fluorescent lamps share a characteristic, which was brought up in publications [7, 8, 9, 10], i.e. their luminous flux is dependent on the ambient temperature. The power charged by the circuit also changes which leads to changes of luminous efficacy. Changes of the parameter in the function of ambient temperature of the researched light sources is presented in fig. 11.

When Poland joined the European Union, EU legislation came into force introducing its directives into Polish law e.g. [2]. According to the requirements of Council Directive 92/75EEC [3] all light sources (including straight fluorescent lamps of power up to 58 W) used in households and fed on mains power must be labeled with their energy efficiency class.

The energy efficiency of the appliances is rated in terms of a set of energy efficiency classes from A to G on the label, A being the most energy efficient, G the least efficient. On the basis of the data obtained from the measurements, using the analytical relationships given by the Directive [3], coefficients of energy efficiency of the researched light sources have been determined. On their basis, individual lamps have been classified into particular energy classes (table 2).

Due to the negative and non-linear voltage/current characteristic of fluorescent lamps, they cannot be directly connected to the power supply. They must cooperate with a conventional ballast (magnetic) or, which has become more frequent, an electronic one. As a result, the calculations in case of coefficients of energy efficiency for the whole circuit (the lamp + choke) have been repeated. The determined energy classes are presented in table 2.

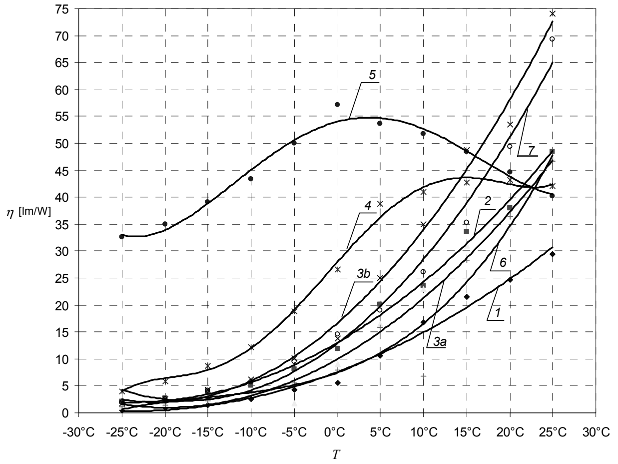

Fig. 11. The courses of changes of luminous efficacy of fluorescent lamps coordinated with a choke in the function of ambient temperature, denominations of individual curves comply with the symbols given in table 1.

Table 2. Changes of energy classes of researched light sources and entire circuits in the function of ambient temperature

T	*Symbols of researched light sources with chokes*													
	1		*2*		*3 a*		*b*	*4*		*5*	*6*		*7*	
	L	C	L	C	L	C	C	L	C	C	L	C	L	C
+25^{0}C	B	B	A	B	A	B	A	B	B	B	A	B	A	B
+20^{0}C	B	B	B	B	B	B	B	B	B	B	B	B	B	B
+15^{0}C	B	B	B	B	B	B	B	B	B	B	B	B	B	B
+10^{0}C	B	B	B	B	B	B	B	B	B	B	B	C	B	B
+5^{0}C	B	C	B	B	B	C	B	B	B	B	B	C	B	C
0^{0}C	C	F	B	D	B	E	C	B	B	B	C	F	B	D
-5^{0}C	C	G	C	F	C	G	D	B	B	B	C	G	C	F
-10^{0}C	E	G	D	G	E	G	F	B	D	B	E	G	E	G
-15^{0}C	G	G	E	G	F	G	G	B	E	B	G	G	G	G
-20^{0}C	G	G	F	G	G	G	G	C	G	B	G	G	G	G
-25^{0}C	G	G	G	G	G	G	G	D	G	B	G	G	G	G
L – lamp, C – circuit (lamp + choke)														

Energy classes of example light sources used in households are presented in table 3.

Table 3. Energy classes of selected light sources

No	Light source	Energy class
1.	integrated compact fluorescent lamps, straight fluorescent lamps	A or B
2.	light-emmiting diodes	A
3.	halogen lamps	C or D
4.	traditional light bulbs	E

Voltage and current time runs

Figures 12-13 present voltage and current time runs on the power terminals of the circuit feeding a straight 18 W fluorescent lamp. Two circuits have been taken into consideration – one with a magnetic choke and one with an electronic ballast. Due to multiplicity of data, it has been decided to present time runs for only three values of ambient temperature i.e. -25^{0}C, 0^{0}C and +25^{0}C.

Values of current harmonic distortion (up to 40th) have been registered and on their basis (in compliance with relationship (3)) THD_i coefficients have been calculated. Values of coefficients in the function of ambient temperature are graphically presented in fig. 14.

$$THD_i = \frac{\sqrt{\sum_{k=2}^{h} I_k^2}}{I_1} \cdot 100\% \tag{3}$$

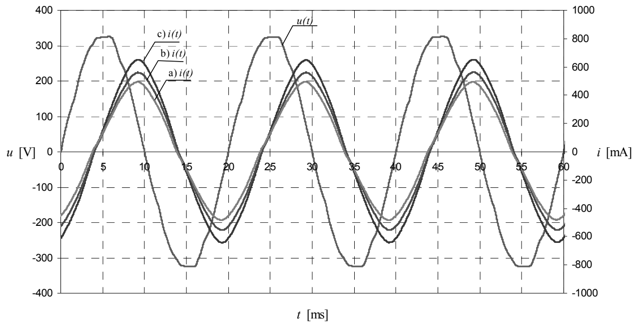

Fig. 12. Voltage and current time runs for a straight 18 W fluorescent lamp coordinated with a magnetic choke in temperature of: a) +25^{0}C, b) 0^{0}C, c) -25^{0}C

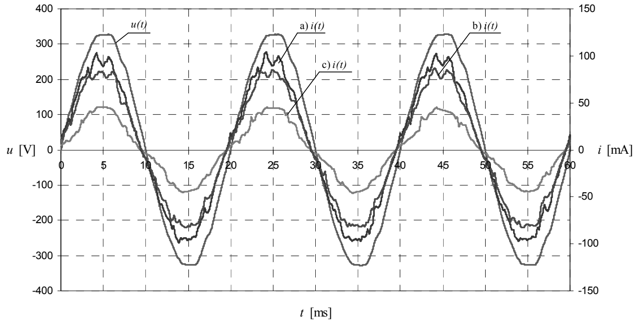

Fig. 13. Voltage and current time runs for a straight 18 W fluorescent lamp (source 3) coordinated with an electronic choke in temperature of: a) +25^{0}C, b) 0^{0}C, c) -25^{0}C

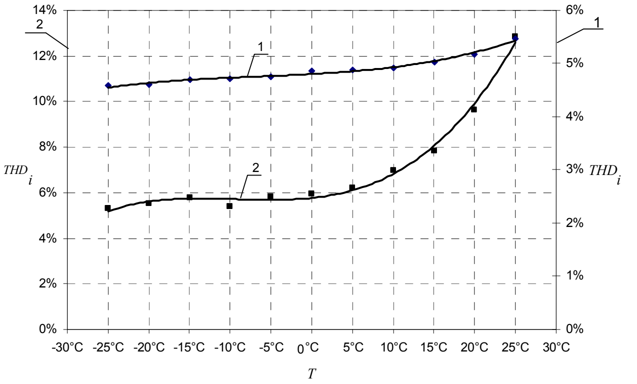

Fig. 14. Changes of THD_i coefficient in the function of ambient temperature in case of a straight fluorescent lamp (source 3) with: 1) magnetic choke, 2) electronic choke

Conclusion

Along with the drop of ambient temperature, due to decreasing pressure inside the tube, the luminous efficacy of generally all straight fluorescent lamps worsens. Even in the case of a frost-proof fluorescent lamp, despite coating the tube with a transparent external cover, the temperature around it has a crucial influence on the lamp's luminous efficiency. Irrespective of the power of straight lamps, in conditions of a freezing cold temperature at –25^{0}C their luminous flux decreases to a few per cent (approx. 2%) in comparison to the value recorded at +25^{0}C. As far as the frost-proof fluorescent lamp is concerned, the situation does not look much better (8%). Replacement of a conventional choke with an electronic ballast practically does not influence the luminous flux in the function of ambient temperature (changes are minor thus they may be ignored). However, the replacement improved the circuit's luminous efficacy in certain scopes of temperatures.

Carried out research, although conducted on single types of fluorescent lamps of various kinds, allows to observe a certain, recurrent regularity. Drop of ambient temperature induces gradual decrease of energy efficiency. Circuits of all lamps (excluding a compact fluorescent lamp) at temperatures below zero, starting at the value of -20^{0}C, fall into the lowest energy class. It means that they are even less energy-efficient than traditional incandescent lamps, which, due to their high levels of energy consumption, are gradually withdrawn from the market.

Out of researched fluorescent lamps, the most optimistic results have been obtained in case of a compact lamp whose discharge tube along with its magnetic choke had been shielded with a prismatic bowl. Closing the lamp with its heat-emitting ballast inside the cover appeared to be the best way to improve the lamp's frost-proof qualities. This type of lamp reaches its best luminous flux at the temperature of 0^{0}C, and at the value of -25^{0}C the luminous flux does not drop below 80%. It also should be stressed that the lamp's energy class stays constant despite the wide range of temperature (from +25^{0}C to -25^{0}C).

As the measurements revealed, ambient temperature additionally influences lamp's voltage and power which tend to decrease along with the drop of temperature. On the other hand, the real power and intensity of current charged by the circuit of a fluorescent lamp coordinated with a conventional choke tend to increase. Yet, the situation seems different in case of a fluorescent lamp with an electronic ballast – the real power as well as intensity of current decrease together with the drop of temperature.

Registration of voltage and current time runs as well as values of current harmonic distortion on the power terminals feeding circuits of straight fluorescent lamps led to an interesting observation. Both in case of coordination the fluorescent lamp with a conventional and electronic choke, the drop of ambient temperature led to the decrease of THD_i coefficient which indicates current distortion. The changes are more noticeable for an electronic ballast.

Low-pressure mercury vapor lamps (fluorescent lamps) in our climatic conditions should not operate outside buildings in the wintertime or in rooms where temperature drops below zero. Due to the fact that their luminous flux decreases considerably, and that entails the decrease of their luminous efficacy, those light sources cease to be energy-efficient.

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