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THE SCIENCE OF LIGHT ENGINEERING, FIELDS OF APPLICATION AND THEORETICAL FOUNDATIONS

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ABSTRACT

The article discussed two important problems, which have not been addressed previously:

– The conceptual interpretation of lighting engineering, and the expansion of its definition beyond illumination, which has became widely accepted. An expanded concept of lighting engineering proposed by the authors includes all fields of application of optical radiation (light): illumination, irradiation, phototherapy (light therapy), light alarm systems, light location, light design, etc;

– The problem of developing the theoretical foundation of Lighting Engineering. Differences between three existing light theories are summarised. The first one is quantum theory, explaining all known light phenomena. The second one is wave theory based on the provision that light spreads in waves. The third theory is beam and photometric based on the light field theory, which is the most widely applied and simple for practical calculations and simulation.

Keywords: illumination, light irradiation, phototherapy, light location, power engineering, light design, light propagation theory, quantum, wave, beam or photometric

The formation and development of light engineering as an applied science occurred alongside the introduction of electric illumination, which was the most important stage of the second industrial revolution, characterising by the transition from steam to electric energy. From today's perspective, it is difficult to overestimate the introduction of electric illumination into our lives: society was no longer dependent on natural light and could create comfortable conditions for work, study and rest at any time. It would not be an exaggeration to say that electric illumination determined to a large extent the enormous scientific and technological progress of the twentieth century.

The generally accepted definition of light engineering science refers to an important but relatively narrow branch of industry. This industry is dedicated to the topics of generating optical radiation (light), its distribution in space and its application for illumination to create a visual image, non-visual exposure of people and other animals, the development of irradiating installations for plants, phototherapy (light therapy) and light alarm systems.

This definition is typical for the absolute majority of documents, books and journals, for the Light and Engineering professional description 05.09.07 of the Russian Federation State Commission for Academic Degrees and Titles and for training programmes of lighting engineers in all higher education institutions.

Telling is the name of the the International Commission on Illumination (CIE) as the scientific association for our field, as are the titles of all reputable lighting journals in the world: *Lighting Design + Application* (USA), *Journal of Lighting* (United Kingdom), *Lighting Research and Development* (United Kingdom), *Lux* (France), *Beleuchtung* (Germany), *Svetlo* (Czech Republic).

But *Lighting* means illumination, as well as *Beleuchtung*. The journals as *Leucos* (USA), *Licht* (Germany), *Lux* (France) and *Light & Engineering* (Russia) have a more holistic approach in to light in their title. The first two also consider the problem of illumination as their key topic.

And this is far from being accidental. Very few branches of science and engineering have are associated with such an impactful aspect of human existence and humanity as illumination. Between 10 % and 25 % of all electric energy generated in different countries and cities is consumed for illumination. Without illumination, cultural life, production and recreation would be impossible. The exploration of the oceans and space would also be impossible.

The introduction of electric illumination into our lives has demanded the development of light devices (LD) and illumination installations (II) calculation methods, methods to measure their characteristics, to determine illumination standards so that certain operations could be performed. A theoretical model of light was created as part of this process. This model was based on previous discoveries in astronomical photometry [1, 2]. Photometry (from the ancient Greek φῶς, or φωτός – light and μετρέω – measure) is an overarching scientific subject applicable to all branches of optics. It is the basis for the quantitative measurements of radiation field energy characteristics. A.A. Gershun [3] considered that the word "measurement" can also be interpreted in a broad sense, without reducing it to an experiment method, but considering the totality of theoretical and experimental questions relating to a quantitative comparison. Bouguer-Lambert's photometry was based on Kepler's ideas of light as a totality of rays [4]. Therefore, this model was named photometric and beam. The model was perfected in A.A. Gershun's works as a theory of the light field, which is being a space studied from the view point of the radiant energy transport happening therein [3].

The light field theory was developed at the same time and in parallel with the light electromagnetic (wave) theory, and later, with quantum electrodynamics. The connection between light field theory and light wave and quantum theories remained unqualified for a long time, which determined the attitude of physicists to it as an approximate, engineering and applied science. This connection was revealed in studies at the end of the twentieth century [5], which determined a hierarchy of three light theories in physics. The primary theory explains all light phenomena known for today: the quantum theory based on light as a collection of photons [6]. This theory is the most abstract, leading to difficulties in the interpretation of real measurements. If the number of photons is very large, their movement can be described as a wave process. This naturally leads to wave optics. In principle [7], wave and beam descriptions are equivalent to each other in the wave uniformity area: the ray is perpendicular to the wave in each point. Therefore, knowing the wave direction in space, the rays can be reassembled and vice versa. A uniformity (quasi-uniformity) condition of a field is its constancy in the wave length scale. If a wave direction changes abruptly in the wavelength scale, the field is non-uniform and its beam description is impossible. Light diffraction on a small opening is an example of this.

However, unveiling the connection between the three light theories showed that within their individual boundaries, each model has internal consistency and does not need any correction. Moreover, one should admit that the photometric beam model is correct in the majority of practical situations, and its deviations only appear in very fine experiments. The essence of the light field photometric model can be reduced to four main axioms [5]:

– The light field is a totality of arbitrary direction rays, along each of which light energy is transmitted. Therefore, spatial and angular power density of the transmitted energy is the luminance in a point of the light field along a set direction.

– The rays coming to the same point in space are independent (not coherent) of each other, which determines the absence of interference and additive luminance in the point.

– The time constant and the size of the radiation receiver are significantly greater than the radiation period and wavelength, which allows using wave field statistical moments when determining photometric values.

– Light fields are ergodic, which allows applying means (averages) to the photons, which is used in statistical optics to evaluate means for a specific implementation measured practically.

The light field theory goes significantly beyond illumination technology and serves as a language to describe almost any technological use of light. Therefore, the scope of lighting science is significantly wider than the problems of illumination. Op-

tical radiation is also used in light location, disinfection of drinking water and of industrial waste water, in deaeration, medicine, light design, solar power engineering and in many other applications.

Let us consider the boundaries of studies in the light engineering field and where the conditional boundary lies which separates lighting engineering from optics, laser engineering, radio engineering and astronomy.

Lighting science only considers the transport of incoherent radiation based on light field laws. This is the main fundamental difference of all lighting studies, developments and of their application in practice.

The purpose and definition of lighting engineering should be the development of light science within the boundaries of beam photometric ideas and its application for comfortable illumination, technological and medical contexts. ***Lighting Engineering*** is a field of science and technology, which takes as its subject the development of methods of generation and spatial distribution of optical radiation, as well as its transformation to other types of energy and its application for a variety of purposes.

The twenty-first century is a century of light. The scope of use for light continues to expand. The existence of a uniform international scientific and technological approach allows considering fundamental theoretical and applied problems in all spheres of light application from uniform first principles. It is noteworthy that *Svetotekhnika* / *Light & Engineering* is the only journal in the world, which publishes papers not just associated with illumination problems, but also the use of light for technological purposes within the boundaries of light field theory.

Modern lighting science and practice are based on the fundamentals of light field theory. However, in the context of rapid progress of adjacent fields of knowledge, lighting installations become automated systems, using light sources with LEDs and detectors, relays and other elements of automated control systems, taking into account the natural change of the surrounding light environment. Such technology is used, for example, in greenhouse facilities, poultry industry, water disinfection systems, etc.

Currently, studies may explore the processes and phenomena of visual and non-visual human perception. All of these are also based on the use of light, with light field theory is their physical foundation.

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