The main directions of smart lighting systems development as one of the ways to improve energy efficiency

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Abstract. The aim of the research was to study and generalize the directions of smart lighting systems development as one of the ways to increase energy efficiency. To obtain statistical data, the Elsevier publisher's Scopus database was used. In order to assess the relevance and significance of research in this area, the work provides statistics of publications over the past five years. As a result, the main directions of smart lighting systems development were identified, aimed at using smart lighting systems as the basis for organizing Smart City services.

1. Introduction
For the first time, the relevance of energy efficiency issues became apparent in the 70s of the XX century, which was associated with overcoming the consequences of the oil economic crisis. Then, many Western countries for the first-time developed measures to save energy and increase energy efficiency at the level of government programs. The measures taken at that time in industry and housing in the United States led to a 2–2.5-fold decrease in energy consumption per unit of output in most industries [1]. In Europe, an additional strategy has been developed to reduce dependence on fossil fuels and switch to alternative energy sources.

In the 90s, energy efficiency issues were further developed. First of all, in Germany, where the Energy Act 1992 gave impetus to the development of new energy saving technologies and the use of alternative and unconventional energy sources [1]. At present, systematic activities continue in almost all countries to improve the efficiency of the use of energy resources.

One of the directions for increasing energy efficiency in general is the development of energy saving and energy efficiency measures in the general lighting segment. The contribution of general lighting to electricity consumption is quite significant. So, in 2015 in the Russian Federation the consumption of electricity for the needs of general lighting amounted to 108 billion kWh or 10.2% of the total electricity consumption [2]. At the same time, for cities that are the main consumers of electricity, electricity consumption for lighting is at the level of 25% of total consumption [3].

The whole range of issues on energy saving and efficiency increase in the field of general lighting, as a rule, is solved within the framework of the implementation of the Smart City concept and, in particular, the Smart Lighting concept. Smart lighting is a lighting technology aimed at increasing the energy efficiency and comfort of using artificial light sources, achieved through the use of automated control, various sensors, as well as the possibilities of modern ways of interacting with humans and other equipment.

Lighting automation systems appeared back in the 90s of the last century, but the efficiency of their use increased significantly only by 2010-2012, when the widespread use of LED lamps began, which
allowed not only to dramatically reduce energy consumption and increase the durability of lamps, but also to adjust brightness light in a wide range. Already in 2015-2017, the active equipping of light sources with communication modules began, which significantly expanded the capabilities of automated lighting control systems.

In the Russian Federation, the state program of the Russian Federation “Energy Saving and Increasing Energy Efficiency for the Period up to 2020” is currently being implemented, which envisages among the main directions and the widespread use of the Smart Lighting concept. For example, in Moscow, it is expected that replacing incandescent and fluorescent lamps with light-emitting diode (LED) lamps will reduce electricity costs by 55%, and the use of automated control systems and various sensors will additionally reduce energy consumption by 20-60% [4]. The results of pilot projects to modernize street lighting have shown that electricity costs are reduced by 70% [5].

According to the consulting company Global Market Insights Inc. the volume of the global smart lighting market in 2018 amounted to $ 7.5 billion, its steady growth is predicted to $ 23 billion in 2025 [6].

The aim of the study was to study and generalize the directions of development of smart lighting systems as one of the ways to increase energy efficiency.

2. Methods

In the context of the constantly increasing flow of information about the results of new research and development work, peer review of publications becomes mandatory, which allows one to summarize and analyze the main achievements in various fields of knowledge.

In the studies, the method of statistical analysis and the method of comparative analysis were used - statistical data were compared on the number of published works in this area. To obtain statistical data, we used one of the largest bibliographic and abstract databases in the world - Scopus published by Elsevier, the most popular among researchers in the field of natural sciences.

As a result of the statistical data analysis, the relevance and importance of the smart lighting systems development was assessed, the main directions of development in this area were identified.

3. Results

To analyze the current state of smart lighting systems development and obtain statistical data, the bibliographic and abstract database Scopus (scopus.com) of the Elsevier publishing house was used, which is distinguished by a wide coverage of publications and has developed tools for analysis.

The information was collected using the query “smart lighting” or “smart light”. The search was performed in article titles, short descriptions and keywords. 1363 links were found (November 2020), of which 1016 were selected, published or accepted for publication in the period from 2015 to 2021. 86% of references were from the fields of Engineering and Computer Science.

The distribution of published articles by year of publication is shown in figure 1.
Table 1 shows the top 20 countries with the most publications in the Smart Lighting area. Authors from these countries represented 90% of the total publications. The specific contribution of each of the 20 countries is illustrated in figure 2.

**Table 1.** List of countries with the highest number of publications.

| Country          | Number of publications | %  | Country        | Number of publications | %  |
|------------------|------------------------|----|----------------|------------------------|----|
| India            | 162                    | 15.9 | Taiwan        | 29                     | 2.9 |
| United States    | 110                    | 10.8 | Brazil         | 26                     | 2.6 |
| China            | 109                    | 10.7 | Canada         | 26                     | 2.6 |
| Italy            | 68                     | 6.7  | Finland        | 25                     | 2.5 |
| South Korea      | 46                     | 4.5  | France         | 24                     | 2.4 |
| Germany          | 45                     | 4.4  | Poland         | 22                     | 2.2 |
| United Kingdom   | 44                     | 4.3  | Australia      | 21                     | 2.1 |
| Netherlands      | 38                     | 3.7  | Indonesia      | 20                     | 2.0 |
| Spain            | 32                     | 3.1  | Japan          | 17                     | 1.7 |
| Malaysia         | 31                     | 3.1  | Singapore      | 17                     | 1.7 |

**Figure 1.** Distribution of published works by years of publication.
Figure 2. The specific contribution of each of the 20 countries to the total number of publications.

India is clearly the leader in smart lighting publishing. The United States is in second place and China is in third place. The Russian Federation, unfortunately, ranks only 28th with 8 articles (0.8%). However, if you build a ranking not of countries, but of universities or research centres that have published the largest number of materials in the field of Smart Lighting, then the situation becomes different. Leading universities or centres of the USA, the Netherlands and Italy are taking the leading positions (table 2).

Table 2. List of universities / research centres with the highest number of publications in the field of Smart lighting.

| Organization                                            | Country       | Number of publications | %  |
|---------------------------------------------------------|---------------|------------------------|----|
| Rensselaer Polytechnic Institute                        | USA           | 13                     | 1.3|
| Delft University of Technology                          | Netherlands   | 12                     | 1.2|
| The University of New Mexico                            | USA           | 12                     | 1.2|
| Technische Universiteit Eindhoven                       | Netherlands   | 11                     | 1.1|
| Politecnico di Milano                                   | Italy         | 10                     | 1.0|
| Vellore Institute of Technology                         | India         | 9                      | 0.9|
| Università degli Studi di Trento                        | Italy         | 9                      | 0.9|
| Alma Mater Studiorum Università di Bologna              | Italy         | 9                      | 0.9|
| Aalto University                                        | Finland       | 9                      | 0.9|
| Ministry of Education China                             | China         | 8                      | 0.8|
| Philips Research                                        | Netherlands   | 8                      | 0.8|
The main direction of the Smart lighting systems development is the development of platforms on their basis for creating the infrastructure of the Smart City [7,8]. Outdoor luminaires are everywhere, they are always connected to the power supply, which makes it possible to create a network based on them that will unite several services. In this case, the transmission and exchange of data can be carried out using already known technologies used for controlling lighting and not only. The collection and transmission of data can also be carried out using standardized hardware and BigData systems or through the use of applications and systems that interact using an API (a universal language that allows data to be exchanged without additional hardware).

Much attention is paid to the development of a new data transmission technology Li-Fi (Light Fidelity). To organize communication, the visible part of the electromagnetic spectrum, emitted by LEDs, is used. Modulation of radiation brightness is performed in such a way that it is not perceived by human vision [9], reception is provided by a photodiode. At present, a transmission rate of 96 Mbit / s has already been achieved [10] and there have been reports of reaching a speed of 250 Mbit / s.

Various applications based on Li-Fi technology are being developed. The indoor LED positioning system helps to orientate in space as accurately (with an accuracy of 30 cm) as possible. Today it is intended for large shopping centres, museums, offices, airports, educational institutions and other places where navigation and information is required.

Lighting poles continue to evolve into multifunctional smart lights. In addition to the lamp itself, stations for charging electric vehicles, television cameras, various sensors, and SOS buttons are installed on it.

Along with the above, the improvement of the hardware of the luminaire itself continues. The electronic ballast is equipped with its own controller which provides on / off and light control functions. In the future, it is planned to divide the ballast into a simplified ballast itself and a luminaire controller that provides ballast control, communication with the control system and nearby luminaires.

4. Conclusion

The information collected indicates that interest in research in the field of smart lighting is at a high level and supported by the governments of developed countries interested in further improving energy efficiency.

In the field of smart lighting, some issues remain unresolved. The main direction of development is the improvement of smart lighting systems as a basic infrastructure to meet the needs of the Smart City. At the same time, it is required to improve the used lighting poles in order to increase their functionality.

Further development of Li-Fi technology continues.

References

[1] State report of the Ministry of Energy of the Russian Federation “On the State of Energy Conservation and Energy Efficiency in the Russian Federation in 2014” https://energo.mos.ru/legislation/common-documents/

[2] National report of the Ministry of Energy of the Russian Federation “Analysis of the state and
prospects of the market of lighting products in the Russian Federation”
https://minenergo.gov.ru/node/7112

[3] Bachurin A A 2015 City Outdoor Lighting System Control. Problems and Prospects Proc. of the 3rd Int. Conf. on Applied Innovations in IT (ICAIIT)

[4] Official website of the Mayor of Moscow Methodological recommendations
https://energo.mos.ru/legislation/lawacts/

[5] Kolomiets V 2020 Features of smart lighting project implementation in the cities of the Russian Federation IOP Conference Series: Materials Science and Engineering 869(2) 022028

[6] Website of Global Market Insights Inc. Smart lighting Market
https://www.gminsights.com/industry-analysis/smart-lighting-market

[7] Website of Company “Intelvizion” https://www.intelvision.ru/blog/infrastruktura-v-umnom-gorde

[8] Website of Company “Signify” https://www.lighting.philips.ru/systems/packaged-offerings/public-spaces/intelligentcity/intelligentcity-for-people

[9] Anwesha Chakraborty, Trina Dutta Sushmita Mondal and Dr. Asoke Nath 2017 Latest advancement in Light Fidelity (Li-Fi) Technology International Journal of Advance Research in Computer Science and Management Studies 5(12)

[10] Nixon J S, Antonysamy A and Tesmamu 2020 Analyzing the performance issues in lifi technology and proposed a solution to improve its performance International Journal of Advanced Trends in Computer Science and Engineering 9(3) 3595-610