Improving the Energy Efficiency of Outdoor Lighting Systems Using the SmartLight Technology

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***Abstract*—This article describes the main approaches to the control of outdoor lighting using the modern means which give opportunities to improve the quality of lighting and improve its energy efficiency. It is about the lighting system of million city control.**

***Keywords*: control system, lighting system, energy efficiency, quality of lighting, control in lighting systems.**

I. Object of Study

a. Public outdoor lighting

The objects of study is outdoor lighting of Perm city. Its length is over 400 kilometers and it includes more than 35000 light points.

The biggest part of all light points are used in street lighting (Fig.1) [2].

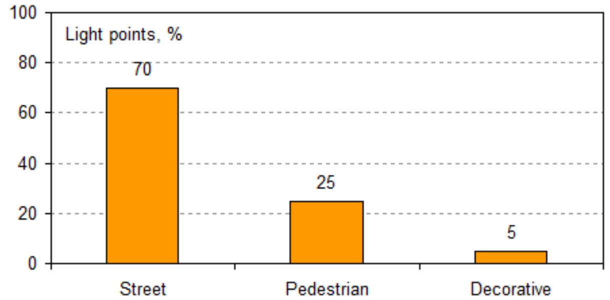

Fig. 1. The ratio of the urban lighting categories.

The greatest effect can be achieved by optimization of the street lighting, which can be divided into 2 groups by operating modes, lighting standards and illuminated objects (Table. 1) [2].

TABLE 1
TYPICAL LIGHTING MODES OF OBJECTS.

Objects	Lighting mode
Highways, Streets	The lights are switched on and off according to the schedule with adjustment for the current value of illumination, at night by low traffic density, the luminous flux can be reduced by 30% while decreasing traffic to 33% and by 50% while decreasing traffic to 20%. Depending on the object, there are different rates of light and illumination should not be reduced at least 4 lux.
Pedestrian crossings, Crossroads	Lighting should switch on and off simultaneously with the appropriate lighting of streets, but the change of the luminous flux at night is not allowed.

Currently, more t han 90% of lamps used in the street lighting comprise sodium lamp (HPS) with control ballast. Lamps with LED and electronic ballasts are present as a "pilot" elements, that demonstrate the development of the lighting system, but not a significant effect in improving the energy efficiency of the lighting system as a whole.

b. Modes of outdoor lighting

Outdoor lighting in the city of Perm operates according to a set of rules 52.13330 [1] and approved schedule on and off outdoor lighting (Table 2).

TABLE 2
SCHEDULE OUTDOOR LIGHTING IN THE CITY OF PERM

Month	January		February		March		April		May		June	
Day	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off
1	18:08	10:22	19:08	9:42	20:15	8:37	21:27	7:06	22:36	5:43	23:56	4:24
2	18:10	10:21	19:10	9:39	20:18	8:34	21:29	7:03	22:39	5:40	23:58	4:22
3	18:12	10:20	19:12	9:36	20:21	8:31	21:31	7:00	22:42	5:37	0:00	4:20
4	18:14	10:19	19:14	9:33	20:24	8:28	21:33	6:57	22:45	5:34	0:02	4:18

The schedule includes two time periods during the day - when the light is switched off and when the light is switched on. Schedule time adjustment allows activating and deactivating of illumination and that's depending on the actual illumination, but no more than 15 minutes. The period when the light is on, is divided into 3 zones: "evening," "night", "morning", according to the intensity of traffic. Morning and evening traffic intensity is the maximum, at night - minimum. This separation makes it possible to control the lighting - to reduce the luminous flux "night" lamps, compared with the maximum luminous flux in the "morning" and "evening". Time of transition zone "evening" in the zone "night" (from the "night" in the "morning") is determined by the municipal administration, it is fixed and does not depend on actual traffic. At the moment, the time zone "night" is valid from 00:00 to 06:00. The lighting system uses electromagnetic and electronic ballasts. Control lamps with electromagnetic ballasts perform per phase (lights powered by a single power point are divided into three approximately equal groups which are connected to different phases of the AC voltage network). Control lamps with electronic ballasts are done in groups (lights powered by a single power point form one group, from which the arbitrary subgroups can be distinguished).

TABLE 3
METHODS OF CONTROL DIFFERENT BALLASTS IN DIFFERENT AREAS (LIGHTING MODES)

Mode	"Per phase" control	Electronic ballast control
Day	Three phases is off	0% light
Morning (evening)	Three phases is on	100% light
Night	One phase is on	70% light

As it can be seen from Table 1, for some objects in the zone "night" (0:00 to 6:00) 100% luminous flux must be saved (could not be switched off to two phases or limit to 70% of the power consumption). To fulfill this requirement, this light points are connected to the "night" phase (in the case of equipment e.m.ballasts) or combined into a single group (if they are equipped with electronic ballasts).

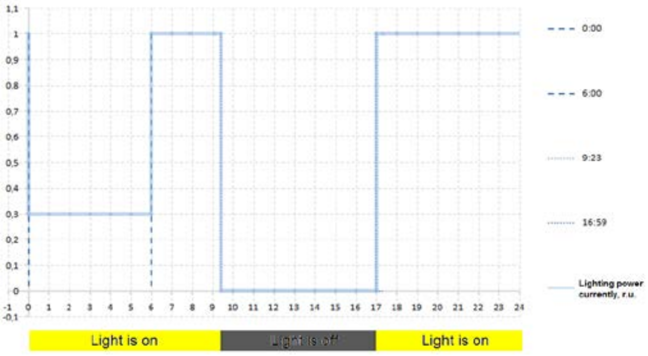

Fig. 2. Schedule outdoor lighting December 22.

Summary. There are three fixed time zones and in each of them the control of outdoor lighting gets a fixed scenario. Light towers are divided into groups based on their electrical connection (power point, phase) and destination (lighting street or crossroads). There are no individual control lamps. Also there are no ambient light sensors, sensors showing the presence of pedestrians and vehicles.

c. Advantages and disadvantages of the existing modes of outdoor lighting

The advantages of the existing modes of outdoor lighting include:

- ✓ Saving up to 50% of electricity in the "night" mode (0:00 to 6:00);
- ✓ Visual selection of crossroads and pedestrian crossings in the "night" mode (0:00 to 6:00);
- ✓ Saving resource of lamps and ballasts in two phases of 6 hours a day.

But there are serious disadvantages in these modes:

- Reduction in excess street illumination in "night" mode (from 0:00 to 6:00);
- Reduction of uniformity excess of in the "night" mode of distribution of pavement brightness (0:00 to 6:00);
- Increase of wear equipment in "night" phase (lamp, ballast, BFC);
- Reducing of the lighting reliability in the "night" mode (0:00 to 6:00) in mind, depending on one phase.

At the moment the merits of used modes (their financial side) significantly outweigh the disadvantages (light quality), so large-scale activities on the modernization of the lighting system and change of lighting modes, that do not provide the same level of budget savings (as at present), are doomed.

d. Implemented measures that improve the energy efficiency of outdoor lighting

There are many well-known ways to improve the energy efficiency of outdoor lighting [2].

The majority of the most common ones have been tried in the city of Perm:

1. Replacement of energy-unefficient lamps with the efficient lamps (90% of the lamps have been replaced on the HPS, LED replacement is not made due to their high cost);
2. Replacement e.m.ballasts with three-mode electronic ballast (replacement is slow, replaced by a small amount in mind the high initial costs and long payback period);
3. Installation of automatic control system into power points (100% of power points are already equipped with automated control systems);
4. On and off illumination in case of the actual illuminance (illumination control sensor installed, but no automatic impact on the system).

These activities are not allowed to abandon the existing algorithm of the lighting control, which has not set lighting parameters with the set of rules 52.13330, although it has significantly reduced power consumption compared to the previous level.

The main reasons for the lack of effectiveness of implemented activities are:

- High cost of equipment (LED, electronic ballasts);
- Failure to revise regulations governing the work of lighting;
- Failure to use 100% of new equipment functions (smooth control, automatic control).

The consequence of these factors is very large payback period of the new equipment, making these events economically ineffective and transforming them into the category of social.

II. SELECTING THE METHOD OF INCREASING ENERGY EFFICIENCY OUTDOOR LIGHTING

It is necessary to bring the lighting parameters with the set of rules 52.13330 and other regulatory documents and thus reduce the power consumption with respect to the current level.

There is a number of ways not previously used, improving lighting efficiency, which does not contradict the set of rules 52.13330 but it’s technically feasible at this time.

a. Using multi-zone control of the luminous flux of outdoor lighting installations throughout the day.

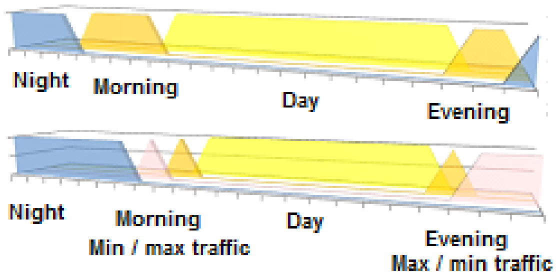

Fig. 3. The four and six-zone graphic works of outdoor lighting.

Time zone "evening" and "morning" is very long (from 2 to 7 hours). In such a large time interval volume of traffic varies very considerably [6]. Rationally it would share these time zones into multiple smaller sub-zones with less traffic scatter values in each.

b. *Switching the lighting from "evening" in the "night" mode, and from "night" to "morning" mode during real decrease (increase) of traffic.*

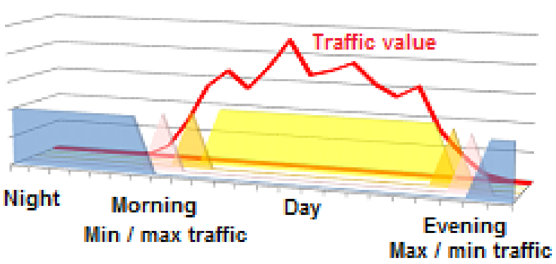

Fig. 4. Six-zones schedule outdoor lighting and value of traffic intensity.

The intensity of traffic has a certain dependence on the day of the week, time of the year, but every day it will have an individual trend. According to this trend, the switching lighting to "night" mode (illuminance decrease) will be carried out on different days at different times [7]. "Night" time zone becomes a "floating" rather than fixed one (from 00:00 to 06:00), and it becomes necessary to measure the value of traffic (number of vehicles per unit of time).

c. *The use of dimming devices in lighting installations to reduce the luminous flux in night mode.*

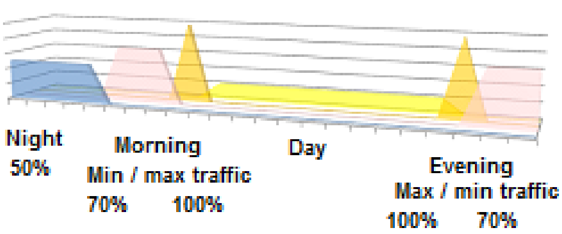

Fig. 5. Six-zones schedule outdoor lighting with different values of the luminous flux in different zones..

The use of dimming devices (electronic ballast), in addition to their other positive properties, is allowed for group control lamps with their union in arbitrary groups that are independent from the electrical wiring (phase). As a result, it becomes possible to reduce the luminous flux at the required luminaires without turning them off. This increases the uniformity of road brightness, removes overload "night" phase, it is possible to install an arbitrary value of the luminous flux from each group of luminaires.

d. *Using multi-zone control of the luminous flux with different boundaries of time zones for different groups of lighting installations.*

According to the set of rules 52.13330 streets are divided into 7 categories (A1, A2, B1, B2, C1, C2, C3) for the purpose of the valuation value of the average illuminance and the average brightness of the road surface. In addition to the various streets volume of traffic has individual character, i.e., at one time on the same street it is already necessary to start "night" lighting mode and the other must still work "evening" mode [4]. Thus, the lighting modes and the luminous flux must be individualized for each street (its homogeneous area) at a time [3].

e. *Smooth (multi) transition from one zone to another on the basis of the value of the actual volume of traffic.*

Above 6 time zones were allocated corresponding to the various modes of operation of outdoor lighting (light flux).

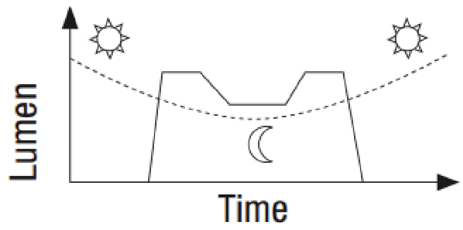

Fig. 5. Smooth change of light flux [5].

The transition from one zone to another is supposed to step, while the value of road traffic - is changing, and the possibility of electronic ballasts is allowed for a gradual decline of the luminous flux. Smooth (multi) transition from one lighting mode to another will improve the energy efficiency of lighting (for proactive move).

f. *Exact simultaneous automatic switching on and off lights throughout the city depending on the ambient light value.*

The amount of ambient light in different parts of the city at the same time can have a sufficiently large variation (up to 20 lux). This is determined by differences of weather conditions and different geographical longitude of a few city parts [2]. For precise simultaneous switching of the lighting it is necessary to measure the outdoor lighting at several points in the city and switching the lighting depending on average value of illuminance.

III. Integrated Using Known Methods of Increase of Outdoor Lighting Energy Efficiency

None of the methods discussed above, as well as already implemented, will not solve the problem **alone**.

Next, we will see **combined** application of these methods, i.e. control of the power level of outdoor lighting by dimming devices, simultaneous management of time borders of zones of different lighting power levels, depending on the traffic value and brightness, splitting power borders and time zones in different parts of the streets.

a. *Exact simultaneous automatic switching on and off lights throughout the city depending on the ambient light.*

Switch on or off the lighting automatically on real illumination will guarantee savings of 5 to 15 minutes of burning every day, without the risk of exceeding the time-limit to switch on or off the lighting. Besides the quality of system performance will be improved - the lighting will be switched on even when it is needed.

Savings are achieved by precise lighting control for illuminance value and due to simultaneous operation of all power points that are not observed in the present manual (and semi-automatic) mode.

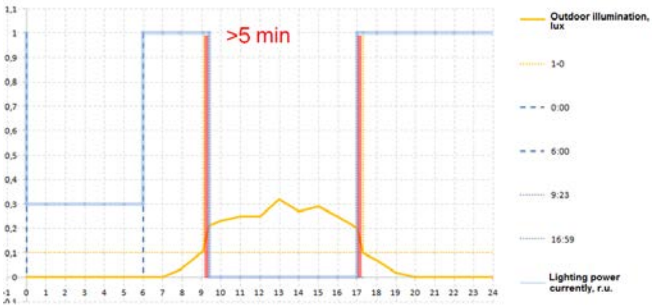

Fig. 7. Reduction of the total burning time when the lighting switching is based on the average data from the ambient light sensor.

b. Multi-zone (6 zones) regulation of the luminous flux depending on the actual value of the traffic fixed by sensors.

According to the set of rules 52.13330 p.7.43 and p.7.32 there is an allowed reduction of the luminous flux on the streets of categories A and B, if the actual illumination is more than 15 lux.

TABLE 3

ELECTRONIC BALLAST CONTROL METHODS IN 6 TIME ZONES OF THE DAY

Mode	Boundary condition of time zone	“Per phase” control	Electronic ballast control
Day		Three phases is off	All luminaries is off
Evening (morning) high traffic	illuminance lower than 20 lux	Three phases is on	100% light
Evening (morning) low traffic	Traffic lower than 34% of it maximal value	Two phases is on	70% light
Night	Traffic lower than 20% of it maximal value	One phase is on	50% light

The borders of time zones with different luminous flux will be determined on the basis of indications from the traffic sensors.

During the day the sensor continuously detects the intensity of the traffic as the ratio of the total time of the car motion for 30 minutes to 30 minutes. Here is a sample for a half an hour: if the car moving stream is 5 minutes, the sensor will value: 5/30 = 0.167. Resolution of calculating traffic intensity values shall be equal to 5-10 minutes, as with such an accuracy comes the definition of boundaries of time zones.

According to the set of rules 52.13330 p.7.43 it is necessary to fix the maximum value (MX) from the sensor during the day and calculate two borders: MX * 0,2 and MX * 0,33 (Figure 8).

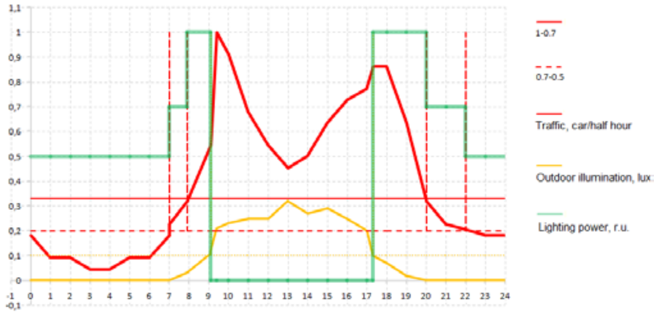

Fig. 8. Reduction of the total burning time when the light switching based on the average value from traffic sensors.

Obviously, depending on the traffic, time zone borders will be different for different parts of streets.

In addition, it should be taken into account that there are individual schedules of major social facilities (hypermarkets, schools, universities, etc.) And a decrease in the luminous flux is unacceptable at lighting of pedestrian crosses and crossroads.

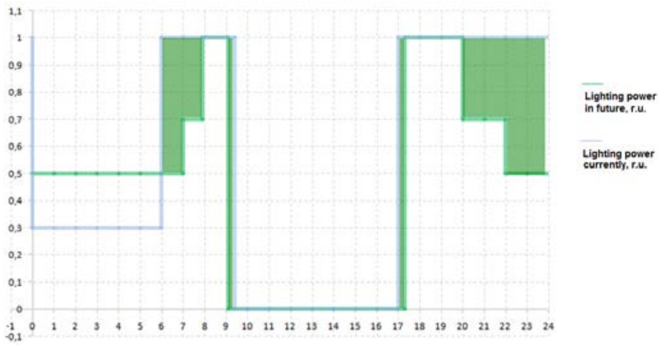

Fig. 9. Reduction of the total burning time when the light switching based on the average value from traffic sensors and outdoor illumination sensors.

These methods, with their complex application, are economically and socially efficient (reduce the amount of electricity consumed up to 50%, increase equipment life, improve lighting conditions and the uniformity of the lighting on the streets, the lighting is provided in accordance with the set of rules [1]). However, the exact calculation value of the effect is required.

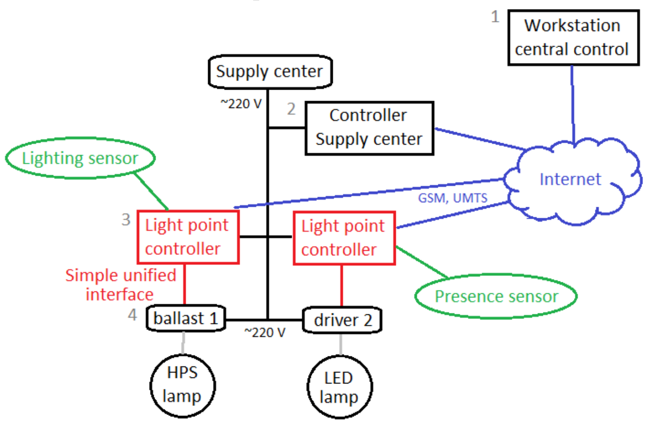

Fig. 10. Structure of lighting control system [2].

The use of these methods is impossible without the usage of electronic ballasts with individual control and use of the global automated control system, allowing control ballasts with algorithms given, when control modes for each light point vary depending on the ambient light, traffic density or pedestrians and others [8].

IV. CONCLUSION

The main reason for the low efficiency of existing modes of lighting is their static nature. In this paper, the main methods of increasing the dynamic modes of outdoor lighting are considered. Here the comprehensive utilization is proposed ways are discussed and a rough analysis of the energy of the event is made. It confirms the need for light points controllers.

As part of this work a micro layout of outdoor lighting systems is developed, which approves the proposed Article lighting control algorithms and hardware layout. Further research directions are also defined in terms of the development of outdoor lighting control systems, lighting control study of algorithms, calculations of economic efficiency.

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