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50 Anniversary

50 Years at the helm of the "Svetotekhnika" Journal and 25 years since the founding and management of the «*Light & Engineering*» Journal!

This amazing anniversary this year celebrated by Professor Julian B. Aizenberg is the rarest event in the history of scientific and technical literature, and it is worthy of inclusion in the Guinness Book of Records.

Many years of work on the preservation of journals in the difficult years of restructuring and transformation and the continuous development and improvement of both publications led to the recognition of "Svetotekhnika" as one of the best scientific and technical journals in our country, and "*Light & Engineering*" - as one of the three best devoted to illumination in frame of CIE.

Congratulations to Julian Borisovich Aizenberg on such a creative Jubilee, we wish him good health, preservation of his irrepressible energy and strength for further creative work.

Edition and Editorial Board of Journals
«Svetotekhnika» and «*Light & Engineering*»

Journal "Light & Engineering" had been founded by Prof. Julian B. Aizenberg in 1993

LIGHT & ENGINEERING

СВЕТОТЕХНИКА

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Editorial Office:

Russia, VNISI, Rooms 327 and 334
106 Prospekt Mira, Moscow 129626

Tel: +7.495.682.26.54
Tel./Fax: +7.495.682.58.46
E-mail: lights-nr@inbox.ru
http://www.l-e-journal.com

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Establishing the English edition "Light and Engineering" in 1993 allowed Russian illumination science to be presented the colleagues abroad. It attracted the attention of experts and a new generation of scientists from different countries to Russian domestic achievements in light and engineering science. It also introduced the results of international research and their industrial application on the Russian lighting market.

The scope of our publication is to present the most current results of fundamental research in the field of illumination science. This includes theoretical bases of light source development, physiological optics, lighting technology, photometry, colorimetry, radiometry and metrology, visual perception, health and hazard, energy efficiency, semiconductor sources of light and many others related directions. The journal also aims to cover the application illumination science in technology of light sources, lighting devices, lighting installations, control systems, standards, lighting art and design, and so on.

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REVIEW OF THE CURRENT STATE AND FUTURE DEVELOPMENT IN STANDARDIZING NATURAL LIGHTING IN INTERIORS

Stanislav Darula

Institute of Construction and Architecture, Slovak Academy of Sciences
E-mail: usarsdar@savba.sk

ABSTRACT

Three elements mainly wind, water and sun seemed to determine in ancient ages the basic phenomena of life on Earth. Architectural history documented the importance of sun influence on urban and building construction already in layouts of Mesopotamian and Greek houses. Not only sun radiation but especially daylight played a significant role in the creation of indoor environment. Later, in the 20th century, a search of interaction between human life in buildings and natural conditions were studied considering well-being and energy conscious design recently using computer tools in complex research and more detail interdisciplinary solutions. At the same time the restricted daytime availability of natural light was supplemented by more efficient and continually cheaper artificial lighting of interiors.

There are two main approaches to standardize the design and evaluation of indoor visual environment. The first is based on the determination of the minimum requirements respecting human health and visibility needs in all activities while the second emphasizes the behaviour and comfort of occupants in buildings considering year-around natural changes of physical quantities like light, temperature, noise and energy consumption.

The new current standardization basis for daylight evaluation and window design criteria stimulate the study of methodology principles that historically were based on the overcast type of sky luminance pattern avoiding yearly availability of sky illuminance levels. New trends to base the daylight standardization on yearly or long-term availability of daylight are using the averages or median sky illuminance levels to characterise local climatological conditions.

This paper offers the review and discussion about the principles of the natural light standardization with a short introduction to the history and current state, with a trial to focus on the possible development of lighting engineering and its standards in future.

Keywords: daylight standardization, daylight criteria, evaluation of daylight in buildings, daylight sources

1. INTRODUCTION

There is a recent call to unify illumination criteria used for daylight and artificial lighting of interiors on common bases of good health and visibility conditions as well as interior environmental wellbeing. The main aspects of healthy and good visual environment can be classified in categories [1–5]:

– Physiological: human health, exposure to daylight and sunlight, appropriate illuminance, nonvisual effects, luminance distribution, avoidance of glare, contrast between background and observed details/objects, visual acuity and possibility to recognize small details in required time;

– Psychological: view out, wellbeing, orientation in a space, saturation of a space by natural light and the principle of creating a mood;

– Aesthetical: colour harmony and enhancing the attractiveness of an indoor space;

– Social: cultural heritage and national/local specification of tradition;

– Environmental: reduction of CO_2 production due to reduction of electricity consumption;

– Economical: maximum utilisation of natural light and costs optimisation, energy savings;

– Technological: function and task oriented devices, performance costs, assembly and maintenance requirements and systems for daylight harvesting.

Daylight design is a complex process requiring respect to all these aspects to contribute the valuable and human scale in building interiors. To this, the standards, codes and guidelines for practice are and have to be elaborated [3, 6]. In the lighting engineering preferable are objective physical units, e.g. illuminance in lux instead of relative Daylight Factors still used in daylighting standards and daylight practice.

2. A SHORT HISTORY OF UTILIZATION OF NATURAL LIGHT IN BUILDINGS

Ever since primitive humans realised the restrictions of daylight and the need of an artificial light source at night-time they learnt to set fire, the fireplace became not only the source of warmth and light but also a social gathering and communication meeting centre.

The first civilisation is dated since 3000 BC when Mesopotamian established towns Ur, Uruk or Kish. Houses had a simple construction with atrium and built with unglazed apertures [7]. Greek houses were constructed more compact with peristyle where colonnades were on three sides. From peristyle, the open space, entrances there were to rooms [8]. Living spaces were illuminated through doors or windows also by old stone lamps causing discomfort of smoke and ash. Later candles with cotton wicks were used in Roman houses instead.

Vitruvius introduced a simple rule for daylight evaluation in a room. If from the place with daylight requirement is seen a substantial part of sky hemisphere, this place is sufficiently illuminated by natural light, Fig. 1, [8]. This rule was applied by architects in the Roman period. It can be noticed that this rule was the first criterion for evaluation of daylight in buildings acceptable by authorities.

When Pierre Bouguer started with his photometric measurements his reference source was a candle in the first subjective luminance meter by Marie [9] with many glass filters to reduce the sky luminance. Anyhow, that meant the start of experimental photometry by Bouguer [10]. Few years later Johann Lambert [11] started his studies theoretically determining interior illuminance as geometrical influence of window solid angle seen from the actual illuminated planar element relative to outdoor illuminance. Lambert´s assumption proved to be a very useful, simple and practical choice for the sky luminance standard for calculating interior daylighting in relative terms:

$$\frac{E_{v,i}}{E_{v,d}} = \frac{L_a\ \omega_{\mathrm{p}}}{\pi\ L_{vZ}} = \frac{\omega_{\mathrm{p}}}{\pi} = R.S.F\,, \qquad (1)$$

where $E_{v,\,i}$ is the indoor illuminance of the illuminated element [lx],

$E_{v,\,d}$ is the outdoor illuminance from the whole unobstructed sky hemisphere [lx],

$L_a = L_{vZ}$ is the luminance of an unity arbitrary or zenith sky element [cd/m^2],

ω_p is the aperture solid angle projected onto the illuminated plane,

π is the solid angle of the sky hemisphere projected onto the horizontal illuminated plane,

R.S.F. is the relative Reference Sky Factor serving as a skylight criterion [11].

Due to the lack of sky luminance data he assumed that a perfect overcast sky was absolutely uniform and even in all azimuth directions which could be equal to constant or unity.

Access to daylight and sunlight was an important aspect in building design some centuries ago. At that time, rules of thumb were used, like window head height to room depth or limit of room depth [12]. Importance of natural light was recognised for first time in UK in Prescription Act, 1832 known as Act Right of Light [13, 14], after which any owner of property can have his previous access to daylight

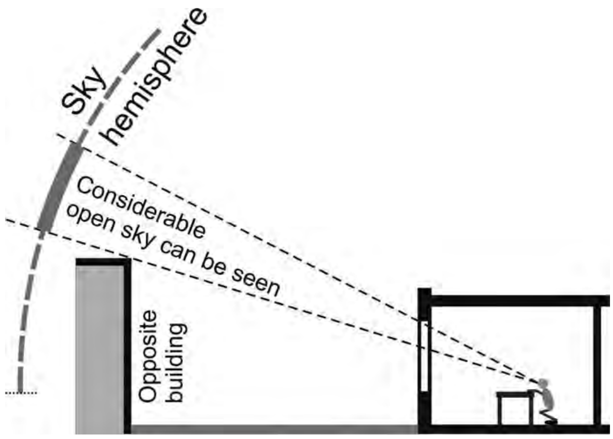


Fig. 1. Ancient rule for daylight evaluation Marie, after [8]

for 20 years. These single rules are based on the geometrical configuration of windows in the room and surrounding buildings.

Industrialization in European countries, e.g. England and Germany in 19th century, led to establishing factories consuming solid fuels and producing in the atmosphere large quantities of pollution. This had negative consequences on the human health and local environment. Logically, the solutions for improvement in health conditions of people were looked for. Elimination of the sunlight absence and increase of daylight in dully building interiors was one, but any important way to improve environment in buildings.

Measurements of sky luminance distribution on the overcast sky, as the worst daylight source, by Schramm [15], Kähler [16], Kimball and Hand [17], Krat [18] showed that real overcast sky has not a uniform luminance distribution but it is characterized by the gradation of sky luminance 1:2–1:3 from horizon to zenith. Moon and Spencer [19] published formula (2), which was recommended for standardization by CIE – International Commission for Illumination [20].

$$L_\gamma = \frac{L_z(1+2\sin\gamma)}{3}, \quad (2)$$

where $L\gamma$ is the luminance in direction of angle γ above the horizon [cd/m²],

L_z is the zenith luminance [cd/m²].

Only now after long term regular sky luminance measurements and e.g. with 1-minute interval, measurements can be more precise for sky situations and daylight conditions in the exterior and building interiors during a day, season or the whole year characterizations [7–27].

Discussions about the importance and sense of standardization in technical branches are often provided by engineers. This process contributes to the developments of new technologies when standard requirements are beneficial or also can be ineffective or result from worse conditions in the case of differences between intention and application conditions [6]. History shows that this process is complicated, depends on current knowledge, climate and national specifications as well as society advancement and prosperity.

The 20th century is characterized by expansion of various architectural styles opened to nature, sun and human needs. Le Corbusier opened interiors of residential buildings to sun exposure when in his principles of Functionalism were formulated 5 points [29]. One of those recommendations is to construct buildings "with horizontal windows preferably running along the whole length of the facade". Glazed façades of office buildings constructed during the second period of last century uncover serious problems with glare, overheating inside and energy performance of buildings.

There are localities with high population and high price of ground, like New York or Hong Kong. The main aspects for consideration in New York City planning was air and daylight on the streets [30–31]. The vertical illuminance on the façade and unobstructed area were criteria for construction of high rise residential buildings in Hong Kong [32–35]. Gifford in [36] caused social problems in densely urban areas i.e. higher crime, children wrong behaviour, a fear from fire or insufficient daylight. These negative experiences lead to re-evaluate the concept of urban density to more human environment. Generally, it provoked new thesis about creation of indoor environment in the human scale.

3. DAYLIGHT METRICS

Daylight in interiors is permanently changing during a day in intensity and spatial distribution while sun and sky are the main sources for indoor illumination and determination of their characteristics, parameters and metrics, still searched [2, 7, 37–39]. Daylight metrics can be applied in three static, dynamic and rating categories comprising daylight evaluation in building.

3.1. Minimum Requirements

Daylight Factor (D)

After the definition [http://eilv.cie.co.at/term/279], the Daylight Factor D is the ratio of indoor illuminance E_i in the point of interest to illuminance $E_{v,d}$ received from the unobstructed hemisphere of an overcast sky where the contribution of direct sunlight to both illuminances is excluded.

Application of D brings several advantages, like simple evaluation of window size design and verification of daylight evaluations and also disadvantages, like any possibility to evaluate time and intensity of illuminance variability, orientation of the room and design daylighting in physical unit lx with independence on the daylight variability.

Illuminance on a working plane

However, respect can be also performance of visual tasks with requirements for to precise recognitions of observed details. In this case the threshold of illuminance in lx on a working plane should be determined.

3.2. Daylight Simulations

Daylight simulation covers computer based calculations of the daylight availability outside or inside of a building during year or other period with one or several sky conditions. Outputs of the simulation are levels of illuminance, luminance or their indoor distributions in the form of a scene or visualization [27]. Several simulation methods can be used for evaluation of daylight.

Daylight Autonomy (DA)

The static and dynamic of daylight autonomy are distinguished. The static daylight autonomy is based on the evaluation of the Daylight Factor at the point of interest when the overcast sky conditions are considered. The dynamic daylight autonomy is based on the prediction of the sufficient illuminance at the point of interest at determined time step (on hourly or less) over the year. DA results in the percentage of the year when a minimum illuminance threshold is met by daylight, [40–42].

Diffuse Daylighting Autonomy

Diffuse Daylighting Autonomy is based on hourly meteorological data, which are processed using the model [23] in order to calculate the hourly value of outdoor horizontal diffuse illuminance or the hourly value of inclined diffuse illuminance. To consider room orientation the parameter diffuse daylight autonomy is weighed [43].

Daylight reference year (DRY)

The daylight reference year is respected by synthetic annual series of probable exterior direct, diffuse and global illuminace generated using statistical methods from precise real photometric and radiometric measurements. The DRY for Bratislava and Athens contains real daily illuminance courses in representative months [44]. The first DRY based on the photometric variables was generated by Petrakis [45]

Useful daylight illuminance (UDI)

Principle of UDI concept is based on the evaluation of illuminances occurring during a year that fall in the range of minimum and the maximum. The minimum illuminance represents threshold for visual task performance and maximum level is the highest illuminance acceptable by occupants [42–43, 46].

Climate based daylight modelling (CBDM)

Climate-based daylight modelling is a method for prediction of annual radiant or luminous quantities, the illuminance and luminance in absolute values are derived from standard meteorological datasets containing data from all sunny and sunless conditions. CBDM offers climatic data from a specific locality for evaluating daylight availability, building orientation and application of shading devices, etc. [38, 47].

Annual daylight exposure

Annual daylight exposure is an indicator defined as the cumulative amount of visible light incident on a investigated point over the year expressed in lx per year [48].

3.3. Certification of Building Sustainability

Parallel to standardization the activities of certification of building environment or building sustainability are present proposed, e.g. LEED, BREEM, DNGB [38, 41]. Daylight plays only a partial role in the scoring evaluation of these systems [49] which does not fully respect principles of photometry. Contrary to standardization, the certification systems can significantly reduce the importance of visual environment within interest for other aspects.

4. A SHORT HISTORY OF ARTIFICIAL LIGHTING

During medieval years were candles standardized and manufactured from animal suet or beewax and later in the 18th century a candle was considered as a light unit. Of course, no artificial light source could compete with the enormous luminance of the sun or the sky that penetrate into rooms.

Besides the utilization of fire as an artificial light source whether in the form of torches, oil lamps or candles, the original and true artificial light source started with the inventions in 1799. Two new sources of energy were discovered in the form of an electric battery by A. Volta and W. Murdoch illuminated his house using lighting gas [50]. The latter gas lighting was applied in U.K. and Europe for more than 200 years especially in street lamps and partly avoided in closed interiors. Electric lighting of interiors needed almost hundred years for many developments in electricity production, transfer of electric current and safe interior sources in form of incandescent glass bulbs.

The first were invented by J. Swan [51] and exhibited in 1879 later followed with more practical alternatives by T.A. Edison [51] including also proposed artificial lighting systems for buildings realized in New York in 1882 while the Yablochkov candle [52] was installed in Paris as a first demonstration for street and theatre illumination during the Paris Exhibition in 1878.

Nevertheless, incandescent electric bulbs wasted a lot of energy due to their back-body temperature radiation. In the further search gas filled neon tubes and fluorescent tubes suitable for interiors enabled further energy savings and cheaper consumption costs and were surpassed in the 21st Century by newer light emitting diodes (LEDs) with possible spectral choice, longer life time, lower energy consumption and price.

Technology progress for the economically prosperous countries became favourable for illumination of interiors in all cases when daylight is low or dark outdoors often in regions with many overcast days. Under these circumstances it seems that previously worst December overcast skies, so critical during 18th to 20th Centuries, are not so important now and in case of necessity the needed illuminance levels can be easily coped with the cheap electric lighting.

To ensure minimum lighting conditions for reading and writing as well as for visual tasks in schools, offices and industry, the horizontal illuminance was standardized in lx levels [53]. Thus, design calculations in photometric units are comparable and can be easily checked.

In the spaces of rooms with insufficient daylighting levels for visual tasks can be applied artificial lighting to supplement daylight in accordance with concept PSALI [37].

5. METHODOLOGY FOR DAYLIGHT STANDARDIZATION

There are two ways of daylight standardization. The first concept is based on the determination of requirements reflecting minimum or maximum acceptable values describing interior daylight conditions. The second way is pointed on the relation between occupant behaviour and year-around changes of natural light quantities. In both, the sky conditions play significant role in daylight standardization.

Standardization of daylight in accordance with the first approach works with simple static criteria and procedures applying assumption: when the limit is complied in practice then visual conditions will be satisfactory during building performance. This philosophy is valid generally until daylight quantities will dominantly exceed limits (e.g. luminance will not arise to glare, or large size of windows will produce overheating etc.). In such cases, the additional measures should be applied (e.g. assembly of shading devices, daylight level control etc.). Generally current standards, regulations and codes are based on the formulation of illuminance, luminance, view out, or glare limits.

The second way of daylight standardization is based on year-round measured data and formulation of human behaviour in annual interior occupation, i.e. not only under limit situation but also behaviour during a day, month, season or whole year respecting also artificial lighting possibilities.

Due to the multiple changes of natural influences (e.g. daily sun path, geographical latitude, cloudiness etc.) as well as human activities in interiors with various well-being and visibility requirements (e.g. circadian biorhythm, life style, visual needs concerning frequent activities etc.), several complex varieties are to be respected when human aspects with energy conscious optimization have to be considered in building and urban design.

However, only until the last years of the 20th Century few momentary measurements of sky luminance were studied almost exclusively under overcast skies and no long term data in different localities were available. Neither the meteorological services nor satellites gathered any photometric data besides irradiance in broad spectral bands. This deficiency was meant to overcome the International Daylight Measurement Programme (IDMP) started by the CIE in 1991. The complex measured data in many localities enabled to study dynamical randomly occurring states influenced by local climate. According to the long-term measured skylight luminance and illuminance collected in time steps in different locations characterized the overall daylight climate worldwide. The set of instant minute horizontal sky illuminance changes with either zenith luminance or luminance sky scans also prepared the possibility to standardize the daylight de-

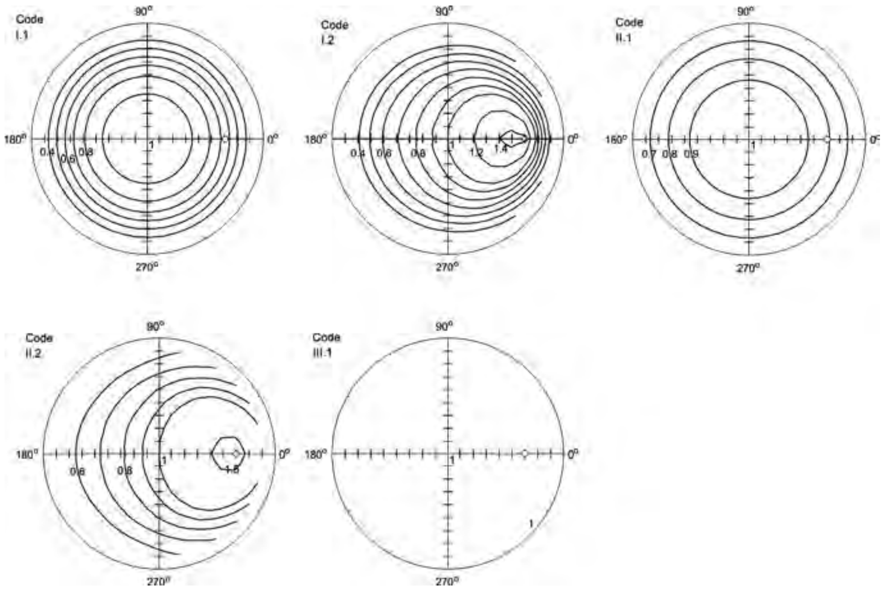


Fig. 2. Examples of sky luminance patterns of ISO/CIE overcast sky types

sign and evaluation after several methodologies, presented below as points A, B, C, D.

A. To derive a set of typical quasi-homogeneous sky types occurring worldwide by selecting such cases from the vast data base within the range from overcast (sunless) to cloudy or polluted clear skies with sunlight.

In fact this method was originally used already by Lambert J.H. [11] assuming the uniform and unity sky luminance on the whole overcast sky which enabled to derive calculation formulae to determine exterior and interior illuminance levels and graphical tools e.g. Danilyuk's charts [54], Waldram diagrams [55, 56] or BRS protractors [57]. Lambert's assumption of a unity sky luminance after measured sky luminance gradation was corrected after the proposal by P. Moon and D.E. Spencer [19] and adopted by CIE as the CIE Overcast Sky [20]. Using this new standard further corrections in the derivation of the Sky Component of Daylight Factor caused by different oblique glass transmittance for single or double glazing or for rough cast wired glass in apertures with different slope [58] enabled to produce a set of more practical protractors [2]. The need to expand the sky range from overcast to clear standards was successfully accomplished applying this methodology when selecting a set of fifteen sky types [59–61], adopted now by CIE and also internationally by ISO [63]. In Figs. 2–4, standard sky luminance patterns are shown of all fifteen types of skies in the relative units presenting overcast, clear skies and quasi cloudy skies expressed as homogeneous models under sun altitude 30°.

All ISO/CIE sky types are identified by number 1–15 or by code characterising the number of the standard gradation function (Roman letter) and standard indicatrix by number [60, 61,63].

Typical overcast skies absolutely block and shade sunlight having only luminance gradation characteristics with a temporary penetration ratio of ground to extraterrestrial horizontal illuminance E_{vd}/E_{voh}. However, clear sky luminance patterns are influenced by sun presence and together with luminance gradation are strongly dependent on sun beam scattering reaching the whole sky vault that can be characterized by the ratio of zenith luminance L_{vZ} to sky horizontal illuminance E_{vd}, i.e. L_{vZ}/E_{vd} [7]. Analysing the sky luminance distribution enables to determine the relative scattering function, which co-acts with gradation forming the relative sky luminance pattern [59, 61]. When absolute L_{vZ} is known or calculated [60] a sky luminance pattern in physical units, e.g. kcd/m^2 is available. When the sky luminance in the window solid angle is given it can serve computer programs input for calculation of indoor illuminance in oriented rooms as well as temporary risk of glare.

B. To represent and study the daily sky and sunlight courses with respect to turbidity and cloudiness influences under clear skies with the aim to determine their mutual interrelation dependent on solar altitude and sky type.

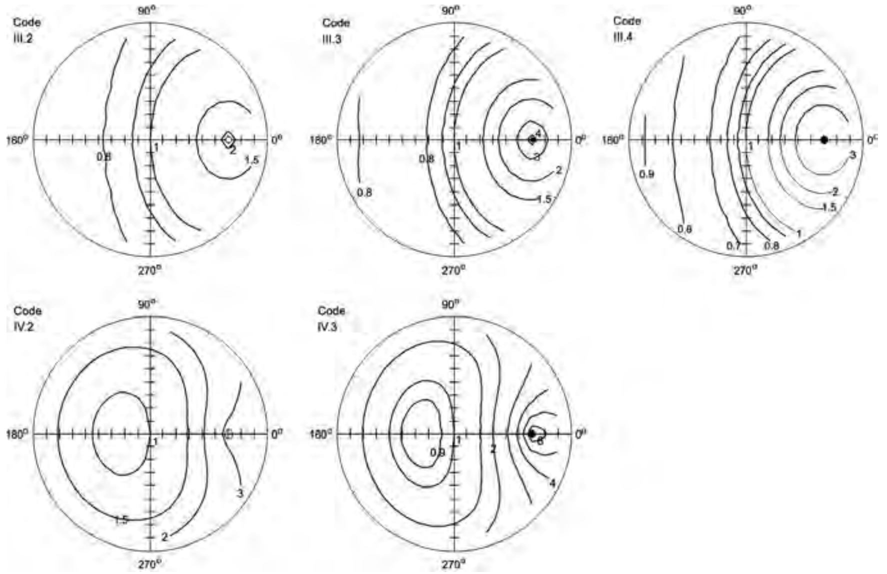


Fig. 3. Examples of sky luminance patterns of ISO/CIE quasi cloudy sky types with sun in position of solar altitude 30°

Although it seems that the typology of sky types is the simplest and evident criterion, but the basic idea is in the definition and determination of luminance distribution on the whole sky vault under sunshine is influenced the mutual participation of skylight and sunlight due to atmospheric turbidity and cloudiness.

The fundamental influence of pollution in atmosphere especially in cities and industrial zones effects considerably relation between sky and sun illuminance level changes [64, 65]. Such transformations also occur in subtropical and tropical climates with lots of sunny days due to humidity rise and dispersed cloud veil gradually covering the whole sky vault [66].

To be able to analyse and categorize the occurrence of individual sky types it is inevitable to have local regular measurement data. The selection has to trace chosen sky types according to parameters like solar altitude, the significant range of L_{vz}/E_{vd} [59, 67].

C. To characterize yearly or long-term skylight conditions and local daylight climate.

In example this method was used to document five year occurrence of CIE/ISO sky types in various seasons after measurements in Bratislava and Athens [68]. Exterior horizontal illuminance levels were selected from 5 min database and sky type occurrences graphically presented in Fig. 5*a*, and Fig. 5*b*. Bratislava represents Central European

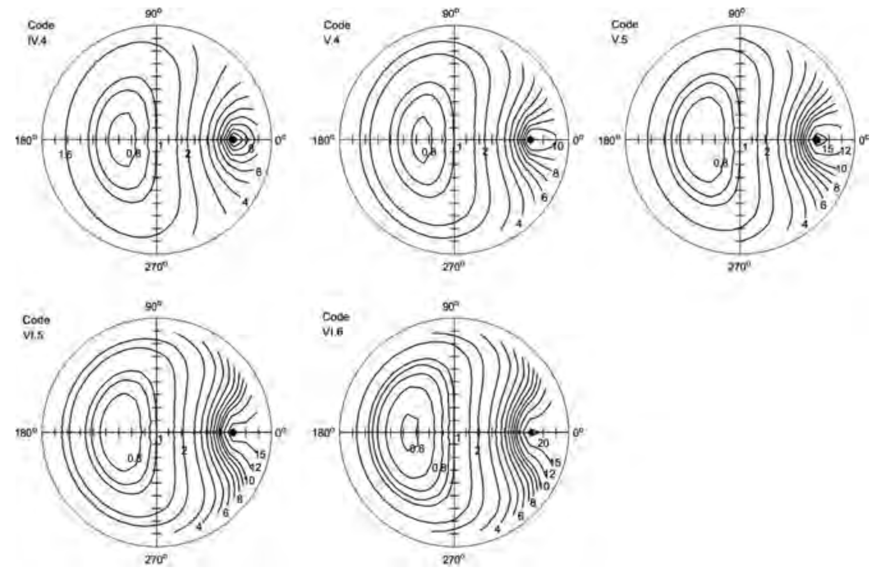


Fig. 4. Sky luminance patterns of ISO/CIE clear sky types

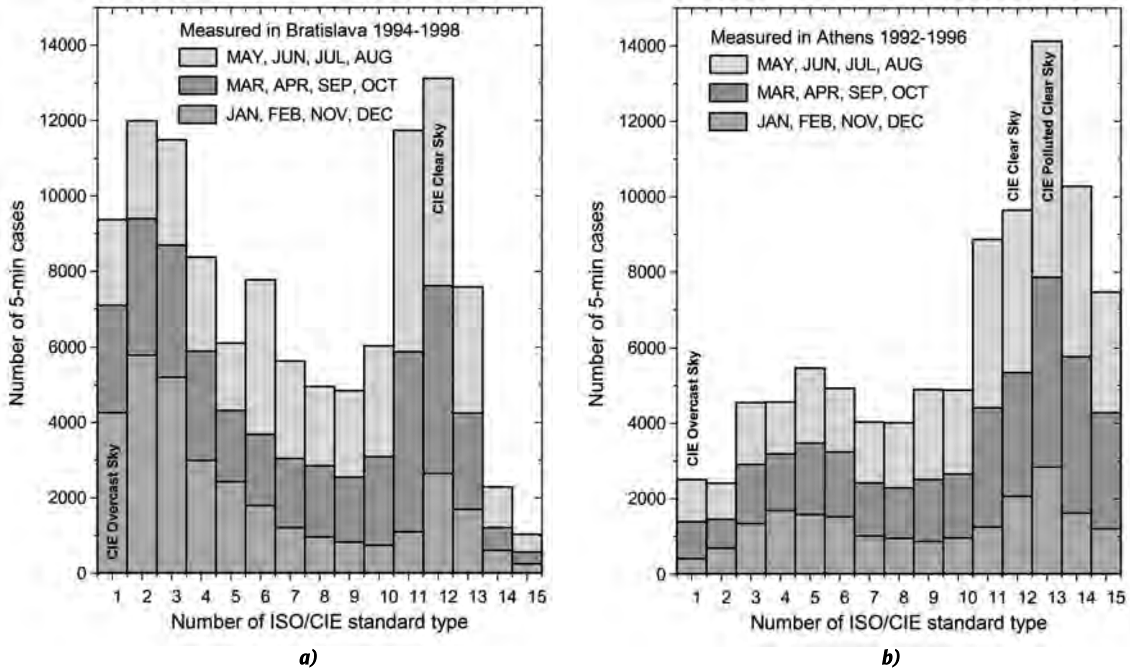


Fig. 5. Sky type occurrence as method for presentation of local daylight climate, [68]
a) Bratislava, Central Europe climate, *b)* Athens, Mediterranean climate

daylight climate with characteristic higher occurrences of overcast/cloudy skies, clear skies mainly in summer while sunny and clear situations are dominant in Athens in Mediterranean location.

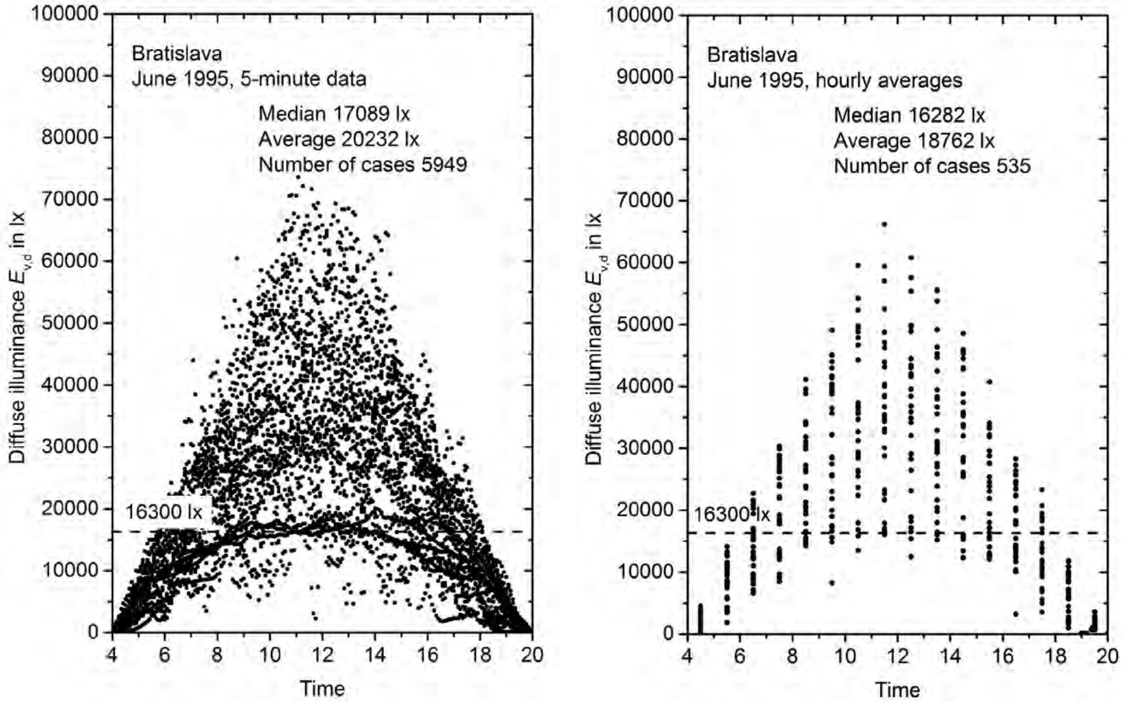
Several assumptions respecting regional lifestyle, activity pattern or target skylight requirements can be taken into account. For instance, in [69] were evaluated some most probable daily activity hours e.g. 7:00–20:00, 8:00–17:00, 8:00–19:00 or 9:00–16:00, but finally for the calculation of the meridian characterization were applied the daily periods from sunrise to sunset. Such yearly meridian skylight illuminance of all CEN capitals was recommended as a standard criterion [70].

D. Determine the yearly statistical characteristics of exterior horizontal skylight illuminance based on the measured data can express local skylight availability.

Having the detail measurement data it is possible to derive few comparisons of skylight illuminance occurrence evaluated from measured precise, short term, data or their hourly averages. However, it is problematic how to use relevant data in formulation of daylight standard criteria. Whether the whole range of measured sky illuminance from sunrise to sunset are to be taken as basic, e.g. for a month with highest illuminance levels in June, Fig. 6, or March representing skylight in equinox, Fig. 7 or referenced specific periods of daily human activities as suggested by [69] or 7:00–16:30 for office buildings and 7:00–14:30 for schools as prescribed in Slovak regulation [71]. Consequences indicated by vertical lines in March are shown in Fig. 7*a* and in Table 1. The prescribed by [70] value 16300 lx of median diffuse illuminance for Bratislava is shown in Table 3. Differences between 5-minute and hourly data are indicated in comparison of *a* and *b* both in Fig. 6 and Fig. 7 and it is evident that hourly averages reduce illuminance levels and offer less information about daylight availabili-

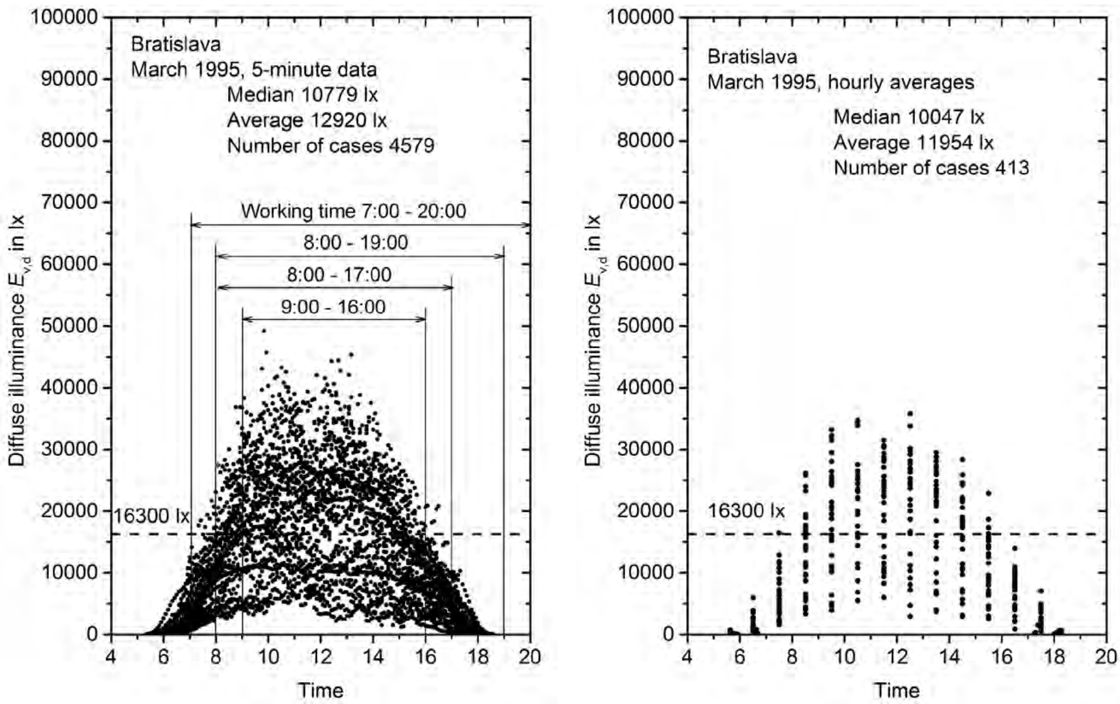
Table 1. Statistical Sky Illuminance of 5-minute E_{vd} in March 1995 in Bratislava for Working Hours

Working time	Sunrise – sunset	8:00–17:00	9:00–16:00	8:00–18:00
Average, lx	12920	16339	17986	15009
Median, lx	10779	15002	17700	13447
Count, number	4579	3379	2635	3732



a) ***b)***

Fig. 6. Daily availability of diffuse horizontal illuminance in June 1995 in Bratislava.
a) Minute averages, *b)* Hour averages



a) ***b)***

Fig. 7. Daily availability of diffuse horizontal illuminance in March 1995 in Bratislava.
a) 5 minute averages, *b)* Hour averages

ty in the locality. When the period of working time will be considered then higher illuminance levels as criterion can be expected.

Daylight is perceived by human eye at the moment of its occurrence, therefore databases applied in daylight standardization should contain the data measured in the shorter intervals.

Table 2. Selected Standards and Documents Containing Requirements and Recommendation for Daylight Evaluation in Buildings

Country	Number	Description
Australia	AS1680.1–2006	Interior lighting – General principles and recommendations
Belgium	NBN L13–002:1972	Dagverlichting van gebouwen – Voorafbepaling van de daglicht-verlichtingssterkte bij overtrokken hemel (benaderende grafische methode)
Brazil	NBR15215–1	Iluminação natural – Parte 1: Conceitos básicos e definições
	NBR15215–2	Iluminação natural – Parte 2: procedimentos de cálculo para a estimativa da disponibilidade de luz natural
	NBR15215–3	Iluminação natural – Parte 3: Procedimento de cálculo para a determinação da iluminação natural em ambientes internos
	NBR15215–4	Iluminação natural – Parte 4: Verificação experimental das condições de iluminação interna de edificações – Método de medição
Canada	PWGSC1989	PWC Daylighting manual, Ottawa
CEN	EN17037	Daylight of building
China	GB50033–2013	建筑采光设计标准
Czech Republic	ČSN73 0580–1	Denní osvětlení budov – Část 1: Základní požadavky
	ČSN73 0580–2	Denní osvětlení budov – Část 2: Denní osvětlení obytných budov
	ČSN73 0580–3	Denní osvětlení budov. Část 3: Denní osvětlení škol
	ČSN73 0580–4	Denní osvětlení budov. Část 4: Denní osvětlení průmyslových budov
Estonia	EVS894: 2008	Loomulik valgustus elu- ja bürooruumides
Germany	DIN5034–1	Tageslicht in Innenräumen – Teil 1: Allgemeine Anforderungen
	DIN5034–2	Tageslicht in Innenräumen; Grundlagen
	DIN5034–3	Tageslicht in Innenräumen – Teil 3: Berechnung
	DIN5034–4	Tageslicht in Innenräumen – Teil 4: Vereinfachte Bestimmung von Mindestfenstergrößen für Wohnräume
	DIN5034–5	Tageslicht in Innenräumen – Teil 5: Messung
	DIN5034–6	Tageslicht in Innenräumen – Teil 6: Vereinfachte Bestimmung zweckmäßiger Abmessungen von Oberlichtöffnungen in Dachflächen
Great Britain	BS8206: Part 2	Lighting for buildings: Code of practice for daylighting
Hong Kong	Regulation APP-130	Lighting and Ventilation Requirements – Performance-based Approach

6. STANDARDIZATION OF NATURAL LIGHT IN INTERIORS

Quality of indoor environment depends mainly on factors affecting human perception of light, warm, noise and air composition. To create good and satisfactory visual conditions for work, rest and various activities in buildings the criteria and rules for illumination system design, building construction and so for evaluation of natural and artificial light utilization should be determined. There are several countries which have adopted regulations, standards and national rules for design and evaluation of daylight and insolation in buildings Table 2, [42, 72–75]**.** In accordance with laws [76] and [77] and regulations [78–80] daylight design and evaluation of sunlight exposure are checked by hygienic authority waving obligation to take official decision in Slovakia.

Country	Number	Description
Japan	JIES-008–1999	Indoor Lighting Standard
Netherlands	NEN2057	Daglichtopeningen van gebouwen
Norway	Regulation No. 77, 14. June 1985	Technical regulations to the Planning and Building. Updated by the regulation No. 1069, 29th August 2001
Poland	Regulation of Ministry for Infrastrukture, (*Dz.U. Poz. 1422*)	W sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie
Russia	СП 23–102–2003	Естественное освещение жилых и общественных зданий
	СП 52.13330.2016	Естественное и искусственное освещение
Serbia	SRPS U.C9.100:1963	Дневно и електрично осветљење просторија у зградама
Slovakia	STN73 0580–1	Denné osvetlenie budov. Časť 1: Základné požiadavky
	STN73 0580–2	Denné osvetlenie budov. Časť 2: Denné osvetlenie budov na bývanie
	STN73 0580–1/Z2	Denné osvetlenie budov. Časť 1: Základné požiadavky
	Regulation No. 541/2007 Z.z.	o podrobnostiach o požiadavkách na osvetlenie pri práci.
Slovenia	Rule UL. RS, No. 43, 3.6.2011	Pravilnik o zahtevah za zagotavljanje varnosti in zdravlja delavcev na delovnih mestih
	Rule UL. RS, No. 61, 2.11.2017	Pravilnik o minimalnih tehničnih zahtevah za graditev stanovanjskih stavb in stanovanj
Sweden	SS91 42 01	Byggnadsutformning – Dagsljus – Förenklad metod för kontroll av erforderlig fönsterglasarea
Ukraine	ДБН В.2.5–28	Природне і штучне освітлення.

Generally daylighting in interiors is evaluated after Daylight Factor criteria e.g. [81–101]. In Sweden simple 1/10 of window area to floor area is applied [102] in other several countries rules for daylight evaluation have been applied e.g. [103–115], as shown in Table 2.

7. NEW STANDARD EN17037 DAYLIGHT OF BUILDING

Progress in the illuminating engineering research increases the role of daylight as an important factor of human health and labour in an indoor environment. In Europe health of people and effective utilization of natural sources are highly respected, therefore a new standard with criteria for evaluation of daylight in buildings is now to be adopted in Europe. The work group CEN/TC169/WG 11 Daylight was established with the mandate to elaborate an EN standard “Daylight of buildings”. The proposed EU daylight standard [70] was approved by experts of CEN countries. This proposal tries to change the current relative Daylight Factor criteria to absolute illuminance units prescribed for certain visual task categories similar as used in artificial lighting in illuminated interiors. Due to the EU geographic territory span from Mediterranean to far Northern countries this standard introduces the new concept of the median exterior diffuse illuminance $E_{v,\ d,\ med}$ representing sufficient daylight availability during the half of the year as a substitution of the unidentified overcast sky and Sky Factor criterion for aperture design. Some interesting capitals from the [70] list are in Table 3.

This standard covers all main subjects associated with design and evaluation of natural visual environment, i.e. daylighting, view out, sunlight and glare, [116–119]. Also specifies minimum recommendations for visual task performance, impression of lightness indoors and for providing an adequate view out as well as recommendations for the duration of sunshine exposure. Standard can be applied to all spaces which are regularly occupied by people for extended periods, except spa-

Table 3. The Median of External Diffuse Illuminance $E_{v,d}$, *med* and D_{TM}, and D_T Requirements for Indoor Illuminace $E_{v,i}$ for Selected CEN Capital Cities, [70].

Country	Capital city	Geographical latitude, deg	$E_{v,d,med}$, lx	$E_{v,i}$, lx			
				100	300	500	750
				D_{TM},%	D_T,%		
Cyprus	Nicosia	34.88 N	18100	0.6	1.7	2.8	4.1
Spain	Madrid	40.45° N	16900	0.6	1.8	3.0	4.4
Croatia	Zagreb	45.48° N	17000	0.6	1.8	2.9	4.4
Slovakia	Bratislava	48.20° N	16300	0.6	1.8	3.1	4.6
Belgium	Brussels	50.90° N	15000	0.7	2.0	3.3	5.0
Germany	Berlin	52.47° N	13900	0.7	2.2	3.6	5.4
Denmark	Copenhagen	55.63° N	14200	0.7	2.1	3.5	5.3
Sweden	Stockholm	59.65° N	12100	0.8	2.5	4.1	6.2
Iceland	Reykjavik	64.13° N	11500	0.9	2.6	4.3	6.5

ces where daylighting is hindering to the work to be performed.

7.1. Daylighting

Evaluation of daylighting is based on the annual availability of the diffuse horizontal illuminance $E_{v,d}$ in the specific locality. As a reference value is proposed as a climatological parameter the median diffuse horizontal skylight illuminance $E_{v,d,med}$, Fig. 8. These medians can be determined from long term regular daylighting measurement or satellite data for any locality.

Application of median illuminance indicates that interiors will be satisfactory illuminated over the summer half year, but during the rest half year, intensities of daylighting are lower and natural light should be supplemented by artificial light. The minimum daylight provision is considered if a minimum target illuminance level is achieved across a percentage of the relevant area of the space for at least 50 % of the daylight hours. Minimum illuminance level 100 lx and adequate level 300 lx represent criteria for just acceptable natural illuminance in interiors. Moreover, it is possible to apply the categories 500 lx and 750 lx of indoor illuminance in the case of requirements for performance of more precise visual tasks over a fraction of the relevant area, e.g. 50 % of the space. If values of indoor illuminance level E_i and median diffuse horizontal skylight illuminance $E_{v,d,med}$ are determined, the Minimum Target Daylight Factor D_{TM} and Target Daylight Factor D_T can be calculated either for indoor illuminance 100 lx as:

$$D_{TM} = \frac{E_i}{E_{v,d,med}} = \frac{100}{E_{v,d,med}} \; [\%], \qquad (3)$$

or for at least indoor illuminance $E_{T,i}$ = 300 lx, 500 lx and 750 lx as:

$$D_T = \frac{E_i}{E_{v,d,med}} = \begin{cases} 100\dfrac{300}{E_{v,d,med}} \\ 100\dfrac{500}{E_{v,d,med}} \\ 100\dfrac{750}{E_{v,d,med}} \end{cases} [\%]. \qquad (4)$$

Inserting a value of $E_{v,d,med}$ into (3) or (4) it is possible to calculate Minimum Target Daylight Factor D_{TM} or Target Daylight Factor D_T for any arbitrary locality, Table 3. It is important to realise that D_{TM} or D_T are not equal to any Daylight or Sky Factor used earlier, because the basic assumption of overcast sky is untrue.

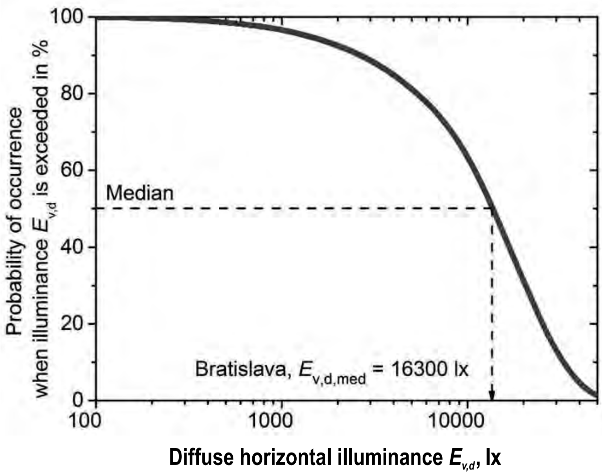


Fig. 8. Median diffuse horizontal skylight illuminance $E_{v,\ d,\ med}$ for Bratislava

Value $E_{v,\ d,\ med}$ = 16300 lx was determined for Bratislava (geographical latitude ϕ = 48,20° N) [69] and it is included in the EN standard proposal [70]. If $E_{v,\ d,\ med}$ = 16300 lx will be applied, then criterion for acceptable minimum daylighting D_{TM} = 0.61 % ~ 0.6 % and should be exceeded over 100 % of the space. Criterion for adequate daylight illumination of at least 300 lx on the working plane over 50 % of the space will be $D_{T,300}$ = 1.84 % ~ 1.8 %.

It is important to notice, that statistical parameter median represents the centre of the available levels of illuminances occurring in the nature, so also in the specific locality. That means, the utilisation of sufficient daylight in interiors is only during half of the year. If interiors are currently illuminated by daylight longer time than 50 % of the year time, there is a risk that in new constructed buildings of the same type will be designed windows of smaller dimensions and consumption of energy for electric lighting will rise. Contrary to this, the energy can be saved in those type of buildings which are illuminated by the artificial lighting more than half of the year.

The methodological derivation of D_{TM} and D_T assumes statistical evaluation of yearly diffuse illuminance data resulting from a mixture of various sky situations. It is important to realise that the Target Daylight Factors do not correspond to the Daylight Factor representing overcast sky conditions defined in ILV [62], therefore these two parameters cannot be exchanged.

Daylighting is evaluated in the grid of points on the reference level 0.85 m above the floor with a perimeter of the grid is 0.5 m from side walls.

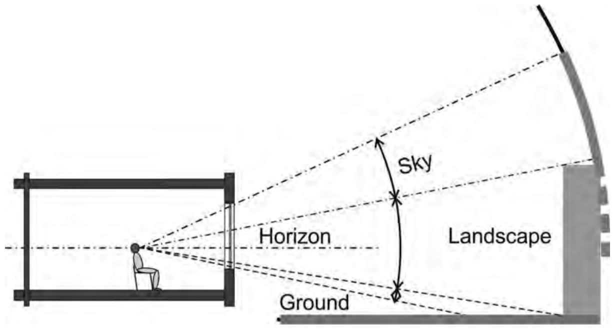


Fig. 9. Composition of the good view

7.2. View

Indoor spaces regularly occupied by people should provide good view to outside to supply information for orientation, weather and changing of the outside scene. View is standardized in three levels with specific functions: a layer of sky, a layer of landscape and a layer of ground, Fig. 9. The most important view layer for human eyes is view to sky because of accommodation of eyes to infinity and sky colour stimulating processes of various organs.

Standard prescribes minimum sight angle, outside distance of the view and position of the reference points (1.2 m for sitting person and 1.7 m for standing person). Minimum distance between room façade and opposite building façade has to be 6 m.

7.3. Sunlight

People in residential buildings or family houses are very sensitive to access of sunlight mainly in Central and Northern Europe. Generally, interiors in Southern European countries are rather protected against excessive overheating from the sun radiation. In these countries there are also people with reduced mobility, with various diseases, or children, which need to have access to sunlight in interiors. The recommended insolation is at least 1.5 hour on a selected date between February 1st and March 21st in apartments of residential buildings or family houses, patient rooms in hospitals and play rooms in nurseries. Possible sunlight duration is considered when solar altitude γ_s is higher than minimum and sun disk is not shaded by surrounding obstructions. Evaluation reference point P is located minimum 1.2 m above the floor and 0.3 m above the sill in the middle of the window width, Figs. 10, 11.

Value of the minimum solar altitude γ_s is determined for all capital cities of CEN member countries after a rule that orientation of the window nor-

Table 4. The Minimum Solar Altitude γ_s on March 21st when Sunlight Duration is 1.5 Hour, [70]

Country	Capital city	Geographical latitude, deg	Minimum solar altitude γ_s, deg
Spain	Madrid	40.45° N	19
Croatia	Zagreb	45.48° N	15
Slovakia	Bratislava	48.20° N	14
Belgium	Brussels	50.90° N	12
Germany	Berlin	52.47° N	11
Denmark	Copenhagen	55.63° N	10
Sweden	Stockholm	59.65° N	8
Iceland	Reykjavik	64.13° N	6

mal n can be considered up to 120° from South to East or clockwise to West, Fig. 11. Values of the minimum solar altitudes γ_s for selected capital cities with the reference day March 21st and sunlight duration 1.5 hour are presented in Table 4. The value of minimum solar altitude for other cities, reference day and sunlight duration can be determined considering the position of the window normal 120° from South.

7.4. Glare

Indoor spaces are illuminated through windows or skylights which can be categorised as large light sources. Glare can be caused by direct or reflected sunlight or by very bright clouds seen in windows during sunny situations. The proposed method applying the parameter Daylight Glare Probability *DGP* based on the formula (5) is standardized. The *DGP* defines measurable physical quantities causing glare from daylight sources.

$$DGP = 5.87\times10^{-5}\times E_v + 9.18\times10^{-2}\times \times log\left(1+\sum_i \frac{L_{s,i}^2\times\omega_{s,i}}{E_v^{1.87}\times P_i^2}\right)+0.16, \quad (5)$$

where E_v is the vertical illuminance at the eye level [lx],

P is the position index,

L_s is the luminance of glare source [cd/m²],

ω_s is the solid angle subtended by glare source,

i is the number of glare sources.

The *DGP* method can be applied in side lit indoor spaces where activities comparable to reading and writing are expected. *DGP* cannot be applied in spaces illuminated by horizontal openings and in position located far away from the window, or where the low levels of daylighting are.

It is important to notice that the method UGR applied in glare evaluation from artificial lighting sources cannot be used for evaluation of glare from natural light sources, e.g. from sun.

8. FUTURE DEVELOPMENTS

We have observed a technological and social development paradox, i.e. very precise and detail results are sent from science and research activities but there are low absorption limits of the praxis. Praxis in daylight design and production of daylight technologies expects simple solutions, which are not expensive, are without extra qualification requirements and consume minimum labour time and

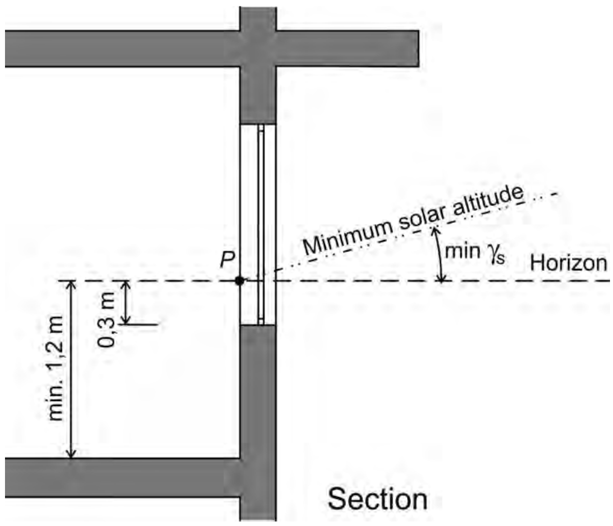


Fig. 10. Placement of reference point for evaluation of sunlight duration

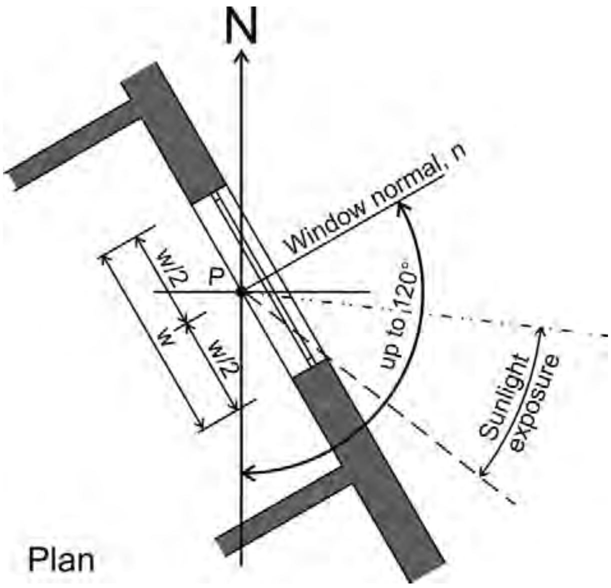


Fig. 11. Scheme of possible window orientation, with the farthest direction from South to East

energy. Quality of outcomes is often taken as a secondary point of interest. Therefore, standards and regulations as engine of activity, rules and development should be applied as basic in lighting engineering. As was mentioned the standardization is specific and an important process in the technical area, which influences the quality of products, visual environment and well-being of occupants in buildings.

For many centuries, human needs are practically the same conditions, but for their accomplishment requirements, assumption, tools and technologies are permanently changing from primitive to more and more sophisticate. New scientific knowledge, technologies and current computerisation leads to study detail relation between natural light conditions and human needs and form a new quality of indoor visual environment. There are several aspects determining trends in future development in the area of interior natural lighting.

8.1. Health

Because all buildings are constructed for people, therefore, imperative for current and future trends is to stimulate health conditions of occupants during their activities and rest by designing indoor illuminance. Daylight as natural source of indoor illumination has to be accessible for all people without any form of discrimination everywhere. Especially spaces designed for children or elderly people must be designed with daylight apertures.

8.2. Science

New research activities are named with a new title but often are periodically solved as the same subjects with new methods and tools. It is very important to formulate problems on the base of photometry, human physiology and psychology in the daylight science. Applying other quantities, e.g. radiant or rating should be avoided because it can incorporate extra errors and substantial deform quality of visual environment and interpretation of achieved results.

Daylight science should be based on the real precise measurements of the sky and sun characteristics as primary daylight sources. There is some information about local daylight availability or daylight climate worldwide. To utilise more effective daylight in interiors its occurrence and dynamic changes should be evaluated in physical units.

The description of spectral properties of daylight sources, colour rendering in the indoors and aspects of the chronobiology matching with artificial sources can be expected in the future research process. New knowledge should be transferred also in to the standardization process with relevant verifiable criteria.

Future research of day and artificial lighting should prove whether less light with daylight than with electric light is sufficient to perform the same visual task [120]. This phenomenon does not allow exchanging quantitative expressions of artificial lighting standard criteria to daylighting and vice versa.

View into near future

The luminous solar constant is one of the basic parameters applied in daylight calculations [121]. To achieve comparable results of daylight solutions the value of the luminous constant should be standardized worldwide.

View into distant future

The standard [70] leaves the classical static approach for daylight evaluation in interiors and brings an opportunity to develop new climatic evaluation methods and tools. Some problem can occur when the statistical parameter as median of daylight availability should be verified. As was mentioned, the sky luminance distribution is crucial in modelling of temporal indoor illuminance. This problem can be studied due to analysis of characteristics of standard sky samples compared with parameters of statistically derived criteria. This approach can be inspiring also for standardization in the simulation of annual daylight availability.

View into horizon close to infinity

Nobody knows what will be in the next century but our civilisation has ambition to conquer the cosmos. As was indicated by Darula in [122], daylight will still be a crucial component of indoor environment. Conditions for life on the Earth and in the Space are totally different. We can expect that new light sources and constructions of luminaires will be developed to supplement natural light source. It is important to respect temporal human physiological needs not to destroy natural body functions. Approach to daylight design can result in the revision of several definitions in lighting engineering.

8.3. Technology

In interior spaces with insufficient daylight the artificial light will be adapted as much as to daylight and will be more and more applied. There is discussion about solutions of artificial sources simulating daylight. Measurements of daily illuminance courses at CIE IDMP stations show, that each exterior daylight situation is original without repetition. Simulation of daylight by artificial sources will require development of such technologies which will produce synthetic lighting situation without repetitions, with intensity changes, relevant colour and dynamic characteristics, and similar influences on human body comparable to daylight courses.

8.4. Economy

Without money, there is no music. Skylight and sunlight are received on the Earth without costs but utilization of daylight and its control in interiors requires investment costs for assembly daylight technologies and costs for their operation. Generally, proper design of natural illumination can save money because electric lighting is switch off when daylight is utilized. New standard [70] is the first bridge for better official application of supplementary lighting and application of artificial lighting in situations with undervalued daylighting.

8.5. Energy

Energy plays an important role in all industrial and tertiary branches in last decades. Energy has become a commodity and its importance will rise also in the future. Tendency is to apply technologies with the lowest energy consumption. This trend is true if respected human needs and will be applied with cheap and effective daylight devices without waste production because nature works without waste.

8.6. Society

Behaviour and expectance of occupants to utilize daylight and sunlight are determined by climatic conditions and activities inside. Generally, people like well lit and sunny rooms in residential buildings. Criteria of standards and system of operation of daylight devices can significantly influence the quality of indoor luminous environment. One can expect redistribution of manual works to more intelligent while people will be more and more replace by robots and computer algorithms in the working process. This can create new conditions for illumination of work places with respect to needs for human, artificial intelligence and coincidence of both.

9. CONCLUSIONS

The gradual progress and development of human civilization and culture were determined by basic needs of mankind and are partly oriented also towards the knowledge of:

– Determination of time and geographical orientation [123, 124] influenced by the sun coordinates or sun path changes with their repetition during years;

– Observation of the sky luminance pattern changes influenced by weather, atmospheric turbidity, cloud type and cover varieties;

– Influences of sunlight and skylight on building fronts with different orientation as well as their penetration through windows inside building interiors.

New knowledge about nature and light are basis for practical design and evaluation of natural and artificial indoor visual environment. Technical standards play a significant role in these activities due to criteria and recommendation. History is showing us, that in the countries with adopted technical standards the economic growth is higher than in other countries. Standards give rules, limits and allow checking effectiveness of lighting systems. Standards are expensive, require a regulatory authority for their administration, and can bring risk when their outcomes are not beneficial, therefore requirements must be realistic and testable [6]. Standards

Table 5. The Comparative Geographical Latitude φ and Longitude λ of Russian Cities with Selected CEN Cities

Russian city	φ, deg	λ, deg	CEN city	φ, deg	λ, deg
Makhachkala, Dagestan	42.58° N	47.30° E	Rome	41.90° N	12.50° E
Volgograd	48.71° N	44.51° E	Paris	48.87° N	2.3° E
Komsomolsk-on-Amur	50.57° N	137.00° E	Brussels	50.85° N	4.35° E
Irkutsk	52.28° N	104.28° E	Amsterdam	52.37° N	4.90° E
Moscow	55.75° N	37.62° E	Copenhagen	55.68° N	12.57° E
Saint Petersburg	59.93° N	30.39° E	Oslo	59.91° N	10.75° E
Archangelsk	64.55° N	40.56° E	Reykjavik	64.13° N	21.82° W
Murmansk	68.96° N	33.08° E			

should create basis for save minimum requirements, as is presented in this study, and, on the other hand, basis for development of industry, economical and society growth.

Standard criteria and rules in the lighting engineering should be based on the photometric quantities and variables. Conversion irradiance measurements to photometric variables should not be applied because of incorporating extra error depending on the quality of used algorithm.

Development in daylight practice is focused to the formulation of daylight climate conditions and looking for relevant criteria for window design and creation of human acceptable visual environment. The definition of daylight sources applicable in practice seems to be a crucial task for future research. Regular measurements of daylight variables should be carried out in the short intervals collecting instantaneous data. Hourly averages do not represent daylight situations momentary perceived by human eyes.

Standards also can contain useful information and paradigms for other parties. Daylight standardization can bring a rather fair and uniform agreement for a vast territory or states geographically prolonged in the North – South latitudes, e.g. in Russia or the European Union. Applying the same methodology [69] which was used in elaboration of the standard [70], it would seem possible to characterize median sky illuminance also in Russian cities, e.g. the comparable city geographical coordinates are presented in Table 5.

For Archangelsk, as representing the polar regions, is roughly similar to Reykjavik, geographical latitude circa 64.13 N.S. Petersburg is a region close to 60° latitude (approximately that of Helsinki, Stockholm and Oslo) influenced by its close distance to the Baltic Sea. Moscow is representing the continental Russian climate with the same latitude as Copenhagen. Volgograd is a major centre of Southern Russia with the geographical latitude close to Paris, Vienna and Bratislava. Furthermore, it would be wise to take into consideration also the extreme climates of Murmansk (68.96° N) on the far North Russian border or the most Southern border region of Dagestan with the same latitude as Rome. Of course, values of $E_{\mathrm{v,\,d,\,med}}$ will slightly differ because of local climate difference.

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Stanislav Darula,
Associate Professor, Ph. D. At present, he is senior researcher at Institute of Construction and Architecture, Slovak Academy of Sciences. His professional interest is focus on the research of daylight phenomena, daylight availability, daylight standardization and daylight design in buildings. He is national member of CIE Division 3, CEN TC169/WG 11 and participated in the elaboration of the European standard Daylight of buildings. As a member of the presidium of the Slovak Lighting Society and member of The Association of Slovak Scientific and Technological Societies as well as The Slovak Chamber of Civil Engineers he contributes in the activities in the research and popularization of illuminating engineering. At the Faculty of Civil Engineering of the Slovak University of Technology he is an external lecturer in the course of Building Physics

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A SIMPLE TECHNIQUE TO DETERMINE SNOW PROPERTIES USING LIGHT REFLECTANCE MEASUREMENTS

Alexander A. Kokhanovsky

VITROCISET Belgium SPRL, Darmstadt, Germany
E-mail: a.kokhanovsky@vitrocisetbelgium.com

All models are wrong but some are useful
George E.P. Box

Devoted to memory of G.V. Rozenberg (1914–1982)

ABSTRACT

In this paper we review theoretical foundations of reflectance spectroscopy of snow. Simple approximate equations are presented, which can be used to calculate snow absorption/extinction coefficients and also snow reflectance. The equations derived could also be used to solve the inverse radiation transfer problem. The technique can be applied to other types of turbid media with large weakly absorbing particles. It has potential for the interpretation both: ground-based and airborne, or satellite, measurements of light reflected from cryosphere of our planet, and also has potential for applications to planetary imaging spectroscopy in general.

Keywords: reflectance spectroscopy, radiative transfer, light scattering, light absorption, light reflectance, inverse problem, snow, snow pollution, snow grain size, cryosphere, remote sensing

1. INTRODUCTION

Reflectance spectroscopy [1] is a standard tool for the characterization of turbid media such as soil, blood, paints, leaves, etc. It is based on the measurements of the light reflectance from a given sample as a function of the wavelength λ and is a rapidly growing science that can be used to derive significant information about various materials with little or no sample preparation. The reflectance spectroscopy is much simpler as compared to the transmittance spectroscopy for the case of turbid media such as, say, rocks and minerals. It can be used to monitor various surfaces using airborne and satellite measurements. Also ground-based and ship-borne measurement systems based on the reflectance spectroscopy principles are often used.

In this paper a simple approach to the characterization of weakly absorbing strongly light scattering turbid media is reviewed and applied to the case of snow characterization (snow grain size, concentration, and pollution absorption coefficient/type). In the next section we shortly describe snow microphysics. Afterwards local optical characteristics of snow are discussed. Section 4 is aimed at studies of radiative transfer processes in snow. Then we solve the inverse radiative transfer problem for natural snow (section 5) and summarize the results.

2. SNOW MICROPHYSICS

Snow grains originate from precipitating crystalline clouds. Therefore, as in ice clouds, grains have very diverse shapes. Snow metamorphism is driven by gradients in vapour pressure, which in turn are driven by temperature gradients. Small temperature gradients (less than 10 degree per meter) result in small vapour pressure gradients and slow grain growth within the snowpack. The result is the formation of rounded snow grains that tend to be

0.1 to 0.2 mm in diameter. One explanation for the formation of rounded snow grains is that vapour diffusion within the snowpack causes a loss of mass from points on individual snow grains to gains in mass in hollows. Depth hoar forms in areas of a snowpack where temperature gradients are greater than 10ºC per meter. The process of forming these snow grains has a number of synonyms, including the historical term of temperature gradient metamorphism (TG metamorphism), constructive metamorphism, and kinetic growth. The large temperature gradient induces a large gradient in vapour pressure, such that water vapour moves from warmer areas of the snowpack with relatively higher vapour pressures across pore spaces to colder areas of the snowpack with lower vapour pressure. These conditions produce angular or faceted grains, which may later develop steps and striations on their surface, resulting in cup-shaped crystals with a hollow centre that generally range in size from (3–8) mm. Under very favourable conditions, individual grains can be larger than 15 mm.

The ice crystals in snow can be solid, hollow, broken, abraded, partly melts, rounded or angular. The surface of crystals can be rimed, stepped or striated. The rounded facets can be present as well. The crystals can be bounded, unbounded, clustered, or arranged in columns.

It is easy to derive the average radius of water cloud droplets characterized by the droplet size distribution

$$f(a):\ \bar{a}=\int_0^\infty af(a)da. \qquad (1)$$

Here a is the radius of droplets. The same procedure is not easy for snow because particles of different shapes and morphology present in snow. The practical way of the solution of this problem is the measurement of the largest snow grain size (diameter for spheres). The snow grain size as determined from optical measurements is close to the Sauter mean diameter d_{ef} defined as the diameter of the sphere having the same volume/surface area (*V/S*) ratio as an ice crystal of interest. This is due to the fact that clear snow spectral reflectance $R(\lambda)$ is determined mostly by the snow spectral single scattering albedo, which is primarily the function of d_{ef}. The value of d_{ef} for snow, having different shapes and sizes, is defined as follows:

$$d_{ef}=\frac{6\int_0^\infty Vf(V)dV}{\int_0^\infty Sf(S)dS}. \qquad (2)$$

Here $f(V)$ is the volume distribution function and $f(S)$ is the surface area distribution function. The integral in the nominator gives the average volume of grains and the dominator is the average surface area of the grains. It is clear that for the mono-dispersed spheres $d_{ef}=2_a$ and it follows for the spherical poly-dispersions:

$$d_{ef}=\frac{2\int_0^\infty a^3 f(a)da}{\int_0^\infty a^2 f(a)da}. \qquad (3)$$

Therefore, the ratio of the third to the second moment of the size distribution is involved in the definition of the Sauter mean diameter. The snow specific surface area (SSA) defined as the total surface area per unit of mass (m^2/kg) can be also related to the Sauter diameter:

$$SSA=\frac{6}{\rho d_{ef}}. \qquad (4)$$

Here $\rho=0.9167g/cm^3$ is the density of ice. Because spectral reflectance depends on diameter of snow grains, it can be used to derive both snow grain size and snow specific surface area, which are important parameters for many applications including snow pollution and climate research.

The snow water equivalent (SWE) is defined as the depth of *water* that would theoretically result if you melted the entire snowpack instantaneously. It can be estimated as follows:

$$\text{SWE}=\rho_s l. \qquad (5)$$

Here l is the depth of the snowpack and ρ_s is the snow density ((0.1–0.8) g/cm^3 depending on snow type). The SSA and SWE are characteristics of snowpack needed for numerous applications. Therefore, they are measured routinely in field and also derived using remote sensing techniques. The value of l can be derived with airborne laser systems us-

Table 1. The Concentration of Soot in Snow in Different Areas [2]

Location	Black carbon concentration (ng/g)
South Pole	0.1–0.3
Summit, Greenland	1–30
Spitzbergen	7–52
Barrow	7–60
Alert, N. Canada	0–127
French Alps	4–826
Urban Michigan	17–5700

ing as a reference terrain not covered by snow (say, in summer).

Natural snow contains various types of pollutants. They originate from atmosphere (e.g., aerosol particles such as dust, soot, etc.), are of biological nature (e.g., algae) or from neighbouring objects such as trees (litter, tree brunches, etc.), rocks, and neighbouring bare soil. The extreme forms of snow pollution are well documented. Although the pristine snow fields are more common. Typical concentrations of soot in snow in different areas are given in Table 1. One can see that the more pure snow is in Antarctica. This is due to large distance to pollution sources. Nevertheless, the snow pollution due to biological material occurs in Antarctica as well.

One important applied problem is the determination of concentration/type of pollutants in snow. The concentration of Table 1 pollutants can be assessed studying level of snow darkening in the visible. The type of pollutants (algae, soot, dust) can be estimated from the spectral shape of measured snow reflectance.

3. LOCAL OPTICAL CHARACTERISTICS OF SNOW

3.1. Light Extinction in Snow

Extinction coefficient σ_{ext} is the basic quantity for any turbid medium. It shows how fast the direct light beam attenuates in the medium due to combined scattering and absorption processes. In particular, it follows:

$$I = I_0 \exp(-\sigma_{ext} l), \tag{6}$$

where l is the *geometrical thickness* of a snow sample, I is the intensity of transmitted light and I_0 is the intensity of incident light. The measurements of spectral extinction coefficients of homogeneous media are quite simple and can be derived from equation given above. This task is not so easy for snow samples because one must remove the contribution of multiply scattering light into the detector. The extinction coefficient is defined via the extinction cross section C_{ext} using the following equation:

$$\sigma_{ext} = N < C_{ext} >, \tag{7}$$

where N is the number of snow grains in unit volume. It is known that for large scatters, the value of C_{ext} is equal to the double of the cross sectional area A (perpendicular to the incident beam) of the particle. Therefore, one derives:

$$\sigma_{ext} = 2AN. \tag{8}$$

The value of N can be expressed via the volume concentration of particles c and the average volume of particles:

$$N = \frac{c}{\langle V \rangle}. \tag{9}$$

Then it follows:

$$\sigma_{ext} = \frac{c}{p}, \tag{10}$$

where the parameter p is given by the following equation:

$$p = \frac{\langle V \rangle}{2\langle A \rangle}. \tag{11}$$

In case of convex particles, the average cross section (at random orientation) coincides with the average surface area of particles multiplied by 4 [3]. Therefore, one derives:

$$p = \frac{2\langle V \rangle}{\langle S \rangle}. \tag{12}$$

Many particles in snow can have concave forms. Then Eq. (12) must be modified:

$$p = \upsilon\langle V\rangle / \langle S\rangle,$$

where the parameter υ depends on the type of snow.

Let us introduce the average diameter of particles:

$$d_{ef} = \frac{6\langle V\rangle}{\langle S\rangle}. \tag{13}$$

Then it follows: $p = d_{ef} / 3$ and, therefore,

$$\sigma_{ext} = \frac{3c}{d_{ef}}, \tag{14}$$

where we have assumed that grains have convex shapes (say, rounded ice particles). Taking into account that c is often close to 1/3 for snow, one derives: $\sigma_{ext} \approx 1/d_{ef}$. Therefore, the light extinction length $L_{ext} = 1/\sigma_{ext}$ in snow is approximately equal to the effective snow grain diameter.

3.2. Scattering of Light in Snow

Snow reflective properties are determined by light scattering and absorption processes inside snow cover. In assumption that close packing effects can be ignored one can use the physical optics approximation for the calculation of the angular scattering pattern by a single ice grain. In this approximation one may assume that the phase function of an ice grain can be presented as a sum of two parts: diffraction part and geometrical optics part. The result for the phase function can be written in the following way:

$$p(\theta) = \frac{C_{sca,d}\, p_{sca,d}(\theta) + C_{sca,g}\, p_{sca,go}(\theta)}{C_{sca,d} + C_{sca,go}}, \tag{15}$$

where $C_{sca,d}$ is the diffraction part of the scattering cross section, $C_{sca,go}$ is the geometrical optics part of the scattering cross section C_{sca}, $p_{sca,d}(\theta)$ is the diffraction contribution to the total phase function, and $p_{sca,go}(\theta)$ is the geometrical optics contribution to the total phase function. The phase function is normalized as follows:

$$\frac{1}{2}\int_0^{\pi} p(\theta)\sin\theta\, d\theta = 1, \tag{16}$$

where θ is the scattering angle equal to zero in forward scattering direction and 180 degrees in the backward direction. In case of equal probability for light scattering by a scatterer at any scattering angle, one can easily derive: $p = 1$ (isotropic scattering). For large ice grains, there is a pronounced asymmetry in light scattering pattern: most of light scatterers in the forward scattering region. Asymmetry of phase function is described by the asymmetry parameter

$$g = \frac{1}{2}\int_0^{\pi} p(\theta)\cos\theta\sin\theta\, d\theta, \tag{17}$$

which is equal to the average cosine of scattering angle. One case also introduce the parameter symmetry $s=1-g$. Clearly, the value of s is equal to 1 for the case of isotropic scattering ($g=0$). It follows from Eqs. (15), (17):

$$g = \frac{C_{sca,d}\, g_d + C_{sca,g}\, g_g}{C_{sca,d} + C_{sca,g}}. \tag{18}$$

In case of large non absorbing grains one can derive [3]: $C_{sca,d}=C_{sca,go}$ and, therefore,

$$g = \frac{1 + g_{go}}{2}, \tag{19}$$

where we accounted for the fact that the diffraction occurs in the forward scattering direction and, therefore, $g_d = 1$. The measurements of g in ice clouds composed of irregular shaped particles [4] give values of g close to 0.75, and, therefore, g_{go}=1/2. The value of g_{go} depends on the shape of particles and also on the refractive index, being larger for rounded scatterers and also for weakly refracting particles with the real part of refractive index close to 1. The snow phase functions are difficult to measure and, therefore, for modelling purposes it is assumed that they are close to phase functions of ice clouds composed of large irregular ice grains. Such phase functions are featureless and almost constant at the backward scattering hemisphere. They produce featureless snow reflectance patterns. In particular rainbows and glories seen in reflected light for water clouds are never observed for snow covers. The equations presented above are valid for a single snow grain. Therefore, the averaging procedure shall be applied to get the local snow optical properties. In particular, it follows for the snow phase function:

$$p_s(\theta) = \frac{< C_{sca,d}\, p_{sca,d}(\theta) > + < C_{sca,g}\, p_{sca,go}(\theta) >}{< C_{sca,d} > + < C_{sca,go} >}, \quad (20)$$

where angular brackets mean averaging with respect to the size of snow grains and also their shapes. The following expression can be derived for the snow asymmetry parameter:

$$g = \frac{< C_{sca,d} > + < C_{sca,g}\, g_{go} >}{< C_{sca,d} > + < C_{sca,go} >}, \quad (21)$$

where we have taking into account that the asymmetry parameter for the diffraction part is close to one. For non absorbing particles, g_{go} does not depend on the size of particles and one can derive:

$$g = \frac{1 + < g_{go} >}{2}, \quad (22)$$

where angular brackets mean averaging with respect to the shape of particles we have taken into account that the geometrical optics and diffraction parts of average scattering cross sections coincide for nonspherical particles and have assumed that $< C_{sca,g}\, g_{go} > = < C_{sca,g} > < g_{go} >$.

The phase function of snow has not been measured *in situ* so far. This function is modelled assuming various shapes of crystals in the framework of geometrical optics (ray tracing). The application of geometrical optics is possible because ice grains are much larger as compared to the wavelength of the incident light. This simplifies the problem in great extent avoiding the use of Maxwell theory, which does not lead to the closed form solutions for the irregularly shaped particles. The parameterizations of the snow phase function useful for studies of radiation transport in crystalline clouds and snow has been developed in [5, 6].

3.3. Light Absorption in Snow

Snow grains not only scatter light but also some portion of light is absorbed by snow grains. The absorption processes can be neglected in the visible. However, they are of importance in the near infrared, where ice absorbs light with various degrees of strength depending on the actual wavelength. The absorption cross section C_{abs} of a single ice grain can be presented in the following form:

$$C_{abs} = \frac{k}{|\vec{E}_0|^2} \int_V \varepsilon''(\vec{r}) \vec{E}(\vec{r}) \vec{E}^*(\vec{r})\, d^3\vec{r}. \quad (23)$$

Here, $k = \frac{2\pi}{\lambda}$ is the wave number, V is the volume of an ice grain, $\varepsilon''(\vec{r}) = 2n\chi$ is the imaginary part of the relative dielectric permittivity of a particle, $m = n - i\chi$ is the complex refractive index of ice grain, $\vec{E}_0$ is the incident electric field, $\vec{E}(\vec{r})$ is the electric field inside the particle. Let us introduce the average normalized intensity of light inside the particle:

$$\Pi = \frac{1}{V} \int_V \frac{|\vec{E}(\vec{r})|^2}{|\vec{E}_0|^2} d^3\vec{r}. \quad (24)$$

Then it follows from Eq. (23) assuming that the particle is internally homogeneous:

$$C_{abs} = n\alpha \Pi V, \quad (25)$$

where the factor Π depends on the size, shape, and complex refractive index of particles and $\alpha = 2k\chi$. It is clear that the value of Π is close to one for weakly absorbing particles as $n \to 1$ because it follows in this case: $\vec{E}(\vec{r}) \approx \vec{E}_0(r)$. Therefore, one derives:

$$C_{abs} = \alpha V. \quad (26)$$

For large non absorbing particles with large differences $\Delta n = n - 1$, the value of Π also does not depend on the size of particles [7]. This is also approximately true for absorbing particles, if $\chi / n << 1$, $\chi x << 1$ (valid for snow in the visible and near – infrared). Here $x = ka$ is the size parameter, a is the characteristic size (radius for monodispersed spheres) of a scatterer. Therefore, Eq. (26) is modified:

$$C_{abs} = B\alpha V, \quad (27)$$

where B depends on the shape of particles and real part of n but not on the size of particles. The experimental measurements of the value of B for the natural snow has been performed in [8]. It has been found that the average value of B is 1.6 with some variation depending on the actual snow type. The value of B for spherical ice grains is close to 1.25 [9]. Therefore, it follows that the use of spherical approximation will lead to underestimation of snow absorption and overestimation of snow reflectance.

The absorption coefficient:

$$\sigma_{abs} = N\langle C_{abs}\rangle, \quad (28)$$

can be presented, therefore, in the following form:

$$\sigma_{abs} = B\alpha c, \quad (29)$$

where c is the volumetric concentration of snow grains equal to the ratio of snow ρ_s and ice ρ_i densities. This ratio is close to 1/3 for many types of snow. This means that the absorption coefficient of snow is approximately two times smaller as compared to that of bulk ice and has almost the same spectral behaviour as bulk ice in the visible and near infrared regions of the electromagnetic spectrum. The result presented above is valid only for the case of weakly absorbing snow grains. It must be modified in case of moderate and strongly absorbing particles (say, ice grains at 1.6 and 2.1 microns, where light absorption by large snow grains is outside weak absorption limit).

3.4. Local Optical Properties of Polluted Snow

Polluted snow is composed of ice grains and various pollutants (dust, soot, algae, etc.). The local optical properties can be found assuming external mixing rules for the extinction coefficient, absorption coefficient, and phase function:

$$\sigma_{ext} = \sigma_{ext,i} + \sigma_{ext,p} \equiv N_i\bar{C}_{ext,i} + \sum_{p=1}^{N} N_p\bar{C}_{ext,p}, \quad (30)$$

$$\sigma_{abs} = \sigma_{abs,i} + \sigma_{abs,p} \equiv N_i\bar{C}_{abs,i} + \sum_{p=1}^{N} N_p\bar{C}_{abs,p}, \quad (31)$$

$$p(\theta) = \frac{\bar{C}_{sca,i}\, p_{sca,i}(\theta) + \sum_{p=1}^{N} \bar{C}_{sca,p}\, p_{sca,p}(\theta)}{\bar{C}_{sca,i} + \sum_{p=1}^{N} \bar{C}_{sca,p}}, \quad (32)$$

where indices i, p is signify the contribution of ice (i) and N pollutants (p) and the scattering cross section:

$$C_{sca} = C_{ext} - C_{abs}. \quad (33)$$

In most of cases one needs to account for the presence of just one ($N=1$) pollutant (let's us say soot). Also in many cases scattering of light by pollutants is small with absorption processes predominated. Then one needs to account for the presence of pollutants just in calculation of absorption coefficient. Although such assumptions are often used in snow applied optics they may lead to biases in calculations because in reality pollutants can have large optical sizes and concentrations. Then one can not ignore scattering of light by pollutant particles anymore. Also some pollutants can be internally mixed [10].

4. RADIATIVE TRANSFER IN SNOW

4.1. Radiative Transfer Equation Approach

The snow radiative transfer characteristics are usually studied in the framework of scalar radiative transfer theory. Therefore, the well known radiative transfer equation (RTE) for the intensity of light filed I given below is solved (for a given direction specified by a solid angle Ω) [11]:

$$\mu\frac{dI(\Omega)}{d\tau} = -I + \frac{\omega_0}{4\pi}\int_{\Omega} p(\Omega',\Omega) I(\Omega')\, d\Omega', \quad (33)$$

where we have assumed that snow can be presented as a horizontally homogeneous plane-parallel light scattering layer and effects of thermal emission can be ignored, which is certainly true in the visible and near IR regions of electromagnetic spectrum. Here, μ is the cosine of the viewing zenith angle counted from the normal to the snow layer, $\omega_0 = 1 - \sigma_{abs}/\sigma_{ext}$ is the single scattering albedo, and we have introduced the snow optical depth (SOD) $\tau = \sigma_{ext} l$.

For inhomogeneous layers, SOD is defined as an integral of the extinction coefficient via vertical coordinate. In reality, due to accumulation processes (say, several snowfalls and pollution deposition events) snow has a layered structure and assumption of a vertically homogeneous layer must be taken with precaution.

RTE can be solved using a number of numerical and approximate analytical techniques providing the dependence of the intensity of reflected, transmitted and internal light field I on a number important parameters such as snow grain size, snow grain shape, snow density, type, concentration of pollutants, size distribution of various pollutants, snow thickness. The snow layer albedo and absorptance can be also calculated.

The influence of underlying surface reflectance (let's say for thin snow layers) can be also studied using appropriate boundary conditions.

It should be pointed out that RTE given above assumes that particles in a scattering layer are not oriented (random distribution of irregular shaped particles) and also they are not in contact and at large distances one from another. The second condition is actually violated for snow because volumetric concentration of ice grains is about 0.3. Therefore, the application of the standard for of RTE can lead to large errors. This is certainly true in the thermal infrared in microwave regions of the electromagnetic spectrum. However, experimental measurements of snow reflectance show that standard RTE can be applied in the visible and near infrared range of electromagnetic spectrum [12]. This is due to the fact that light scattering in snow occurs in geometrical optics domain because the grains are typically have the sizes (100–1000) times larger as compared to the wavelength of the incident light. Also the particles are irregularly shaped. Therefore, dense media effects are washed out.

4.2. Analytical Approximation of the Snow Spectral Reflectance

In applied research it is often desirable to have analytical equations relating the measured characteristics, let's say, snow layer spectral reflectivity, with snow microstructure parameters such as snow grain size and concentration of pollutants. This makes it possible to simplify the inverse problem solution. In this section we shall derive such an equation based on the statistical approach not directly relying on the RTE, which has limitations as far as dense media effects are of concern.

Let us consider the case of absorbing snow. The reflectance $R = \pi I / \mu_0 E_0$ (μ_0 is the cosine of the incident zenith angle, E_0 is the incident light flux on the unit area perpendicular to the incident beam) can be presented in the following way:

$$R(\beta) = \sum_{n=1}^{\infty} a_n (1-\beta)^n, \quad (34)$$

where $\beta = 1 - \omega_0$ is the probability of photon absorption (PPA) by unit volume of snow. In the case of non absorbing snow it follows:

$$R(0) = \sum_{n=1}^{\infty} a_n . \quad (35)$$

Therefore, one derives for $\Re = R(\beta)/R(0)$:

$$R = \frac{\sum_{n=1}^{\infty} a_n (1-\beta)^n}{\sum_{n=1}^{\infty} a_n}. \quad (36)$$

Expanding $(1-\beta)^n$ as $\beta \to 0$, we derive:

$$R \approx 1 - \beta < n > +$$
$$+ \frac{\beta^2}{2} < n^2 > - \frac{\beta^3}{6} < n^3 > + ... \approx < \exp(-\beta n) >, \quad (37)$$

where

$$\langle n^k \rangle \equiv \sum_{n=1}^{\infty} f_n n^k, \ \langle \exp(-\beta n) \rangle \equiv \sum_{n=1}^{\infty} f_n \exp(-\beta n),$$

$$f_n = \frac{a_n}{\sum_{n=1}^{\infty} a_n}, \quad (38)$$

and we assumed that $n(n-1) \approx n^2$, $n(n-1)(n-2) \approx n^3$, … in our derivations. This is possible because β is close to zero and the number of scattering events in snow is high in the visible and near infrared regions of the electromagnetic spectrum. For the same reason we have:

$$< \exp(-\beta n) > \approx \int_0^{\infty} f(n) \exp(-\beta n) dn. \quad (39)$$

This integral can be evaluated assuming the function $f(n)$. In particular, it follows from the random walk theory [13] that that the probability of a particle (photon) appearing at a given place, time, and direction after *large* number of iterations can be presented as

$$f(n)=\sqrt{\frac{\eta}{\pi}}n^{-3/2}\exp\left\{-\frac{\eta}{n}\right\}, \quad (40)$$

where the parameter η depends on the process studied. The substitution of Eq. (40) into Eq. (37), (39) gives:

$$R=\exp(-2\sqrt{\eta\beta}). \quad (41)$$

Therefore, we can write

$$R(\beta)=R_0\exp(-\sqrt{s\beta}), \quad (42)$$

where $R_0\equiv R(0)$, $s=4\eta$. This equation shows how the spectral snow reflectance depends on the probability of photon absorption β. The parameter s depends on the scattering and not on absorption processes and, therefore, one may assume that it does not depend on the wavelength for snow composed of large snow grains in contact. Eq. (42) is very general and can be applied to many types of light scattering media. It has been derived for the first time in [14]. In the next section we shall apply Eq. (42) for the interpretation of the experimentally measured snow spectral reflectance and also for the solution of the inverse radiative transfer problem for the case of a homogeneous semi-infinite snow layer.

The value of s can be related to the asymmetry parameter g of ice grains using asymptotic results of RTE valid as $\beta\to 0$. Then it follows [15]:

$$R(\beta)=R_0-yu(\mu_0)u(\mu), \quad (43)$$

where

$$y=4\sqrt{\frac{\beta}{3(1-g)}} \quad (44)$$

and

$$u_0(\mu_0)=\frac{3}{4}(\mu_0+\varphi(\mu_0)), \quad (45)$$

$$\varphi(\mu_0)=2\int_0^1\left\langle R_0(\mu_0,\mu)\right\rangle\mu^2d\mu, \quad (46)$$

$$\left\langle R_0(\mu_0,\mu)\right\rangle=\frac{1}{2\pi}\int_0^1 R_0(\mu,\mu_0,\psi)d\psi. \quad (47)$$

One can show [16] that the following approximation holds:

$$u(\mu_0)=\frac{3}{7}[1+2\mu_0]. \quad (48)$$

Comparing Eqs. (43) and (42) (at small values of PPA), one derives:

$$s=\frac{16u^2(\mu_0)u^2(\mu)}{3(1-g)R_0^2(\mu_0,\mu,\psi)}. \quad (49)$$

5. THE APPROXIMATE SOLUTION OF THE INVERSE RADIATIVE TRANSFER PROBLEM

Equations presented above can be used to establish the analytical relationship between the snow spectral reflectance and diameter of ice grains. To simplify, we assume that there is just one type of pollutant in snow. Then it follows for PPA:

$$\beta=\frac{\sigma_{abs,i}+\sigma_{abs,p}}{\sigma_{ext,i}+\sigma_{ext,p}}, \quad (50)$$

where indices *i*, *p* are signify ice grains and pollutants, respectively. Under assumption, that extinction of light by pollutant is much smaller (see Table 1) as compared to that by ice grains, one derives (Eqs. (14), (29)):

$$\beta=\left[\frac{B\alpha(\lambda)}{3}+\frac{\sigma_{abs,p}(\lambda)}{3c_i}\right]d_{ef} \quad (51)$$

and, therefore,

$$R(\lambda)=R_0\exp\left\{-\sqrt{\left[\alpha(\lambda)+F\sigma_{abs,p}(\lambda)\right]D}\right\}, \quad (52)$$

where

$$F=\frac{1}{Bc_i}, \quad (53)$$

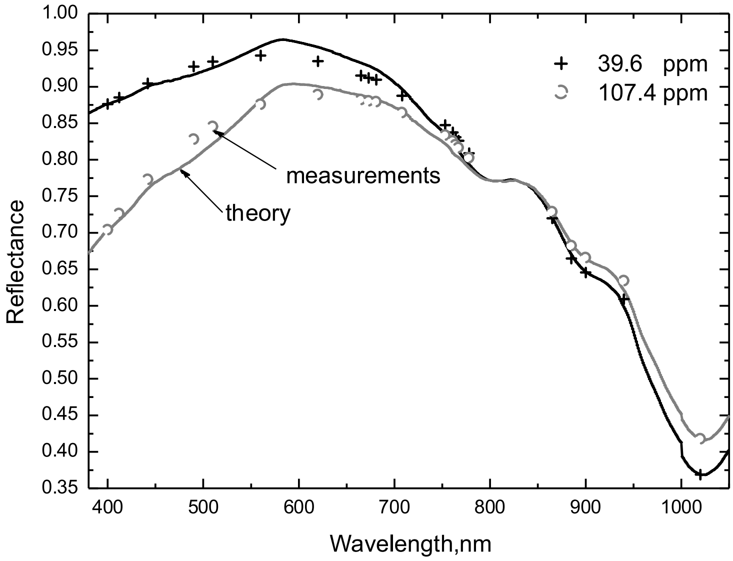

Fig. 1. The spectral reflectance of dust – polluted (with dust concentration 39.6 and 107.4 ppm) snow measured in European Alps as described in [17] and theoretical modelling according Eq. (57) with the bulk ice absorption [19] coefficient calculated using the spectral ice refractive index tabulated in. The derived values of m, d_{ef} were 4.1, 2.5 mm for the case of weakly polluted and 6.4, 1.5 mm, respectively, for the case of strongly polluted snow. The derived absorption coefficient of pollutants at the wavelength 560 nm was 0.12 for the weakly polluted (39.6 ppm) snow and 0.31 for the strongly polluted (107.4 ppm) snow under assumption that the volumetric concentration of ice grains is 0.3. The observation has been performed in the nadir direction at the solar zenith angle equal to 52 degrees

$$D = \frac{B}{3} s d_{ef}. \quad (54)$$

In case of pure snow Eq. (52) is simplified:

$$R(\lambda) = R_0 \exp\left\{-\sqrt{\alpha(\lambda) D}\right\}. \quad (55)$$

Because the spectrum of the bulk ice absorption coefficient is a well known function $\alpha(\lambda)$ one can see that just two parameters (D, R_0) are suffice to determine the clear snow reflectance spectrum in the visible and near infrared. These two parameters can be derived from measurements at two wavelengths 0.4 and 1.02 micrometers providing simultaneously snow grain size/SSA and R_0.

The absorption of pollutants can be parameterized as follows [17]:

$$\sigma_{abs,p}(\lambda) = c_p \kappa \tilde{\lambda}^{-m}, \quad (56)$$

where c_p is the volumetric concentration of pollutants, κ is the absorption coefficient of pollutants normalized at the wavelength λ_0 to the value of c_p, $\tilde{\lambda} = \lambda / \lambda_0$. Then it follows (see Eqs. (52), (56)):

$$R(\lambda) = R_0 \exp\left\{-\sqrt{\left[\alpha(\lambda) + \Phi \tilde{\lambda}^{-m}(\lambda)\right] D}\right\}, \quad (57)$$

where

$$\Phi = \frac{\tilde{c}_p \kappa}{B} \quad (58)$$

and

$$\tilde{c}_p = \frac{c_p}{c_i}. \quad (59)$$

Eq. (57) can be used to find the parameters R_0, D, Φ, m using, e.g., optimal estimation approach [18].

This enables the determination of the effective ice grain sizes ($d_{ef} = 3D / Bs$, see Eq. (54)) and also the spectral absorption coefficient of pollutants (at known values of concentration of ice grains, see Eqs. (56), (58), (59)).

Knowing the volumetric absorption coefficient of pollutants

$$\kappa = \frac{\bar{C}_{abs}(\lambda_0)}{\bar{V}_p}, \quad (60)$$

where $\bar{V}_p$ is the average volume of impurity particles, $\bar{C}_{abs}(\lambda_0)$ is the average absorption cross section of impurity particles, one can also find the normalized concentration of pollutants (say, soot) in snow (see Eqs. (58), (59)), which as an important applied problem. The four unknown parameters can be also found from Eq. (57) analytically from measurements at four wavelengths assuming that absorption of ice grains is negligible at the wavelengths λ_1, λ_2 in the visble and the absorptance of light by pollutants can be neglected in near – infrared, where bulk ice absorbs stronger (at the wavelengths λ_3, λ_4). The result is [17]

$$m = \frac{\ln(p_1 / p_2)}{\ln(\lambda_2 / \lambda_1)},\ \Phi = \frac{p_1 \tilde{\lambda}_1^m}{D}, R_0 = $$
$$= R_3^{\varepsilon_1} R_4^{\varepsilon_2},\ D = \alpha_4^{-1} \ln^2 \left[\frac{R_4}{R_0} \right], \qquad (61)$$

where $R_1, R_2, R_3,$ and R_4 are the reflectances measured at four wavelengths, $p_k = \ln^2(R_k / R_0)$, and

$$\varepsilon_1 = (1-b)^{-1},\ \varepsilon_2 = 1 - \varepsilon_1,\ b = \sqrt{\alpha_3 / \alpha_4},$$

is the bulk ice absorption coefficient at the wavelength $\lambda_{3(4)}$.
The application of this approach to the measurements of polluted snow spectral reflectance is given in Fig.1. The parameters given by Eq. (61) have been found at the following wavelengths: 400, 560, 865, and 1020nm. A similar approach but applied to the measurements of both snow reflectance and albedo is presented in [17].

6. CONCLUSIONS

In this paper we have reviewed the theoretical foundations of snow reflectance spectroscopy. Although, an accurate treatment of the problem must be based on the integro-differential radiative transfer equation, we show that the approximations given by Eqs. (52), (55), (57) simplify the problem in great extent making it possible to perform snow spectroscopy using inexpensive instruments and simple software based either on analytical solution of the inverse problem (see Eq. (61)) or optimal estimation technique. Our approach is valid not only for snow but also for other types of materials with large weakly absorbing scatterers.

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Alexander A. Kokhanovsky,
Doctor of Physical and Mathematical Sciences, Senior Research Scientist, VITROCISET Belgium SPRL. He has graduated from the Physics Department of the Belarussian State University in 1983. Dr. Kokhanovsky has received the Ph.D. in 1991 and degree of Doctor of Physical and Mathematical Sciences in 2011. Currently he is engaged in satellite remote sensing of terrestrial atmosphere and surface using optical instrumentation

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RESEARCH INTO INFLUENCE FROM DIFFERENT RANGES OF PAR RADIATION ON EFFICIENCY AND BIOCHEMICAL COMPOSITION OF GREEN SALAD FOLIAGE BIOMASS

Leonid B. Prikupets[1], George V. Boos[2], Vladislav G. Terekhov[1], and Ivan G. Tarakanov[3]

[1] VNISI of S.I. Vavilov, LLC, Moscow; [2] MPEI NRU, Moscow
[3] RSAU- MTAA (Moscow Timiryazev Agricultural Academy) of K.A. Timiryazev,
E-mail: prikup@vnisi.ru

ABSTRACT

Results of the first photobiological studies of optimisation of LED phyto irradiators spectrum and irradiance level, when growing salad-greengrocers plants in greenhouses and plant factories in photoculture conditions, are presented in the article. The results are given as a series of producing capacity curves for salad and basil plants when irradiating by quasi-monochromatic spectrum for three PAR ranges: blue, green and red. In the experiment, levels of photosynthetic photon irradiance (70 ÷ 230) μmol/s·m^2 and of irradiance (13 ÷ 60) W/m^2 were varied within a wide range. "Rough" spectra of optical radiation action estimated over producing capacity of plants with different irradiance levels are given, and questions of additivity of different spectral radiation influence in forming vegetable biomass are considered.

Evaluations of efficiency of various PAR intervals for synthesis of biochemical combinations determining nutrition facts of the studied cultures are performed.

Keywords: photobiological studies, productivity light curve, photosynthesis, photoculture, LED phytoirradiator (LED PI), photosynthetic active radiation (PAR), action spectrum, photosynthetic photon flux (PPF), photosynthetic photon flux density (PPFD)

1. INTRODUCTION

A possibility of creating quasi-monochromatic radiators based on light emitting diodes (LED) for main intervals of PAR range for facilitating biomass formation, morphogenesis and metabolism of plants, stimulates the correspondent photo biological studies around the world. The known *McCree* curve [1], which obtained *in vitro* using a rather complex optics, describes photosynthesis action spectrum on separate leaves of plants at low levels of irradiance. This curve was a peculiar "Gospel for photo biologists" during about five decades but now it is opened to questions [2]. Due to LEDs, photo biologists have obtained a new effective exploratory tool, which allows carrying out studies of radiation influence of PAR various intervals on producing capacity and quality of plant biomass in a wide interval of irradiance being of interest for the practical photoculture. Such problem namely is set by authors of this work. They have selected as an object of the studies a group of greengrocer vegetable cultures (as exemplified by the Landau salad and the Russian Giant basil, which are of prospective interest for growing in industrial greenhouses).

2. SHORT CHARACTERISTICS OF THE SPECIFIED CULTURES

Salads have many versions, and most widespread is leave salad with a rich vitamin and mi-

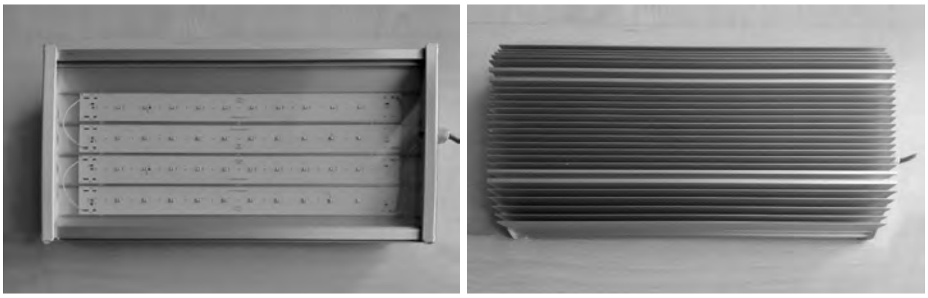

Fig. 1. Appearance of quasi-monochromatic phytoirradiators (PI)

neral composition, including vitamins of B and C groups, as well as calcium, boron, copper, iodine and phosphorus. As a food, salads are very useful for human body.

Basil is a valuable spice-and-flavour culture, and its usefulness for human organism is very big. Most of its necessary for health properties are due to formation of ether oils in its biomass.

3. RESEARCH METHODS AND EXPERIMENTAL INSTALLATION

Reaction of plants on influence of quasi-monochromatic radiation of some PAR intervals when changing within a wide range of irradiance was investigated. The reaction of plants means change of gross weight of economically-useful biomass (producing capacity). In the specified conditions, concentration of most important components of the product biochemical composition determining its nutrition value was estimated.

As a result of the studies, it was supposed to obtain for each spectral version a series of productivity light curves, based on which a real efficiency of separate PAR ranges can be estimated, and search of phytoirradiators (PI) spectrum and irradiance optimum requirements can be determined for plants growing in accordance with the photoculture technology.

Especially for these studies, in LLC International Lighting Corporation BOOS LIGHTING GROUP and in the VNISI, a series of quasi-monochromatic PIs was developed and manufactured. Their parameters are presented in Table 1. Fig. 1 shows photos of PIs, in which colour selective LEDs of Cree Company (USA) were used.

Spectra of optical radiation of the quasi-monochromatic PIs used in the research are presented in Fig. 2.

It can be easy seen from Fig. 3 that “blue”, “green” and “red” PI radiation is in the sensitivity areas of most pigments being photodetectors of plants.

In the PIs, controlled drivers of OT180W/UNV1250C type were used. Current adjustment within (350 ÷ 1300) mA allowed changing power of irradiators and irradiance over the technological area.

To estimate a possible interval of irradiance control, dependence of radiation flux relative value on current was previously measured for each PI type (Fig. 4).

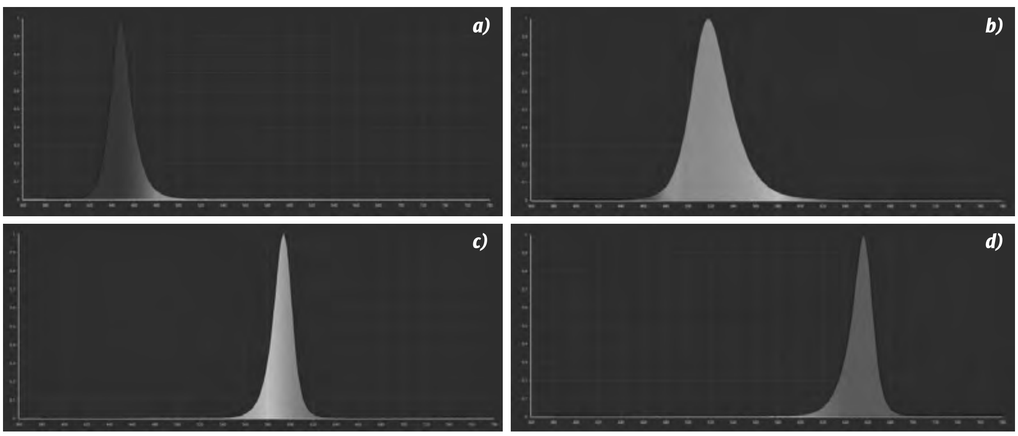

Fig. 2. Spectra of radiation quasi-monochromatic PI used in the research: *(a)* blue, *(b)* green, *(c)* amber, *(d)* red

Table 1. Key Parameters of a Series of Quasi-monochromatic Phytoirradiators Used in Research

No	PI type	U_m, V	LED type, manufacture company	Peak wavelength, nm	Spectral interval of radiation, nm (by 0.5 level)	Current adjustment interval, mA	Electric power, W (with current I = 600mA)
1	GALAD Fito LED red	220	XPE HE Photo Red Light Emitting Diode, CREE	656	645 ÷ 666	350–800	68
2	GALAD Fito LED blue	220	XLamp XT-E Light Emitting Diode Royal Blue, CREE	447	435 ÷ 458	350–1100	84
3	GALAD Fito LED green	220	XLamp XP-E Light Emitting Diode Green, CREE	517	500 ÷ 540	600–1200	84
4	GALAD Fito LED amber	220	XLamp XP-E Light Emitting Diode Amber, CREE	597	585 ÷ 605	600	35

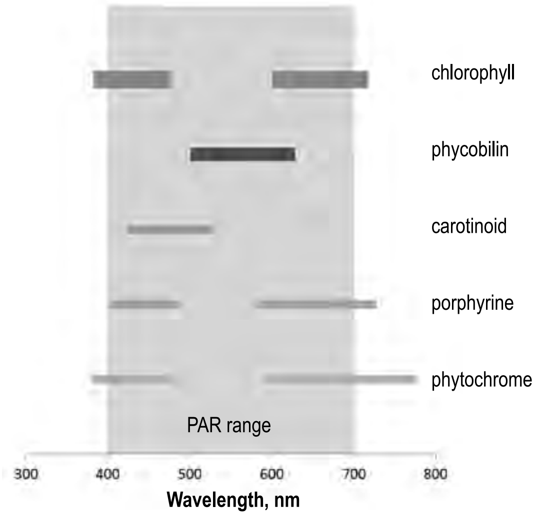

Fig. 3. Spectral intervals of effective absorption of main plant photopigments

The studies were carried out using a phytothrone of the Artificial Climate Laboratory in the *RSAU-MSHA* of K.A. Timiryazev on an exploratory complex consisting of six unified modular installations with reflecting screens of specula film. General view of the installations is given in Fig. 5[1]. The interval of possible changes of irradiance in the LED modules was set within (60 ÷ 300) µmol/s·m^2. In order to obtain the data necessary to create productivity light curves with stable irradiance values for a specific spectral version, not less than four vegetations were performed. Choice of the working area (size of placing plants on the bedding area) was determined by the requirement to provide irradiance uni-

[1] In parallel with the study of exposure of quasi-monochromatic radiation fluxes, experiments with radiation sources of a continuous spectrum in the PAR interval were made. The results will be presented in a separate article.

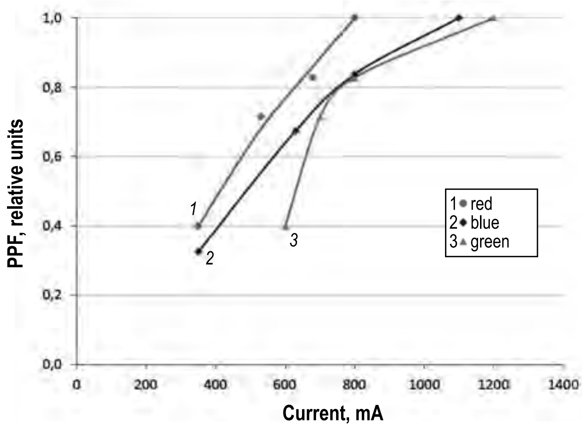

Fig. 4. Photosynthetic photon flux current dependence for Phytoirradiators

Fig. 5. General view of the research installations

formity E_{av} = ± 10 %. The working area was equal to (0.25 ÷ 0.35) m^2 depending on the conditions of a specific experiment. Adjustment of the irradiance was made according to the flow chart in Fig. 6 by means of a programmer and a computer with specially installed software. To determine spectrum of PI radiation, photosynthetic photon and energy irradiance in the PAR interval, the Li-250A device for PPFD integral measurements with quantum detector Li-190R (Li-COR Company, USA) and MK 350S spectrometer (UPRtek Company, Taiwan) were used. At the request of the authors, INTEX Lighting Company (St. Petersburg) by agreement with UPRtek Company installed an additional option on the MK 350S device, which allows measuring irradiance within the PAR interval using energy units (W/m^2). Choice of the devices was an extraordinary problem, because it was connected with introduction of GOST P 57671–2017 and PNST 211–2017 developed in the VNISI [3–5].

Besides the lighting parameters of the studies methods stated above, other experimental conditions corresponded to the requirements of the technology of growing salad-greengrocers cultures accepted in the phytothrone are briefly described below.

The experiments were made during a constant photo period of 18 h. Air temperature in the day-time was 22°C, and at night 18°C. The plants were grown up in vegetative containers with the “Agrobalt C” nutritious mixture by tree pieces of salad, or five pieces of basil. As a substratum, an upper neutralised sphagnous peat of a low decomposition level with humidity no more than 65 % was used. It contained calciferous (dolomitic) powder, combined fertilizer (N_{gen} = 150 mg/l, P_2O_5 = 150 mg/l, K_2O = 250 mg/l, Mg = 30 mg/l, Ca = 120 mg/l and microelements). Its pH was equal to 5.5–6.6. Watering was carried out by mass with quadruple frequency. The humidity of full moisture capacity was maintained to be equal to 70 %.

Account of the harvest biomass and other determinations were performed in 35 days beginning from the seedling, general biomass for every container was also taken into consideration.

Concentration of vitamin C (ascorbic acid) in plant tissues was determined by a method based on Tillmans’s reaction with decolouration of 2.6-dichlorophenol-indophenol. Nitrate concentration was determined using an ion-selective electrode after extraction with aluminium potassium sulphate. To determine quantitative and qualitative composition of accumulated biologically active aromatic components being a part of basil ether oil, gas chro-

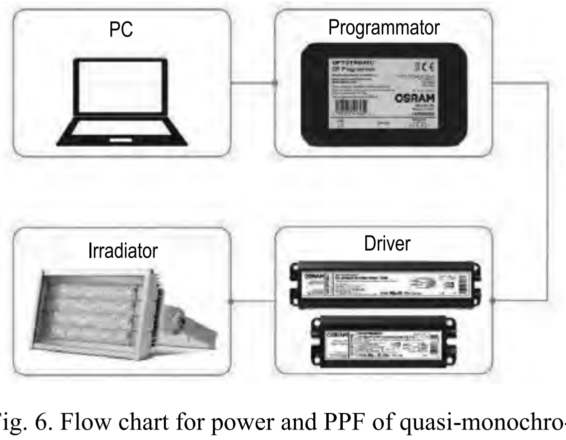

Fig. 6. Flow chart for power and PPF of quasi-monochromatic PI adjustment

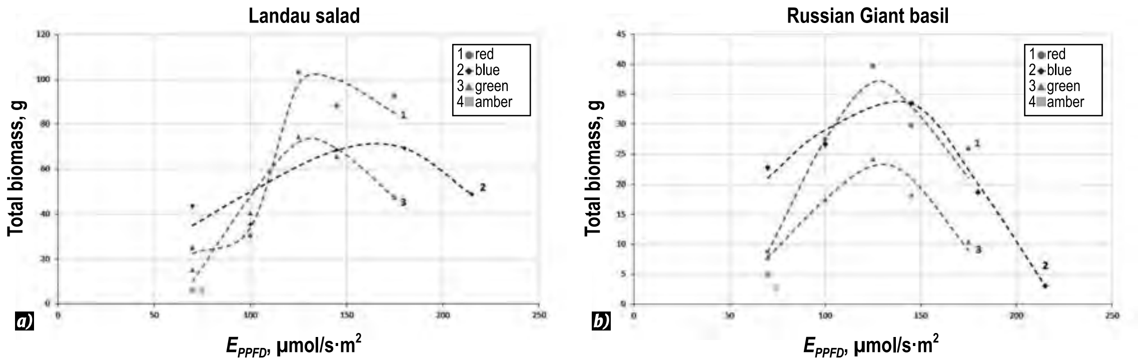

Fig. 7. A series of productivity light curves of salad (a) and basil (b) for the photosynthetic photon values

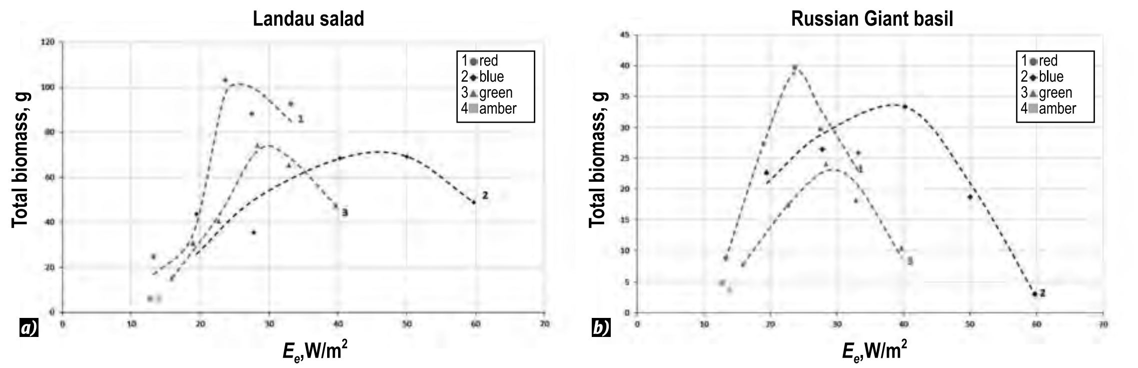

Fig. 8. A series of productivity light curves for plants of salad (a) and of basil (b) for the energy values

matography was used with mass-selective flamingly-ionisation detection. Identification of the ether oil components was carried out using mass-spectra libraries.

4. ANALYSIS OF THE RESEARCH RESULTS

At present, the fact is practically assured that photosynthesis is a quantum process, in which quantum efficiency (or intensity of photosynthesis) depends on the absorbed photon number within the PAR interval. Thereupon, photosynthetic photon values are now actively introduced in practice of radiation metrics in protected ground constructions, primarily in greenhouses with the plant photoculture.

It should be remembered, however, that photosynthesis in a real plant being a photobiological system has in essence stochastic nature. It is shown in theoretical photobiology, from 8 to 12 photons are corresponding to produce one molecule of the organic substance or O_2 [6]. It follows from this that even for photosynthesis, without mentioning vegetable biomass process synthesis, the photon values is no more than a convenient measure for conventional character calculations.

In connection with the specified above and taking into account the photonic metrological opportunities, it is advisable not to abandon the energy values for the PAR interval very popular in the last century in the photobiological studies and even in the plant practical photoculture[2]. An integrated energy "thread" is rather distinctly traced. This thread connects the consumed electric power of a lamp, part of its radiation in the PAR interval, efficiency of a luminaire, PAR usage coefficient in an illumination device (ID) from the one hand, with the technological area irradiance, the ID specific power consumption and even with the energy equivalent of the produced biomass from the other hand.

From these point of view, it is especially interesting, based on the research data, to consider the results of biomass synthesis being the function of both photon and energy irradiances, a connection between which is determined by the following expression:

$$E_{ph} = K_{eph} \cdot E_e, \qquad (1)$$

[2] A preference to the energy values is given by some leading plant photo-physiologists, in particular by professor. A.A. Tikhomirov [7].

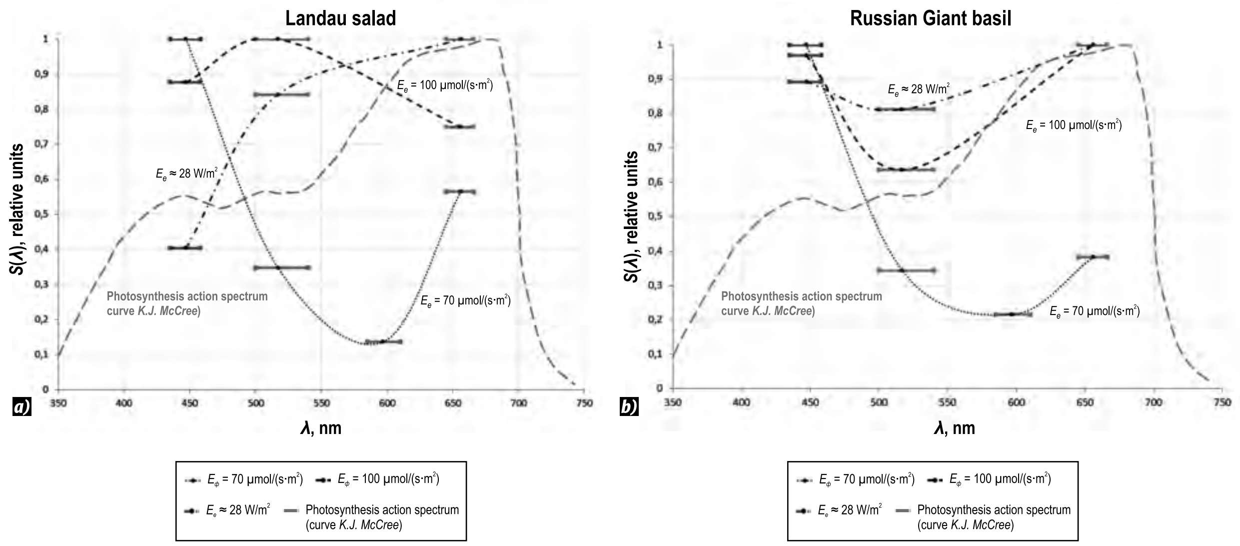

Fig. 9. "Rough" action spectra of salad biomass (a) and of basil (b) synthesis

where

$$K_{eph} = \frac{\frac{1}{h \cdot c \cdot N_A} \cdot \int_{400}^{700} e(\lambda) \cdot \lambda d\lambda}{\int_{400}^{700} e(\lambda) \cdot d\lambda}, [\frac{\mu mol}{J}],$$

where $e(\lambda)$is the spectral concentration of irradiance, [W·m^{-2}·nm^{-1}], λ is the radiation wavelength in the PAR interval, [nm], h is the Plank constant, [J·s], c is the light velocity, [m/s], N_A is the Avogadro constant, [µmol^{-1}].

A transition from E_e to E_{ph} or vice versa is possible by means of a calculation or using the correspondent type devices, which, as it was stated above, were used in this work.

The research main results presented as producing capacity light curves for salad and basil plants are given in Figs. 7–8.

For the presented producing capacity average values, root-mean-square deviation was equal to ± 10.3 % (salad) and ± 18.5 % (basil).

It should be noticed that growing of plants under quasi-monochromatic radiation, i.e. in the light mode, when throughout all vegetation a part of photosynthesis spectrum only is involved, allows not only obtaining direct data on efficiency of a certain PAR interval but also estimating possibilities of a plant as self-controlled system.

An analysis of ***Landau salad*** producing capacity dependence on the PPFD level shows a rather abrupt plant reaction to low-energy red radiation quanta. With low irradiance, the reaction efficiency was lower than for blue radiation. With average PPFD equal to 100 µmol/s·m^2, the effect was slightly lower than for blue radiation and even for green, but within the higher irradiance interval of about (130 ÷ 140) µmol/s·m^2, a maximum level of producing capacity for all series of the experiences was reached.

Length of the "ascending section" of the productivity light curve is the biggest for blue radiation. Maximum values of producing capacity are reached in this case at the PPFD about (170÷180) µmol/s·m^2. This fact confirms the previously obtained data [8] and means that support of high part of blue spectrum irradiation in LED phytoirradiators is not prospective for industrial growing of salad cultures.

The results of this research demonstrate that green interval of the spectrum when growing salad is not an "outlaw" at all and provides a higher producing capacity than red and blue radiations at PPFD equal to 100 µmol/s·m^2.

An experiment with a specially made yellow-orange (amber) PI with E = 70 µmol/s·m^2 is a direct confirmation of the assumption of a low efficiency of the yellow-orange PAR interval, which radiation is absorbed practically by carotinoids and phycobilins only. In further experiments, this LED irradiator was not used.

As it was stated above, when transiting from PPFD scale to energy irradiance E scale, W/m^2 (Fig. 8a), in the results data for the first time, we could notice an addition influence of PAR various intervals on producing capacity of the salad due to the new hardware abilities. Naturally, the scale inversion slightly changed relative position of the light curves, significantly expanded the experiment

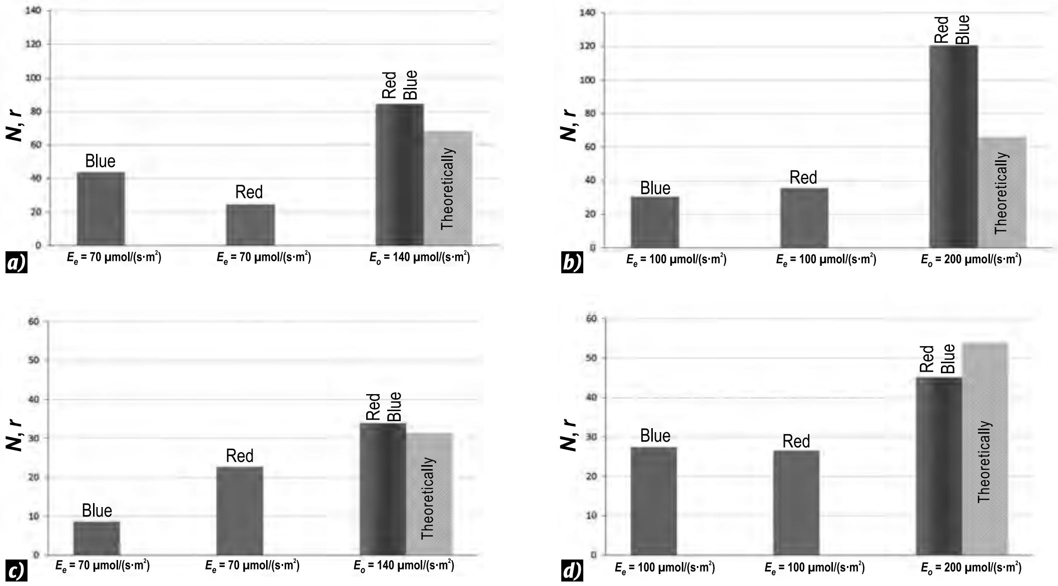

Fig. 10. Additivity of action of different-spectral PAR range in useful biomass synthesis N

range and presented the data in the form more habitual for lighting engineers and photobiologists.

It should be noticed that the productivity light curve for blue PAR interval for the energy value has the most flat nature and reaches a producing capacity maximum with rather high irradiance (40 ÷ 50) W/m², which is considerably lower than for red radiation optimum with E in range (23 ÷ 25) W/m².

Productivity light curves for the ***Russian giant basil*** somewhat differ from the salad curves. PAR red interval is also the most effective to provide a high producing capacity. An experiment with red radiation at $E > 140$ μmol/s·m² revealed an effect of a quick decreasing plant growth, which is hard to be explained. In the curve family $N = f(PPFD)$, positions of maxima for all PAR intervals are very close and correspond to E about (125 ÷ 150) μmol/s·m².

Apparently for industrial basil growing, an optimum by spectrum will be a combination of red and blue PAR intervals, because green radiation efficiency is significantly lower.

Inversion of the irradiance scales for basil leads to a noticeable change of the productivity light curve positions probably connected with different energy "weights" of green, red and blue photons (Fig. 8b.).

Maxima of dependences in the irradiance scale of red and blue PAR intervals are displaced by

$\Delta E \approx 15\frac{\text{W}}{\text{m}^2}$, which indisputably provides essential

energy efficiency advantages for red radiation.

The data under consideration are in addition vividly illustrated using so-called "rough" *action spectra* of biomass synthesis of the two studied cultures[3] (Fig. 9). The action spectrum is a reaction of plants (in this case it is producing capacity) to radiation within separate spectral intervals with a constant irradiance (photosynthetic, photon or energy). The action spectrum allows determining influence of a certain photopigment type on biomass synthesis.

As it follows from the data (Fig. 9) the producing capacity action spectrum character drastically depends on the irradiance (μmol/s·m² or W/m²). Depending on the producing capacity value, efficiency of a specific PAR interval can differ radically. From here, an uncertainty of many research results, which were carried out for one or two irradiance levels only with contradictory data, is quite understandable, and this is discussed, for example, in [10].

Introducing the methodological content only into our research next element and considering it as a prologue to the following experiments, we made some tests to estimate an ***additivity*** of radiation influence of blue and red PAR intervals on biomass synthesis.

Generally the additivity is a property of values, which is consists in the fact that a va-

[3] The concept of a "rough" spectrum is introduced in [9] and used, when width of the selected spectral interval is equal to several tens nanometres.

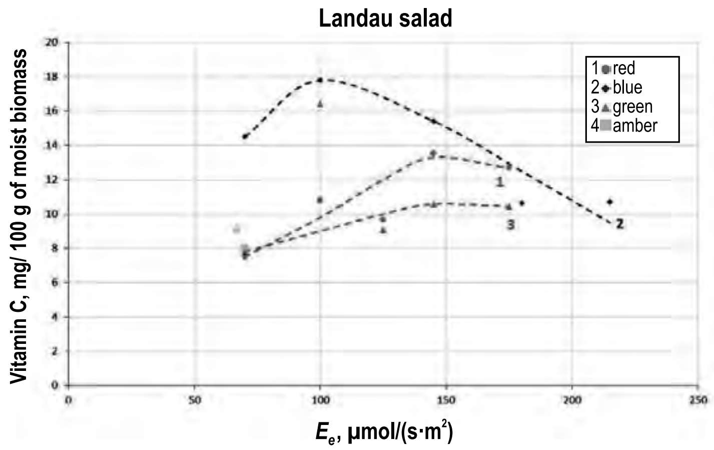

Fig. 11. Dependence of vitamin C concentration for Landau salad on the PPFD level

lue relating to the whole volume and correspondent to it, is equal to the sum of the values corresponding to its parts. So any arbitrary function *f* is additive, if

$$f(x_1+x_2)=f(x_1)+f(x_2). \quad (2)$$

If the specified equality is not observed, and relation of the left and right parts of equation (2) $f(x_1+x_2)/\left(f(x_1)+f(x_2)\right)>1$, then the considered function can be named superadditive, and if this relation is < 1, then the function is subadditive.

It should be noticed that *McCree* in his experiments with photosynthesis of an insulated leaf doubted that different-spectral radiation influence is additive [1]. According to (2), the additivity criterion can be formally written down as follows:

$$A=\frac{N(E_0)}{\sum_{i=1}^{n}N_i}, \quad (3)$$

where $E_0=\sum_{i=1}^{n}E_{\Delta\lambda_i}$, $N(E_0)$ is the producing capacity in case of combined action of *n-spectral* intervals with general irradiance E_0, N_i *is* the producing capacity of quasi-monochromatic irradiator *i* radiating in the wavelength interval $\Delta\lambda_i$ and providing photon irradiance $E_{\Delta\lambda_i}$.

As it was stated above, in our research, $n=2$, and for each experience, $E_{\Delta\lambda_i}=const$.

When carrying out the additivity studies, it is expedient to select $E_{\Delta\lambda_i}$ levels on the ascending sections of the correspondent productivity light curves. For these reasons, in our experiment PPFD were selected as $E_{\Delta\lambda 1}=70 \mu\text{mol/s}\cdot\text{m}^2$ and $E_{\Delta\lambda_2}$ = 100 μmol/s·m^2. Thus for $E_{\Delta\lambda i}$ according to (2), two values 140 μmol/s·m^2 and 200 μmol/s·m^2 were set.

The results for salad and basil plants presented in Fig. 10 are quite logical and explainable. For the primary level of $E_{\Delta\lambda_i}=70$ μmol/s·m^2, the obtained effect for both cultures can be estimated as superadditive (according to (3), A> *1*). This confirms perspective of further research by optimization of binary red-blue PI spectrum. A qualitatively similar result is also obtained for salad plants with a higher primary PPFD μmol/s·m^2 taking into account the productivity light curve flat nature at high PPFD levels. The subadditivity effect of red-blue radiation at $E_{\Delta\lambda_i}=100$ μmol/s·m^2 for basil can be explained by a more abrupt nature of the productivity light curve decrease already with PPFD higher than 150 μmol/s·m^2.

The fact of influence of PAR on plant synthesis for some biochemical compositions determining nutrition value of vegetable products [11] is well known. According to the modern concepts, much attention is paid to this question when growing products of an increased ecological quality under the photoculture conditions.

At this stage of research, we wanted to obtain estimation data assuming then to clarify them and to lead to a level of technological indicators at the closing stage of the studies.

As the main component of the biochemical composition for Landau salad, vitamin C concentration of 1mg/100 g of biomass was accepted, and for basil plants it was concentration of eugenol being the main type of ether oil. Concentration of nitrates in biomass was also estimated.

Fig. 11 shows a series of dependences on vitamin C concentration in moist biomass of Landau salad. A general effect for all three PAR intervals is an increase of ascorbic acid concentration with increase of irradiance. And position of maximum for the blue interval corresponds to lower irradiance than for the producing capacity light curve. In the PPFD interval, which is of interest for practical photoculture, concentration of vitamin C can be (20 ÷ 40)% higher than for salad cultures average level (10 mg/100 g).

During the studies of the spectrum and of the PAR irradiance exposure on biosynthesis of eugenol in basil, one could not reveal a stable influence of them. High share eugenol concentration rates (50 ÷ 55)% were stably revealed when irradiating with red light of PPFD (125 ÷ 150) μmol/s·m^2.

By nitrate concentration, parameter dispersion was at the first order values level while remaining (2 ÷ 3) times lower than the maximum allowable value (2500 mg/kg).

CONCLUSION

The photobiological research was performed using the last achievements of light engineering are indisputably important and show great opportunities of LED radiators for development of reasoned requirements to systems of phytoillumination for plant photoculture of different types.

For two types of vegetative plants in a wide intervals of PPFD [μmol/ s m^2] and irradiance [W/m^2], data of the main spectral PAR intervals influence on producing capacity is obtained, and maximum efficiency of the PAR red interval is confirmed.

The research results given in the article firmly show that reaction of plants (producing capacity) not additively changes depending on spectral composition and irradiance, and that searches of universal spectra influencing plant producing capacity are doubtful. A producing capacity action spectrum even for vegetative plants depends on the irradiance and should be in general estimated using two-dimensional scales (λ and *E).* Summarising the all above said, it should be noticed that at present there is no alternative for the experimental method of optimising key lighting parameters for plant photoculture.

Along with the scientific and practical importance, studies of photophysiological efficiency of PAR separate intervals have methodical nature and can be applied in training courses for students of the following specialties: “Light and Engineering” and “Physiology of Plants”.

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Leonid B. Prikupets,
Ph.D. Graduated with honors from MPEI in 1970. At present, he is the head of laboratory in VNISI by S.I. Vavilov and member of editorial board of Svetotekhnika and Light & Engineering Journals

George V. Boos,
Ph.D., graduated from MPEI in 1986, President and Member of Board of Directors of BL Group, Head of the chair "Light and Engineering" NIU MPEI. He is a Laureate of the State Prize of the Russian Federation (for architectural illumination of Moscow), chairman of the editorial board of the "Svetotekhnika" and "Light & Engineering" Journals, Member of the Russian Academy of Natural Sciences

Vladislav G. Terekhov,
engineer. He graduated with honors from Moscow State University of Economics, Statistics and Informatics with a degree in Applied Informatics in Economics, and at present, he is a Head of the Department for the Promotion of LLC International Lighting Corporation BL GROUP and researcher in VNISI of S.I. Vavilov. He is a member of the Organizing Committee of the All-Russian Conference "Gallium, Indium and Aluminum Nitrides. Structures and devices" and an expert on energy-saving technologies in the lighting of the Russian Union of Builders

Ivan G. Tarakanov,
Prof., Dr. of Biological Sc. He graduated in 1978 from the Moscow Agricultural Academy of K.A. Timiryazev. At present, he is a Head of Department "Plant Physiology" RGAU-MTAA of K.A. Timiryazev

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ON THE ENVIRONMENTAL DESIGN ILLUMINATION: TEACHER'S ATTITUDE

Elena A. Zaeva-Burdonskaya[1] and Jury V. Nazarov[2]

[1]Moscow State Stroganov Academy of Design and Applied Arts
[2]National Design Institute
E-mail: nounid@mail.ru

For ye were sometimes darkness, but now are ye light
in the Lord: walk as children of light
(Ephesians 5–8)

ABSTRACT

As a special professional discipline the design of lighting is a part of learning program of the department of Environmental Design in Moscow State Stroganov Academy of Design and Applied Arts. The training of designers working with light and lighting equipment requires the special methodize, and the elaboration of such methodize becomes more and more urgent in modern school. We see solution in the combination of traditional art studies and environmental design with modern digital design technologies. All the factors of the lighting content of our environment such as lighting technique and technologies are considered during the learning process. Those branches of professional training are closely connected with the whole design culture and that gives us an opportunity to use a multidisciplinary approach.

The study in the lighting design takes one term. That's enough for the concept of the fragment of urban environment including the elements of the lighting content. The basics of art and the skills of creative thinking also help to achieve a high level of final design and to develop aesthetic skills of students.

The new horizons of the lighting design are opened with the new profile of education on our department: a Multimedia Design providing an extensive digital ground for design process.

All these means can help us to create a unique ground for the design education, for the contacts between students and possible customers, and also to attract some new, talented tutors.

Keywords: lighting design, environmental design, educational design, educational methods, art education, light installations, interdisciplinary approach, project concept, environmental approach

1. INTRODUCTION

Being relatively new field of design, lighting design is even younger in the area of design education. The development of a new subjects on the department of Environmental Design in Moscow State Stroganov Academy of Design and Applied Arts requires a new methodology.

The area of the learning design concerning lighting design is based on such specialities of the creative process as innovative design that requires a lot of scientific and technical research.

The mostly used themes of the learning projects besides lighting equipment is the highly dynamic urban environment, especially during festivities, dramatized shows, sport events or promo actions. That means usually the design for a re-creation-al exterior space for urban inhabitant. That task is developed up to the stage of design concept inside some fragment of an urban environment including the lighting content. The use of a conceptual approach becomes on our department an educational model for future lighting designers.

Analyzing the practice of contemporary European design (which is strongly oriented on the customer's need) we can see the leading role of conceptual design [1]. Conceptual design as an example of non-linear process different from traditional "good" design means a multidimensional coverage of environmental themes – especially in such visually and technically complicated fields as lighting design. Lighting design as well as architecture is neither an art nor a science but is derivative of both [2].

Defining the strategy and tactics of the domestic school of lighting design it's necessary to remember the "interdisciplinary nature of that discipline standing at the intersection of art, design, architecture and lighting technologies, its dialectical origin and integration character" [3]. But any school as a professional integrity is always focused on the reproduction of knowledge and activities, and its status would not be complete without the support of professional education.

The strategy of educational design of the Department in the field of lighting design is based on the best achievements of the theory and methodology of the development of the light environment. Like the principle of "expensive Opera" methods in "amateur art", that task is one of the tasks of non-existent professional education of lighting designers" [4].

First experiments of light architecture in town planning (N.M. Gusev, V.G. Makarevich) have found valuable methods in fundamental works of Professor N.I. Shchepetkov [5] (who taught the course of lighting design at the department of Environmental design in the 2010s) and a number of authors of textbooks on the design of architectural [6] and interior [7] environment.

The problems of semiotics (M. Chervyakova) and semantics (P. Volchok) of the light tectonics of the architectural object were included in a number of methodological recommendations for the improvement of night time urban environment, especially in the cities with vivid historical pattern (A. Prikhodko). Stages of creation of "lighting model" of architectural object [8] are defined within the concept of a lighting panorama of the city (V.E. Karpenko). The professional competence of lighting designer outlines the design process on stages of conceptual design, detailed project and supervision (D. Makarov) [9] more fully with the transition to the stage of forecasting the development of the profession of lighting designer (S. Sizyi) [10].

An integrated approach to the formation of the urban lighting environment [11] (N.V. Bystryantseva) and the interdisciplinary nature of lighting design allowed to consider this field as an important factor of public communication and urban "scenography" (M.N. Bulygina, N.L. Korzun) similar to the spatial composition of paintings, movie screen, theatre stage and architecture [12]. The openness to innovation of the adjacent forms of visual art and science becomes the best and promising design methodology in the work with the lighting content. At the intersection of architectural lighting design and synthetic arts some innovative forms of the environmental objects of the modern light-art are emerging in the format of lighting installations, art objects and land art (E.V. Karpenko), luminous clothes (Yu.V. Nazarov, T.S. Vasilyeva), theatrical costume with such technical innovations as miniature light fixtures and power supplies; Hussein Chalayan's "architectural" approach to the design of clothing with a commitment to new technologies [13].

2. MATERIALS AND METHODS: THEORETICAL BASIS

Educational design at the Department of "Environmental design" is an interdisciplinary model, closely related to scientific and technical innovations. Openness to novelty allowed creating artistic environmental concepts with various elements of lighting design. The principle of conceptual design provides an approach to the environment as a "process", where the main participant becomes a spectator, similar to the methods of artistic theatrical realization of space, based on the classical method of "scenario modelling" (V.F. Sidorenko). The scenario makes a stable nature of the light environment visually more dynamic. The design of lighting content lies outside the methods of classical morphological formation and is still in the process of its formation. The importance of a theatrical scenario lies in the possible visualization of a disembodied, naturally virtual lighting environment, which immerses us in the world of illusion. (The first one who laid the basics of the use of technical lighting systems in the design of a full-scale urban environment was a well-known theorist and practitioner of lighting design, N.P. Shchepetkov.) This study is limited to the analysis of exclusive objects of the urban environment and does not including the widest area of special environmental contexts such as industrial or interior spaces.

The study projects of dynamic lighting environment changed our department's focus aiming it on socially significant design. According to John Maeda "design isn't just about beauty; it's about market relevance and meaningful results" [14].

Project of light environment for music festival "COS.MOS" on the territory of the Moscow Exhibition Centre is an example of a large-scale project of lighting design – a conceptually new, spectacular, technically equipped event that meets the obligatory conditions of successful event marketing ("event marketing", Fig.1). One of the tasks the festival "COS.MOS" has to achieve is to solve the actual problem of territorial branding of an exhibition area by the means of outdoor advertising and special decoration.

"One of the main features of modern light installations is a combination of polychrome LED light and web-technologies that allows you to control lighting effects and dynamics at a remote distance" [15] to develop a project scenario and timing of the event taking into account the time of the day with its natural lighting. The concept of "Space Geometry" is based on the visual image of the hexagon: the images of the Solar system, the North Pole, and Saturn, the crystal lattice of carbon – the most common element in the Universe. The hexagon module includes the entire environment complex from graphic style and up to lighting installations, to lighting navigation and video mapping with the developed plot and scenario on the facade of the Cosmos pavilion; from the design of the lighting system up to the architectural illumination of the main buildings of the festival and the lighting design of the stages.

Three Festival stages are equipped with LED IPX8 strips. Illumination of entrance groups consists of LED strips and LED-lamps. Daytime installations are illuminated at night with LED lamps and ribbons. Media content consists of 3DLP projectors. Large-scale projection is achieved using Christie's RGB laser systems, the Christie® Freedom™ light system with a adjustable laser light source equipped with a fibre optic projection head. Pandora's Box system allows you to synchronize all video and audio sources in real time. Phoenix EP system is installed directly on compatible Christie displays, which serve as a power source and are connected to the network via CATx cable. Screens mounted in interactive stands can be either Secure Touch or Thru Touch type.

Some student's training studies turned into a field of prognostic design, Fig.2. "Another situation is possible when designers developing an idea of a new product are ignoring the technical

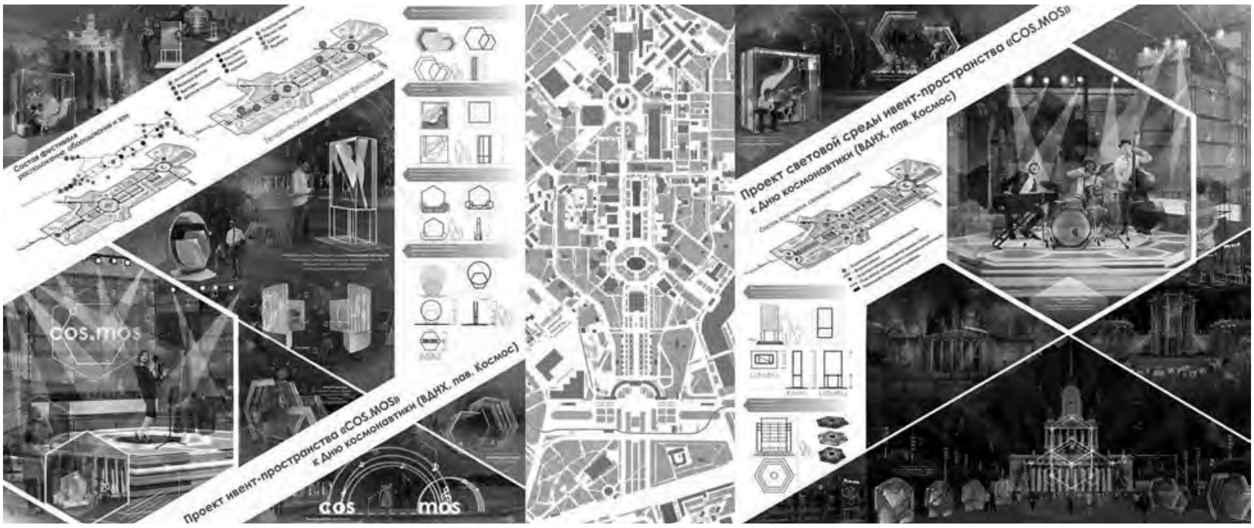

Fig.1. Project of lighting environment for "COS.MOS" event at Russian Cosmonautics Day (Moscow Exhibition Centre, "Space exploration" pavilion)", 2018
(Lighting installations, 3D mapping techniques, architectural lighting of buildings are used for creating a unique atmosphere of the music festival. Graduation project, bachelor course, department of Environmental Design. A. Galstyan, E. Gozhaya. Tutors: Prof. E.A. Zaeva-Burdonskaya, Prof. E.I. Ruzova)

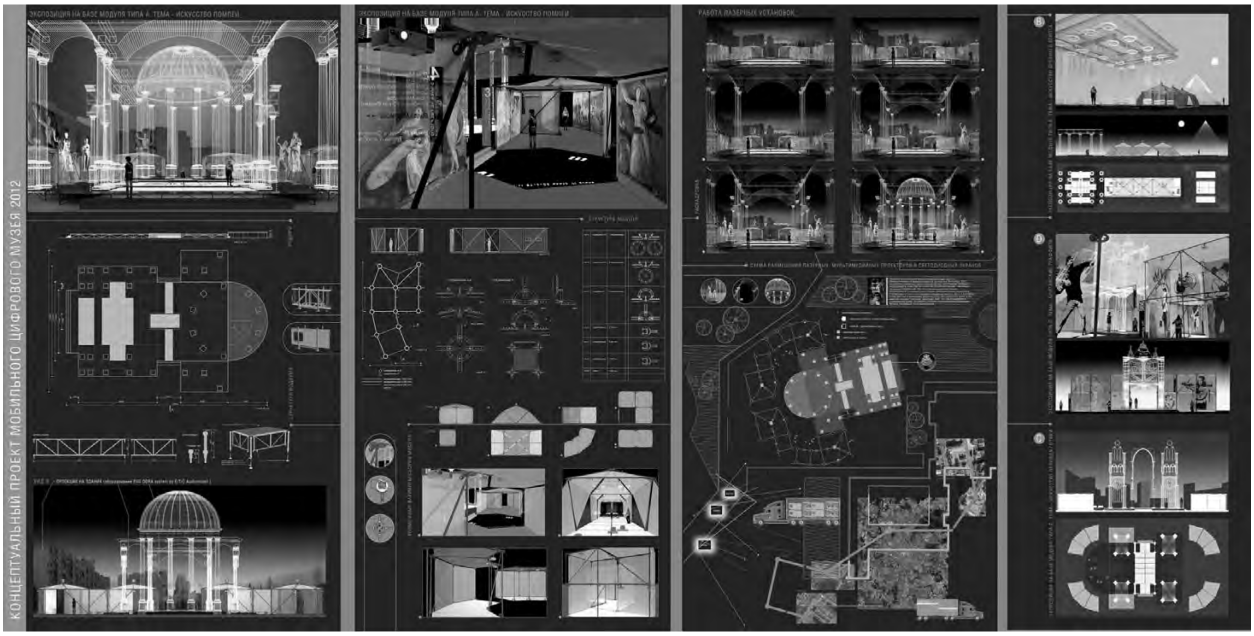

Fig.2.Conceptual project of the mobile digital Museum – 2012", 2008
(Technologies of holographic architectural structures creation in the urban environment are designed for the use of equipment planned for development and implementation in 4 years after the project presentation (2008). Graduation project, Specialist degree, department of Environmental Design. O. Simatova. Tutors:
Prof. E.A. Zaeva-Burdonskaya, Prof. E.I. Ruzova)

and technological capabilities and create a promising project (new function), which turns out to be unrealizable or expensive. In this case, design becomes an incentive for the development of new technologies, for the search of solutions for possible implementation of the project [16]. National Institute of Advanced Industrial Science and Technology, AIST (Japan) has developed a device that uses lasers to create three-dimensional images in open space. The device creates realistic three-dimensional images using a laser beam focused by lenses at the points of space above the projector. The laser operates in the invisible range of light to the human eye and the resulting plasma emission of nitrogen and oxygen causes a bright glowing effect. Due to the limited duration of the projection, the device is able to reproduce three-dimensional shapes by moving the focal point. The number 2012 in the name of the project is not accidental, fixing the year of creation of this equipment designed for large-scale projects in the urban environment.

The light component in contemporary visual art often appears in the format of lighting installations forming the visual environment of the event. "One of XX century's innovations is an introduction of such concepts as art object and art installation. Initially this experiment with a departure from the utilitarian object… consists in the ultimate sharpening of the "idea of an object" and the ideal correlation of function and form in it" [17]. One of the most beautiful places in Moscow, Vorobyovy Gory, gained a new look thanks to the lighting art objects in the figurative concept of the festival environment "Christmas light-2018" under the motto "Ornament as the language of cultural communication", Fig. 3. The ornament was presented as a symbolic system based on such geometric figures-symbols as Circle (beam, halo, spiral, etc.) and Square (triangle, cross, etc.). A single modular grid was developed for the construction of groups of ornaments with ethnic symbols and colour and composition characteristics. The spatial character of sculptural art objects is achieved with the help of multi-layering, or so-called "facade lamination"; of low objects – "elevating" elements from the plane into space at different angles (the "raised plan"). The modular principle allows you to adjust the size and configuration of the luminous arches and portals. The structure is to be built of aluminium grid, PET and PMMA sheets. Lighting technology: CHROMEX Steady LED rope lights (36 LED/m; Anti-UV treated). LED colours: White (051079), Blue (051082), Red (051083), Green (051081), Yellow (051084).

Lighting optical effects and illusions in the three–dimensional composition solved at the level of primary creative tasks are practiced in the frame-

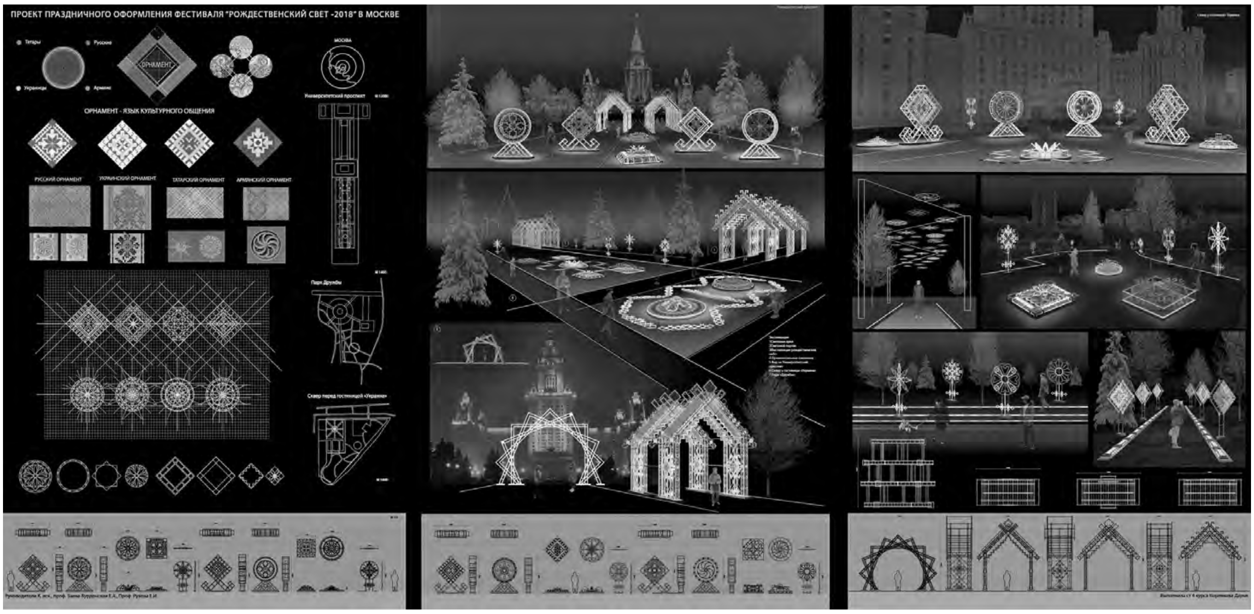

Fig.3. Project of decoration of the festival "Christmas Light-2018" in Moscow", 2017 (Customer: "Adline Project" company. The main project's feature is the domination of imaginative and emotional ethno-design. Graduation project, bachelor course, department of Environmental Design. D. Korlyakova. Tutors: Prof. E.A. Zaeva-Burdonskaya, Prof. E.I. Ruzova)

work of propaedeutic courses, Fig.4. "Morphogenesis in environmental design as the method of stylization" program held on third year helps to solve the problems of adaptation of the historical stylistics to the modern problems of environmental design.

The quality of any project measures most often with its implementation. As a result the design has to adapt creative ideas to practice, to make technological innovations interesting to the spectator. Successful long-term cooperation of the Department with the company "LEBLANC RUS" in the framework of conceptual training projects and summer practical training has become a path to practical design in the field of lighting design. The project of the New Year's animated light show in Gorky Park dedicated to the 100th anniversary of the "Christmas Tree" (1918) rhymes for children is based on the works of A. Benois and K. Chukovsky, Fig.5. The project included kinetic and fixed lighting installations (LED panels) equipped with motion sensors changing the brightness of light according to human movement; geo-plastics with interactive graphics for mobile games; kinetic furniture with LED strip lights, equipped with motion sensors; small architectural forms based on of the lighting panels and video mapping on the central entrance arch. The in-

Fig. 4. Design adaptation of the antique ornament. Meander. Composition, 2014
(Non-functional installations and art-objects as an example of innovative technologies creating an artistic image with the priority of semantics, emotional aspect of the artistic image with the priority semantics of form, the emotional sound, etc. "Morphogenesis in environmental design" program. Bachelor course, department of Environmental Design. A. Budaeva
Tutor: Prof. E.A. Zaeva-Burdonskaya

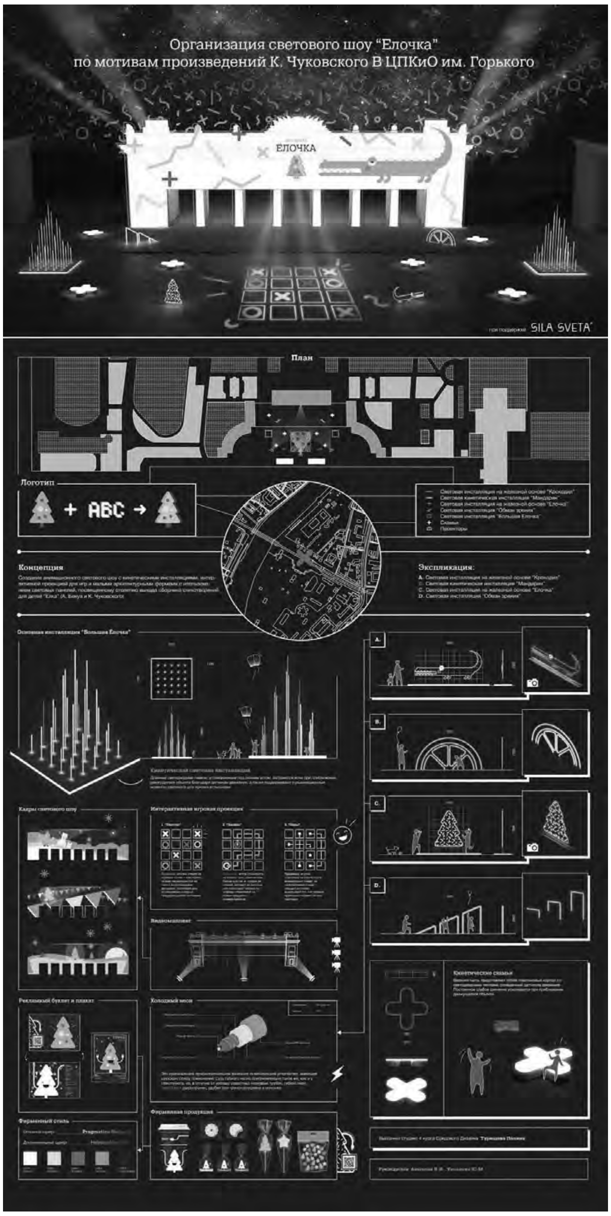

Fig.5. “The project of the “Christmas Tree” light show based on the works of K. Chukovsky in Gorky Park”, 2017 (Customer: “LEBLANC RUS”. Conceptual training projects based on manufacturer’s orders open the way to practical design in the field of lighting design. Bachelor course (4th year), department of Environmental Design. P. Turisheva. Tutors: Prof. V.I. Ampilov and J, M. Hasanova

stallations use a professional linear lighting device (cold neon) Neon Flex (Voltage is the (90–120) V, Frequency is the 1 kHz).

The tasks of the practical training are limited to the preliminary study of the project. Technical, technological parameters and functional requirements for the object are defined by the customer in the specification. For the light installation of the parking space in front of the ocean-aquarium at the Moscow Exhibition Centre the image of the Wave is chosen – a dynamic symbol of the ocean tides carrying deep-water creatures (or the inhabitants of the marine aquarium) in their streams, Fig.6. Technologically the wave is made of perforated aluminium frame with a flat LED strip along the perimeter of the perforations. Fish sculptures are made of LED Tape-colour Ribbon. Equipment: CHROMEX lighting products catalogue “The white book of illumination” group Leblanc 2014–2016.

The Hermitage garden in Moscow was chosen as a platform for creating a light environment for the celebration of the 130th anniversary of S.Y. Marshak, the famous Russian poet. The project concept covered a series of lighting installations “Heroes of fairy tales” and a swing structure “Cat’s House”, supplemented with projection of Marshak’s filmed works on the elevation of the Hermitage theatre building, Fig.7. One of light-art’s directions is projecting of video or animation images on the facade surfaces of urban objects with the help of media systems, emphasizing or destroying the tectonics of the building, making environmental objects “open to interpretation” [18].

Taking into account the serious animation component, the project was held as part of the summer practical training on the basis of the department’s new specialty – Multimedia Design. Different types of mapping: single projection, flat mapping, volumetric or 3D mapping allowed to realize the maximum natural volume of the surrounding space. As the basis for 3D mapping any existing 3D Show Platform can be used. The elaboration of the project is divided into following stages: building of a three-dimensional copy of mapping-space; the search for the best variant of arrangement of projectors and other equipment (lighting, laser and pyrotechnics, dynamic structures, etc.); creation of the textured scans of three-dimensional objects and the development of video content (motion-design); programming of video content according to script; the physical connection of the projection and other equipment; final correction and running the show. 3D models are assembled directly on the platform as a construction set. Complex objects are imported from external 3D modelling sources such as 3D Studio Max, Maya, Cinema 4D, Vector works, Autocad, etc. The placement of video projectors according to their physical characteristics is greatly relieved due to the fact that the mapping system takes care of the photometric correction of the given sur-

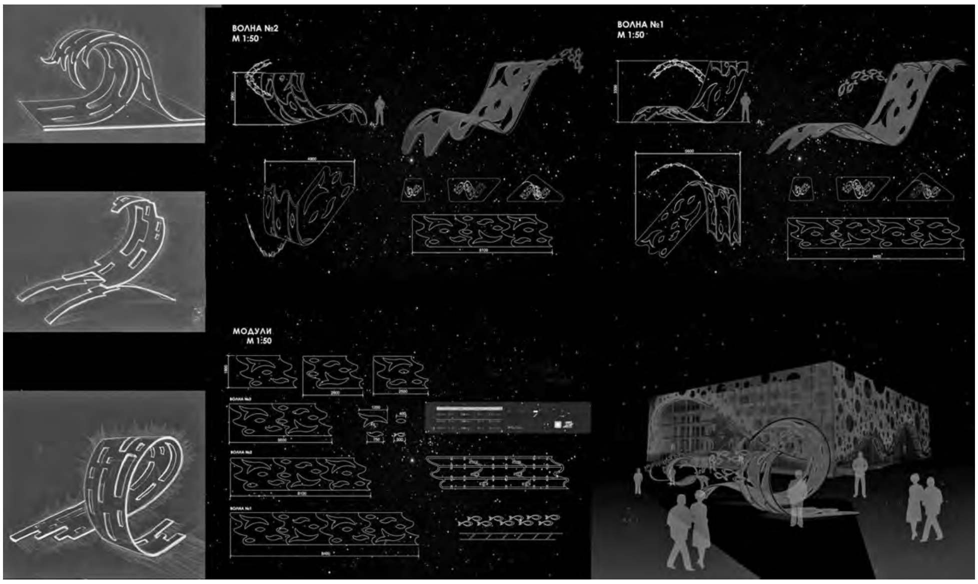

Fig.6. ““Wave” – the concept of light installation for the ocean-aquarium in the territory of Moscow Exhibition Centre”, 201
(Customer: “LEBLANC RUS”. The design is based on S-shaped modules performing a 3-dimensional sculptural animation. A. Kuznetsova. Tutors: Assistant Prof. N.P. Bogatova and A.I. Lobachova)

faces, compensating reflective properties of the materials and the possible overlay of the projections of each other. The design of light installations is determined by the corporative stylistics of Leblanc products. Equipment: CHROMEX lighting products catalogue “The white book of illumination” group Leblanc 2014–2016.

3. RESULTS

New methods of project training in a new field of design – the public environment – with the inclusion of lighting content at the department of Environmental Design in Moscow State Stroganov Academy of Design and Applied Arts does not balance between traditional design and digital programming, between “artistic and technical” but is based on a combination of these methods, using different expressive nature of each one. Classical principles of traditional image-style morphogenesis, innovative computer programming and immaterial achievements of research design methods are boiling in a single pot into conceptual design format. This method passes through the entire sequence of learning tasks: from propaedeutic courses and one-term projects to practical training and graduation projects. This allows one to work with a fairly wide range of urban spaces with different functional characteristics and scale. A single basic platform for all projects is the principle proclaiming “light as art”, taking into account the most important ergonomic aspect of design: its orientation on the human person in his psycho-emotional diversity, dynamic perception of such environment where the person remains the main element. Basic training in arts, traditional art education retains its priority in the formation of professional taste and becomes a major factor in the formation of artistic and aesthetic criteria for the evaluation of the project. Textbook on creative three-dimensional arts will be of little help to the designer. The formation of visual sensations, skills and further fixation of such intellectual structures as “beauty” and “perfection” in the project result can be achieved only with personal handcraft skills. Computer modelling and software support of the project process are only the instruments of the incarnation of the image that emerges on the mental level. Those instruments can help to turn that mental image into “picture” but are not laying claim on the imaginative origin of creativity.

One of the most important aspects of the development of lighting design and methods of lighting designer’s training is an opportunity to test the virtual design in a situation close to reality. This is only possible through experimentation. Analysis of domestic and international experience enriches the design with new experimental data, for example, virtual laboratories equipped with a facility with a breadth of 360 angular degrees. Some kind of “planetarium” for the lighting designer is neces-

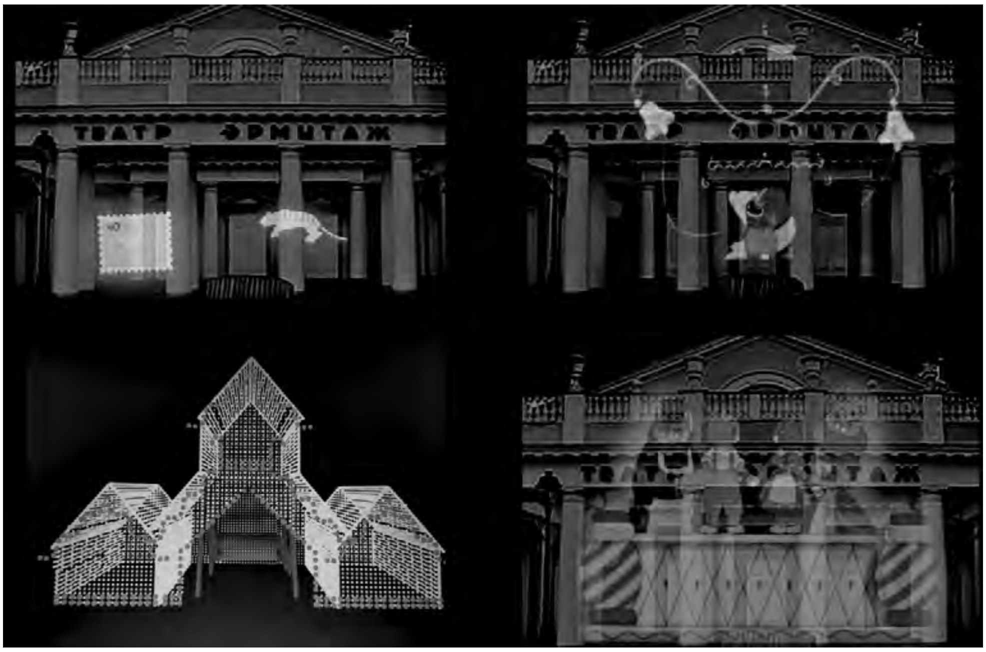

Fig.7. The concept of lighting installation for the 130th anniversary of S.Y. Marshak", 2017 (Customer: "LEBLANC RUS". The dynamism of thematic video projections based on animated images of Marshak's plays and poems provides the Hermitage garden with new qualities of visual illusion, continuing the theme of dematerialized architecture, reviving the images of familiar fairy-tale characters.Practical training. Bachelor course (2th year), department of Environmental Design, specialty Multimedia Design. V. Litvinenko. Tutor: Senior Teacher E.A. Kuznetsova)

sary – the device that could transfer the design model into the spherical space, allowing reproduce the real scale of the environment, brightness and contrast scale, i.e. to introduce the picture on the computer screen into the situation of reality. But this is the subject of a separate study.

Use of serious computer modelling in the educational process within the new specialty "Multimedia Design" allows creating of a virtual light environment with the parameters close to the real human vision, taking into account factors of seasonal changes, weather conditions, the stylistic context of the environment, etc. The main design principle remains the same: the constant search for ways to integrate artistic and technical principles which, unfortunately, remain still separate from each other. One can hope that the innovative design of the lighting environment in the new profile of training with solid support of traditional art education will transform into a separate area of design and will take its rightful place in the structure of the educational process of the Academy.

GLOSSARY

ENVIRONMENTAL DESIGN is the formation (design and implementation) of environmental situations, objects of urban, industrial and residential environment and systems, performed with the help of professional designers and manufacturers, purposefully looking for the specifics of life and especially the visual appearance of the environment. It is a complex multi-stage process (pre-project analysis, design of environmental components and the environment as a whole, taking into account changes in the environment in the process of operation and evolution of the environmental situation), requiring the involvement of specialists in various fields – from architects, designers and artists to technologists and economists [19].

DESIGN CONCEPT is the basic idea of the future object, the definition of its semantic content as an ideological and thematic basis of the design concept expressing the designer's artistic and design judgment about phenomena larger than this object; an integral ideal model of the future object, describing its main characteristics [19].

ARTISTIC IMAGERY in design is an ideal-sensual representation of meanings and ideas, works of design art arising in the process of formation of the idea, design process, creation and perception of final product; artistic model created by the imagination of the designer, expressing his attitude to reality [19].

COMPOSITION in DESIGN is the structure of design product, the relative location and interconnections of its parts according to their layout appropriate to the purpose and technical idea of this product and its artistic (imaginative) design, reflecting the consumer's emotional and sensual expectations of the product [19].

ENVIRONMENTAL CONCEPT considers the environment as a result human activity changing the surrounding world. Accordingly, human activity and behaviour are taken as a determining factor linking the individual elements of the environment in integrity. From that point of view the environmental concept serves as the main foundation of modern project thinking, as the principle of formation of our environment as an organic unity of the whole system of visual-sensual and functional specificity of the place [19].

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Elena A. Zaeva-Burdonskaya,
Prof., Ph.D. in Science of Art, graduated from Moscow State Stroganov School of Design and Applied Arts in 1987. At present, she is the Acting Head of the department of Environmental Design in Moscow State Stroganov Academy of Design and Applied Arts, Member of Russian Designers Association and the Union of Artists of Russia, Laureate of Moscow City Award

Jury V. Nazarov,
Prof., Dr. of Arts, graduated from Moscow State Stroganov School of Design and Applied Arts in 1972. At present, he is the President of National Design Institute, Corresponding Member of Russian Academy of Arts, Honorary President of Russia Designers Association, Laureate of the Russian Federation State Prize, Distinguished art worker of Russian Federation

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THE EXPERIENCE OF CHINA'S LED LIGHTING INDUSTRY'S DEVELOPMENT

Jingyi LIU[1] and Zongyi YIN[2*]

[1]*School of Economics, Wuhan University of Technology, Wuhan, 430070 China*
[2]*School of Management, China Research Centre for Emergency Management, Wuhan University of Technology, Wuhan, 430070 China*
**E-mail: yinzongyi1984@163.com*

ABSTRACT

As a big country with the production and sale of lighting products in the world, LED lighting products are widely used in China, and the LED lighting industry is playing an important role in the whole national economy. To analyze the characteristics and experience of the development of China's LED lighting industry, the development history of China's LED lighting industry was reviewed, the characteristics of the development of China's LED lighting industry were summarized, and the development prospect of China's LED lighting industry was forecasted. Results show that the development of LED lighting industry in China is divided into three stages, which show the characteristics of industrial policy support, core technology leap breakthrough and industrial agglomeration effect. The conclusion has guidance and reference for the development of LED lighting industry in developing countries.

Keywords: LED lighting, industrial development, China

1. INTRODUCTION

With the increasing global greenhouse gas emissions and the deterioration of the ecosystem environment, there is a worldwide consensus on the development of a low-carbon economy. Countries around the world have introduced energy saving and emission reduction policies, actively develop new sustainable energy, and seek a more green energy saving and environmental protection lifestyle. As the new generation of light source in the world, LED is known as the most promising green lighting source in the twenty-first Century because of its advantages of energy saving, environmental protection, good colour display and long life. LED green lighting technology has gradually aroused the attention of all countries [1]. Under the same illumination brightness, the average power savings of LED lamp are more than 40 %-50 % than that of the ordinary lamp, and there is almost no maintenance cost in 3–5 years after installation. The LED lamp does not contain harmful substances such as mercury, lead, and harmful gases, such as the ordinary energy saving lamp, and the average service life of the LED lamp can reach 50 thousand –10 million h, which is 3–5 times that of the ordinary lamp [2]. At present, lighting consumption accounts for about 20 % of the total electricity consumption, and greatly reducing the use of general lighting is an important way to save energy. Therefore, the major developed countries such as the United States, Germany, Japan and other countries have also introduced relevant support policies to accelerate the development of LED industry. China, as a major energy consuming country, has no time to delay in strengthening green lighting technology.

At the same time, as a big country in the production and sale of world lighting products, lighting industrial economy is also playing a pivotal role in China's national economy. China's LED industry has made great progress under the guidance of national support policies and industrial base construction, and has been listed as a new strategic development industry. According to the export amount of LED lighting, the related data showed that in 2014, it was $14 billion 200 million, an annual increase of 59 %. In 2015, it reached 16 billion 400 million US dollars, the annual increase was 15 %, and the export volume in 2016 was 16 billion 960 million US dollars, a small increase of 3 % compared with 2015. The export volume of 1–7 months in 2017 was $8 billion 220 million [3]. It can be seen that, after the rapid growth of the previous years, China's LED lighting industry has entered a mature period, and the advantages and competitiveness of the enterprise also change the scale of enterprise and the cost of product from the product and technical ability. Therefore, the analysis of the characteristics and experiences of the development of LED lighting industry in China and the characteristics of the economic development of the LED lighting industry are instructive and useful for the development of the LED lighting industry in developing countries.

2. DEVELOPMENT PROCESS OF LED LIGHTING INDUSTRY IN CHINA

The development of China's LED lighting industry began in the late 1960s. Because of the limited application field of LED lighting research and development, the development of industry is slow, which is dominated by the enterprises of scientific research institutes or with the background of scientific research institutes, and the ability of industrialization is relatively weak. In twenty-first century, because of the continuous growth of China's macro economy, the support of the national industrial policy, and the continuous breakthrough in the related technical fields, the LED lighting industry has ushered in a breakthrough period of development. From the perspective of its development process, the development of China's LED lighting industry is closely related to the development of LED lighting technology. According to the different development stages of LED lighting technology, the development process of the LED lighting industry in China can be roughly divided into the following stages.

1st stage: 1969–2002 years, LED lighting products had shown the initial symptoms

In 1965, the first commercial light-emitting diode was born in the world. In 1968, nitrogen doping technology enabled the *GaAsP* device to reach 1 lm/W efficiency, and it could emit red light, orange light and yellow light [4]. In the early 1980s, the *AlGaAs* LED lighting technology developed was able to glow with a luminous efficiency of 10 lm/W. In 1990, the industry improved *AllnGaP* technology which is 10 times higher than that of *GaAsP* devices. In 1994, development of blue light diodes has accelerated the application of large screen display, and many media, large sports venues and entertainment places began to use LED large screen display. After that, scientists generated white light by using blue light to generate white light on a single LED. The LED production enterprise, which was primarily used for instrument display and automobile instrument lamp, appeared gradually.

Following the development of LED lighting technology in the world, China's R & D in LED lighting has been another major breakthrough. In 1999, the Semiconductor Research Institute of the Chinese Academy of Sciences and Peking University jointly carried out research on nitride materials, and achieved some results. But until 2003, blue light LED chips have been produced independently, China's blue light LED chips are all dependent on import, and the number of Chinese LED lighting enterprises is few, the main application products are mainly production indicator light, automobile instrument lamp and signal display, technology research and development ability and enterprise independent development ability are weak.

2nd stage: 2003–2008 years, China gradually had formed the LED lighting industry and the scale of the industrial economy

In June 17, 2003, the Ministry of science and technology of China announced the creation of a national semiconductor lighting project coordination leading group to start the "national semiconductor lighting project" to open a new era of China's LED lighting. LED lighting products through independent innovation, breakthrough white light lighting part of the core patents, to solve the urgent industrialization of LED lighting market key technologies, establish a perfect system of technological innovation and industrial clusters, improve the LED lighting industry chain, to form a new industry with international competitiveness of the LED lighting.

The Ministry of science and technology has carried out the entire industry chain deployment on the breakthrough of LED lighting core technology and key technologies for industrialization. The efficiency of white light LED lighting has jumped from only 20–30 lm/W in 2003 to more, than 60 lm/W efficacy in 2008.

At this stage, China started the application of LED functional lighting, and LED lighting industry has made certain achievements. By the end of 2008, with the large number of traditional lighting enterprises involved in the production of LED lighting products, the total number of enterprises has exceeded 3000, and the Yangtze River Delta and the Pearl River Delta have developed into a certain industrial base. The relevant data show that the total output value of LED lighting industry in China in 2008 is nearly 70 billion yuan, but the scale of LED lighting enterprises is generally small, of which 70 % are concentrated in the downstream industry, and the technical level and product quality are uneven. Upstream chip enterprises have no independent intellectual property rights and the industrial concentration is not high, and the overall coordination between the regions is lacking. With the interaction and cooperation, there are still blind investment, low level duplication, product homogenization, and inferior products disrupting the market. Although there are a lot of enterprises in the application, they lack leading enterprises.

3rd stage: 2009–2017 years, the industrial scale is improving and the industrial economic benefits are gradually emerging

In 2009, in order to further promote the development of China's LED lighting industry, expand the market scale, stimulate consumption demand, reduce energy consumption, promote the development and innovation of industrial core technology and improve the overall competitiveness of China's LED lighting industry, the Ministry of science and technology introduced the "LED lighting should be covered in 21 developed cities" in China. Utilizing the project demonstration city plan, we carried out the LED lighting application demonstration [5]. In October of the same year, the 6 departments of the national development and Reform Commission, such as the national development and Reform Commission, introduced the "opinion on the development of energy saving industry for semiconductor lighting", pointed out the problems existing in the development of China's LED lighting industry, and put forward the guiding principles, development targets, key areas and specific policies and measures to promote the development of industry. In addition, various local governments have also issued a number of related industrial development incentives, which have played a beneficial role in promoting the rapid development of the LED lighting industry. In 2017, efficiency of industrialization of Chinese power white LED has reached 160 lm/W, and the efficiency of industrialization of LED chips with independent intellectual property right is more than 150 lm/W. The scale of China's LED lighting industry rose from 120 billion yuan in 2010 to 521 billion 600 million yuan in 2017, of which the size of the upstream epitaxial chip was about 18 billion 200 million yuan, the scale of the middle reaches of the package reached 74 billion 800 million yuan and the downstream application was 428 billion 600 million yuan. With the expansion of the LED lighting industry in China, the industrial structure is constantly improving. The industrial pattern of small and medium-sized enterprises has changed greatly. The prelude of industrial integration has been opened. The pattern of industrial competition is becoming more and more obvious. The number of listed companies based on LED lighting business has increased from 2 in 2010 to 26 in 2017. Purchasing and integration has become an important trend in the development of the industry. The group with leading enterprises is gradually formed. At the same time, the industry begins to move from the coastal to the Midwest, the regional development features show, the industrial structure is further optimized and promoted, and China has entered the ranks of the big country in the production and application of the lighting industry.

3. DEVELOPMENT CHARACTERISTICS OF LED LIGHTING INDUSTRY IN CHINA

Looking at the progress of China's LED lighting industry in recent years, the growth rate of 20 %-30 % for a permanent year is determined not only by the strong support of national policy but also from the advanced characteristics of the industry itself. The following three points are summarized. First, characteristics of LED lighting industry conform to the direction of national development, and are conducive to obtaining industrial policy support. The theory of industrial economics holds that the leading industry has five selection benchmarks, which are the benchmark of the industrial association effect, the growth potential benchmark, the technology intensive benchmark, the employment benchmark and the sustainable development benchmark [6]. Developing countries should first develop industries that conform to these five benchmarks and give priority to government support and development in order to promote the development of the economy as a whole. The LED lighting industry organization shows the dual characteristics of the application driving the entire industry chain, with the dual characteristics of technology intensive and labour intensive. After years of development, China's LED lighting industry has developed into a more complete system including the production of epitaxial LED, the preparation of LED chips, the package of LED chips, and the application of LED products.

3.1. Industrial Chain

Relevant data show that as of 2016, China's LED lighting industry employs more than 4 million people. In addition, the development of LED lighting industry cannot only form new industries and export growth points, but also save energy, reduce environmental pollution and give full play to the advantages of China's labour resources. At the same time, China is one of the major lighting production and exporting countries. The development of LED lighting industry can improve the proportion of high-end industries and high-tech products in China, enhance the international competitiveness of the lighting industry, and also meet the national policy of China's new road to industrialization. Therefore, as a new generation of revolutionary lighting technology, LED lighting has been favoured by the government with its advantages of energy saving, environmental protection, high scientific and technological content, strong industrial drive and so on. The state and various provinces and cities have issued relevant policies to support it and laid a good policy foundation for the rapid development of the LED lighting industry.

Second, thanks to the rapid progress of related science and technology, the core technology of LED lighting in China has been leaping forward. Since the beginning of twenty-first century, China has gradually increased investment in the field of LED lighting research and technology. During the period of "fifteen", China invested more than 1 billion yuan in the field of LED lighting technology research and development, and promoted the research and development of LED lighting technology through the special major national scientific research plan. With the further development of China in the fields of new materials and technology, LED lighting technology has made breakthroughs in chip technology, and packaging technology, luminescence intensity and luminous efficiency, to achieve independent research and development, some areas have reached the leading level in the world. The development of LED lighting technology in China has made great achievements; LED lighting production the core technology of the upper reaches of the industry has made breakthrough progress. The middle reaches of the package have been achieved and maintained obvious advantages. The downstream application is sustained and the development of various kinds of application products is more active. This also creates excellent conditions and opportunities for the development of various functional LED lighting products at the same time, national semiconductor optoelectronic products. A batch of national LED lighting research institutions, such as the key laboratory and the national semiconductor lighting supervision and inspection centre, have been set up in succession, which further promoted the rapid progress of the development of LED lighting technology.

Third, the agglomeration effect of China's LED lighting industry is obvious, and gradually formed industrial agglomeration advantages and regional characteristics. At present, China's LED lighting industry has basically grown up in the triangle, Pearl River Delta, Bohai economic circle and the four major LED lighting industry areas in Fujian and Jiangxi. All the signs indicate that the agglomeration development has become the trend of the development of China's LED lighting industry. As an economic phenomenon, agglomeration development is very common in the industrial development of many countries. The theory of industrial economics holds that, under the guidance of the principle of resource benefit and benefit attracting resources, the industry is bound to form the agglomeration in the region with high benefit. This is the regional comparative advantage theory of industrial agglomeration [7]. The southeast coastal area is mainly distributed in the LED lighting industry gathering area is undoubtedly the consumption concentration area of

LED lighting products. At the same time, it is the first area of China's reform and opening up. The advantages of the policy are obvious, and the LED lighting enterprises in China are from dispersing to centralization to the scale development, which conforms to the law of industrial development. The LED lighting industry has gradually formed a complete industrial chain of substrate, epitaxial chip, chip, packaging, application and supporting equipment in the four major agglomeration areas, and has formed a certain scale effect in the field of packaging and application [8].

In the development process of the four major industrial agglomeration areas, the regional characteristics are gradually formed according to the different industrial forming time, regional conditions and policy orientation. For example, the overall characteristics of the Yangtze River Delta industrial zone and the Pearl River Delta industrial area are that the industrial chain is relatively complete, the industrialization is high, the market advantage is obvious, and the advantages of the Bohai Bay industrial zone. It is characterized by strong product R & D strength, but weak competitive edge. With its own advantages, the region has a clearer location for the development of LED lighting industry in the region, such as the area of the Yangtze River Delta in intelligent lighting, intelligent manufacturing, health lighting and other fields. The Pearl River Delta focuses on large-scale manufacturing and starts to pay attention to quality improvement; Jiangxi has optimized the industrial chain, innovation chain and service chain around the silicon based LED. To build Nanchang Optics Valley; Sichuan and Chongqing pay attention to the application of subdivision. With the increasing cost of enterprises in the eastern coastal areas, the industry began to transfer to the inland, and the central and western regions such as Nanchang and Chengdu became the principal industries.

4. PROSPECTS FOR THE DEVELOPMENT OF LED LIGHTING INDUSTRY IN CHINA

After more than ten years of rapid growth, China's LED lighting industry has formed a relatively complete industrial chain, expands industrial scale and agglomeration advantages, and has a good foundation for industrial development. With the increase of the state policy, the international related industries have accelerated to the domestic industry, the domestic industry investment is increasing rapidly, the industrial technology level is rapidly increasing, and the LED lighting industry in China has a new period of development opportunities.

(1) Core technological fields will be made fundamental breakthroughs. A latest round of technological revolution and industrial change is creating new historical opportunities. From the current overall industrial technology level and trend, the technology of each link of the industrial chain is still at the stage of development, the improvement of production materials, the improvement of the efficiency of light production and the improvement of cost control are made in China. The development of the industry provides opportunities. With the increase of investment in the field of scientific and technological innovation, the bottleneck problem of capital talents will be cracked. The gap between the key technologies of China's LED lighting industry and the international advanced level will be narrowed, and the core equipment and principal raw materials will be fully realized in China.

(2) The effect of policy orientation will further strengthen the trend of deep integration of semiconductor lighting industry. With the gradual appearance of the policy effect, the accelerated landing of policy rules and regulations supporting the development goals of intelligent energy and intelligent cities, as well as the products of LED light, colour, light maintenance, colour stability and so on. The further improvement of performance will speed up the expansion of LED lighting application to the development of intelligent lighting, healthy lighting and other fields. LED lighting technology will deepen the integration with other technology fields, and continue to produce new applications, and the range of high-end applications will be greatly expanded.

(3) The growth rate of the industry is changing from super high speed to medium speed, and the acceleration of enterprise integration and upgrading. At present, the development of China has entered the new normal state. All industries have accelerated the pace of transformation and upgrading, and eliminated backward production capacity and backward enterprises. The upgrading of industrial integration will be the only way for the development of LED lighting industry. Most of China's LED lighting enterprises are still in the low end of the industry chain, with low product technology, small market share and backward production capacity. This

situation will be accelerated with the accelerated pace of industrial upgrading. The market environment and policy environment of the LED lighting industry are optimized and perfected, and then LED lighting production will be guided. The industry is developing healthfully.

5. CONCLUSIONS

In order to analyze the characteristics and experience of the development of China's LED lighting industry, this paper reviews the development course of China's LED lighting industry, sums up the characteristics of the economic development of China's LED lighting industry, and obtains the following conclusions: 1. The development course of China's LED lighting industry is divided into three stages, the first stage: 1969–2002 years, semiconductor lighting the product is beginning to appear. The second stage: 2003–2008 years, China gradually formed the LED lighting industry and the scale of the industrial economy. The third stage: 2009–2017 years, the industrial scale is improving and the industrial economic benefits are gradually emerging.

2. The development of LED lighting industry in China is characterized by industrial policy support, leap-forward breakthrough of core technology and obvious industrial agglomeration effect. The research conclusion has guidance and reference for the development of LED lighting industry in developing countries.

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Jingyi LIU, studying at the school of economics, Wuhan University of Technology, her research interests are industrial economics, global value chain and other directions

Zongyi YIN, Ph.D. in Management. Graduated from Wuhan University of Technology. His research area is emergency industry

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IMPROVING ENERGY EFFICIENCY AND THE LEGAL RIGHT

(On the Example of Artificial Lighting and Related Industries)

Illumination in our country consumes about 14 % of all generated electricity. In Moscow and St. Petersburg, more than a quarter of the electricity goes to lighting. Thus, lighting installations are one of the main single-type consumers of electricity. Therefore, the creation and implementation of energy-efficient new lighting products (lamps, lighting devices, ballasts, etc.) is a major task for the lighting industry, and designing, installing and operating energy-saving illumination systems is no less significant part of the overall energy saving problem.

Among the tasks of lighting engineering science and technology on energy conservation, which systematically examines our Journals "Svetotekhnika / Light & Engineering", are tasks of jurisprudence, or legal right.

The role of these issues has increased especially lately. Today, the production of lighting products is carried out along with several large manufacturers (for example, the Boos Lighting Group, Lighting Technology, LISMA) of more than 1500 small manufacturers, with a large part of them operating on the basis of extensive use of cooperation. At the same time, legal issues play a primary role.

At the moment, for the domestic economy, the importance of increasing the effectiveness of legal regulation of such socially important areas as: energy saving, establishing energy efficiency requirements for lighting equipment, protecting domestic manufacturers, import substitution policy in the field of lighting equipment, saving budgetary resources in public lighting and municipal entities, security of lighting products, copyright in the creation lighting equipment, increasing the role in promoting energy conservation of energy-service contracts and contracts for mutual corporate supplies.

Therefore, improving the efficiency of legal regulation of such socially significant areas as:

– Energy saving,

– Establishment of energy efficiency requirements for lighting equipment,

– Protection of domestic producers,

– Import substitution policy in the field of lighting,

– Saving of budgetary resources in terms of expenditures on the coverage of state and municipal entities,

– Safety of lighting products,

– Copyright in the creation of lighting equipment,

– Enhancing the role of energy-service contracts and contracts for mutual corporate supplies in the promotion of energy conservation are much essential for the national economy at the moment.

In light of this, the editorial board of the Light & Engineering Journal presents a wide range of specialists with articles by leading lawyers in the field of Russian law, in which the author highlights current issues and problems directly related to lighting and related sectors of public relations.

Editor of the special selection of articles
Elena Yu. Matveeva, Ph.D. in Jurisprudence,
Assistant Professor, Financial University under the
Government of Russian Federation

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THE RELEVANCE OF ENERGY SERVICE CONTRACTS IN THE BUDGET SPHERE

George V. Boos[1] and Elena Yu. Matveeva[2]

[1]*National Research University "MPEI", Moscow*
[2]*Financial University under the Gorvernment of the RF, Moscow*
E-mail: duma5@mail.ru

ABSTRACT

The problematic aspects related to the implementation of energy saving policy in the budget sphere are examined in the article. The factors hindering the mass and effective implementation of energy-saving measures are highlighted in the article. Among these factors, there is the technical complexity of energy-saving projects, the presence of innovative and investment risks, problems with the financial provision of costs in the face of increasing debt burden in most public budgets. The article concludes that in these circumstances only the energy service contract is a tool that allows implementing energy-saving measures without the first participation of budgetary funds in financing and allows transferring the risks of making technically inefficient decisions directly to the investor. In the article, the authors substantiate the importance of the institutional development of energy services directly in the public sector and analyze the measures of the comprehensive plan to improve the energy efficiency of the economy of the Russian Federation aimed at expanding the scope of energy service contracts in the public sector.

Keywords: energy saving, budget expenditures for lighting, energy service contract, investment risks

1. INTRODUCTION

Energy saving is a national problem and a public interest. Effective use of energy resources allows:

– To reduce the energy intensity of the Russian economy and thereby increase its competitiveness;
– To reduce the negative anthropogenic impact on the environment;
– To implement a policy of resource saving in conditions of limited reserves of fuel and energy resources in the interests of both present and future generations;
– To reduce the negative impact of the fuel and energy complex on the health of citizens;
– To make a positive contribution to the system of maintaining energy security, which is one of the main directions for ensuring of the national security of our country in the economic sphere.

Also, energy saving should be considered as an urgent task in the context of optimization (economy) of state and municipal expenditures.

The law "On energy saving and energy efficiency and on improving energy efficiency..." sets for the authorities the task of reducing the cost of budgets for the provision of energy resources of state and municipal institutions [1]. Objects of the public sector are quite energy-intensive and according to the Ministry of economic development "energy costs for lighting and heating in the public sector can be reduced by almost a third" [2]. At the same time, the problem of energy saving in the public sector is not easily solved, due to the lack of real commercial interest of users in saving energy resources and the lack of motivation for the introduction of technologies that reduce energy consumption. The purpose of the article is the scientific justification of the relevance of the use of energy service tools in the implementation of energy saving tasks in the public sector.

2. SCIENTIFIC AND LEGAL MATERIALS AND METHODS

The authors used the following methods: general scientific (analysis, synthesis, methods of systemic and functional approach) and private-scientific (formal-legal, statistical, comparative-legal).

3. RESULTS

In April 2018 the government of the Russian Federation approved a Comprehensive plan of measures to improve the energy efficiency of the economy [3], according to which the budget system in 2030 should achieve an annual energy saving of 10.3 billion roubles, and for thermal energy in the amount of 22.72 billion roubles (in prices comparable to the prices of 2016). Thus, in the budgetary sphere, the State has vast reserves of management of effective consumption of energy resources. However, in this area, the issue of the possibility of financing energy-saving measures is most acute since the state of public finances does not allow most municipal and regional budgets to invest in energy saving.

Today, the problem of the budget deficit is relevant for 2/3 of the subjects of the Russian Federation. Almost all the subjects have debt obligations. According to the date of the Ministry of Finance, the sub-Federal debt was 2 trillion 190 billion roubles as of 01.07.2018. For comparison: the same figure as of 01.07.2013 was 1 trillion 311 billion roubles. Thus, the increase in the debt burden was 67 % for regional budgets over the five years. Municipal debt increased by 44.5 % over the same period [4]. The increase in the absolute size of the debt obligations of the subjects of the Russian Federation and municipalities, the increase in the debt burden on their budgets, the possible bankruptcy are threats to the economic and political security of the country. In the context of the deficit of monetary funds, the priority expenditures for the state and municipal budgets are the expenses for the execution of public obligations. At the same time, energy saving requires additional substantial financial investments. The energy strategy of Russia until 2030 contains the following indicators: the necessary investments in energy saving in the period 2009–2030 are estimated at the amount of 244–259 billion US dollars, in 2007 prices [5]. In these conditions, even though the introduction of energy-saving measures should ultimately reduce budget expenditures, the vast majority of regional and municipal budgets cannot find funds for initial investments.

Another problem in the implementation of energy saving policy is the lack of professional experience of energy consumers, which allows evaluating the effectiveness of energy-saving measures offered by the market, and then implement them. The problems of Russia's technological backwardness from foreign countries are related not only to the lack of financing but also to the lack of skills of business entities to transfer knowledge into competitive products and technologies, which are demanded in the market [6]. Moreover, it applies to such entities as state and municipal institutions and such technically complex sector as energy saving and energy efficiency. It is believed that "investment in energy saving is a very complex, ambiguous and in principle, difficult to implement in the practical plane concept" [7]. Energy-saving measures usually have an innovative character. Professional activity in the energy saving market is associated with the need to understand the current state of scientific thoughts, new developments, implementations and the results of their experimental testing have innovative character. Energy saving is usually an innovative activity, which is focused on the latest achievements of science and technology. It is appropriate to highlight the issue of risks that arise in the implementation of energy-saving measures.

As a rule, investments have long-term character. In the implementation of any investment project, the investor faces the difficulty of forecasting inflation processes and in the implementation of investments in energy saving, to assess the possible savings from the introduction of energy-saving measures, and it is also necessary to predict the dynamics of changes in tariffs for energy resources over time with enough accuracy. In investment activities, there is always the possibility that the investment will be wholly or partially lost or will pay off in a more extended period than initially estimated.

As a rule, energy-saving measures are based on the latest achievements of science and technology, projects in energy saving are often unique, and indeed have their own specifics for each specific energy consumer, as they require considering the specifics of loads, technical and operational characteristics of the equipment used, operating modes, climatic factors, etc. Energy saving is not only an investment activity but also an innovative one. G.I. Lukyanov in his doctoral dissertation "Risk as a Phenomenon of Social Reality" notes that the innovative activity is associated with risk, which is due to the uncertainty of the economic situation, and to the uncertainty of the results of research and development, multivariate solutions to innovative problems. If the economic risk is generally understood as the probability of losses because of production and financial activities, the risk in innovative entrepreneurship can be defined as a probability of losses arising from investing in the development of material or managerial innovations, which may not bring an expected effect [8].

Investments and innovations are always fraught with risks. Risk always accompanies business activities. A.S. Vlasova points out, that business activity is burdened with risk [9].

In our opinion, there is a different connection between the concepts of "entrepreneurship" and "risk", and this connection can be seen directly from the legal definition of entrepreneurial activity. According to Article 2 of the Civil Code of Russian Federation "business is an independent, carried out at – risk activities aimed at systematic profit".

From this article, it follows that the business has the right to risk, because the entrepreneur carries out activities in his interest and at the same time risks his property, to make a profit. The situation with the right to risk is entirely different when we talk about the Public finance system and the budget sector. The risk is recognized as a companion of freedom. Freedom is characterized by the possibility of choice, the ability to act independently. Subjects in the budgetary sphere do not have the purpose of their activities to make a profit. Their activities are aimed at the execution of state and municipal mandates. They operate not their own, but public finances, and for this activity is not an appropriate risk, but reasonable prudence, conservative and balanced financial policy aimed at excluding factors related to the possibility of not accurate forecasting, a significant change in circumstances over time.

In economic theory, there are two forms of regulatory risk function: constructive and destructive. Constructability is manifested in the fact that the risk allows overcoming stagnation, psychological barriers, and in solving economic problems, it serves as a catalyser, which is especially crucial in the implementation of innovative investment decisions. The destructive nature of risk is manifested in the fact that the decisions containing unreasonable risk lead to voluntarism, adventurism, and as a risk acts as a destabilizing factor. In public finance, risks should be avoided where possible, bearing in mind their destructive function.

Based on the above stated, it can be concluded that the effective and large-scale implementation of energy saving in the public sector is hampered by some circumstances:

– Limited possibilities of financing of energy saving measures, performed by the subjects of the budgetary sphere;

– The lack of necessary professional training for the subjects of the budget sphere, which allows to evaluate and implement complex technical solutions in energy saving, as in a non-core area for them.

The same group can be supplemented by the risk of innovation and investment activities that should be avoided in public finance.

The energy service agreement (contract) is the tool allowing realization energy saving actions in the budgetary sphere in the conditions of the above-stated problems. Such a contract is a generally recognized common method of work in the field of energy saving.

The energy service company is an investor, and it implements energy-saving measures at the expense of the customer's financial resources and receives reimbursement of costs only in the case of successful implementation of the contract from the amount of savings in energy consumption.

Thus, the energy service contract is a particular way of financing energy saving. It allows the customer to implement energy-saving measures without using of their finances, to pay for the services of the energy service company already from the savings and transfer all the risks of making an inefficient decision directly to the investor.

The state attaches great importance to the development of energy service activities in Russia. The energy strategy of Russia puts its task to form the market of energy services in the period 2009–2015, in the amount of not less than 200 billion roubles per year, in the period 2015–2022 in the amount of not less than 300 billion roubles a year, in the period 2023–2030, in the amount of not less than 400 billion roubles a year. According to the results of the market research of energy service contracts, the volume of the energy service market amounted to 5,021 billion roubles in 2016 [10]. It is quite evident that with the planned indicator of 200 billion roubles per year, this indicates that the market for energy service contracts is not developing to the proper extent.

Specific tasks and activities for the development of energy services in the public sector are formulated in the framework of the Comprehensive plan of measures to improve the energy efficiency of the Russian economy, adopted by the Government of the Russian Federation in April 2018 [3].

By the above-mentioned Comprehensive plan, regulatory acts regulating the procedure for establishing requirements that oblige state and municipal institutions to reduce energy consumption must be adopted by the end of 2018. It is assumed that a target volume of consumption of energy resources based on the specified consumption standards will be set for the organizations of the public sector. State and municipal institutions will perform energy-saving tasks under the control of a specially created monitoring system. In case of exceeding the established standards of consumption of power resources, the organizations of the budgetary sphere will be obliged to realize power service actions.

Some activities of the integrated plan are directed at simplifying of the procedures for concluding energy service agreements (contracts). For this on the end 2018, the Ministry of economic development, Ministry of Finance, and Ministry of Energy of Russia should prepare draft regulations, which will establish mechanisms for removing barriers to attract extra-budgetary investments through the mechanism of energy service contract in the public sector and will develop approaches to facilitation of involvement of participants of energy service activities in a contractual relationship. The government of the Russian Federation will consider proposals for the establishment of specialized organizations in the constituent subjects of the Russian Federation to carry out preparatory work for the conclusion of energy service contracts. A unique information portal, through which it will be possible to use an automated system for concluding and monitoring the implementation of energy service contracts, would be created in the second quarter of 2019. It will automate both the preparation of tender documents and the tender procedures themselves at the conclusion of energy contracts. The monitoring system will allow controlling the implementation of energy service contracts and will reduce the risks of participants in energy service relations. The share of energy service contracts concluded with the use of an automated Contracting system would be 10 % in 2025 and would be 90 % in 2030. To improve the skills of employees in the field of energy saving, the government of the Russian Federation proposes to create a system of distance additional professional education and training of employees of organizations operating in the field of energy service procedures. Thus, the Government of the Russian Federation has identified the need for the development of energy services in the public sector and has planned some activities using methods not used in practice before. The study presented in this article allows us to conclude that the introduction of energy service contracts becomes particularly relevant namely in the budgetary sphere.

3. CONCLUSION

The concept of energy service agreement (contract) was introduced by the Federal Law No. 261-FZ dated 23 November 2009 "On Energy Saving and Increasing Energy Efficiency and Amendments to Certain Legislative Acts of the Russian Federation" [11]. A state program of the Russian Federation "Energy Efficiency and Energy Development" was approved by the RF Government Resolution No. 321 on April 15, 2014. The Program implementation period is 2013–2020. The Appendix N3 of the Program contains the list of the primary actions which part development of institutional mechanisms of stimulation of energy saving is the conclusion of power service contracts [12]. The formation of a sufficient energy service market is a guarantee of the implementation of several state public interests, and the problem of the development of energy service activities and the Institute of energy service contracts (contracts) is particularly relevant about the budgetary sphere.

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***George V. Boos*,**
Ph.D., graduated from MPEI in 1986, President and Member of Board of Directors of BL Group, Head of the chair "Light and Engineering" NIU MPEI. He is a Laureate of the State Prize of the Russian Federation (for architectural illumination of Moscow), chairman of the editorial board of the "Svetotekhnika" and "Light & Engineering" Journals. Member of the Russian Academy of Natural Sciences

Elena Yu. Matveeva,
Ph.D. (Low Science), Assistant Professor of Financial University, Financial Director of ILEC "BOOS LIGHTING GROUP"

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TRANSFORMATION OF THE ENERGY SECTOR IN CONDITIONS OF DIGITAL ECONOMY

Nina A. Efimova, Margarita O. Ruchkina, and Olga Yu. Tereshina

Financial University under the Government of the Russian Federation
E-mails: efimovanina@yandex.ru; ruchkina.margarita@mail.ru; olga.tereshina.vkr@gmail.com

ABSTRACT

Negative climate change processes on our planet, along with rapid development of macroeconomics, stipulate the necessity of the energy sector transformation. Constant increase in energy consumption due to the growing needs of industry and population, including electric lighting, which according to OECD and IEA is going to increase by 80 % by 2050, accentuates the need to address issues related to energy conservation and energy efficiency on a global scale. At the same time, steady economic growth of any state is closely related to the availability of sufficient electricity volume. Given the current trends in the development of digital economy, which depends entirely on reliable and efficient electricity supply, the transition to low-carbohydrate power systems is a matter of concern for the vast majority of countries interested, on the one hand, in a favourable environment, and on the other hand, in stable and sustained economic growth. The given study is devoted to the interrelationship between improving energy efficiency and solving environmental problems, which, under the national idea of developing digital economy and joining the Paris Agreement on climate, is extremely relevant for Russia.

Keywords: energy saving, energy efficiency of lighting equipment, green economy, digital economy, climate change

1. INTRODUCTION

The purpose of this paper is to study the relationship between energy efficiency improvements, including energy efficiency of lighting equipment, and the need to address environmental problems in the context of the national idea for the development of digital economy and the accession of Russia to the Paris Agreement on Climate Change. To achieve this goal, the following tasks were formulated: to consider the prerequisites that necessitate the transformation of the energy sector; to study major trends in the development of digital economy in Russia and in the world, as well as its impact on energy efficiency; to explore the existence of legal foundations that promote energy saving and energy efficiency in Russia; to study the best experience of foreign countries on energy saving and energy efficiency.

In 2011, the "OECD Green Growth Studies: Energy" was prepared and published by the Organization for Economic Cooperation and Development (OECD) together with the International Energy Agency (IEA), the main aspects of which are devoted to the need to transform the energy sector to preserve the environment and stimulate economic growth [1]. This can be done by reducing the adverse impact on the environment by promoting policies for energy efficiency, introducing low-carbon energy technologies, and eliminating state support in the form of subsidies for fossil fuels. The OECD and the IEA estimate that, given the growth rate of the world economy, it is expected to increase by at least four times by 2050, which will naturally affect the growth in energy consumption (by 80 %), so that global CO_2 emissions will be also increased (twice). The World Meteorological Organization assumes that an increase in the concentration of carbon dioxide contributes to the aggravation of the greenhouse effect. According to the World Health Organization (WHO) analyst, about 7 million people die every year from diseases caused by environmental pollution, by air pollution in particular, such as cardiovascular diseases, stroke, cancer, respiratory diseases, including asthma and pneumonia [2]. WHO, in 2005, developed an Air quality guidelines, which set thresholds for the level of atmospheric pollution that adversely affect human health. At the same time, in 2016 almost the entire population of the world (91 %) lived on territories where WHO recommendations were not implemented. According to WHO estimates, as for May 2018, 9 out of 10 people breathe constantly contaminated air, in which the concentration of pollutants exceeds all permissible standards [3].

Thus, global economic growth is closely related to the growing demand for electricity, which in turn has a negative impact on the state of the environment and on human health.

2. METHODS

To carry out research and achieve the goal, the author used universal methods of cognition (analysis, synthesis, generalization, induction, deduction), methods of empirical research (scientific research, comparison, description), methods of theoretical knowledge, comparative law method, historical method, formal-logical method.

3. RESULTS

The international community, in the name of recognized international organizations and institutions, is concerned about energy efficiency issues and is doing serious work aimed at studying the emerging architecture of electricity consumption and its impact on the global state of the environment. The International Energy Agency in 2011 prepared a set of 25 recommendations for improving energy efficiency in various areas, including lighting. The identified recommendations, among other things, contribute to reducing CO_2 emissions. In terms of lighting, the IEA proposes to phase out inefficient lighting devices and systems, as well as to ensure the introduction of energy-efficient lighting systems [4].

In 1992, more than 180 states signed the United Nations Framework Convention on Climate Change, which goal is "to stabilize the concentration of greenhouse gases in the atmosphere at the level that would prevent a dangerous anthropogenic impact on the climate system" [5]. In 2015, within the framework of this convention, an agreement on the climate in Paris was adopted (the Paris Agreement) [6]. The purpose of the agreement correlates with the objectives of the United Nations Framework Convention on Climate Change, but it also seeks to "strengthen the global response to the threat of climate change in the context of sustainable development and efforts to eradicate poverty", also by minimizing the prerequisites for increasing temperature growth and limiting the rate of greenhouse gas emissions. The Russian Federation is also a party of the Paris Agreement that is why it committed itself to reduce greenhouse gas emissions by (25–30) % by 2030.

The Institute for Natural Monopolies Research in 2017 conducted a study "Carbon regulation models – lessons for Russia", as a result of which experts came to the conclusion that it is necessary to provide incentives to reduce emissions, otherwise, Russia may incur reputational risks associated with non-fulfilment of taken over obligations under the Paris Agreement [7]. The study identified various approaches to current models of greenhouse gas emission regulation in the world: direct payments for emissions; taxation of motor and energy fuel; stimulating the development of renewable energy sources; promoting energy efficiency. As the most optimal for Russia, experts noted a model aimed at stimulating energy efficiency, which is due to the presence of positive experience of implementing the fundamentals of energy efficiency principle, including energy efficiency standards for consumer electronics and household appliances and lighting equipment as well. The main goal of this model is to reduce the specific energy consumption for each of its consumers. The indicated can be provided through tariff and price regulation, implementation and compliance with technical standards, the extension of the system of obligations and penalties, the provision of tax incentives and other methods.

The efficiency of the energy-saving approach is highlighted in the scientific literature. For example, A. Bhattacharjee and S. Mazumdar, in the framework of the study comparing different light sources for museum illumination, emphasize that the use of LED lamps within the energy-saving approach, including the design of museum lighting, contributes to the "green" future of our planet [8].

The Energy Strategy of Russia for the period until 2030 notes that in the implementation of a similar strategy until 2020, substantial work was carried out on one of the priority areas such as "Energy and energy saving", thanks to which new technologies were developed, including "energy-saving and environmentally friendly lighting devices of a new generation with light emitting diodes and mercury-free gaseous discharge lamps" [9]. At the same time, among the main tasks of the Energy Strategy of Russia for the period up to 2030 is a task aimed at "enhancing energy and environmental efficiency of the Russian economy and energy, through structural changes and activation of technological energy conservation" [9]. Within the framework of the Energy Strategy for the period up to 2035 a new subsection "State Policy in the Field of Energy Saving and Energy Efficiency Enhancement" was added, where various types of state support in the field of energy efficiency are envisaged, including introduction of tax incentives for the acquisition of energy efficient equipment, etc. [10] That causes the need for further changes in this area.

Among other things, the Institute of Natural Monopolies Research experts note that stimulating energy efficiency as the most effective model for regulating greenhouse gas emissions in Russia will contribute to the successful implementation of the principles of best available techniques (BAT) widely used in the European Union countries. These principles are set out in the framework of the Directive of the Council of the European Union on the Integrated Pollution Prevention and Control (IPPC) (2010/75/EU) [11] and the OECD Council Recommendation on the Integrated Pollution Prevention and Control C (90) 164 [12]. The vector of BAT principles is aimed at creating conditions for the modernization of industrial equipment, thereby ensuring environmental protection in the most effective way in comparison with other technologies used. In Russia, the benchmark for BAT was reflected in the Federal Law of 21.07.2014 N219-FZ "On Amending the Federal Law "On Environmental Protection" and certain legislative acts of the Russian Federation" [13]. BAT can be applied to those areas of activity that have a "significant negative impact on the environment", including those caused by the application of certain technological processes, equipment, technical methods and techniques. The list of such areas is established by the Government of Russia and currently includes 29 points [14].

For the transition to the principles of BAT, similar to the experience of foreign countries, in Russia special information and technical reference books on BAT are being developed that contain information on the type of activity, indication of the negative effects on the environment from its implementation, the methodology for determining BAT aimed at reducing the negative environmental factors from such activities, etc. [13] In addition, the Russian Government's Order N398-r of March 19, 2014 approved a set of measures, the implementation of which aimes to ensure the abandonment of the use of obsolete and inefficient technologies, as well as to implement the transition to the principles of BAT and the introduction of modern technologies [15].

Thus, energy efficiency is fixed by the legislator as one of the guidelines of the state policy aimed at ensuring energy saving in accordance with the universally recognized international standards for the prevention of environmental pollution.

Turning to the prospects for increasing energy efficiency, it seems necessary to pay attention to the current trend – the digitalization of economy. World trends show that the main reference point is currently focused on the universal digitization of various spheres of human life: the Internet infrastructure continues to improve, which stimulates the use of digital tools in everyday life.

The OECD report the Digital Economic Outlook of 2017 notes that in 2016 83 % of the population of the OECD countries had access to the Internet, while in 2005 only 56 % of the population had access to the Internet and only 30 % uses the Internet constantly [16]. At the same time, there is a fall in the cost of Internet connection services: for example, the cost of connecting for one month with 200 GB traffic decreased for the period from 2013 to 2016 from $43 to $37 in 2016; the cost of mobile Internet with 2 GB traffic decreased for the period from 2013 to 2016 from $71 to $39. Currently, almost half of the world's population uses the Internet, while in 2001 the number of users was only 500 million [17]. The IEA estimates that for the acquisition of various services, the number of connected devices to the Internet of Things (IoT) technologies will increase from 8.4 billion in 2017 to more than 20 billion by 2020 [18]. The OECD emphasizes that the key to the digital economy is the mobile use of data: the use of mobile applications for purchases, payment for digital services, payment of current bills, etc.

Thus, digital innovations inevitably transform the economy and society. At the same time, the digitalization of economy is positioned as a blessing and is strongly encouraged at the highest levels. For example, the OECD calls on all states, not limited to member countries, to intensify efforts and encourage the widespread use of digital technologies for the flourishing of the global digital economy [19].

In Russia in 2017, the government of the Russian Federation approved the program "The Digital Economy of the Russian Federation" [20], the direction of which, in essence, is determined by the provisions of the Strategy for the Development of the Information Society in the Russian Federation for 2017–2030 [21]. Both documents presume the necessity of creating an enabling environment conducive to the development of digital economy in order to improve the standards of living. The program defines the definition of digital economy, which is understood as "… economic activity, the key factor in the production of which is digital data… contribute to the development of the information infrastructure of the Russian Federation, the creation and application of Russian ICTs, and the formation of a new technological basis for social and economic development" [20].

At the same time, the program for the development of the digital economy in Russia provides for the need for its widespread distribution, also by increasing the use of broadband Internet access for households, including sparsely populated areas, medical and preventive organizations and educational institutions, public authorities and local governments, defining a stable vector for ensuring the use of data in a digital format. It is also planned to implement other large-scale measures to introduce digitalization, as envisaged by the "road map" of the "Digital Economy of the Russian Federation" program.

Undoubtedly, digitalization, on the one hand, contributes to the development of economic growth, but on the other hand it tends to form stable dependence on electricity, which is due to the constant need for information and communication technologies (ICT), through which access to products of digital economy and electricity becomes possible. To catch this close relationship, it seems quite enough to be an active user of any iPhone model: a rare user can do without the need to recharge his or her phone for one day. Thus, it is obvious that the progressive development of national economic growth based on digital economy is due, among other things, to the need to modernize the corresponding energy infrastructure systems.

Having compared the Energy Strategy of Russia, other normative acts in this area, including state programs on energy efficiency, with documents aimed at the development of digital economy in Russia, the author concluded that in the "Digital Economy of the Russian Federation" program there is no indication of approaches to compliance with energy conservation measures and energy efficiency, as well as in documents dealing with energy efficiency there is no mention of the need to take into account the increasing demand for electricity caused by the development of digital economy.

Within the framework of the "road map" for the implementation of the program on the digital economy, there is only one mention of energy, in particular, to implement the direction of the development of the digital economy in Russia it is supposed: "4.9. Ensure the availability of data storage and processing services throughout Russia for citizens, businesses and authorities". This item should be implemented also by elaboration of a general scheme for the development of data storage and processing infrastructure, taking into account the development plans for the energy and telecommunications infrastructure (the deadline is the end of 2018). Obviously, this can not be regarded as a system-forming approach to implementing the idea of energy efficiency, taking into account the interrelation between increases in the use of the necessary electric power resources for the implementation of the tasks set for the development of digital economy of Russia. Thus, data storage and processing are carried out by data processing centres (data centres), the number of which is steadily growing in proportion to the increase in the volume of transmitted information. For example, Google has chosen Denmark to host data centres in Northern Europe. For a general understanding of the scale, we note that the area of this data centre is approximately 23 football fields [22]. According to the estimates of the independent state enterprise of the Ministry of Climate and Energy of Denmark, three data centres located today in the country (Facebook, Google and Apple) will increase Denmark's energy consumption by 11 % by 2022 [23]. In general, according to experts, global data centres consume about 3 % of the total world electricity supply and allocate 2 % of the world's greenhouse gas emissions, essentially the same as the aviation industry [24]. At the same time, attention is drawn to the presence of an active position of developed countries with regard to the "making more eco-friendly" data centres. Thus, for instance, in the USA the federal program of energy consumption management is launched, the main idea of which is energy saving in the data centre. For this purpose, the program includes publications on best practices in energy efficiency and energy conservation, recommendations for data centres, training programs for energy specialists, other tools aimed at supporting organizations in implementing measures to improve the energy efficiency of the data centre, including the Data Centre profiling tool, which allows data centre operators to estimate the use of energy [25]. Also, Centres for expertise on energy efficiency in data centres and requirements for energy efficiency of national data processing centres were established [26]. Consequently, there is observed a certain activity to maintain the balance of the development of the digital economy and energy efficiency.

In its turn, Russia has a fragmented approach to the two interrelated vectors of the country's national economy development: Russia is guided by international approaches to the introduction of energy efficiency frameworks; it actively joins global digitalization processes. At the same time, the effect from achieving each of the indicated processes is not taken into account. In other words, at the present stage, the elaborated strategies and programs aimed at developing digital economy do not consider negative factors of widespread digitization to the results of implementing approaches to energy efficiency, in turn, documents that fix the benchmark for energy efficiency underestimate the potential risks of not achieving the objectives set in the conditions of the country's transition to digital economy, which, in the context of Russia's accession to the Paris Agreement on Climate, forms reputational risks of non-fulfillment of international obligations.

4. CONCLUSION

Under conditions of the need to transform the energy sector, in connection with the obligations assumed by Russia within the framework of the Paris Agreement, when Russia moves to the global processes of digitalization of economy, it is advisable to take into account the effects of such integration in terms of their impact on achieving the set targets for energy saving and energy efficiency. Currently, the indicated priority in national approaches to the development of digital economy and the achievement of energy efficiency in Russia is not indicated, which states that this aspect is missing from the legislator's field of vision. In connection with the above, it is proposed to make changes to the program "Digital Economy of the Russian Federation", concerning the consolidation of priorities for the registration of national benchmarks for energy conservation as well as due to Russia's accession to the Paris Agreement. It is also advisable to introduce changes to the Energy Strategy of Russia for the period until 2035 to take into account the potential impact of the effects of the digitalization of the national economy on achieving benchmarks for energy efficiency. The indicated changes should be strategic in nature and consider Russia's long term interests, having respect to the undertaken obligations to the international community. It is regarded as advisable to borrow the US experience in implementing the federal energy management program aimed at saving energy in the data centre and initiatives to optimize the energy efficiency of the data centre. In general, it seems that linking such topical vectors of Russia's development as energy efficiency and digital economy will meet international experience in this matter and will allow to ensure most efficiently the transformation of the energy sector in the conditions of digitalization of economy.

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Nina A. Efimova,
Senior Lecturer, Department of Legal Regulation of Economic Operations, Financial University under the Government of the Russian Federation

Margarita O. Ruchkina,
Second year student of the Faculty of Law, Financial University under the Government of the Russian Federation

Olga Yu. Tereshina,
lecturer, Department of Language Training, Financial University under the Government of the Russian Federation

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INFLUENCE OF CLIMATIC CONDITIONS OF RUSSIA AND THE COUNTRIES OF THE NEAR EAST ON LIGHTING EQUIPMENT

Dmitry N. Ermakov[1], Oleg Yu. Kazenkov[2], and Ravil K. Khusnulin[3]

[1] Financial University under the Government of the Russian Federation
[2] Moscow Institute of Contemporary Academic Education
[3] State Duma of the Federal Assembly of the Russian Federation
E-mails: DNErmakov@fa.ru; khusnulin@duma.gov.ru

ABSTRACT

The digital economy assumes an increase in the role and importance of the lighting engineering science in the industrial countries. Nowadays, the development of a country is largely characterized by its "light supply" with minimum energy consumption. In modern Western Europe, for example, it is impossible to separate climate protection policies from energy policy. In the countries of the Middle East, there is a rapid development of the construction industry as many residential and public buildings are being built, and energy consumption issues are acute. The article studies the influence of the light climate of Russia and the countries of the Middle East on the development of construction lighting equipment, which enables to optimize energy consumption, create comfortable working and leisure conditions.

Keywords: light, local climate, cloud cover, sky brightness, SNiP, daylight, artificial lighting, energy audit, energy saving, energy efficiency

1. INTRODUCTION

The standard of living and civilization in the twenty-first century are determined by the use of energy resources. The growth of energy consumption all over the world put on the agenda the need for enterprises and organizations to implement the international standard ISO 50001: 2011. Achievement of energy efficiency in modern industry is achieved not through the introduction of new energy-saving technologies, but through the changes in methods and management techniques [1,2,3]. Energy saving plays a primary role in shaping the world environmental policy. Thermal power plants running on coal and fuel oil, lead to pollution of the atmosphere and water. Currently, artificial lighting amounts to more than fifteen percent in the global energy consumption of the world community. Increasing energy consumption (Fig.1) and CO_2 emissions (Figs.2, 3,4) to the atmosphere contributes to the greenhouse effect and ultimately leads the world civilization to global climate change.

The British standard BS8207: 1985 with the changes introduced in 1994 continues to operate up to the present. The standard is used in the design of new buildings, repair of existing buildings, maintenance activities for residential buildings. Australian standards AS3595: 1990 and AS3596: 1992 are dedicated to financial aspects. For example, the standard AS3595: 1990 provides guidance for the financial evaluation of business projects under the energy management program. The standard AS3596: 1992 includes guidelines that allow users to analyze energy saving proposals.

The second edition of the Australian/New Zealand energy AS/NZS3598: 2000 is dedicated to the energy audit. The Danish standard DS2403: 2001 is focused on organizations implementing a full-fledged energy management system. The Irish Standard IS343: 2005 is developed by the Task Force of the National Standards Authority of

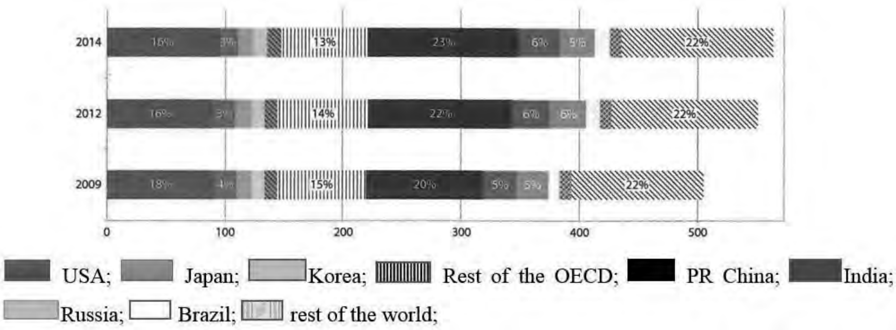

Fig. 1. Use of energy by countries or a group of countries in 2009, 2012 and 2014. [Calculations based on Extended World Energy Balances (IEA, 2016b)]

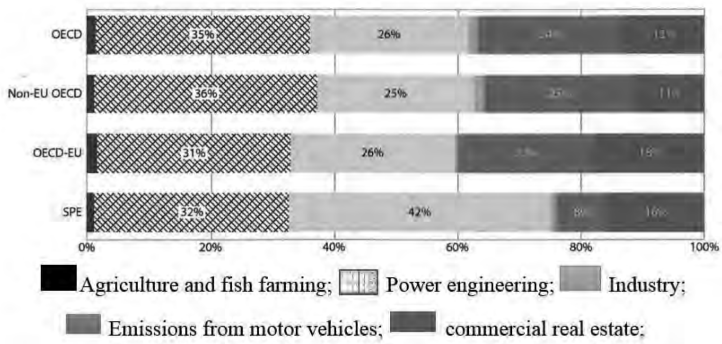

Fig. 2. Composition of CO_2 emissions from various economy sectors, 2014, in %. [Calculations based on Extended World Energy Balances (IEA, 2016b)]

Ireland (NSAI). The American national standard ANSI/MSE2000 for management system for energy (MSE) is adopted in the US in April 2005. The introduction of the standard allows organizations to lower energy costs and energy consumption provide control over the state of the environment. The American Standard ANSI/IEE739: 1995 contains a set of practical recommendations for energy management [2].

In the Russian Federation, in the field of energy conservation in 1999, next national standards were published:

– GOST R51387–99 "Energy Saving Normative and Methodical Support Basic Provisions";

– GOST R51379–99 "Energy saving; Energy Passport of the Industrial Consumer of Fuel and Energy Resources; Basic Provisions; Typical Forms";

– GOST R51541–99 "Energy saving; Energy Efficiency; Composition of Indicators; General Provisions".

The Federal Law of November 23, 2009, N261-FZ "On Energy Conservation and on Improving Energy Efficiency and on introducing Amendments to Certain Legislative Acts of the Russian Federation" is important for national lighting technology [3].

In accordance with the Federal Law of the Russian Federation "On Energy Saving and on Improving Energy Efficiency and on Amending Certain Legislative Acts of the Russian Federation", the Ministry of Energy of the Russian Federation issued Order No. 400 of June 30, 2014 "On Approval of Requirements for Conducting an Energy Survey and its Results and Rules for Directing Copies of the Energy Passport Compiled Based on the Results of the Mandatory Energy Audit". The order specifies the requirements for conducting an energy survey and its results, which are assigned to self-regulated organizations in the field of energy inspection (hereinafter referred to as SRO), as well as to individuals entitled to conduct energy audits and to members of the SRO (further – energy auditor).

With clear-sky models, the countries of the Middle East need to abandon the British standard for natural light systems characteristic of the cloudy sky. The British colonization of the Middle East undoubtedly increased the level of lighting engineering culture. Today, when building residential and industrial buildings, it is necessary to take into account that the characteristics of the light climate in the UK, when designing natural lighting systems, are not applicable to the Middle East. The Middle East is a region with a total area of about 5,207,538 square kilometres, which is located in South-West Asia [5].

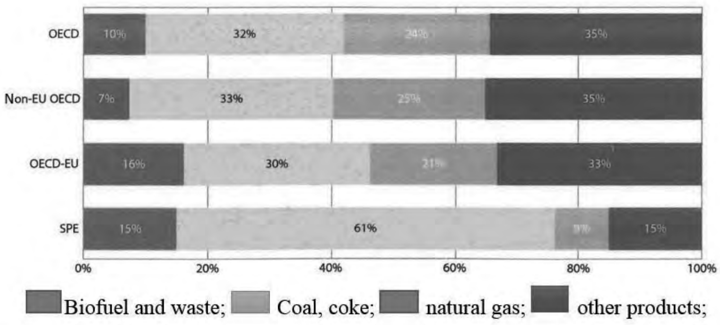

Fig. 3. Composition of CO_2 emissions as a result of using fuel energy for various groups of countries, 2014, in %. [Calculations…]

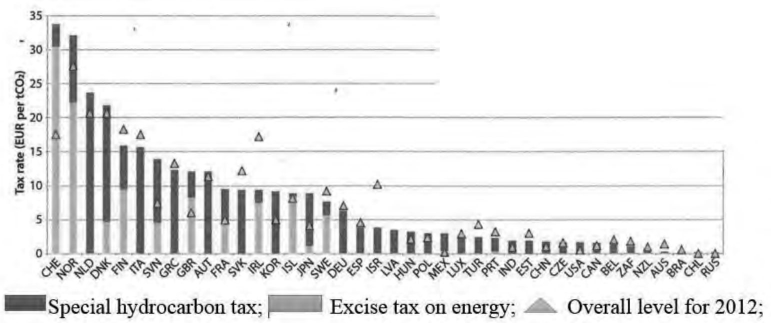

Fig. 4. Average effective tax rates from taxes and specific taxes on carbon by country in the road sector in EURO/tCO_2, 2015 and 2012. [Taxing Energy Use 2018. Companion to the taxing use Database]

2. THE PLACE OF LIGHT-CLIMATIC FACTORS IN THE CONSTRUCTION OF PUBLIC AND PRIVATE BUILDINGS

In the distant 1930s, the Soviet Union adopted the "Rules and Norms for the Development of Populated Areas, Design and Construction of Buildings and Structures", regulating the ratio of the light area of windows to the floor area in residential buildings: from 1/10 to 1/7 for southern regions and from 1/8 to 1/6 for the middle and northern regions. Important was the climatic paradigm of the Soviet Union: in 1934, four regions were identified (based on the air temperature data for January and June): northern, middle, southern and subtropical [6]. In 1938, design temperatures were set to determine the amount of required resistance to the heat transfer of the outer walls (Chaplin's formula). In 1948, in the "Rules for the Design of Residential Buildings," the country's territory is divided into five regions. Important for understanding the meaning of light engineering in construction is SNiP II-4–79 "Natural and Artificial Lighting", 1980. In 1995, the Ministry of Construction approved SNiP 23–05–95. Beginning in 2011, in accordance with the Decree of the Ministry of Regional Development of the Russian Federation, the updated SNiP 23–05–95 began to be applied in the framework of the Code of Rules SP.52.13330.2011 [7]. In 2016, SP.52.13330.2011 partially lost its validity except for SP.52.13330.2011 "SNiP 23–05–95" "Natural and Artificial Lighting", included in the List of national standards and codes of practice [7].

Methods for calculating climatic parameters for the Russian Federation are based on the scientific and applied guide to the climate of the USSR 1–34, parts 1–6 (GIDROMETEOIZDAT, 1987–1998). Simultaneously, on January 1, 2015, SNiP 23–02–99, which sets the climatic parameters that are used in the design of buildings and structures, heating, ventilation, air conditioning, water supply, planning and building of urban and rural settlements, operates on the territory of the Russian Federation [8].

The decree of the Chief State Sanitary Doctor of the Russian Federation of October 25, 2001 N29 "On the implementation of SanPiN 2.2.1/2.1.1.1076–01" contains mandatory requirements for the insolation of residential and public buildings, children's educational and health institutions. The parameters of the light climate are calculated according to the formula:

$$E_{gl} = E_d + E_s + E_e,$$

where E_{gl} is the Global illumination, E_d is the direct sunlight; E_s is the diffuse light of the sky; E_e is the light reflected from the earth, on four sides of the world. The British standard of illumination is not applicable for the Middle East region: measurements of global illumination have shown that the level of outdoor illumination during working hours is above 2000 lx, while the British standard provides 5000 lx. The level of global coverage for most countries in the region ranges from 20,000 to 1,200,000 lx and allows the use of light potential for both industrial and residential premises. The category "light field" is defined through the concept of a light vector [9]. The definition of the light field is given in A.A. Gershun "Theory of the Light Field" (1936) [10].

Examples of natural illumination in the countries of the Middle East are much important. As an example, let us take a seven-story office building in Jordan, painted in beige with a reflection coefficient p and an area of 1000 m^2. As a source of daylight in the building, side windows with dimensions of (2×1.2 m) and upper zenith lanterns of 1.5 m in diameter are used. The illumination within the office premises during the calendar year was measured using sensors (Luxmeter-Pico), located at the level of the working surface. The measurements showed that the level of natural lighting of office premises (300 lx) for eight months is sufficient without the use of artificial lighting. Let us look at the calculation of the cost of consumed electricity in public lighting systems. As a basic example, consider a typical public building in Jordan. For artificial lighting, lighting systems with fluorescent lamps of 2×36W are used with electromagnetic ballasts [11]. These lamps have a loss of 10 % of the power consumption. For calculation, we use the fifth-floor systems: the number of lamps (including ballasts), their power, losses in the EM-ballast system, and the cost of consumed electricity. The total number of lighting chandeliers is 264 pieces, power and 10 % loss in ballasts, 72+10 = 82 W; 264×82 = 21.648 kW; working hours (7 hours); daily power consumption – 21.648×7 = 151.536 kW; daily power consumption of seven floors: 151.536×7 = 1061 kW; monthly power consumption (22 working days) 1061×22 = 23342 kW, all seven floors per year consume 22770×12 = 280104 kW; the cost of 1 kW of electricity is 0.11 Euro. Thus, the annual cost of electricity consumed in the seven-story office building is equal to 280104×0.11 = 30811.4 Euro [12].

3. CONCLUSION

The article substantiates the necessity of further development of construction lighting for the economy and reproduction of generator capacities of electric energy. For the Russian Federation, the correct light-climatic zoning is extremely important, enabling to calculate the economic effect from the introduction of new building technologies that provide for the use of energy-saving technologies. The paper explains the economic efficiency of using natural lighting systems in public buildings. The climatic conditions of the states of the Middle East and South of Russia, with differences in the temperature regime and the amount of precipitation, have many common features: numerous sunny days a year, beautiful ecology. The use of positive experience of the Middle East countries will find wide application in the construction lighting equipment of our country. In the "southern" regions of the Russian Federation, it is advisable to reduce the areas of light-holes.

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Dmitry N. Ermakov,
Professor of the Department of Management of the Federal State Educational Institution of Higher Education "Financial University under the Government of the Russian Federation", Doctor of Political Science, Doctor of Economics, Candidate of Historical Sciences, Professor, Honoured Worker of Higher Professional Education of the Russian Federation, Honoured Worker of Science and Technology of the Russian Federation

Oleg Yu. Kazenkov,
Director of the Russian Academic Fund, Associate Professor of the Department of Civil Law Disciplines, Moscow Institute of Contemporary Academic Education (MISA)

Ravil K. Khusnulin,
Member of the State Duma of the Federal Assembly of the Russian Federation, Head of the Regional Executive Committee of the ALL-RUSSIAN PEOPLE'S FRONT in the Republic of Tatarstan

Fig.2.Conceptual project of the mobile digital Museum – 2012", 2008
(Technologies of holographic architectural structures creation in the urban environment are designed for the use of equipment planned for development and implementation in 4 years after the project presentation (2008).Graduation project, Specialist degree, department of Environmental Design. O. Simatova. Tutors: Prof. E.A. Zaeva-Burdonskaya, Prof. E.I. Ruzova)

Fig.3. Project of decoration of the festival "Christmas Light-2018" in Moscow", 2017 (Customer: "Adline Project" company. The main project's feature is the domination of imaginative and emotional ethno-design. Graduation project, bachelor course, department of Environmental Design. D. Korlyakova. Tutors: Prof. E.A. Zaeva-Burdonskaya, Prof. E.I. Ruzova)

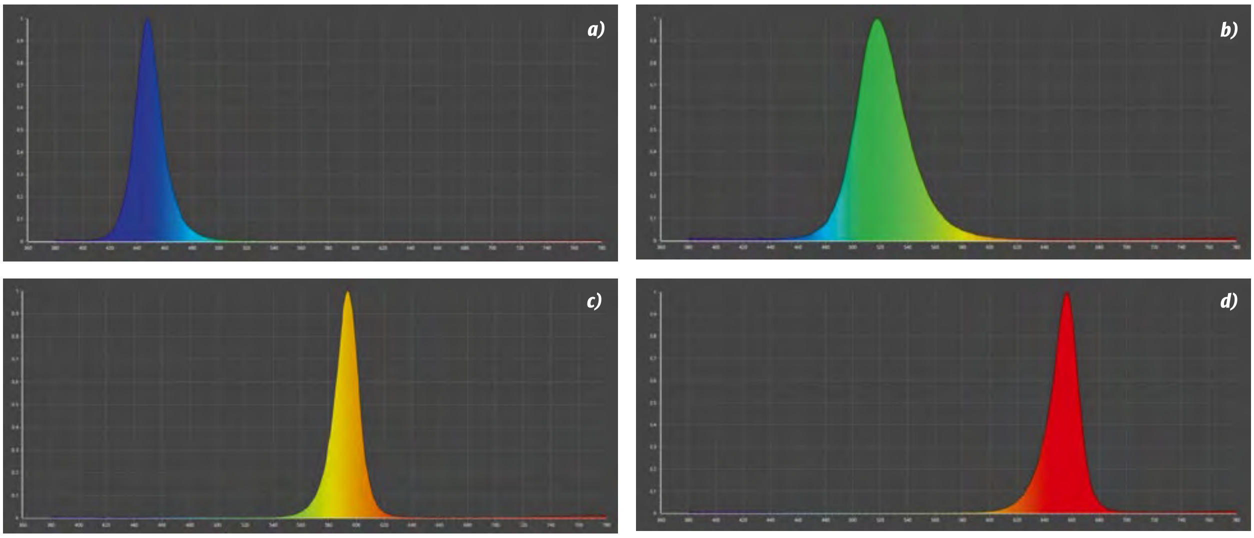

Fig. 2. Spectra of radiation quasi-monochromatic PI used in the research: *(a)* blue, *(b)* green, *(c)* amber, *(d)* red

Fig. 5. General view of the research installations

Leonid B. Prikupets, George V. Boos, Vladislav G. Terekhov, and Ivan G. Tarakanov

Research into Influence from Different Ranges of PAR Radiation on Efficiency and Biochemical Composition of Green Salad Foliage Biomass

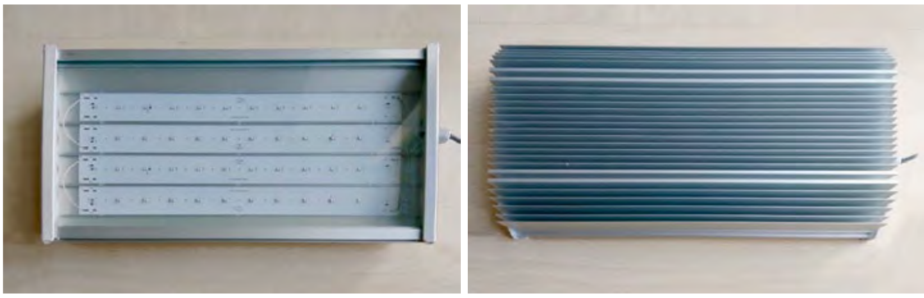

Fig. 1. Appearance of quasi-monochromatic phytoirradiators (PI)

General view of the research installations

Fig.1. The illumination manifold as a result of “selling” reflections of the LED module luminous flux (a) and mirror reflection LED module (top view through a manifold in the channel of hollow tubular light guide) (b)

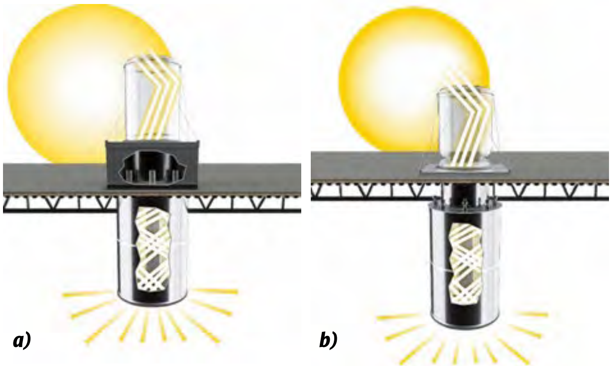

Fig. 6. Mounting options HLC “ Solar LED-S”:
a– outdoor installation, ALB set in the border; on roof;
b – interior installation, ALB is installed in the room

Fig.7. HLC “Solar LED-S” in the “Meeting room “ (installation process). ALB is located in the space of the technical floor, located above the ceiling of the “Meeting room” under the roof (internal design)

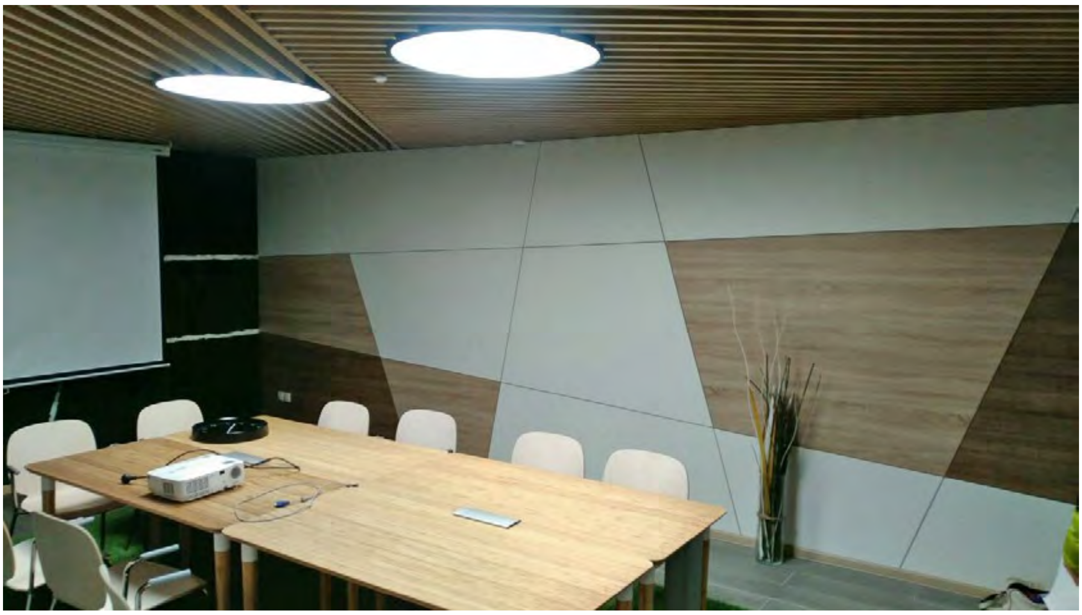

Fig.8. Meeting Room (Daylight illuminance about 400 lx at high clouds of the sky. In sunny weather, natural light flow is regulated by means of dimmer, which allow to regulate the natural light flow and to perform a complete shutdown of natural lighting during video presentations)

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MAIN DIRECTIONS OF RUSSIAN STATE ENERGY SAVING POLICY IN THE FIELD OF ELECTRIC POWER ENGINEERING

Lyudmila S. Chikileva, Svetlana S. Gorohova, and Anna V. Popova

Financial University under the Government of the Russian Federation
E-mails: lchikileva@fa.ru; sgorohova@fa.ru; avpopova@fa.ru

ABSTRACT

The article describes the issues of strategic planning and legal regulation of activities aimed at energy saving and energy efficiency in the Russian Federation. The authors set the goal to determine the directions for strategic planning of the energy saving policy of the Russian Federation based on a comparative legal analysis in order to achieve the goals of sustainable development of an energy-saving economy. The article considers advanced technologies designed to ensure the most effective implementation of the provisions of legal acts adopted in the last decade in Russia.

The methodology of this scientific research is the use of hermeneutics, interpreting legal texts and application of formal logical instruments within the system analysis of current Russian strategic planning acts for long-term (medium-term) period to coordinate the activities of economic entities and public authorities in the appropriate direction. Besides, it includes normative acts that establish the legal, economic and organizational basis for stimulating energy conservation and improving energy efficiency as well as legal documents of other countries that determine their policies in this area.

The authors come to the conclusion that it is required to consult various specialists, including ophthalmologists, when creating norms of Russian legislation in the field of energy saving; to account for technical and technological characteristics of LED (light emitting diode) modules, chips, other light sources; to take into consideration the possibility of their use in various fields in order to achieve energy efficiency.

Keywords: electric power industry, energy saving, energy efficiency, LED light sources, lamps, energy-saving technologies

1. INTRODUCTION

Energy saving and increasing energy efficiency is no longer a problem only for consumers of energy resources. It has become a nation-wide global problem affecting among other things, the state of economic security. Therefore, it is stated in the Strategy for Economic Security of Russia, adopted in May 2017, for the period until 2030, that the main challenges and threats to economic security are as follows. They include a change in the structure of global demand for energy resources and consumption patterns, development of energy-saving technologies and reduction of material consumption as well as development of “green technologies” in this area. In the situation when energy consumption is growing in a geometric progression and opportunities in this area are limited, issues related to the creation of legal, economic and institutional framework for stimulating energy conservation and increasing energy efficiency, have been taken up by state authorities in the countries with a high level of economic development. According to the statistics of the International Energy Agency, in the USA, by 2020, it is planned to reduce the energy intensity of the economy by 25 % compared to 2005. In China, the current task is to reduce the energy intensity of the economy by 49 % in relation to the indicators of 2006 [1], and in the European Union by 20 %, compared with the 2007 data [2]. Russia is not an exception in this sense. Taking into consideration the fact that the Russian Federation is neither the last nor the first in the production and consumption of electricity [3], it is worth noting that in terms of energy efficiency the situation is not encouraging. "… Being the third in the world in terms of energy consumption, Russia spends more energy per unit of GDP than any other country belonging to the top ten energy consumers" [4] though Russia began to deal with issues of energy conservation and improving energy efficiency long ago. The legal basis for such a focus is the Federal Law of April 3, 1996 on energy conservation. It means that more than 20 years have passed since the implementation of the state course aimed at increasing the efficiency of the use of consumed energy.

Energy conservation and energy efficiency issues are considerably relevant for the electrical industry. Electric power industry is not only the basis of lighting technology but also of energy as it provides power for the entire economy of the country on the basis of rational production, distribution and consumption of electricity. This type of energy is in demand in all spheres of life of modern society, while the consumption of electricity in recent years has been steadily growing. According to the data of "SO EU" JSC, the electricity consumption in the Unified Energy System of Russia in 2017 amounted to 1039.7 billion kW / h, which is 1.3 % more than the consumption volume in 2016. Electricity consumption in Russia in 2017 was 1059 billion kW / h, which is 0.5 % more than in 2016 [5]. In this regard, it should be noted that the cost of creating kW generation capacity in power plants of different types is about from $1,000 up to $3,000 while a reduction in installed capacity per kilowatt of lighting costs $150 – $200. Besides, this is connected with the solution of the most important problem of reducing harmful emissions into the atmosphere [6]. At the same time, artificial lighting systems are the most common end-users of electricity, which accounts for about 13 % of all generated electrical energy [7]. It is apparent that effective implementation of the state energy saving policy in such a significant segment of electricity consumers will significantly affect the overall picture of the economy and increase the energy efficiency of energy-consuming systems.

The relevance of the topic has determined its goal: to prove the need for further development of the legal provision of energy-consuming systems efficiency in general and electro-savings in particular, namely the use of LED technology. Achieving this goal requires the solution of the following tasks:

– To analyze the system of legislation regulating the sphere of energy saving;

– To identify corresponding gaps and shortcomings in legal support;

– To substantiate the need for further improvement of the legal framework on the basis of a comparative analysis of Russian and foreign experience;

– To reveal the relationship between the guarantee of the right to health of Russian citizens, technical and economic effectiveness of LED technologies;

– To show the prospects for the development of LED technology.

2. METHODS OF SOLUTION

The research has shown that in the modern scientific and technical literature much attention is given to the analysis of technical and economic advantages of the development of various energy-saving systems. At the same time, the analysis of the legal support for this problem, the protection of human and citizen's rights and freedoms, when using various technologies, primarily modern lighting, is not necessarily in the spotlight. The authors of this article believe that the problems of financial and economic development often take priority while incorrect application of social, technical and legal norms, as well as the legality of legislation in the field of energy conservation can lead to irreversible consequences. Therefore, it is necessary to improve the legislation in the sphere of energy saving and adopt the Technological Regulations on the requirements for the energy efficiency of electric energy consuming devices.

3. RESULTS

Taking into consideration the main directions of the state policy in the sphere of energy saving and energy efficiency improvement, it should be noted that the act fixing these most basic directions is not provided in the legislation. However, according to p. 1 of Article 6 of the Federal Law "On Energy Saving and on Improving Energy Efficiency and on Amending Certain Legislative Acts of the Russian Federation" [8], one of the powers of the bodies of state power in Russia is the formation and implementation of state policy in the field of energy conservation and energy efficiency. In this case, item 14.1 of Article 6, introduced by Federal Law No. 399-FZ on December 28, 2013 assigns to state bodies the function of monitoring and analyzing the effectiveness of the implementation of state policy, regulatory and legal regulation in the area under consideration. In 2009 the Government of the Russian Federation approved "Main Directions of the State Policy in the Sphere of Improving the Energy Efficiency of the Electric Power Industry Using Renewable Energy Sources for the Period until 2024" [9]. There is no doubt it was an important decision but it did not completely determine the state policy in the field of energy saving and increasing energy efficiency. We believe that under such circumstances it is worth taking into consideration that monitoring and analysis of the effectiveness of state policy implementation cannot but face some difficulties in practice. Nevertheless, it should be noted that despite obvious difficulties, the work is undoubtedly being carried out. Implementing one more item of Article 6, namely 14.2, which provides for the preparation of an annual state report on the state of energy conservation and improving energy efficiency in Russia, the Government of the Russian Federation approved the Resolution "On the preparation and dissemination of the annual state report on the state of energy conservation and energy efficiency in the Russian Federation" [10]. This document was designed to summarize the results of the implementation of the state policy under consideration for the previous reporting year. According to this Resolution, the Report is prepared by the Ministry of Energy of the Russian Federation and includes among other things the following:

1) Indicators that characterize the level of technologies implementation that have high energy efficiency;

2) Information on planned initiatives in the field of energy conservation, energy efficiency and proposals on the directions for the development of public policy in this regard;

3) Information on the potential for energy conservation and improving energy efficiency.

It presents certain interest to find out whether there are some achievements in these areas and whether the lighting industry and issues of artificial lighting are mentioned in connection with it. In this regard, it is interesting to become familiar with the content of similar reports made in recent years. Unfortunately, it is not yet possible to get acquainted with the results of 2017, in the area under study, for the reason that the Rules for the preparation and dissemination of the annual state report on the state of energy conservation and improving energy efficiency. The deadline for placing the Report on the Internet is October 15, following the previous year, therefore it is missing in the information system. As follows from the text of the State report on the state of energy conservation and increase of energy efficiency in 2016 [11], the average specific electricity consumption for the supply of state and municipal health facilities in Russia in 2016 was 57.99 kW / h / m^2. In the Central, North-western and Southern Federal Districts, the average electricity consumption for supplying state and municipal health facilities is higher than in Russia by 6 %, 9 % and 15 %, respectively. The average specific electric power consumption for the supply of educational institutions in 2016 increased by 4 % and amounted to 31.8 kW / h / m^2. In the North-western Federal District, the average specific electricity consumption for the supply of educational institutions is higher than in Russia by 45 %. To analyze the general state of energy conservation and improve energy efficiency in the budgetary sector, indicators of the introduction of key energy-efficient technologies, including the share of LED light sources in public and municipal institutions were used. It follows from the data of the Report that the average share of LED light sources in the coverage of state and municipal institutions, according to energy declarations in 2015, was 5.6 %. The average share of such sources in the coverage of these institutions for 2016 has already increased by 1.2 and amounted to 6.6 %. At the same time, the share of LED light sources in all subordinate institutions of the federal executive authorities reviewed is above average for Russia for all budget institutions. For example, the supply of LED sources in the institutions of the Ministry of Justice of Russian Federation and the Federal Penitentiary Service of Russia is almost twice as high as the average for Russia. Despite this growth, such a situation indicates a significant potential for energy conservation with the help of the further introduction of LED sources. As shown in Table 1, these light sources, by all parameters, are much better and more often used for lighting purposes than incandescent lamps.

However, despite obvious leaders among the light sources, the Ministry of Construction approved the orders on August 17, 2016, No. 572 "On the ap-

Table 1. Indicators of Light Sources [6]

Type of light source	Average service life, thousand hours	Colour rendering index, R_a *	Luminous efficacy, lm/w	Specific luminous energy produced during the service life (average)	
				mlm h/W	Units
Incandescent lamps (IL)	1	100	8–17	0.013	1
Fluorescent lamps (FL)	10–20	57–92	48–104	1.140	88
Compact Fluorescent Lamps (CFL)	5–15	80–85	65–87	0.780	60
Arc mercury lamps (AML)	12–24	40–57	19–63	0.738	57
High Pressure Sodium Lamps (HPSL)	10–28	21–60	66–150	2.050	157
Metal halide lamps (MHL)	3.5–20	65–93	68–105	1.020	78
LEDs	25	85–90	(80–90)→120	2.5	192

proval of the code of rules "Buildings of educational organizations. Design Rules." And on August 17, 2016, document No. 573 "On the approval of the code of rules "Buildings of pre-school educational organizations. Design Rules" was approved, which do not contain provisions aimed at stimulating the introduction of energy-efficient technologies. In particular, the Order No. 572 contains a proposal to provide compact and tubular fluorescent lamps containing mercury compounds and incandescent lamps for lighting in educational institutions. Taking into account that the vast majority of educational institutions are built and reconstructed at the expense of the budget, the application of these design rules can lead to inefficient spending of budget funds at the stage of operation of educational institutions.

Item 8 of Article 10, the Law on Energy Saving, provides that from January 1, 2011, incandescent lamps with the power of 100 W or more are not allowed to circulate in Russia, which can be used in alternating current circuits for lighting purposes. In addition, from the same moment it is prohibited to purchase electric incandescent lamps to provide state or municipal needs that can be used in alternating current circuits for lighting purposes. As prospective measures, the same item 8, satisfies the possibility of prohibiting the turnover of electric incandescent lamps with the power of 75 W or more, and from January 1, 2014, with the power of 25 W and more. However, so far such a ban has not been implemented. In addition, Government Resolution No. 898, August 28, 2015, "On Amendments to Clause 7 of the Rules for Establishing Energy Efficiency Requirements for Goods, Works, and Services in the Conduct of Procurement for Provision of State and Municipal Needs" introduced a number of restrictions on procurement from July 1, 2016 energetically inefficient light sources and lighting devices, namely: double-capped fluorescent lamps with phosphor sodium halo-phosphate and a colour rendering index of no more than 80, arc mercury fluorescent lamps, compact luminescent [12]. These measures were to stimulate the introduction of LED technology at the regional level.

Item 6 of Article 48 of the Law on Energy Conservation contains a standard on specific requirements for lighting devices, electric lamps used in alternating current circuits for lighting purposes, which should have been put in place by the Government of the Russian Federation before March 1, 2010. These rules were adopted in 2011. The Government Resolution No. 602 "On Approval of Requirements for Lighting Devices and Electric Lamps Used in Alternating Current Circuits for Illumination", and in November 2017 by Government Resolution No. 1356 "On Approving Requirements to Lighting Devices and Electric Lamps Used in Alternating Current Circuits for Lighting Purposes "(hereinafter the "Rules"). As mentioned above the "Rules" establish that the application of the requirements for lighting devices and electric lamps used in alternating current circuits for lighting purposes is carried out in two stages: Stage I from July

Table 2. Minimum Normalized Values of Light Output

Rated lamp power, W	η_{min}, lm / W	
	Stage I	Stage II
5	50	65
7	50	65
11	55	70
15	55	70
20	60	75
24	65	75
26	65	75
30	65	75
45	70	80

1, 2018 to December 31, 2019; Stage II from January 1, 2020. In both stages, special requirements are implemented on lamps and general purpose lamps, in accordance with which they must meet the requirements for energy efficiency and performance characteristics, as stipulated in the relevant document. In addition, at Stage II, the level of active power loss in the starting and regulating equipment of luminaires for public and industrial premises with fluorescent or induction lamps should not exceed 8 %. Further, according to the text of the Rules, the requirements for the energy efficiency of lamps and general purpose lamps are established, depending on their type and their nominal power, as well as the performance characteristics of lamps and general purpose lamps.

As an example of the requirements for individual types of lamps, it is given that the requirements for fluorescent lamps with integrated ballast: minimum normalized values of light output (η_{min}) of compact fluorescent lamps (hereinafter referred to as CFLs) of non-directional light with a general colour rendering index of less than 90 (Table 2).

The following requirements are established for the performance of CFLs (Table 3).

As an example of the requirements for individual types of luminaires, the requirements for luminaires with dual based fluorescent and induction fluorescent lamps of different power (P) are given. For such luminaires intended for use in public premises, the minimum normalized values of the light output (η_{min}) at stages I and II are the values indicated in Table 4.

The following minimum requirements for power factor of the luminaires are illustrated in Table 5.

Similar requirements are established for other types of lamps and luminaires. In the new Rules, unlike in previous ones, tungsten incandescent lamps are not mentioned at all, that is, the use of the latter is not implemented. This, of course, can be considered a positive direction in energy saving and improving the energy efficiency of lighting systems. However, the extent to which the national economy will be ready to apply these rules is primary. Taking into account fact that in the absence of the previous requirements for energy efficiency of lighting equipment the use of price as the main criterion in procurement for government or municipal needs often lead to the acquisition of the cheapest and most energy efficient goods. It should be noted that in order to solve this predicament, the Resolution of the Government of the Russian Federation "On the Approval of the Rules for Establishing Energy Efficiency Requirements for Goods, Works, and Services in the Conduct of Procurement for Ensuring State and Municipal Needs", Decree No. 486 of the Government of the Russian Federation April 21, 2018 [13], changes were made. The Ministry of Economic Development of the Russian Federation is required starting from 2018 to conduct an annual analysis of the goods, their energy efficiency in procurement for the provision of the state or municipal needs. It is done for the purpose of identifying the categories of goods that use energy resources in amounts that make up a significant share in the consumption structure of certain groups of

Table 3. Phased Performance of CFLs

Characteristic	Stage I	Stage II
Ignition Time	not more than 2 seconds	for lamps with a rated power less than 10 W not more than 1.5 seconds; for lamps with a rated power of at least 10 W not more than 1 second
Flare time to achieve 60 percent steady-state luminous flux	less than 60 seconds (less than 120 seconds for lamps that contain mercury amalgam)	less than 40 seconds (less than 100 seconds for lamps that contain mercury amalgam)
Lamp power factor	for lamps with a rated power less than 25 W not less than 0.5; for lamps with a rated power of at least 25 W not less than 0.9	for lamps with a rated power less than 25 W not less than 0.5; for lamps with a rated power of at least 25 W not less than 0.9
Total Colour Rendering Index	not less than 80	not less than 80
Coefficient of pulsation of the luminous flux	not specified	not more than 10 %

Table 4. Minimum Normalized Values of Luminous Efficiency

Lamps / Construction	Fluorescent T8		Fluorescent T5 (diameter 16 mm) (high light output)		Fluorescent T5 (diameter 16 mm) (high luminous flux)		Induction luminescent	
	P, W	η_{min}, lm/W	P, W	η_{min}, lm/W	P, W	η_{min}, lm/W	P, W	η_{min}, lm/W
Mirror reflector and diffuse diffuser	18	45	14	50	not used		70	45
			21	50			100	50
	36	50	28	55			150	50
	58	50	35	55			250	50
Mirror reflector and prismatic diffuser	18	50	14	55	not used		70	50
			21	55			100	55
	36	55	28	60			150	55
	58	55	35	60			250	55
Mirror reflector and open outlet	18	55	14	60	24	55	70	55
	36	60	21	60	39	60	100	60
			28	65	49	60	150	60
	58	60	35	65	54	60	250	60
					80	60		

state or municipal customers. The customers carrying out similar activities as well as the requirements of energy efficiency of goods, works, services in the implementation of public procurements, established by the legislation of foreign states, and the possibility of their application in the Russian Federation.

4. CONCLUSION

The study showed that the process of developing an energy-efficient economy, in general, and the electric power industry, in particular, in Russia, is at the stage of progressive development, al-

Table 5. Minimum Requirements for the Power Factor of Luminaires

Type of luminaire	Power factor, not less than	
	Stage I	Stage II
With fluorescent lamps	0.9	0.95
With sodium lamps of high pressure, with metal-halide lamps or with mercury lamps of high pressure	0.85	0.85
With LEDs at power consumption no more than 8 W	0.7	0.75
With LEDs at power consumption from 8 to 20 W	0.85	0.9
With LEDs at a power consumption of more than 20 W	0.9	0.95

though, not as active as is necessary for the purpose of building an information economy. At the same time, Russia still lags behind the leading countries in this area which actualizes the need for its careful legislative regulation. Despite the successful steps towards enhancing the efficiency of light energy, it must be remembered that LEDs and LED chips, which are becoming increasingly popular, despite their cost-effectiveness, progressiveness and ease of production may lead to a growing number of health concerns in the opinion of a number of health professionals as a result of the use of new technologies in the electric power industry [14]. Section 2.2 of the EU Green Paper states that the countries are responsible for the quality and safety of the LED products that are purchased and sold in Europe, and the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) Preliminary Recommendations of the Scientific Committee on New and Revealed Health Risks require that action be taken to reduce the abuse of artificial lighting in general. Therefore, before introducing LEDs with certain technical characteristics in Russian market and, primarily, with a large dose of blue light, especially for lighting schools and health care institutions in Russia, which is conducted under the SCENIHR and under UNDP (United Nations Development Program) program, it is required to obtain opinions from ophthalmologists, hygienists and electrical engineers of All-Russian Scientific-Research Light Engineering Institute, named in honour of S.I. Vavilov on the possibility of their use in public institutions without harm to human health. Therefore, it is required to include in the current legislation norms that not only promote the development of light energy in Russia but also to protect the health of Russians achieving the goals of constant development, for which it is apparent in determining all the technological characteristics of used LED modules and chips.

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Lyudmila S. Chikileva,
Ph.D. in Philology, Associate Professor, Professor of the Department of Language Training, Financial University under the Government of the Russian Federation. L. Chikileva is interested in implementation of information and communication technologies in language teaching, cross-cultural communication and pragmatics. Her research focuses on the implementation of electronic educational platforms in foreign language learning. She has published more than 200 articles and manuals

Svetlana S. Gorohova,
Ph.D. in Law, Associate Professor of the Department of Legal Regulation of the Economic Regulation in the Financial University under the Government of the Russian Federation. S. Gorohova specializes in the field of state-legal development of the Russian Federation. She is interested in General theory of state and law, Russian legal system, legal technique, law-making, national security of the Russian Federation. She has published more than 100 articles and manuals

Anna V. Popova,
Doctor in Law, Ph.D. in Philosophy, Associate Professor, Professor of the Department of Legal Regulation of the Economic Regulation, Financial University under the Government of the Russian Federation. A. Popova specializes in the field of state-legal development. Her research interests include Russian legal system, comparative law, legal technique, law-making process of the Russian Federation and other countries, History of state and law. She has published more than 300 articles and manuals

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LIGHTING PRODUCTS: PROBLEMS OF TECHNICAL AND LEGAL REGULATION OF ENERGY SAVING AND ENERGY EFFICIENCY

Anna A. Bakulina, Dmitry V. Karpukhin, and Marina A. Lapina

Financial University under the Government of the Russian Federation
E-mails: Abakulina@fa.ru; dimak7571@mail.ru; MALapina@fa.ru

ABSTRACT

One of the key problems in the state of the Russian energy sector is the creation of effective energy-saving technologies for both organizations and ordinary consumers. The forecast of scientific and technological development of the Russian Federation for the period until 2030, approved by the Government of the Russian Federation, mentions low volumes of energy saving in the sphere of final consumption as one of the threats to Russia's economic development.

In 2009, the Federal Law No. 261-FZ "On Energy Saving and Increasing Energy Efficiency" was adopted. The corresponding Resolution of the Government of the Russian Federation No. 961 of September 20, 2014 prescribes the creation of a database on the most effective technologies used in apartment houses, administrative and public buildings.

Federal Law No. 184-FZ of December 27, 2002 (as amended on July 29, 2017) "On Technical Regulation" establishes an imperative order, according to which technical and legal regulation in the field of application of energy efficiency requirements, requirements for lighting devices, electric lamps, used for lighting purposes, should be implemented at the level of the federal law approving the relevant normative legal act.

However, as of today this federal law has not been adopted. The technical and legal regulation of lighting products is carried out fragmentarily, at the level of national standards. The adoption of a federal law that establishes a technical regulation for lighting products will effectively respond to the challenge outlined in Presidential Decree No. 208 of May 13, 2017 "On the Strategy for Economic Security of the Russian Federation for the Period until 2030" regarding the development of energy-saving technologies and reducing the material consumption.

Keywords: users of lighting equipment, lighting costs, energy saving, energy saving technologies, producers and consumers of energy-saving technologies, energy efficiency, technical regulations, national standard

1. INTRODUCTION

Currently, the Russian Federation has faced numerous problems in the socio-economic, scientific, technological and environmental spheres that require the adoption of adequate measures aimed at their effective resolution. Decree of the President of the Russian Federation No. 208 of May 13, 2017 "On the Strategy for Economic Security of the Russian Federation for the Period until 2030" (item 12 of Section II "Challenges and Threats to Economic Security) contains an extensive list of the main challenges and threats to the economic security of the Russian Federation, in accordance with subparagraph 6, "changes in the structure of the global demand for energy resources and consumption patterns, the development of energy-saving technologies and the reduction of material intensity, the development of "green technologies" [1].

In fact, the problem of energy conservation is of a strategic nature, being one of the components of the complex of economic threats and challenges that the Russian Federation has had to face. The Government of the Russian Federation approved the "Forecast of the scientific and technological development of the Russian Federation for the period until 2030", according to which energy conservation and energy efficiency have been identified as one of the priority areas for the development of science, technology and equipment [2]. Section VII of the Forecast "Energy Efficiency and Energy Conservation" formulates low volumes of energy saving in the sphere of final consumption as one of the threats to the economic development of Russia, and "mass introduction of energy saving technologies" as one of the potentials for the development of this priority area.

A well-known scientist in the field of lighting engineering, Professor J.B Aizenberg revealed in 2005 the interconnection between the levels of development of the state and the economy, depending on the energy consumption for coverage: "the degree of state development can be characterized, to a large extent, not so much by the volumes of steel and iron, oil or gas production, the number of manufactured machines, but by "light sufficiency" of the state with minimizing energy consumption" [3].

In 2009, Federal Law No. 261-FZ "On Energy Saving and Increasing Energy Efficiency" (hereinafter – the Law on Energy Saving) was adopted, [4]. Article 2 of this legal act structures the concepts of "energy saving". Thus, energy conservation is interpreted as "the implementation of organizational, legal, technical, technological, economic and other measures aimed at reducing the volume of energy resources used while maintaining the relevant useful effect from their use (including the volume of products manufactured, work performed, services rendered)".

Consequently, energy conservation as a set of measures and characteristics associated with the rational and efficient use of energy resources covers all without exception economic parties – consumers of energy resources. Professor J.B. Aizenberg in his article points to the importance of solving the problem of efficiency: "in lighting engineering science, technology and industry, the effectiveness of decisions taken when creating new products and installations is one of the cornerstones of technical policy" [3].

2. SCIENTIFIC TASK

The scientific task of the research is to analyze the state of technical and legal regulation of energy saving and energy efficiency of lighting products in the Russian Federation from the standpoint of realizing the interests of the economic security of the Russian Federation and developing a conceptual legal approach to regulating public relations in the sphere in question.

3. SOLUTION METHOD

The research conducted by the authors is based on the results of analysis of Russian regulatory, legal and technical legal acts, scientific works in the field of technical and legal regulation, comparative legal analysis of the provisions contained in the EEC Directives and Russian legal acts regulating energy efficiency and energy saving of lighting products.

4. RESULTS

In normative legal acts, the definition of lighting technology is considered in a technical perspective in the context of manufactured lighting products [5–7].

Among the legal acts affecting the problem of energy saving technologies in relation to lighting products, it should be noted the Order of the Government of the Russian Federation of November 13, 2009 No. 1715-r "On the Energy Strategy of Russia for the period until 2030" [5]. In this act, it was noted the creation in Russia of energy-saving and environmentally friendly lighting devices of a new generation on light emitting diodes and mercury-free gaseous discharge lamps.

By Order of the Ministry of Industry and Trade of the Russian Federation No. 529 of June 17, 2009, the Strategy for ensuring the uniformity of measurements in Russia until 2015 (hereinafter referred to as "the Strategy") was approved. So, in clause 4.4.6. "The development of metrological support in priority areas, including nanotechnology and nanomaterials" of the Strategy noted that "the creation of a complex of reference tools of a new generation to ensure the unity of optical-physical measurements in the field of space metrology and dual-use technologies will solve a number of important tasks, including … the introduction of new types of energy-saving lighting technology, advanced domestic technologies for the production of lighting products " [6].

In 2015, the leading lighting consulting company LLC "Lighting Business Consulting" analyzed the state of the market of lighting products in the countries of the EAEU and the EU, which also affected legal problems [7]. Thus, in the analysis it was noted that "in accordance with the Kyoto agreement on the reduction of atmospheric emissions of CO_2 in 1997, the European Union has defined the following energy saving goals for the lighting industry:

- Reduction of energy consumption when using lamps;
- Reducing the consumption of mercury in the manufacture of lamps.

To implement these goals in the period 2005–2009, Directive 2005/32 / EC was adopted on setting framework requirements for eco-design (energy efficiency) for energy-consuming products, EU244/2009 on requirements for eco-design to household lamps and EU245/2009 on eco-design requirements for fluorescent lamps without ballasts, for high-intensity discharge lamps, as well as to the ballasts and lamps. In 2012, the EU Directive 1194/2012 was adopted to the requirements of eco-design for directional lamps and LED lamps [7].

The authors note that 2007 was a turning point for energy saving in lighting. However, the reasons for this were not EU Directives, which were adopted two years later, but consumer demand for compact fluorescent lamps and halogen lamps. In 2007, the market capacity for these types of lighting products increased, which reached the level of 32 %. The authors draw the conclusion that the market situation was the direct cause of the decline in energy consumption, and the EU Directives only legislatively supported the market trend [7].

At the same time, the role of the institution of technical regulation is growing, which acquires a trans boundary character. So, in the publication "Administrative and legal problems of the establishment of the Institute of Technical Regulation" one of the authors of this article, M. Lapina, drew attention to the importance of the international aspects of the institute of technical regulation, since "the state enters into interdependence relations as a result of the need to ensure the common interests with which the national interests are connected" [8]. In addition, technical regulation is one of the forms of state regulation of economic relations. Researcher A.S. Panova notes that "technical regulation is closely related to the economy, since it affects the systems of use of productive resources within the states. With the help of technical regulation, the state influences the activities of entrepreneurs by establishing technical requirements for the products (goods) and the processes of its life cycle. Moreover, at the present time, such an impact is more realized at the interstate level (within the boundaries of the EAEU) [9].

Federal Law No. 184-FZ of December 27, 2002 (as amended on July 29, 2017) "On Technical Regulation" contains a blanket rule, formulated in paragraph 6.1 of Article 46, on the basis of which, before the day of entry into force of the relevant technical regulations, technical regulation in the field application of energy efficiency requirements, requirements for lighting devices, electric lamps used for lighting purposes, is carried out in accordance with the Law on Energy Saving, other federal laws adopted in accordance with other legal acts of the Russian Federation in the field of energy conservation and energy efficiency. In addition, paragraph 1 of this article contains an imperative prescription, which fixes a list of purposes in accordance with which the requirements for the products are subject to mandatory implementation before the entry into force of the relevant technical regulations. These include the provision of energy efficiency and resource conservation [10].

Thus, the provisions of the law under consideration underscore the socially significant nature of resource saving and the need to follow mandatory requirements in terms of setting requirements for energy saving in the field of lighting products. Belykh V. and Panova A. note that "along with protection, technical regulation is designed to maintain and develop the national material and technical base, ensure energy efficiency and resource-saving, eliminate technical barriers to trade between countries" [11].

However, as of today the Russian Federation has not adopted a federal law that establishes technical regulations for energy saving in relation to lighting equipment. In this regard, it seems reasonable to analyze technical and legal acts containing technical norms that reflect the requirements for energy-saving technologies in relation to lighting products.

In technical and legal acts, the definition of lighting technology is presented in the context of lighting requirements for instruments that directly provide lighting.

In addition, it should be noted that the level of legal regulation of energy efficiency of lighting products is much higher than the level of legal regulation of energy saving of said products, despite the fact that the legal design of these definitions at a formal legal level is set forth in the Law on Energy Saving. Thus, RF Government Resolution No. 1356 of November 10, 2017 "On Approval of Requirements for Illumination Devices and Electric Lamps Used in Alternating Current Circuits for Illumination" sets strict mandatory requirements in terms of performance and energy efficiency in relation to lamps and general purpose lamps [12].

The implementation of the provisions of the Russian Federation Government Resolution No. 1356 will lead to a ban on tubular fluorescent lamps, as well as most high-pressure LED and mercury lamps, from July 1, 2018 in Russia. Since January 1, 2020 under the ban will fall fluorescent lighting and sodium high-pressure lamps [12]. In fact, RF Government Resolution No. 1356 continues the logical sequence of requirements and prohibitions initiated by the Law on Energy Conservation. Thus, in accordance with paragraph 8 of Article 10 of the Law on Energy Conservation, from January 1, 2011, incandescent lamps with a power of one hundred watts or more were prohibited to circulate on the territory of the Russian Federation, which could be used in alternating current circuits for lighting purposes from January 1, 2011 was introduced prohibition of the purchase of electric incandescent lamps to provide state or municipal needs that can be used in alternating current circuits for lighting purposes. Decree of the Government of the Russian Federation of 20.07.2011 N602 "On approval of requirements for lighting devices and electric lamps used in alternating current circuits for lighting" approved the requirements for lighting devices and electric lamps used in lamps with respect to the minimum permissible values of their light return (energy efficiency) [13].

The stated discrepancy between the requirements for energy efficiency and energy efficiency indicators established for lighting products can be eliminated by adopting a single normative act containing requirements for energy saving in relation to lighting products.

Analysis of technical and legal acts that contain regulations on lighting technology indicates the lack of a holistic approach to determining the parameters of energy conservation in relation to lighting products. Despite the fact that the Federal Law "On Technical Regulation" directly spelled out the need to adopt a federal law that establishes technical regulations for lighting products (lighting devices, electric lamps), this normative act is not adopted. This circumstance negatively affects the state of energy saving, since the use of lighting devices is ubiquitous.

Nor can we fail to note the ambiguous nature of the definition of "technical regulation", formulated in the current version of the Federal Law "On Technical Regulation". Thus, in paragraph 2 of Article 2 of this Law, technical regulation is interpreted not only as a mandatory, but also voluntary regulation of relations in the field of establishing, applying and executing mandatory requirements for products or products and associated design requirements (including exploration), production, construction, installation, commissioning, operation, storage, transportation, sale and disposal [10]. A similar ambiguity of legal terminology is contained in Federal Law No. 162-FZ of June 29, 2015 "On Standardization in the Russian Federation" [14].

In accordance with Clause 1 of Article 2 of the Federal Law "On Standardization in the Russian Federation", a document on standardization is defined as a document in which, for voluntary and repeated use, general characteristics of the standardization object are established, as well as rules and general principles with respect to the standardization object,, if the mandatory application of the standardization documents is established by this law. This duality of legal concepts blurs the clear distinction between national standards and technical regulations, but at the same time makes it possible to adopt strict energy-saving requirements in relation to lighting products not only at the level of technical regulations, but also in the form of an obligatory national standard. The latter, in our opinion, is possible in the case of introducing in the Federal Law "On Standardization in the Russian Federation" appropriate additions, in accordance with which the standardization documents establishing energy-saving requirements for lighting products must be mandatory. Adoption of appropriate technical regulations or a national standard setting energy-saving requirements in relation to lighting products and its inclusion in the fund of the federal information of technical regulations, and standards will facilitate not only the implementation of strategic tasks in the field of economic security, but will also increase the level of transparency in technical and legal regulation in the field of lighting products.

In addition, it should be noted that in the resolutions of the Government of the Russian Federation on the problems of technical and legal regulation of lighting products, there is a certain compliance with the requirements and prohibitions fixed in the EEC Directives. The adoption of the latter, as noted above, was due to the market situation of demand for lighting products. In the Russian Federation, the development of energy-saving technologies is an element of the economic security strategy formulated in Presidential Decree No. 208, so in this part one should not go only along the path of borrowing the technical and legal imperatives of the EEC in relation to lighting products.

The technical regulations or the national standard establishing mandatory energy-saving requirements in relation to lighting products should combine the requirements fixed in the considered standards and apply to lighting products used in public places-plazas, streets, roads, parks, squares, institutions, entrances, and etc. Adoption of this act will be an important legal milestone in ensuring economic security in the Russian Federation.

5. CONCLUSION

Thus, the technical and legal regulation of lighting products in the Russian Federation has faced a dilemma: to develop along the path of implementing the provisions of the EEC directives or to move in the direction of ensuring economic security with regard to the use of energy-saving technologies. Currently, the technical and legal regulation of energy saving and energy efficiency of lighting products is dispersed in various regulatory legal and technical and legal acts, which makes it difficult to implement the strategic direction outlined in Presidential Decree No. 208 of May 13, 2017 "On the Strategy for Economic Security of the Russian Federation at Period until 2030 "in the development of energy-saving technologies and reducing the material intensity. The Russian Federation needs a single legal act – a technical regulation or a national standard that must organically integrate the mandatory energy-saving requirements in relation to lighting products fixed in the standards reviewed, and extend to lighting products used in public places such as squares, streets, roads, parks, squares, institutions, entrances of houses, etc. Adoption of this act will be an important legal milestone in ensuring economic security in the Russian Federation.

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Anna A. Bakulina,
Associate Professor, Ph.D. in Economics, Professor of the Department of Corporate Finance and Corporate Governance, Deputy Vice-Rector for Scientific Work of the Financial University under the Government of the Russian Federation

Dmitry V. Karpukhin,
Associate Professor, Ph.D. in History, Associate Professor at Department of Legal Regulation of Economic Activities, Financial University under the Government of the Russian Federation

Marina A. Lapina,
Professor, Ph.D. in Law Science, Professor of the Department of Legal Regulation of Economic Activity of the Financial University under the Government of the Russian Federation

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PECULARITIES OF PROTECTION AND LEGAL REGIME OF OFFICIAL WORKS IN THE FIELD OF LIGHTING DESIGN

Rimma Sh. Rahmatulina, Ekaterina A. Sviridova, and Angela S. Voskovskaya

Financial University under the Government of the Russian Federation
E-mails: rshrahmatulina@fa.ru; esviridova@fa.ru; asvoskovskaya@fa.ru

ABSTRACT

The legal regime of official works has a complex dichotomous construction. The issues connected with the creation of an official work are subject to the labour law, while the issues of official work usage are governed by copyright. The protection issues of lighting design works have their own characteristics due to technical, artistic creativity and use of special technologies. These objects are subject to copying, and because of this fact a lot of legal issues in the field of not only copyright, but contract law arise.

The authors of the article aim to determine the signs of creativity for the recognition of a lighting design work as an object of copyright; to develop the criteria for assessing the identity of a design work, created under a contract, and the result of creative activity, the rights to which are transferred to the customer; to identify subjects of copyright for lighting design works. The article uses special legal methods (comparative legal method, formal-legal method and system analysis of legal phenomena method).

On the assumption of Article 1295 provisions of the Civil Code of the Russian Federation, it can be concluded that it is possible to conclude an agreement on granting the employer the exclusive right to official lighting works, which were not yet created at the time of concluding such an agreement. The absence of a direct prohibition on the transfer or alienation of the exclusive right in respect of a future work may lead to the probability of recognizing such a contract as not concluded due to the inconsistency of its subject matter. In foreign jurisdictions, there is a ban on inclusion in the agreement of the condition on the result of intellectual activity not yet created (future works). At the same time, in advance to accurately identify the official work, which is to be created by the employee during his labour activity, should not deprive of legal force the contract on the use of official works by the employer. The article proves that the lack of definiteness of the subject, provided that such a subject can be classified as definable, does not entail recognition of this contract as not concluded, and its subject matter is not harmonized.

Keywords: official work, employer, employee, work of lighting design, result of intellectual activity, lighting, light environment

Lighting design is a separate branch, which is connected with art, science, technology and architecture. This industry is based on technical devices. Any lighting is designed to emphasize the style, to influence the feelings and emotions, to give the surrounding space attractiveness and comfort. So, for example, with the help of facade lighting it is possible to change the external appearance of the building at different times of the day. The design of lighting is simultaneously influenced by science and art. And the faster the science develops in this direction, the more interesting the design of lighting becomes.

As J.B. Aizenberg pointed out in his article, artificial lighting constitutes a significant percentage (more than 15 %) of the global energy consumption of modern society [1]. It is artificial lighting that plays a major role in creating lighting design works.

In accordance with the founder of Russian design Yu.B. Soloviev, the theoretical basis of design is technical aesthetics, a scientific discipline that studies the socio-cultural, technical and aesthetic problems of the formation of harmonious subject environment created for the life and activities of man by means of industrial production [2]. Aesthetics is called the science of the essence of beauty in nature, creativity, and in art. Correctly selected lighting using different designs, forms of buildings, decor elements, technical equipment, etc. creates light design.

The objectives of the investigation are analysis of Russian and foreign experience in determining the criteria for the protection of lighting design works; analysis of distinctive features of the attribution of the lighting design result to a certain type of intellectual activity result; development of recommendations on confirmation of compliance of the intellectual activity result received under the contract with the criteria described in technical specification; analysis of the legality of concluding an agreement on granting the employer the exclusive right to the so-called "future" official works of lighting design.

In accordance with Council Regulation (EU) No. 6/2002, design means "the appearance of the product as a whole or part there of, developing in particular from such distinctive features as lines, contours, colours, shape, texture and (or) the material itself of the product and (or) its decorative ornament" [3].

As Jeremy Phillips pointed out, design is most frequently protected as an industrial design, and in Europe, like in many other countries; it is difficult to find a law on industrial designs that would not operate with the term "dishonesty". At the same time, the author notes that the current legislation as a whole is mostly focused on the technical nuances of legal protection, which greatly complicates the identification of the moral "spirit" of the law [4].

According to point 1 of Article 1349 of the Civil Code of the Russian Federation (hereinafter referred to as Russian Civil Code), an industrial design is the result of intellectual activity in the field of design. Moreover, this result of intellectual activity can also be recognized as a work of art. A design object, having a dual nature, must be original and creative.

"Originality" from Latin means "initial", "authentic". It turns out that "an industrial design must be both popular and original at the same time. This is the dichotomy of the legal approach to this object of industrial property" [5].

The creative result, accompanying the creation of lighting design objects, represents technical and artistic creativity. The sphere of artistic creativity relates these design objects to copyright objects. But, nevertheless, the protection of design works (point 1, Article 1259, Russian Civil Code) has its own characteristics due to technical, artistic creativity and the use of special technologies.

The sign of originality and novelty (paragraph 2, point 1, Article 1352, Russian Civil Code) of industrial design brings it closer to copyright objects, in respect of which courts often apply these characteristics (Decree of the Court on Intellectual Rights of June 29, 2017, No. C01–465/2017 in case No. A56–23644/2016; Decree of the Court on Intellectual Rights of October 30, 2017, No. C01–1/2017 in the case No. A40–92472/2016), although the sign of originality and novelty is not a mandatory feature of copyright objects in accordance with the rules of the fourth part of the Civil Code of the Russian Federation.

Light and lighting in our modern life is difficult to overestimate. Today, lighting design is a popular branch. High level of competition in the market requires faster product updates, which lead to the application of increasingly new technologies. Beauty, style, energy efficiency, functionality, and aesthetic perception have an impact on lighting design. State bodies often act as customers for the development of street lighting projects, illumination of historical and cultural monuments. This fact raises the question: who will own the rights to the elaborated lighting design? To answer this question, firstly you need to decide whether the lighting design is an art and what is to be recognized as a work in this case.

In the field of lighting design, there are different approaches: for some people, light is a purely functional element that allows you to see in the dark, for others – light is a view item that makes you feel.

V.I. Serebrovsky defined a work as "a combination of ideas, thoughts and images that, as a result of the author's creative activity, has been expressed in a form that is accessible to human senses and which can be reproduced" [6]. The signs of the work, as a result of which it acquires protection, are an objective form of expression and its creative character.

The form of a lighting design work makes a spiritual impact on the people, but still, the form is material embodiment of a work. The form of a work is important not only when the result is considered creative, but also when works are compared on the subject of borrowing, and it is the form that is the manifestation of certain aesthetic properties of the work.

The essence of a work is its content, that is what the author wanted to express with his work; and the form is how the author expressed the content. The objective form of expression of lighting design works is the projects of creating lighting, layouts, drawings, sketches, illustrations, etc.

Proceeding from this, A.P. Sergeev noted rather exactly that it is important to distinguish between the work itself, having intangible nature, and the form of its embodiment, i.e. that material form, which is the material carrier of the work (for example, a manuscript, a drawing, a musical notation, etc.). It turns out that the form and content are important components of the work, "where the content is an ideal component and the form is material components existing in inseparable unity" [7]. The content and filling of lighting design objects are also of significant importance due to the peculiarities of the object itself in contrast to traditional copyright objects.

Festivals of light, light shows and various types of video projections can be called popular modern commercial projects with the use of lighting design.

One of such popular projects using lighting technology is video mapping; mapping means reflection or projection. This is the audio-visual information content, which is a three-dimensional modelling (3D projections) of the object, to which the video is distributed. Although this object is considered modern and new, it originated in 1969, when a new attraction called "Haunted Mansion" was opened in Disneyland with the use of video mapping. Because of the high cost of this technology only for the third time, already in the late nineties, 3D mapping began to develop thanks to new capabilities of technology and the Internet. There are different types of video mapping: architectural mapping, video-mapping of interiors, individual objects mapping, for example, mapping of a car, a costume, a picture or entire collection of paintings, etc. The use of these objects is broad: in the advertising sphere, in the cultural sphere, in education, entertainment, services and other spheres. Thus, as a new kind of creative activity with a combination of architectural objects and graphics, objects of fine arts, graffiti, etc., this type of audio-visual art is recognized as an object of copyright protection.

As it is pointed out by I.G. Lander and A. Kh. Kubach, "such installations actively supplant the traditional forms of show, such as salute or laser show, and the play of light and shadow creates the impression of transformation and movement of space, external change in the geometry of objects, transformation or even destruction (fracture, incision) of the usual architectural form of the object to which the projection is directed" [8].

Video mapping can be created purposely for specific goals, for a particular object, as well as a template in one area or another in an interactive form.

In light shows, projectors and their technical characteristics are of great importance. Lamp projectors are replaced with laser projectors; it helps create interesting creative show projects. Light installations in combination with sound systems allow them to be used at concerts, Olympiads and other major events. For example, lighting on the Eiffel Tower is protected as a work of art. The decision of the Cassation Court of France of 1992 states that legal protection is granted to "a composition of actions and light intended to disclose and emphasize the forms of the Eiffel Tower, which constitutes the original visual work" and, consequently, the creative work. The court stressed the legitimacy of photographing the lighting of the Eiffel Tower, if it is done for personal purposes, but this action is not allowed, if afterwards these photographs will be reproduced in the publication, distributed as postcards, will be used in the play without the permission of the authors of the lighting.

Due to the peculiarity of the lighting design, the creation of such art objects is possible within the framework of an official work. The works created in the course of performance of the service assignment are not only the result of the activity of the legal entity, but also of its employee-author whose creative activity is related to the labour relationship with this organization. It should be noted that an official work is the result of the creative activity of an author, an employer in such legal relationships acts as an investor who carries out various material costs. Therefore, it is necessary to balance the interests of both parties, both in legislation and in practice.

In practice, there is frequently a dispute over the identity of a work, created by an employee or a contractor under an author's contract, and the result of the creative activity used by the organization. Solving this problem affects the possibility of using a work of lighting design by an employee irrespective of the employer, the need for payment, and the legitimacy of transferring the right to it to third parties.

So, the court pointed out that when proving the ownership of copyright on the object of exclusive rights, it is necessary to establish the fact of transferring the result of intellectual activity to the customer. In the case under consideration, the performer transferred the works on a tangible carrier in the form of a flash card, which was confirmed by the act of reception-transmission. However, in the court session, the plaintiff provided the CD-R disc as evidence, the examination of which showed that the files submitted for the study had been changed, while previous changes could not be tracked, because files did not have cryptographic protection of information. Thus, the court concluded that it was not possible to determine whether the files provided were original, and also to establish the possibility of using other files for their production. In this connection, the court rejected the plaintiff's argument of transferring the exclusive rights to him on disputed images under an order contract [9].

According to Article 432 of the Civil Code of the Russian Federation, the inconsistency of the essential terms of the contract entails its non-inclusion, but the essential condition for any type of contract is its subject. Contracts in the field of intellectual rights are not an exception. However, the non-material nature of the result of intellectual activity in combination with in most cases the lack of the possibility to determine in advance the result that will be achieved on the basis of the performance of works in the field of lighting engineering can lead to difficulties in identifying the subject matter of the contract and proving the identity of the result obtained by the subject specified in the contract.

In this issue, problems do not arise unless only with already patented decisions, when the subject of the contract is determined by indicating the date and number of the patent. However, how to prove that the solution obtained, capable of patenting is the one that was subsequently granted a patent?

If we talk about contracts for the transfer of rights in relation to the already achieved results of intellectual activity, then the individualization of their subject is possible by describing their signs and characteristics. It is about contracts on the alienation of the exclusive right and on licensing agreements. It is not enough to specify only the name of the work; moreover, improvements and corrections on the part of its authors are not excluded, which can lead to the loss of identification of the subject.

That is why, in practice, individualization of the contract subject is frequently resorted to by pointing to a material carrier containing the result of intellectual activity and being subjected to transfer under the contract. In addition, here we should carefully consider the type of such a material carrier. Of course, in this case the most protected one will be a paper copy containing the results of intellectual activity (for example, drawings, plans, lighting design projects). You may specify such a carrier in the contract as an annex to it and make it an integral part. Because of practical impossibility to make changes in the content of a work recorded on paper, the risk of a dispute over the ownership of intellectual rights to a work is practically reduced to zero. However, the large volumes of such carriers, as well as the difficulties of their storage, which require the allocation of significant areas and the staff providing accounting and classification, make this method of identifying the subject of the agreement not always convenient.

More often in civil circulation, the work is transmitted on an electronic material carrier. In this case, as mentioned above, the use of USB storage devices without special means of protection against overwriting is not recommended. A. Shvedchikov suggests using an optical CD-disk with the finalization of the recording process by specifying its serial number in the contract [10].

Works created by employees are often transferred to the customer through information and telecommunication networks to the e-mail address of the responsible person. However, in such a situation it is necessary to specify in the contract for the coordination of its terms through electronic document circulation. According to point 3 of Article 75 of the Code of Arbitration Procedure of the Russian Federation, documents received by facsimile, electronic or other communication, including the information and telecommunication network "Internet" usage, as well as documents signed by an electronic signature in the order established by the legislation of the Russian Federation, are allowed as written evidence in cases and in the order provided by this Code, other federal laws, regulatory legal acts or by the contract.

It should be considered that the result of intellectual activity transmitted via e-mail will serve as evidence of the performance of the contract of the author's order or performance of the service assignment if the contract contains a provision stating that the transfer of a lighting design work in the form of a layout, project or drawing in electronic form is appropriate fulfillment of obligations. In this case, you should list the e-mail addresses to which you should send such a design work. In addition, it should be noted that electronic exchange of letters, claims and any other documents necessary for the performance of the concluded contract is permissible.

At the same time, in some cases, in the absence of such a condition, courts proceed from the length of the legal relationships of the dispute parties, who have repeatedly used e-mails to exchange documents [11]. In another case, the court indicated that receiving or sending a message, using an e-mail address known as the person's mail or the official mail of his competent employee, indicates that the person has committed these actions until proven otherwise (when establishing compliance with the procedure for conducting an audit and seizing evidence) [12].

The issue of the possibility of concluding agreements on the transfer of rights with respect to the so-called "future works", which at the time of the conclusion of the contract have not yet been created, is the subject matter of legal regulation in foreign countries. So, the Austrian Copyright Law allows the transfer of rights only to those "future works", which will be created within five years from the date of the conclusion of the contract. At the same time, the above mentioned Law specifies the right to unilaterally renounce the contract at any time, if the conditions of the agreement on the transfer of rights to the future work do not allow individualizing its subject [13].

The German Copyright Law contains similar rules, specifically stipulating the insignificance of any provision of the contract on the transfer of rights in respect of future results of intellectual activity excluding the right to unilaterally terminate it [14].

Article X.131–1 of the French Intellectual Property Code allows the conclusion of contracts with respect to future works only on the condition of their detailed individualization, which makes it possible to identify the subject matter of the contract [15].

Proceeding from the provisions of Article 1295 of the Civil Code of the Russian Federation, it can be concluded that it is possible to enter into an agreement on granting the employer the exclusive right to official works that have not yet been created at the time of concluding such an agreement.

Another issue connected with the acquisition of rights in respect of lighting design works is related to the identification of the range of subjects that can be recognized by the authors of this work.

There are four types of specialists. First, the lighting engineer who performs calculations on which the lighting and its compliance with the established standards depend. Second, the lighting technician who is responsible for the functioning and compliance of the illumination degree for achieving the tasks that the project implements under the given conditions. Third, the lighting designer who creates a form and performs an aesthetic search through the prism of functionality and technical requirements. In addition, finally, the lighting artist, who provides the light component of the presentation and emphasizes the general idea of representation through a light-colour solution.

These four types of specialists cannot be revealed in one single person, since the difference between an engineer and a designer is enormous, and not only because of their skills (artistic / technical), the conditions for their implementation (degree of freedom: creative activity / restriction by technical requirements), their abilities (different competencies), but mainly because of the difference in their practical skills (the rigidity of the requirements for the engineer work performance against the freedom of self-expression of the designer; the objectivity associated with the need for the requirements compliance of the engineer against the subjectivity of the designer opinion).

Louis Clair, one of the first presidents of Association of Light Designers and Lighting Technicians, draws an analogy between the lighting designer activities and the world of music. A composer is one who gives directions and creates common features of a work, just like the scheme of a city's light-illuminating device. The conductor carries out the realization of the created work outward by his personal actions, using the work. The soloist chooses the appropriate instrument with all the necessary settings. Apparently, the composer has more freedom of creativity. He corresponds in this analogy to a light artist and a lighting designer [16].

In conclusion, it seems possible to come to the following logical deductions. Objects of lighting design represent the result of technical and artistic creativity, which predetermines their dual legal protection as objects of copyright and patent law. Unlike the traditional idea of copyright protection of the form of the work, the content and filling of objects of lighting design are of significant importance due to the peculiarity of the object itself. Persons of copyrights to the lighting design works should be recognized as a light artist and a lighting designer.

The problem of identifying the subject matter of the contract and determining the compliance of the achieved result with the requirements stated in the contract can be solved by using the method of determining the subject matter of the contract in a material carrier, in which the obtained result of intellectual activity will be fixed.

As regarding the identification of the subject matter of the contract in the form of lighting design future works, we should state the legality of the transactions on the transfer of exclusive rights to copyright objects that do not exist at the time of the conclusion of these transactions.

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Rimma Sh. Rahmatulina,
Ph.D. in Low Science, Associate Professor, Department of Legal Regulation of Economic Activity, Federal State Educational Institution of Higher Education "Financial University under the Government of the Russian Federation"

Ekaterina A. Sviridova,
Ph.D. in Low Science, Associate Professor, Department of Legal Regulation of Economic Activity, Federal State Educational Institution of Higher Education "Financial University under the Government of the Russian Federation"

Angela S. Voskovskaya,
Ph.D. in Pedagogic Science, Associate Professor, Department of Language preparation, Federal State Educational Institution of Higher Education "Financial University under the Government of the Russian Federation"

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LEGAL REGULATION OF PUBLIC-PRIVATE PARTNERSHIP SUPPORTING THE DEVELOPMENT OF ENERGY-EFFICIENT LIGHTING INDUSTRY

Maksim Yu. Beresin, Svetlana S. Dakhnenko, and Ekaterina E. Kuvshinova

Financial University under the Government of the Russian Federation
E-mails: myberezin@fa.ru; ssdakhnenko@fa.ru; eekuvshinova@fa.ru

ABSTRACT

The paper is devoted to certain forms of public and private partnership in the sphere of light technologies, special investment contracts, regional investment contracts, industrial parks, and industrial clusters. It studies the prospects of the development of general and special lighting considering the rise of population and its needs in high-quality social, medical and educational services. Authors analyze specific conditions of granting tax preferences to innovative companies that help to stimulate the production of high-tech goods. The authors explain why legal definitions of regional investment projects and special investment contracts need clarification. The paper specifies the conditions for setting up new productions in the territories of advanced economic development. The options of unification of legal mechanism, which regulates the creation and support of industrial parks and industrial clusters, are offered.

Keywords: lighting, industrial policy, public-private partnership, investment contract, investment project, industrial cluster, industrial park, subsidies

1. CONDITIONS OF LIGHT TECHNOLOGIES PRODUCTION IN RUSSIA

With the help of scientific methods of analysis, comparison, formalization and systematization the scientific tasks on determining the prospects for development of light technologies on the base of investment models of joint participation of the state and the private companies are solved and the proposals on the clarification of legal mechanism for stimulating accelerated development of innovative productions are formulated.

The latest research has shown that by 2020 the turnover of the world lighting market will reach almost €110 billion with annual growth of 3 % from 2016 to 2020. Herewith, the dominating segment of this market (75 %) is general lighting market, which turnover is expected to reach €80 billion by 2020. The second segment, represented by automotive lighting, is lagging dramatically, as by 2020 its growth is not anticipated, and the third one is illumination segment, its turnover by 2020 is going to decrease.

Forming the Concept of long-term socio-economic development of the Russian Federation for the period up to 2030 [1], the Ministry of economic development of the Russian Federation has specified the main industries and projects based on the analytical data of the leading centres for scientific and technical development. The main vectors are electric power industry and energy-efficient development, transport infrastructure and space systems, information communication technologies, i.e., all they belong to high-tech industries [2] and their development is impossible to imagine without the developments in the sphere of lighting.

Development of any industries needs finance, search of investment sources, creation of the effective mechanism for stimulation of investment process and further management of new projects. Thus, now different legal mechanisms are under formation, they are aimed at the development and improvement of implementation of lighting industry in Russia, and creation of competitive lighting production, LED and OLED technologies.

At present, there are treaty laws establishing rules of joint investment by the state and the subjects of activity in the sphere of lighting industry activity [3]. There have been established the territories with special economies where the lighting industry enterprises in the process of production can obtain diversified benefits both in the form of tax and customs privileges and in the simplified system of attracting foreign labour and simplified administrative procedure [4].

Lighting industry enterprises in certain constituent entities of the Russian Federation are potentially able to participate in the regional investment projects and special investment contracts that are being signed according to the Federal Law of 31.12.2014 No. 488-FZ "On Industrial Policy of the Russian Federation".

Thus, in the territory of the Republic of Sakha (Yakutia) there was implemented a unique investment project on setting up a greenhouse complex which due to instalment of modern lighting technology of general lighting with high luminous efficiency helps to grow crops in the severe climatic conditions.

2. ECONOMIC MEASURES FOR LIGHT TECHNOLOGIES DEVELOPMENT

This proves that such sector of lighting technology as general lighting has a substantial potential for development in Russia because taking into account geographical position of the country and its climatic conditions the creation of special conditions for substitution of natural lighting with artificial lighting supports plant growing and cattle breeding almost in any part of the country.

Lighting technology is necessary not only at the farms. Development of new technologies in the automobile industry, TV production, portable computers and mobile phones industries leads to the necessity to stimulate developments and implementation of new technologies in light sources.

Moreover, urbanization and, consequently, the growth of population in cities, the increase in consumption of services and evolution of social and cultural life results in the formation of such segments as architectural lighting, office lighting, store lighting, hotel lighting, lighting of educational facilities and lighting in housing and utilities sector. In all above mentioned sectors the specific characteristics of "consumers of light" should be considered.

Furthermore, it is expected that by 2020 the population of the planet will approach 7.7 billion people, thereby there will be the significant growth in the demand for lighting both in residential and non-residential buildings that are used for production and educational purposes, especially in the cities that historically have been home for the major part of the population.

Population growth factor objectively predetermines the increase in the production of light sources as well as stimulation of the development of energy efficient light sources that goes in accordance with general energy saving economic tendency.

At the same time, the development of industries, medicine and social life is forming the base for new developments in the sphere of special lighting, such as emergency luminaires, cold storage light fixtures, fixtures for extreme clean facilities and fixtures for education institutions.

Development and industrial approbation of new lighting technologies are long-term risks so they need relative stability of financing and legal regime.

Still, tax incentives for the development of new industries face certain difficulties. Analyzing the norms written in the Article 25.9 of the Tax Code of the Russian Federation it can be stated that the tax status is made equal for the lighting enterprises – the participants of the regional investment projects (RIP) and special capital investment projects (SPIC).

Legislation does not differ these institutions, probably because both have the same domineering subject (the State) as the unifying factor. This, of course, raises some questions.

It is not clear whether the rules of the Tax Code of the Russian Federation that establish requirements for the participants of the RIP are extended on the legal status of the SPIC, including such requirements as ban on the presence of branches and representations outside the territory of the constituent entities of the Russian Federation where the project is being realized, or the implementation of the project exclusively in the territory of the constituent entities of the Russian Federation listed in Clause 1, Article 25.8 of the Tax Code of the Russian Federation.

These problems need solutions because the management of the lighting industry enterprise can focus on the development of business by establishing a branch network, and to achieve the balance between the concentration (preservation) of main production in the territory of constituent entity of the Russian Federation is possible not only by forbidding the existence of isolated branches in the territories of other constituent entities of the Russian Federation but by softer measures such as determining the lowest share in the total amount of fixed assets (for example, not less than 80 %), and the fixed assets of the business concentrated in the territory of the specific constituent entity of the Russian Federation must not be lower the established share.

Besides, we consider the possible solution is to fix in the law the clear definitions of federal and regional investment projects, explain the special contract terms which represent the legal framework for the realization of relevant projects, and we also concentrate the attention on the fact that legal status and requirements that are imposed on the potential investors and projects are determined both by federal and regional law in the case of RIP and in the case of SPIC by federal norms – in accordance with the Federal Law of 31.12.2014 No. 488-FZ.

Existing regulations, which establish requirements to the participants of the RIP in the federal act: Article 3.3 of the Tax Code of the Russian Federation, give the participants the possibility to pay income tax to the federal budget at the rate of 0 %, i.e., not to pay it at all. As the federal budget is deprived of additional income, the order and conditions on which the participants can be granted these benefits is regulated at the federal level, but the constituent entities of the Russian Federation are authorized to deal with the issues of taxation regarding the income tax rate. Revenues on the income tax rate are compulsory for payment in the territory of the relevant constituent entity of the Russian Federation.

Such mechanism may prove its effectiveness because the tax reduction directly affects the investment flow into the territory, increase of production capacities, creation of jobs, income growth, and – by the means of increased effective demand – the growth of consumption as a factor of economic development.

In the conditions of international competition on the market of lighting production, the establishing of clusters on the development of new technologies of light sources is one of the macroeconomics competitive advantages.

Taking into account the existing sectors of lighting production, which include general lighting, automobile lighting systems, and illumination, the development of competitive production in every of the above mentioned sectors can be encouraged by temporary decreasing income rates alongside with the guarantee of stable legal regime of economic activity.

For the participants to have equal rights in the system of tax incentive it is necessary to supplement Clause 1, Article 25.9 of the Tax Code of the Russian Federation with the new provision relating the RIP (SPIC), videlicet, the new participants should have no tax debts and other debts on obligatory payments.

At the same time, the existing external constraints of the usage of international funding sources and the mobilization of internal resources leads to the decrease of economic activity and thus to the shortage of revenues into the regional budgets and the growth of their deficit. All this slows down the process of accepting regional regulation in the areas of tax incentives.

Nevertheless, some possibilities for the development of the lighting industry enterprises can be found in the territories of advanced economic development in Siberian Federal District and Far Eastern Federal District, and single-industry towns. The study of the legal regime in the territories of advanced social and economic development reveals that the lighting industry enterprises enjoy the maximum competitive advantages in comparison with the regime in other territories [4–8].

As the state offers preferential terms, it has the right to demand from the subject of lighting activity operating in the territory of the advanced social and economic development to take upon itself to refuse to use physically and morally obsolete fixed assets and to replace them – at its own expense – with new production assets as well as to use the maximum amount of the local labour in the production process.

Apart from the support of investment activity in industry the Federal Law of 31.12.2014 No. 488-FZ declares in the frames of special capital investment projects the implementation of new incentivizing mechanisms intended to support the residents of industrial (production) parks and industrial clusters in order to develop regional industrial production.

Currently, was established and continue to develop lighting industrial cluster "Fibre optics and optoelectronics" in the Republic of Mordovia (est. 16.03.2016). The cluster, or consolidation of a few enterprises, allows to establish close cooperation between independent companies that work functionally and geographically in one area of economy so that to provide a continuous process of development, approbation and implementation of new products with the simultaneous training of the workers who in future will apply the knowledge of these technologies in practice.

Clusterization (the process of unifying companies) in the lighting industry is essential for this type of enterprises because they are knowledge-incentive, ingenious and necessary for industry implementation.

The current legislation sets requirements on the industrial (production) parks, industrial clusters, management companies and specialized agencies. Based on the selection process, some regions get the rights to imply incentive measures and to subsidize expenses on creating the required infrastructure [9].

The legal model defines industrial parks as aggregation of the objects of industrial infrastructure handled by the management company, however, law continues to develop in this area including terminology and it does not define the role of "anchor resident" of the industrial park. In contrast with other residents and participants of the industrial park, anchor resident is obliged to invest not less than 10 % of the aggregate amount of extra-budgetary investment of the residents at the end of the 10th year since the start of the project realization [10]. As for the foreign legal practice, according to it *major user* is responsible for managing the industrial park.

The legal status of the participant of the industrial park and the investor of the industrial park is not defined, neither is defined the legal mechanism of cooperation between them and the management company in the case when the company does not carry out the investment functions. In the case of Greenfield-type industrial park, the definition of terms "Resident" and "Developer" also need clarification.

3. LEGAL BASIS FOR FINANCIAL SUPPORT OF LIGHT TECHNOLOGIES ENTERPRISES INVESTING ACTIVITY

Apparently, the role of the industrial (illuminant) park in the lighting industry is to generate educational, scientific, innovative, and enterprising initiatives on development and implementation of new materials and compounds used in the process of production of light sources, and new technologies used in production of light sources, new systems of light sources management, new fixtures of high luminous efficiency and new lighting solutions in manufacturing and agriculture sector.

For that reason, the main part of the state support provided to the industrial parks residents should be focused on the reimbursement of expenses on making and reconstructing of industrial infrastructure.

In this context, legislation can determine the industrial park as a subject of lighting industry activity and provide it with a parcel of land, on which it constructs manufacturing or warehouse premises, or purchases, or leases the ready-made properties for usage in the production process. In the former case, the state support can be represented in the form of partial reimbursement of expenses on construction, in the latter case it can be the provision of favourable lease terms or subsidizing a part of lease costs.

At present, at the federal level specific measures are provided, such as reimbursement of expenses on required infrastructure in the territory of constituent entities of the Russian Federation and the reimbursement of the interest rates on loans to the management company.

The size of reimbursement depends on the amount of taxes and fees paid by the residents. Consequently, preferential regime for the residents must be set by the constituent entities of the Russian Federation but the secondary legislation is still under development.

Thus, some constituent entities of the Russian Federation provide special benefits for the subjects of industrial parks depending on their status (anchor resident, resident, and participant) and the amount of investments made. Other constituent entities of the Russian Federation prefer grandfathering clauses of the regional investment regulation.

Finally, neither federal nor secondary legislation establishes liability for the breach of obligations written in the contract on creating the industrial park and conducting business on the territory of the industrial park.

Nor does it clearly define the legal consequences following the reorganization of the management company.

The solution could be found by analyzing the successful experience of implementation of organizational and legal forms of interaction between the regional authorities and industrial parks and the further development by the Ministry of Industry and Trade of the Russian Federation of the relevant methodical recommendations subject for enforcing by all constituent entities of the Russian Federation while forming the legal base for establishing in their territories the industrial parks and industrial clusters.

The adoption at the federal level the common methodology necessary for creation of industrial parks and other forms of innovative development does not deprive the constituent entities of the Russian Federation of their independence in choosing the forms and methods of interchange with the companies in ensuring beneficial financial and legal conditions for the development of industrial parks.

At the same time, the establishment of industrial structure facilities in the lighting industry can be implemented for creating industrial parks, industrial clusters and state subsidizing of precision spending, state contribution to the expenses on concession agreements, and state and private partnership.

To establish measures of public support for the development of industrial parks it is expedient to assume that state preferences are provided for investment projects in the key economic sectors only if the financing sources or financial guarantees do not belong to funds of the budgetary system and the investment activity do not fall under the scope of the public-private partnership laws and concession agreements because these spheres are covered by other laws.

The above described issues connected with the forming of legal and financial conditions for establishment and development of industrial (production) parks can be solved by working out and adopting of special federal law “On industrial (production) parks”.

The vision of the law must include conceptual system, the principles of creation and functioning of industrial (production) parks, the procedure of implementing the right on creation of industrial parks and the normal requirements on the industrial parks, general provisions for concluding contracts on creation and functioning of industrial parks and performance of production activity in their territories, specifics of production activity in industrial parks.

4. PERSPECTIVES OF CLUSTER FOUNDATION IN LIGHT TECHNOLOGIES PRODUCTION

Legal support for the participants of industrial clusters including lighting industry clusters is the Resolution No. 41 of the Government of the Russian Federation of 28.01.2016 “On the approval of the Rules of the federal budget subsidies to participants of industrial clusters for reimbursement of costs in the implementation of joint projects in industrial production of import substitution”.

The industrial clusters concept is able to provide mutually beneficial cooperation between the participants and promote regional development. The international practice of formation of industrial cluster proves the importance of implementation of systematic supporting efforts that include allocation of land lots, creation of a searching system of suppliers and consumers, and placing of long-term orders with the public and private companies.

In accordance with the Resolution No. 41 of the Government of the Russian Federation of 28.01.2016, granted subsidies are aimed at equity financing of project or technical activities. We consider it necessary to widen the list and include there a new item of expenditure – cost financing of joint R&D in the amount of 50 % of the total expenditure, which can reduce the innovative activity risks in the lighting industry and ensure the relative financial stability of designs in the process of development and approbation of new technological solutions, and creates conditions to get patents quickly for the objects of intellectual property of the lighting industry cluster participants both, with the National Registry and foreign patent offices.

The suggestions offer the clarification of regional investment projects and special investment contracts participant financial status, formulating of the federal and regional investment projects definitions; they insist on making additional conditions for becoming the participant of the advanced development territories, come with the idea of creation mechanisms unification and support of industrial parks and industrial clusters, government financing implementation of the R&D in the amount of 50% of the total expenses on these projects.

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Maksim Yu. Beresin,
Ph.D. in Economics, Professor of Department of Legal Regulation of Economic Operations of the Financial University under the Government of the Russian Federation

Svetlana S. Dakhnenko,
Ph.D. in Juridical Sciences, Associate Professor at the Department of Legal Regulation of Economic Operations of the Financial University under the Government of the Russian Federation

Ekaterina E. Kuvshinova,
Ph.D. in Historical Sciences, Associate Professor at the Department of Language Training of the Financial University under the Government of the Russian Federation

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EVALUATION OF FISCAL POLICY EFFECT OF CHINA'S PHOTOVOLTAIC INDUSTRY

Gang AN[1] and Hang WANG[2] *

[1]*School of Economics and Management, Wuhan University, Wuhan, 430072 China*
[2] *The Centre of Finance Research, Wuhan University, Wuhan, 430072 China*
**E-mail: 34604169@qq.com*

ABSTRACT

To explore the role of fiscal policies in promoting the development of photovoltaic industry, the effects of financial subsidies on the development of China's photovoltaic industry were analyzed by using the micro data of listed companies. The empirical analysis results in this study indicate that the fiscal policies represented by financial subsidies play a remarkable positive impetus function and financial subsidies are positively correlated with the operating performance of Photovoltaic enterprises. With larger the asset size and higher the Research and Development (R&D) investments, the operating performance of Photovoltaic enterprises is the better. Based on the above results, this study puts forward some policy suggestions on optimizing fiscal policy tools and further promoting the development of photovoltaic industry.

Keywords: photovoltaic industry, fiscal policy, evaluation

1. INTRODUCTION

With the global energy shortage and environmental pollution becoming increasingly serious, the importance of clean energy is becoming increasingly prominent. China has a large population and huge energy demand. How to solve the contradiction between increasing energy demand and environmental carrying capacity is extremely urgent. Traditional energy sources are usually non-renewable, often accompanied by severe environmental pollution. The new energy industry in the context of low-carbon economic development has been given the responsibility of seizing the strategic high ground of the future, and it has also promoted economic transformation and upgrading and promoted economic and social sustainable development.

1.1. Major Features

China has abundant solar energy resources in natural conditions. In the long run, if China can widely use solar photovoltaic power generation technology, the pressure on energy supply and demand encountered by domestic economic development will be greatly eased.

However, development of China's photovoltaic industry has not been smooth sailing. It was initially regarded as a sunrise industry and has been tilted by national policies. Later, it has been vigorously developed as a pillar industry throughout the country, with the consequent lack of overall planning and blind investment. There is a serious overcapacity. At the same time, with the global economic downturn, trade protectionism, and European and American double-reverse investigations, the global PV market demand growth slows, product export resistance increases, photovoltaic power plant financing becomes more difficult, and power station construction is suspended. The industry entered an adjustment period.

As an emerging strategic industry, the photovoltaic industry has a strong positive externality: on the one hand, the development of photovoltaic industry and technological innovation can drive the development of other related industries; on the other hand, the use of renewable energy such as solar energy as a substitute for traditional energy is beneficial to Energy saving, pollution prevention and control. From the perspective of domestic and international practice, many countries have vigorously supported the development of the photovoltaic industry by implementing tilting policies such as on-grid tariffs, financial subsidies and credit concessions for photovoltaic power generation, and promoted the development of the photovoltaic industry. The photovoltaic industry is one of the emerging strategic industries. It is an industry supported by the government using macro-control measures. How to optimize fiscal policy tools to achieve government intervention in the economy and solve market failure has become an urgent problem to be solved. To this end, it is necessary to analyze and evaluate the effectiveness of China's current fiscal policy to promote the development of the photovoltaic industry, and provide reference for optimizing the design of fiscal policy.

Many scholars at home and abroad have carried out in-depth research on the development and the existing dilemma of photovoltaic industry, and analyzed the problems and challenges encountered in the development of photovoltaic industry in China and foreign countries. Lawrence pointed out that the key to the development of photovoltaic industry lies in technology research and development. The improvement in the cost of applying products and the reduction of the cost of applied products, the country should pay more attention to the development of the international market [1]. Dusoncher and Telaretti targeted the photovoltaic industry in various countries in Eastern Europe, and the results show that in some cases, the macro industrial policy does not generate positive incentives. Due to different national conditions, the same policies have achieved different effects in different countries. When formulating policies to support the development of the photovoltaic industry, we must pay attention to local conditions [2]. China's PV industry development faces difficulties in grid connection, subsidy misplacement, and the incentive mechanism, which has affected China's PV industry policy development [3]. Feiyang and Fansheng analyzed the stock performance of listed companies in mainland China before and after the introduction of policies to test the effectiveness of supportive policies. The research shows that different policy effects have different effects [4].

Many scholars have studied the effectiveness of fiscal and taxation policies in promoting the development of emerging industries. However, due to differences in research methods, variable settings, and data types, the research conclusions are different. Candelise et al. pointed out the shortcomings of the current fiscal and taxation policies in the UK, and proposed some practicable policy instruments, such as "incoming tariffs" and "target cost reduction", and further analyzed these policies. The impact of tools on the development of the UK PV market [5]. For different types of ownership companies, finance stickers and tax incentives encourage innovation has differences [6]. Guangqiang et al. studied the different effects of financial subsidies and tax incentives based on the perspective of industrial development. The results show that tax incentives are more effective in inspiring corporate technological innovation than financial subsidies [7].

Based on the existing research literature, this study uses the data of listed companies in China's photovoltaic industry to construct a quantitative regression model to analyze the impact of financial subsidies on the operating performance of listed companies in the photovoltaic industry, and then study the incentive effect of fiscal policy to explore whether fiscal policy starts.

2. THE CURRENT STATUS OF CHINA'S PHOTOVOLTAIC INDUSTRY FISCAL POLICY

At various stages of the development of China's photovoltaic industry, the government has used fiscal policy means to achieve the objectives of industrial policy, and has shown different characteristics as the development of the industry changes. Before 2005, the relevant policies of China's photovoltaic industry were mainly reflected in the "Power Transmission to the Countryside" project implemented by the former National Planning Commission. The goal was to use the abundant solar energy, wind energy, water energy and other renewable energy sources in the remote areas of the western region to solve the production of the local population with electricity problems in life. The promulgation of the "Renewable Energy Law of the People's Republic of China" provided a legal framework for the promotion and utilization of renewable energy such as solar energy. Since then, the state has successively issued a series of supporting policies, especially after

2009, the relevant ministries and commissions have intensively introduced Targeted policy documents to promote the development of the photovoltaic industry, aimed at promoting the use of voltaic power generation technology and the health and sustainable development of the industry.

In order to promote the development of the new energy industry, China has formulated a variety of policies to support the development of the photovoltaic industry after entering the new century. The "Renewable Energy Law of the People's Republic of China" was officially implemented in January 2006. This law is in resource survey and development planning, industrial guidance and technical support, promotion and application, price management and cost sharing, economic incentives and supervision measures, and legal responsibility. Provisions have been made in other areas, opening the beginning of China's support for the development of new energy. Subsequently, in the aspects of on-grid tariffs, fund disbursement, power station construction, tax incentives, etc., the state has successively issued relevant policies, which provided a good guiding role for the domestic PV industry. However, with changes in the global PV product market, the upstream and downstream development imbalance of the domestic PV industry chain has become increasingly significant. The relevant departments of China have adjusted their fiscal and taxation policies in order to develop the healthy and orderly development of the domestic PV industry.

After the promulgation and implementation of the "Renewable Energy Law of the People's Republic of China", the Ministry of Finance and other relevant departments successively issued the "Solar Roof Plan" and "Golden Sun Demonstration Project" to carry out the initial installation of grid-connected power generation in photovoltaic building applications and photovoltaic power generation demonstration projects. Subsidy, in 2011, the National Development and Reform Commission issued the "Notice on Improving the On-grid Price Policy for Solar Photovoltaic Power Generation", formulated a national unified solar photovoltaic power generation benchmark on-grid price, and approved a unified verification standard for the on-grid price of solar photovoltaic power generation projects. "Distribution Measures for Distributed Photovoltaic Power Generation Projects" issued by the Ministry of Finance has made relevant provision on subsidy project confirmation, subsidy standards, subsidized electricity and fund disbursement. Since then, the Ministry of Finance has issued documents on the financial subsidies for the Golden Sun demonstration project in the pre-allocated areas and the government fund for the self-generated electricity for distributed generation.

In terms of taxation policies of the photovoltaic industry, the state has also introduced relevant tax incentives to support the development of the photovoltaic industry, mainly involving value-added tax, corporate income tax, and resource tax. In 2013, the Ministry of Finance issued "Notice on the Value-added Tax Policy for Photovoltaic Power Generation", which stipulates that the implementation of VAT on the sale of self-produced photovoltaic products will be refunded. The income tax preferential policy is mainly the "three exemptions and three reductions" policy, that is, the conditions for new solar power projects approved by the government investment department, exempt from the first to third year from the year when the project obtains the first production and operation income. Income tax, half of the fourth to sixth year of corporate income tax. China began to levy a resource tax with various taxable natural resources as the object of taxation, and reformed the oil and natural gas resource tax. Starting from Xinjiang, the pilot will change from the quantitative levy to the ad valorem, and the reform will be extended to Provinces.

It must be acknowledged that in recent years, the state has successively issued a series of policies and measures to promote the development of the photovoltaic industry, giving strong support to the development of the photovoltaic industry in terms of industrial positioning and layout, photovoltaic grid-connected power generation pricing, tax reduction and other aspects, and more emphasis on domestic. The development of the market and the digesting of production capacity have injected "incentives" into the market for revitalizing photovoltaic products. However, the ultimate goal of this series of fiscal policy measures should be that the photovoltaic industry itself continues to develop healthily, free from dependence on fiscal and taxation policies, and adapt to market competition.

3. METHODOLOGY

From the existing literature, when analyzing the incentive effect of fiscal policy on the development of the industry, many scholars at home and abroad

Table 1. The Definition of Related Variables

Variable type	Variable name	Variable symbol	Variable meaning
Interpreted variable	Enterprise annual total income	ZSR	Annual operating income + non-operating income
Explanatory variable	Financial subsidy	CZBT	Government subsidy income received by enterprises
Control variable	Total assets	ZZC	(total assets at the beginning of the period + total assets at the end of the period)/2
Control variable	Total operating cost	ZCB	Annual total operating cost
Control variable	R&D spending	YFZC	Annual R&D expenditure

mainly rely on the theory of public finance and the theory of industrial development. Among them, according to the theory of public finance, fiscal policy mainly plays a role in correcting market failures and realizing the role of effective allocation of resources, and from the perspective of industrial development theory, the role of fiscal policy is mainly to give preferential treatment to specific industries during the germination and growth of industrial development. In order to study the incentive effect of fiscal policy on the development of photovoltaic industry, this paper intends to select the micro-data of listed companies in the photovoltaic industry to conduct empirical research on the incentive effect of financial subsidies. As the photovoltaic industry includes different links in the upper, middle and lower reaches, in order to facilitate analysis and comparison, the analysis objects selected in this paper are all downstream power generation enterprises in the photovoltaic industry. Based on the data of the listed companies of the downstream photovoltaic power generation enterprises in 2012–2015, the panel data model is constructed. To study the impact of financial subsidies on corporate development, the sample data comes from Guotaian database, Sina Finance News, Juchao Information Network and the annual reports of listed companies.

Based on the above analysis, the panel data model constructed in this paper has the following variables:

Interpreted variable: enterprise Annual Total Income (ZSR), this paper mainly studies the incentive effect of fiscal policy on PV enterprises, and the core indicator to measure business performance is the income level of enterprises, which reflects the competitiveness and sustainability of enterprises and markets. Operating capacity is an important indicator that comprehensively reflects the business performance of the company. The total annual income of the enterprise in this paper is the sum of operating income and non-operating income.

Explanatory variables: financial subsidies (CZBT), financial subsidies are the core independent variables in the empirical study of this paper, reflecting the increased income of enterprises due to financial subsidies. According to the detailed data disclosed in the financial statements of the sample enterprises, the financial subsidies obtained by the enterprises are mainly reflected in the government subsidy subjects under the income statement of the income statement, and the financial subsidy details obtained by some enterprises are listed in the notes to the financial statements. Government grants listed in the company's financial statements and notes.

Control variables: total assets (ZZC), total operating costs (ZCB), research and development expenditures (YFZC) and other variables that affect the total income of enterprises. The control variables mainly include factors other than the core explanatory variables that affect the explanatory variables. The total assets refer to the stock of assets owned by the enterprise [8]. It is the material basis for ensuring normal business activities and the necessary condition for the sustainable operation of the enterprise; the total cost reflects the enterprise. The sum of production materials and labor costs consumed by production and operation activities, the level of enterprise control costs directly affects the business performance of the enterprise; R&D expenditure refers to the funds invested by the enterprise in research and development in the same year, representing the long-term development strategy and investment tendency of the enterprise, re-

Table 2. Panel Data Regression Results (Fixed Effect Model)

	1	2	3
Fiscal subsidy	0.034***	0.027***	0.023***
	(12.55)	(9.54)	(6.69)
Total assets	0.421***	0.326***	0.306*
	(14.30)	(4.68)	(1.79)
Operating cost		0.683***	0.617***
		(9.31)	(8.43)
R&D spending			0.295*
			(1.73)
R^2	0.5096	0.5383	0.5475

Note: The values in brackets are *t* values, and ***, ** and * are significant at 1 %, 5 % and 10 % levels respectively.

flecting the development capability and Growth potential. The definition of related variables is illustrated in Table 1.

On this basis, the paper constructs the panel data regression model as follows:

$$ZSR_{it} = \alpha_{it} + CZB_{it} + ZZC_{it} + ZCB_{it} + \\ +YFZC_{it} + \varepsilon_{it} \quad (1)$$

4. RESULTS ANALYSIS

Since this paper conducts the empirical analysis based on panel data from 2012 to 2015, which is typical of short panel data, the impact of single cross-section data on time series is negligible, so the mixed regression hypothesis is rejected. The Hausman test results significantly reject the assumption that the fixed-effect regression coefficient and the random-effect regression coefficient are unbiased and consistent, so the random effect is rejected, and the fixed-effect estimation model is used, and the robust standard deviation is used for correction. In order to ensure the reliability of the regression results, this paper uses stepwise regression method to introduce control variables.

Table 2 shows that the financial subsidy has a significant positive incentive effect on the PV business performance. The financial subsidy is positively correlated with the PV business performance, and passed the test at the 1 % significance level. In other words, the government's financial subsidies to PV companies have made the company's operating performance better, indicating that the government's financial subsidies have played a positive role in promoting the development of photovoltaic enterprises. Financial subsidies mainly play a role in influencing the investment and product sales of PV companies: financial subsidies will change the relative prices of factor income between the PV industry and other industries, causing changes in supply and demand, guiding PV companies to expand investment and expand sales. Subsidies promote the consumption of PV products through income effects and substitution effects. The income effect of financial subsidies refers to the government's adoption of financial subsidies, which changes the actual purchasing power of relevant consumers and encourages relevant consumers to purchase photovoltaic products. The substitution effect of financial subsidies refers to the pricing of products after PV companies receive financial subsidies. It is reflected that the financial subsidy changes the relative price of photovoltaic products and their competing products, thereby attracting consumers to purchase photovoltaic products and improving the operating performance of photovoltaic enterprises.

The empirical research results show that the total assets, operating costs and R&D expenditures of PV companies in the sample range are positively correlated with the income. The higher the total assets, operating costs and R&D expenditures of enterprises, the higher the total income level of the enterprises, and the regression results is passed the significance test at the 10 % level. This shows that the larger the scale of assets and the higher the R&D investment, the better the operating performance of PV companies. This shows that the PV industry has certain economies of scale. This result reminds us that we should pay attention to the advantages of economies of scale when adjusting and optimizing relevant policies.

5. CONCLUSIONS

The empirical analysis of this paper shows that the fiscal policy represented by financial subsidies plays a significant positive role in promoting the development of the photovoltaic industry. The financial subsidies are significantly positively correlated with the operating performance of photovoltaic enterprises; the larger the scale of assets, the more R&D investment. Higher PV companies have better business performance. The results of this study provide enlightenment for the adjustment and optimization of fiscal policy. As a emerging strategic industry, the photovoltaic industry is still immature, the investment return period is long, it is difficult to profit in the short term, and the final result of technological innovation investment is uncertain. The financial subsidy contributes to the risk of the enterprise and partially reduces the operational risk, thus positively stimulating the development of the photovoltaic enterprise.

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Gang AN, Ph.D. in Public Finance from School of E&M, Wuhan University

Hang WANG, Ph.D. in Public Finance from the Centre of Finance Research, Wuhan University

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FEATURES CHOICE OF LIGHT SOURCES FOR BIO-TECHNICAL LIFE SUPPORT SYSTEMS FOR SPACE APPLICATIONS

Alexander A. Tikhomirov, Sofia A. Ushakova, and Valentin N. Shikhov

Institute of Biophysics SB RAS, Krasnoyarsk
E-mail: alex-tikhomirov@yandex.ru

ABSTRACT

The historical aspects and prospects of the use of artificial light sources in the biological and technical systems of life support for space applications are considered. According to the given data, the most promising for such systems are LED light sources. Based on the results of photobiological studies it is shown that radiation, perceived by a man as white, in his spectral efficiency unreliable differs from radiation, a spectral curve similar to the average action spectrum of photosynthesis the green sheet ("Phyto"). In accordance with this, the possibility of choosing either a phyto spectrum or a spectrum close to the equal energy for the cultivation of plants in life support systems is justified.

Keywords: light sources, light spectral composition, LEDs, LED lamps, life support systems

1. INTRODUCTION

Active researches on **b**io-**t**echnical **l**ife **s**upport **s**ystems (BTLSS) began in the 60-s years of the last century after the first human flight into space and are continuing to the present time in Russia, USA, China, EU, Japan, etc. In fact, all the established BTLSS provide for the use of artificial lighting, which is energetically used as a light power for the functioning of the phototrophic link that provides humans with plant food, water, regenerates the atmosphere and participates in the involvement in the circular process of organic waste.

The first real operating BTLSS for man was created in the Physical Institute of the USSR in the middle of the 60-s years of the last century. In the first such system ("BIOS-1") as a source of water and regenerator of the atmosphere for humans Chlorella was used [1]. Xenon lamp with water cooling DXt-6000 was selected as a light source for such systems [2]. The reasons for the choice of this source were mainly: – A large radiation flow in the area of photosynthetically active radiation (PAR), which causes a high photosynthetic activity (in this case, Chlorella) in the production of oxygen for humans and utilization of carbon dioxide released during its breathing; – The spectral composition of the PSAR, like sunlight, is conducive to the photosynthesis of Chlorella; – High sustainability of the design (the destruction of the lamps does not add toxic substances in BTLSS); – Easy operation (the lamp is compact enough, and therefore several lamps of this type easily fit into the internal space of cultivators for plants (in this case Chlorella). The practice of using Xenon lamp 6000W in "BIOS-1" was so successful that in the next, more advanced system " BIOS-2", containing Chlorella or higher plants (wheat and a number of vegetable crops), we used lamps of this type. At the same time, these plants, cultivated under the light of these lamps, showed good growth, development and productivity. Based on these results, the xenon lamps 6000 W were further used in the creation of a full-scale closed ecosystem "BIOS-3" for the cultivation of both Chlorella and a whole set of grains, oilseeds and vegetables, providing a complete plant-based diet of man. Xenon lamps 6000 W radiation, which has a spectrum in the visible region close to the Sun one, provided high productivity levels of wide range of cultivated plants [3]. At the same time attempts were made to create BTLSS with a person in the Institute of biomedical problems of Ministry of health of the USSR. As light sources in such systems, incandescent lamps with water cooling were initially used, and xenon lamps were used later [4]. These studies have not received further development, as the Institute focused mainly on the study of medical and biological problems to ensure human flight in microgravity. Life support systems with a person were created and tested in the United States in the 90-s years of XX century. A special chamber ("NASA's Biomass Production Chamber"), in which various species of higher plants were cultivated as the basis of the photosynthetic link of a closed ecosystem [6, 7], was functioning in the Space centre named by Kennedy [5], USA, in 1988–2000, as part of the NASA program. Metal halide lamps (MHL) with white radiation and high-pressure sodium lamps (HPSL) were used in these studies for the cultivation of plants. Further researches on justification of possibility of use of blue-red radiation in life support systems [8] were conducted in this organization. At the same time the research on the creation of BTSA with a person when using higher plants was conducted in the Houston space centre of L. Johnson [9]. The MHL with radiation perceived by the eye as white was used for growing wheat plants, and LEDs, which give combined radiation in the blue and red regions of the spectrum [10], was used for growing lettuc.

At the same time BTLSS, which used either artificial or natural or mixed light for the cultivation of plants, was created in Japan. Only artificial light created by HPSL was used in a number of "compartments" of this system [11].

Over the last few years new modern BTLSSs were created in Beijing and Shenzhen (China). Both of these systems are equipped with irradiators with LEDs, giving a combination of blue-red and white radiation for the cultivation of plants [12, 13]. In spite of the fact that the prospects for the use of LED in future BTLSS is no objection, now still there is no clear idea of what type should be the emission spectrum of these lamps in conditions BTLSS. The first attempts to use LED-lamps in BTLSS were made at the turn of the 80–90-ies years, when the first samples of irradiators with red LED lamps were tested on irradiation of plants in BTLSS [14, 15]. However, these attempts were not widespread, since the first samples of LED-lamps gave too weak, practically only red radiation that did not provide a light flow full-fledged for the production process in various plant species. Further progress in the improvement of irradiation technology with LED lamps primarily associated with the creation of blue LEDs allowed LEDs irradiators creation with virtually unlimited possibilities of variation of the visible radiation spectrum. The understanding of high spectral efficiency of radiation, similar in the structure of the spectrum of the green leaf photosynthesis [16, 17], has led to the fact that the lighting industry began to mass-produce irradiators, giving blue-red radiation, supplying photo spectrum. Experience in the use of such irradiators for the cultivation of plants has shown that it is not always the LEDs of photo spectrum deliver higher plant productivity than the white LEDs deliver it. Comparable productivity results are often obtained. In particular, such results are obtained on salad [18].

To find out how this may relate to other cultures within the main range of phototrophic link BTSA, we carried out experiments on the cultivation of wheat line 232, chufa and radishes in a temperature controlled, sealed growing chambers with LED-reflectors, giving a white and blue-red radiation spectrum.

2. EXPERIMENTAL TECHNIQUE

Plants were grown by hydroponic method using a standard nutrient solution (Knop medium with the addition of citrate of iron and trace elements). The air temperature in the chambers was maintained within (23 ± 1) °C. The selected plant species were successfully cultivated in a closed ecosystem "BIOS-3" [3]. To conduct the experiments, the company used the lamps of the company "LED-ENERGOSERVICE", Ltd. (trade mark "OPTOGAN"), giving the radiation perceived by the eye as white, and lamps, giving mainly blue-red radiation (Fig. 1). The density of photosynthetic photon flux for radish was 750 μmol/m^2•sec, and for more light-loving crops (wheat, chufa) – 1000 μmol / m^2 •sec. In radiometric measurements the "LI-250A" (LiCOR, USA) was used. The spectrum of radiation produced by irradiators (Fig. 1) was measured by the spectrometer "AvaSpec-ULS2048-USB2" (Avantes, Netherlands). More detailed methods and methods of cultivation of plants are described in articles [19, 20].

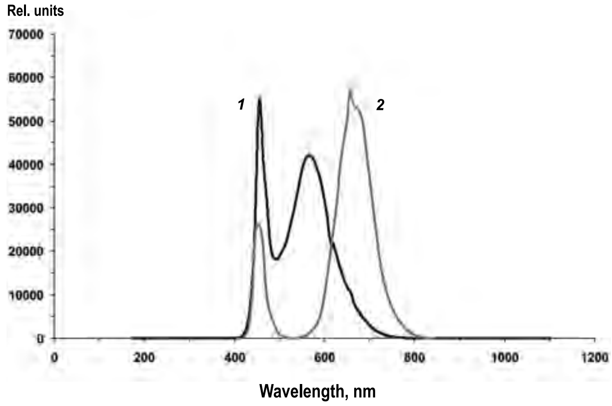

Fig.1. The relative spectrum emission of the irradiators, supplying white (1) or blue-red (phytospectrum) (2) radiation

3. EXPERIMENTAL RESULTS AND THEIR DISCUSSION

The results obtained (Fig. 2) show that the differences in the production characteristics of the studied plant species are within the measurement error. A similar conclusion was obtained for the salad in [18].

Long-term studies on the spectral efficiency of radiation in the production process [21] showed that the correct selection of irradiation levels at the radiation spectrum in the region of HEADLIGHTS (close to the equal energy) allows having a high productivity of virtually all species of cultivated plants [3]. With regard to the achievement of potential plant productivity, it is possible at certain deviations from the energy efficiency of the radiation spectrum. It is also necessary to take in account that to achieve high productivity in the cultivation of crops, the key for the formation of plant based human diet needs a very high irradiance in the PAR range. In this case, phytocenoses must have a high optical density (large sheet index) [22]. These circumstances can significantly affect the shift of the spectral efficiency of radiation from the red spectral region to the shorter-wave part of the PAR region [23, 24]. In this case, there is certain dependence between the radiation spectrum and the plant species [21, 22]. When working in a light environment created by LEDs with a strong difference between their radiation and white radiation, the staff can quickly get tired of vision: colour perception is distorted and there is a feeling of discomfort. This is confirmed by the data that the light sources with a sufficiently large blue component of the PAR spectrum can have a very harmful effect on the structure of the human eye and its physiological state as a whole. In particular, the article [25] is devoted to this issue, which emphasizes that this drawback is typical for LEDs with a share of blue radiation of the order of 30 % or more. Unfortunately, many modern irradiators with LEDs related to the so-called “phyto lamps”, have in the visible spectrum of the blue share of just about 30 % or more, which probably allows us to refer them to the kind of products with an increased risk of negative effects on the human eye. Although for detailed understanding of the mechanisms that underlie this “negative” requires specific additional research for us, while it is clear that for a person it is very undesirable, and for the inhabitants BTLSS, which

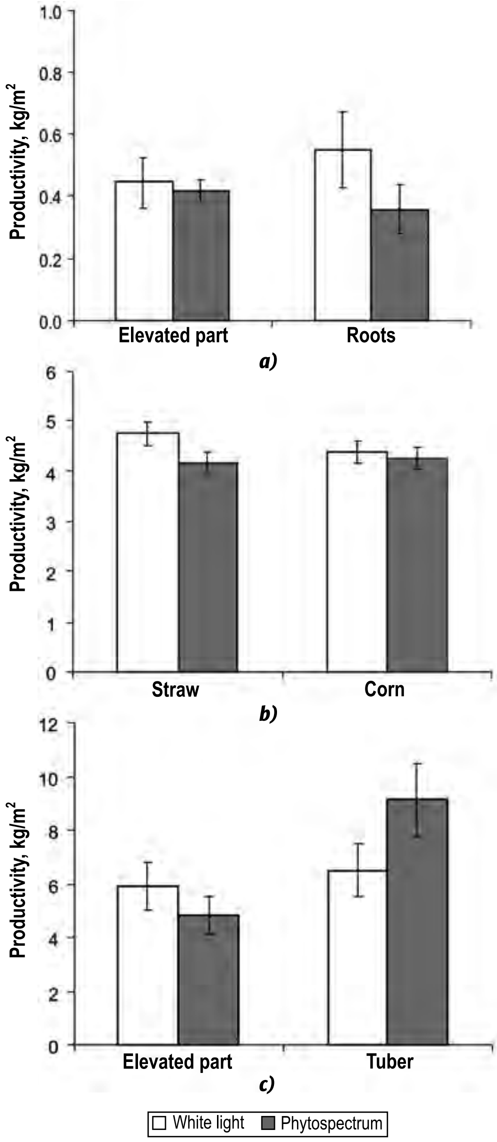

Fig. 2. The productivity of plants when using illuminators with LEDs of different emission spectrum: a – radish; b – wheat; c – chufa

can be isolated out of ground conditions, is unacceptable. Therefore, when using irradiators with LEDs in BTLSS, it is advisable to focus on a close to equal-energy spectrum of their radiation. In this case, two important tasks are solved to create a light environment for plants and humans: high productivity of plants is ensured and the negative impact of visible radiation on the human eye is eliminated. Therefore, now there is a tendency of "escape" from the light environment created in the BTLSS by irradiators with blue-red LEDs. In particular, blue-red radiation in this case is "diluted" by mixing it with white [12, 13, 26].

4. CONCLUSION

Today the reflectors with LEDs have top priority to be used in BTLSS. The selection of the radiation spectrum of such irradiators should be a compromise between the requirements for the spectral efficiency of radiation for different plant species cultivated in BTLSS and the creation of a comfortable light environment for the human eye. Preference should be given to such LED-irradiators, whose radiation is close to white light.

The study of the efficiency of irradiators with LEDs for the cultivation of wheat, radish and chufa was carried out at the Institute of Biophysics of SB RAS with the support of the Russian scientific Fund (project No. 14–14–00599P), and its results correspond to the topic of state assignment VI.56.1.4.

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Alexander A. Tikhomirov,
Prof., Dr. of Bio. Science, in 1970, he graduated from Krasnoyarsk State University with a degree in physics, biophysicist. At present, he is a Head of laboratory of biosynthesis control of phototrophs in Institute of Biophysics SB RAS and the Head of the Department "Closed Ecosystems" of Academician M.F. Reshetnev Siberian State University of Science and Technology. His research interests**:** photoclinometry, photophysiology of plants, closed ecosystems

Sophia A. Ushakova,
Ph.D. in Bio. Sciences, in 1968 she graduated from Novosibirsk State University with a degree in physics as biophysicist. At present, she is leading researcher of the Laboratory of phototrophs biosynthesis control of the Institute of Biophysics SB RAS. Her research interests: photosynthesis and productivity of higher plants as a component of artificial ecosystems, plant resistance to adverse environmental conditions

Valentin N. Shikhov,
Ph.D. in Bio. Sciences. He graduated from Krasnoyarsk State University in 1997 with a degree in physics and biophysics. At present, he is a researcher at the laboratory of biosynthesis control of phototrophs of the Institute of Biophysics SB RAS. His research interests**:** biophysics of photosynthesis, chlorophyll fluorescence, age physiology of plants, stress reactions in higher plants

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HYBRID LIGHTING COMPLEX FOR COMBINED LIGHTING SYSTEMS: RESEARCH INTO OPTICAL PATH OPTIMIZATION USING THE COMPLEX "SOLAR LED-S" NEW MODIFICATION

Alexander T. Ovcharov[1, 2], Yuri N. Selyanin[3] and Yaroslav V. Antzupov[2]

[1] *Tomsk State University of Architecture and Construction, Tomsk*
[2] *"Lighting Systems", Ltd., Tomsk*
[3] *"Solar" Ltd., Krasnodar*
E-mail: oat_08@mail.ru

ABSTRACT

A new concept of the architecture of hybrid lighting systems for installations of combined lighting is considered. The cascade principle of constructing the optical path of such complexes is described, in which the design contains two stages of the cascade: the upper and lower stages. The upper (input) structure is made on the basis of the corresponding modification of the hollow tube "Solatube®" (daylight), and the lower one, based on the "Solatube®" fibre of a larger diameter, is combined with LED artificial light block and is designed to transmit mixed light (daylight and artificial light). The results of studies on the efficiency of light transmission made it possible to optimize the solution of the new modification of the hybrid lighting complex "Solar LED", lower stage of the cascade, and to develop the nomenclature of the production line "S". The description of the first experience of using this complex in the pilot combined illumination system of the "meeting room" in the shopping centre "IKEA Belaya Dacha" headquarters is given. A completely autonomous power supply system for a lighting installation based on solar panels has been implemented.

Keywords: system of combined lighting, hybrid lighting complex (HLC), daylight, artificial light, hollow tubular light guides (HTLG), optical cascade, LED artificial light block (LED-ALB)

1. INTRODUCTION

Despite the recent appearance of the first prototypes of hybrid lighting complexes (HLC), the evolutionary path of their development in the technical, economic and social aspects is now visible [1].The first domestic experience of using combined lighting systems (CLS) based on the ***"Solar LED-S"*** has confirmed the expected (calculated) parameters of the lighting system and effects: energy efficiency and high quality of the light environment. At the same time, during the installation and subsequent operation of the HLC, two significant drawbacks were identified, the elimination of which would significantly increase the consumer qualities of these devices [1]:

• Artificial light block (ALB), placing the LED in the collimator zone (similar to the construction described in [2]), causes a high percentage of reflected light ("reverse"), which manifests itself in a fairly bright glow of the domes at dark time, Fig.1, a. Calculations showed that the back luminous flux of the LED unit is about 22% of the total, which significantly reduces the energy efficiency and efficiency of HLC. The effect of the "reverse" reflection of the luminous flux of the LED modules (LED-M) is shown at Fig. 1, b (photo from the dome side on the roof). A radical solution of this problem is achievable with such an arrangement of the LED emitter in the cavity of a hollow tubular fibre (HTF), in which the optical axes of the LED-M

Fig.1. The illumination manifold as a result of "selling" reflections of the LED module luminous flux (a) and mirror reflection LED module (top view through a manifold in the channel of hollow tubular light guide) (b)

and the HTF and the plane of the reflecting surface of the HTF are parallel, which will significantly reduce the return luminous flux as a result of reflections from the inner surface of the HTF. The study of the optical pathway of HTF and of HLC in the context of the foregoing is described below.

• Placement of ALB inside the room with a large height of the diffusers installation creates serious operational problems with ALB and its automatic control system (ACS). In particular, the installation and maintenance of the mine at a high installation height (5–20) m necessitates the construction of additional structures for access to the HLC or the attraction of industrial climbers for work. This causes complication and increase in cost of installation, repair and maintenance of ALB, which contradicts the innovative spirit of HLC. Below are the technical solutions that reduce the severity of this issue.

Solving the named problems, the authors changed the concept of the architecture of the HLC and conducted studies of its optical path, aimed at increasing the efficiency of the transmission of the luminous flux of ALB through the optical channel of the HTLG. Based on the research, the new HLC named **"*Solar LED-S*"**is proposed constructively and a series of modifications is presented.

2. A NEW CONCEPT OF THE OPTICAL PATH OF THE HLC

The design of the HLC**"*Solar LED-S*"** implements a cascade principle of constructing an optical path [3, 4] represented by two stages: the upper and the lower. The upper (input) stage of the cascade is combined with a light-receiving dome and is made on the basis of a corresponding modification of the "Solatube®" (daylight), and the lower stage of the cascade is based on the "Solatube®" of larger diameter, following in a series of modifications "Solatube®" – combined with LED-ALB and is designed

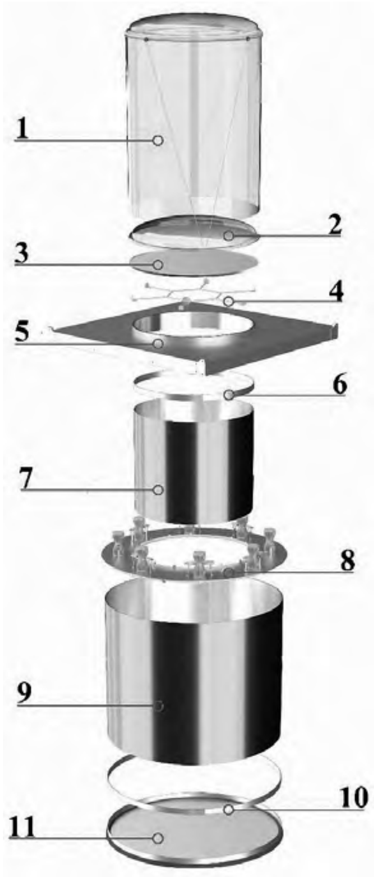


Fig.2. Decomposition of HLC "Solar LED-S" (based on HTLG Solatube® M74"):
1– collector "Solatube® M74 "series " SkyVault";
2– external dome;
3 –internal protective dome; 4–element of protection against liquid penetration; 5 – border fleshing; 6 – ring, fixing the light guide;
7–light guide of the upper stage of the optical cascade;
8 –annular mounting plate where LED units, radiator cooling and control unit (CU) of LED modules are hermetically mounted(each LED module is fixed on the end surface of the cooling radiator so that after installing the radiator on the mounting panel LED module is turned into the cavity of the lower stage of the optical cascade);
9–light guide of the lower stage of the optical cascade;
10–ring fixing the lens; 11–prismatic diffuser

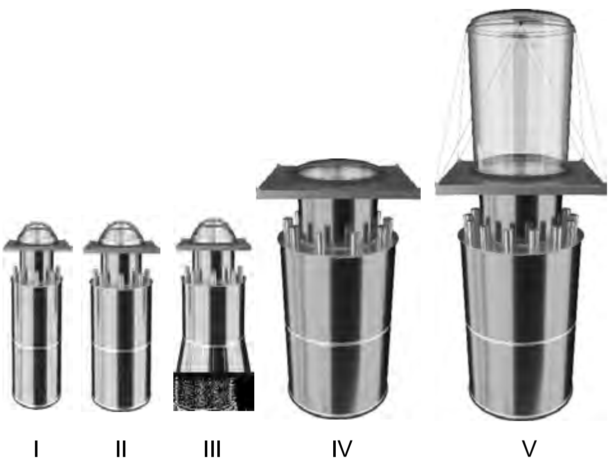


Fig. 3. Appearance of the units of the product line of HLC "Solar LED-S" of the corresponding modification

to transmit mixed light (daylight and artificial). Detailed description of modifications of the HTLG "Solatube®" is given in article [5].

In the HLC **"*Solar LED-S*"** (Fig. 2), unlike its predecessor – HLC "Solar-LED", LED-M are located on the mounting panel in such way that the front side of the printed circuit Board LED-M faces into the cavity of the lower optical stage. In this combination, the optical axes of LED-M, HTLG and plane of the reflecting surface of the HTLG are parallel, thereby eliminating the most likely causes of "reverse light" in the HLC.

3. RESEARCH OF THE HLC LOWER OPTICAL STAGE

First, we note that the upper stage of the optical path has the configuration and parameters of the HTLG, in design of which has not been made any changes. A feature of the lower stage of the optical stage of the HLC is the integration of natural and artificial (LED) light transmission systems. The lower stage conveys mixed light. The mounting plate with built-in LED blocks (Fig.2, item 8) combines the stages of the cascade and acts as a transition node from the upper to the lower stage [4].The lower stage of the optical cascade along the entire length is a hollow tube of the same diameter. This decision of the HLC was preceded by studies of the optical path of the lower stage of the cascade by computer simulation in the software environment of "Light Tools". The efficiency η_i of the luminous flux transmission by the optical path HLC is the desired result and a criterion for comparative evaluation of design solutions. The following initial conditions are accepted for modelling:

- The angle of divergence of the light beam LED-M α is equal to120°;
- Length of the lower stage of the optical path *L* is equal to 600 mm;
- Input luminous flux (input of LED-M) Φ_{in} is equal to 12000 lm;
- The HTLG inner surface reflection coefficient is equal to 99,7 %;
- Φ_{out} is the luminous flux measured at the plane of the HLC diffuser;
- η_i is the ratio $(\Phi_{out}/\Phi_{in})\cdot 100$ %.

The results of computer modelling and calculations are given in Table. 1.

The results of modelling and evaluation of the η_i depending on the design solution, confirm the correctness of the selected configuration of the lower stage of the optical stage, at which the $\eta_i > 99$ %. The obtained simulation data were used as the basis for the development of optimal design of HLC **"*Solar LED-S*"**.

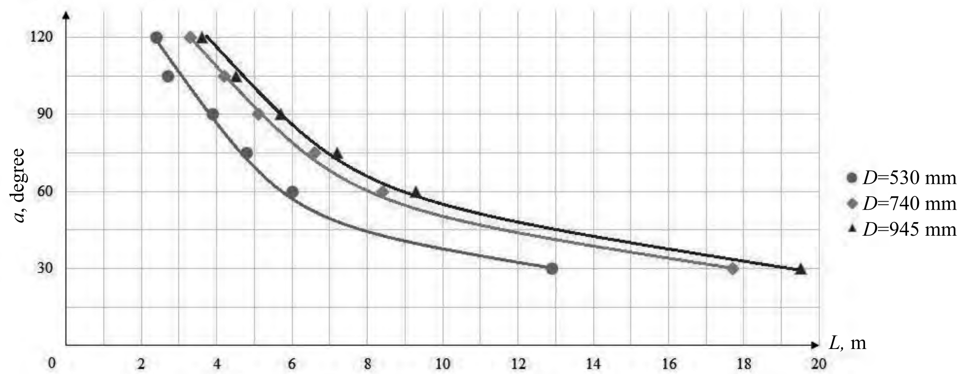
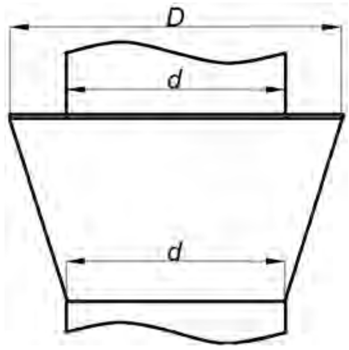
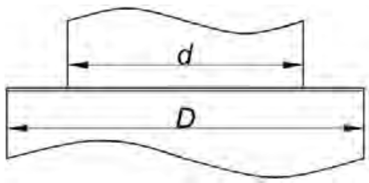
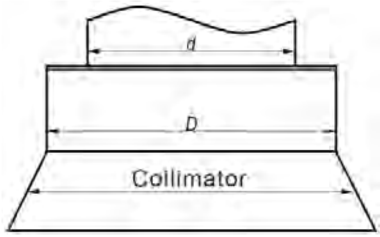
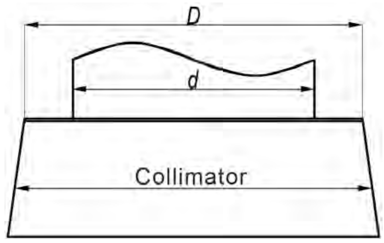


Fig. 4. The dependence of the maximum length L of the lower stage of the optical tube cascade HLC (in which the light transmission efficiency $\eta_i \geq 95$ %) from the divergence of angle α of the light beam of LED module

Table 1. Efficiency η_i of Luminous Flux Transmission Depending on the Design of the Optical Path HLC

№ option's	A constructive solution of the lower level	Schematic image	η_i,%	*d*, mm	*D*, mm
1	Panel–truncated cone		53,7	350	530
2	Panel–pipe		99,3	350	530
3			99,5	530	740
4			99,6	740	945
5	Panel – the pipe with the transition to the collimator		99,6	530	740
6	Panel –collimator		99,8	530	740

4. NOMENCLATURE OF THE PRODUCTION LINE OF HLC *"SOLAR LED-S"*

The results of modelling and calculations, and the existing type of **HLC** "Solatube®" formed the basis for the development of the product line nomenclature of **HLC "*Solar LED-S*"** (Table. 2).

The table shows the nominal values of the daylight luminous flux $\Phi_{v,\,\mathrm{DL}}$ for the corresponding modifications of the HLC "Solatube®" [1], which are the basic for determining values of the artificial luminous flux $\Phi_{v,\,\mathrm{AL}}$. The latter are given taking into account the MF operating factor according to the instructions [6, Table 4.3]. For example, for rooms with normal environmental conditions, MF is assumed to be 0.71.

In accordance with the Table 2, Fig.3 shows the appearance for the HLC from the HTLG nomenclature **"*Solar LED-S*"** structures.

5. INFLUENCE OF LED MODULES SECONDARY OPTICS ON THE EFFICIENCY OF LUMINOUS FLUX TRANSMISSION IN AN EXTENDED HOLLOW LIGHT GUIDE (EHLG)

The variety of architectural and engineering structures causes the use of the different length HLC at the lower stage of the optical cascade, up to 20 m.

Table 2. Nomenclature and Characteristics of Modifications of HLC "Solar LED-S"

№ mod.	*Legend of modification HLC	**$Φ_{V, DL}$, lm natural light	***$Φ_{V, AL}$, lm artificial light	Complete set LED-ALB	Recommended installation height of the diffuser, m
I	350/ LED-ALB /530	3000	6000	4 LED-module × 15W 4 УУ	≤ 4
II	530/ LED-ALB/740	8000	12000	8 LED-module × 15W 8 УУ	≤ 7
III	530/ LED-ALB/740У	8000	12000	8 LED-module × 15W 8 УУ	≤ 7
IV	740/ LED-ALB/950	18500	27000	9 LED-module × 30W 9 УУ	> 7
V	К/740/ LED-ALB/950	30000	42000	14 LED-module × 30W 14 УУ	> 7

Comments.
The structure of the conventional notation is based on the principle of listing the top-down elements of the HLC. For example: modification III-530 / LED ALB /740C: 530-diameter of the tube of the optical fibre of the upper optical stage, mm; LED ALB-mounting panel with blocks of LED- modules; 740-diameter of the tube of the optical fibre of the lower stage of the optical stage, m; C-cone-shaped amplifier (collimator);** $Φ_{V, DL}$ is the nominal natural light flow passed through the tube-light guide of the upper stage of the optical cascade; ***$Φ_{V, AL}$ is the nominal luminous flux of LED-ALB passed through the tube-light guide of lower stage of the optical cascade.

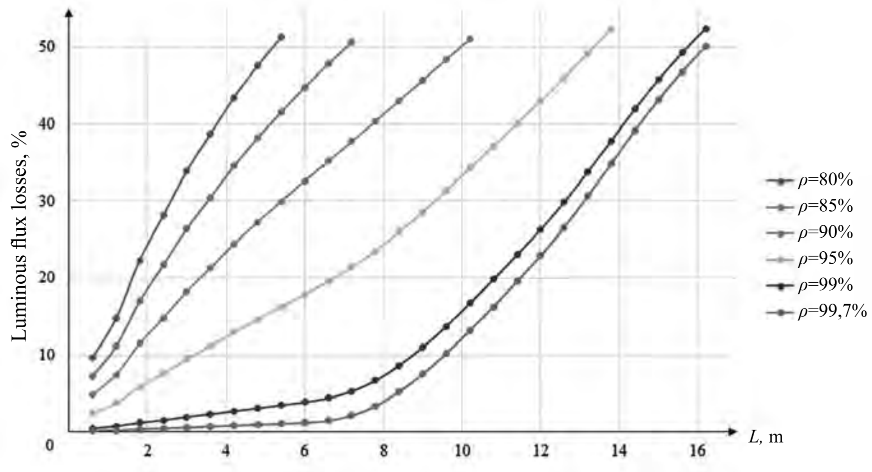


Fig. 5. Dependence of luminous flux losses on the length L of the light transmission channel having different reflection coefficients of the internal coating

In this regard, despite the high value of the reflection coefficients (99.7 %) of the light guide inner surface, light losses are possible due to the nature of light propagation along a hollow tube, determined by the angle of divergence of the light beam emitted by the LED module. Light loss limits the maximum light transmission distance according to the length of tubular guide. To assess optical losses and determine the distance of effective transmission of the luminous flux of the LED module by EHLG, authors studied the dependence of light losses on $α$ within the process of optimization of the LED mo-

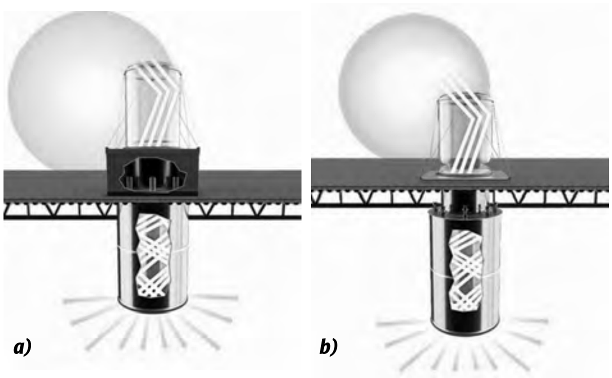


Fig. 6. Mounting options HLC " Solar LED-S":
a – outdoor installation, ALB set in the border; on roof;
b – interior installation, ALB is installed in the room

dule secondary optics parameters to evaluate the optical losses and to determine the distance of effective transmission of the LED-module luminous flux by EHLG. The research was carried out in the program "Light Tools" for the lower stages of the optical cascade as the lower stages have different pipe diameters. The loss of luminous flux at the level of 5 % corresponding to the distance of effective light transmission at the level of $\eta_i \geq 95$ % was selected as the boundary criterion for the selection of simulation data. The results of the study are shown in Fig. 4 and indicate the dependence of light losses on the divergence angle of the light beam of LED-M, which reflects the relationship of losses with the nature of multiple reflections and suggests the choice of optimal secondary optics for LED-M. Fig.4 shows that the best parameters are provided at $\alpha < 60°$.This determined the choice of secondary optics for optical system of HLC"*Solar LED-S*" with α in range (30–60) °. At the same time, such HLC provide high light transmission efficiency for most of the lighting projects of architectural structures. On the other hand, the optimal choice of the secondary optics for the lower stages of the optical cascade of different length allows minimizing indicators of the HLC price and provides the ability to control the light distribution in the plane of the diffuser, affecting the luminous intensity distribution curve (LIDC) of HLC light flow. The criticality of the choice of the material for the reflecting coating of the tubular hollow light guides demonstrates the dependence of light losses on the length of the light path at different reflection coefficients of the coating (Fig. 5).The dependence has a classical form, demonstrating the dynamics of growth of light losses when light propagates through the long hollow tubular light guides (as a result of multiple reflections) at a given coefficient of reflection of the coating. The coatings with a reflectance of 99.0 % and above have satisfactory performances for a long tubular hollow light guides (THLG).

6. PECULIAR PROPERTIES OF INSTALLATION OF HLC "*SOLAR LED-S*"

The new concept of cascade construction of the optical path of the HLC [3, 4] successfully solves the issue of exploitation, eliminating the hardship associated with a large installation height of the HLC. The solution of the problem lies in the location of ALB and control elements outside, above the roof of the building (exterior, (Fig. 6a). At the same time ALB is placed inside the border mounted on the roof. All the elements located inside the border are protected from the top by the border flash, which provides reliable water proofing. In each of the four walls of the border, there are service hatches, which provide access to the installation panel of the ALB for repair and maintenance work. Completeness of products of the nomenclature of HLC

Fig.7. HLC "Solar LED-S" in the "Meeting room " (installation process). ALB is located in the space of the technical floor, located above the ceiling of the "Meeting room" under the roof (internal design)

Fig.8. Meeting Room (Daylight illuminance about 400 lx at high clouds of the sky. In sunny weather, natural light flow is regulated by means of dimmer, which allow to regulate the natural light flow and to perform a complete shutdown of natural lighting during video presentations)

Fig.9. View on the roof: HLC- inlet and solar panels

"*Solar LED-S*" is given in Table.2. Controlled ALB has a block structure that provides service without the use of special tools. The HLC design is made in such a way that between the upper stage of the cascade HTLG pipe, the border, the flushing and the panel, there is a free volume sufficient to accommodate the ALB and to perform works on their maintenance. At the same time, the service staff works on the surface of the roof of the building at the level of service hatches. In working condition, the hatches are closed with sealed doors. External construction and installation design minimizes the cost of installation, service and repair work in the maintenance of the HLC.

Cascade construction of the HLC has universality in terms of method and place of installation. In addition to the external design, there are options and internal installation, which may be preferable (Fig.6, b), as in the example of the application of HLC "*Solar LED-S*", given below (under certain circumstances or architectural features of the structure).

7. THE USE OF HLC "*SOLAR LED-S*"

In 2017–2018 years HLC "*Solar LED-S*", was first used in the "meeting room" of the shopping centre "IKEA Belaya Dacha" (Fig.7–9), with two modifications II – 530/ALB/740 – Table. 2, equipped with ACS and constant light sensor (Fig. 8) mounted on the ceiling between the diffusers. At the same time, a fully autonomous power supply system of the lighting system is implemented by means of solar batteries (Fig. 9).

8. CONCLUSION

Developed nomenclature of HLC "*Solar LED-S*" is innovative, designed to create high performance and, due to its universality, is applicable in almost any architectural solutions. The first experience of the HLC "*Solar LED-S*" in the "meeting Room" of the shopping centre "IKEA Belaya Dacha" initiated their implementation in the practice of lighting.

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Alexander T. Ovcharov
Professor, Doctor of Technical Science, graduated from the Tomsk Institute of Radio Electronics and Electronic Engineering in 1966. At present, he is the professor of the Chair "Architectural design" of the TGASU and Director of Lighting system LLC, full member of MANEB, member of editorial Board of Svetotekhnika and Light & Engineering Journals

***Yuri N. Selyanin*,**
an engineer, graduated from the Taganrog radio engineering institute in1973, in1981 graduated from the Military Academy named after F.E. Dzerzhinsky, in1992 graduated from the Adjunktura at the Military Academy named after F.E. Dzerzhinsky. At present, he is the General director of "SOLAR", Ltd., official distributor of technology "Solatube Daylighting Systems"on the territory of Belarus and Kazakhstan

***Yaroslav V. Antzupov*,**
Mr. Dg. in electrical energy industry and electrical engineering, graduated from the Tomsk Polytechnic University (TPU) in 2017. At present, he is an engineer of Lighting Systems LLC and first year postgraduate student of the TPU NI

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SOLAR PHOTOVOLTAIC POWER GENERATION WIRELESS MONITORING SYSTEM BASED ON IOT TECHNOLOGY

Erhua SUN

Chongqing Real Estate Career Academy, Chongqing, 400035 China
E-mail: cydwmc52@sina.com

ABSTRACT

In order to further improve the real-time detection of power generation, a wireless monitoring model of solar photovoltaic power generation based on Internet of things (IoT) technology is proposed. Firstly, the application of remote monitoring in power generation technology is introduced, and the monitoring model of solar power equipment is constructed by wireless network, and the corresponding feedback mechanism is established by means of the (IoT) algorithm. Finally, the data processing ability and analysis effect of the wireless monitoring model are tested and studied. The test results show that the monitoring model can record and optimize the solar power generation data in real time, which greatly reduces the failure rate in power generation. It is proved that the monitoring model used in this paper has good feedback effect.

Keywords*:* Internet of things (IoT) technology, solar photovoltaic power generation, wireless monitoring

1. INTRODUCTION

The development of the national economy inevitably requires the use of a large amount of photovoltaic power generation, and the increasing use of photovoltaic power generation has driven the frequency of use of solar photovoltaic power generation equipment [1]. It is known that power generation equipment will have various faults in the process of use, but it can't be monitored 24 hours a day. Therefore, research on a remote control and wireless monitoring model for solar photovoltaic power generation equipment is getting louder and louder [2]. In response to this requirement, a remote control and wireless monitoring model of solar photovoltaic power generation equipment is established based on IoT technology through the combination of IoT technology. Real-time monitoring of solar photovoltaic power generation equipment and real-time monitoring of faults is achieved by using a computer wireless monitoring model [3]. However, the establishment of this detection model requires a comprehensive understanding of the performance of computers and photovoltaic power generation. This kind of interdisciplinary research is quite difficult. In this paper, the research on remote control and wireless monitoring model of solar photovoltaic power generation equipment is firstly an in-depth understanding and research on the IoT technology, and the optimization process of the calculation process and calculation formula of the IoT technology is given to the following wireless monitoring model. The establishment provides a basis for calculations. Then certain analysis and research on the performance of solar photovoltaic power generation equipment are conducted, and then the IoT technology is combined to establish the final remote control and wireless monitoring model of solar photovoltaic power generation equipment based on IoT technology. Through the use of this wireless monitoring model, the use of solar photovoltaic power generation equipment has been greatly improved, and at the same time, the revenue of the enterprise has been increased to reduce expenses and maximize the benefits of solar photovoltaic power generation equipment.

2. STATE OF THE ART

The use of power generation equipment was a product of the industrial revolution, dating back to the first industrial revolution in the UK in 1860 [4]. In the past two hundred years, the problem of solar photovoltaic power generation equipment has always been the focus and difficulty of our research. Because the failure of photovoltaic power generation is not regularly found, there is always the possibility of failure [5]. The improvement of the use of equipment has always been developed in two aspects. The first is to improve the performance of the equipment, and the second is to improve the detection effect [6]. With the rapid development of computer technology since the 1950s, we have gradually entered the information age, which facilitates the wireless monitoring of solar photovoltaic power generation equipment, and can remotely monitor solar photovoltaic power generation equipment by using computer computing models. And wireless monitoring is used for research. In particular, the IoT technology that emerged in the 1990s has brought convenience to wireless monitoring of photovoltaic power generation [7]. This new type of computer algorithm has a strong ability in information processing to classify and summarize information [8]. Through the research of IoT technology, it is not difficult to realize remote monitoring and wireless monitoring of solar photovoltaic power generation equipment [9]. In addition, after several decades of computational research and development of various forms of computing, the IoT technology gives us the use of great convenience has come, and the computational research in this paper is based on this [10].

3. METHODOLOGY

3.1. Research on the Computing Form of IoT Technology

In a strict sense, the IoT technology is a new form of computing that combines other computer algorithms. The computational research in this paper uses a combination of neural network algorithms for computational analysis. The neural network algorithm has a special property, that is, it can have multiple synapses for collecting information, and has multiple information export modes. In the wireless monitoring and remote monitoring of solar photovoltaic power generation equipment, it is needed to monitor and analyze multiple information of the equipment, which requires us to use computer algorithms with information collection points, and the neural network algorithm just meets this requirement. And combined with the IoT technology, in-depth learning and mining of the collected information can be carried out. This combination also has an important advantage, that is, the algorithm can be called by the data recorded by the previous deep learning process when performing similar calculations, reducing the calculation time of the algorithm and greatly increasing the computational efficiency of the algorithm. From a variety of perspectives, it is found that using this kind of IoT technology combined with neural network algorithm will bring us the best computing experience, and also provide a strong theoretical calculation basis for the establishment of later computational models.

The neuron node serves as the basic arithmetic unit of the neural network, and its unit model is shown in Fig. 1. $x_1, x_2, \cdots x_n$ is the input of neurons, simulating the output signals from other neurons, $w_{1j}, w_{2j}, \cdots w_{nj}$ is the connection weight of the neurons and other neurons, simulating the strength of signal transmission, θ is the Min value of neurons, and the function *f* represents the activation function of the neuron, and *O* is the output value of the neuron.

Among them, for the activation function of the IoT technology, the Sigmoid function is used. The function formula is as follows:

$$f(u) = \frac{1}{1+e^{-u}}. \quad (1)$$

Among:

$$u = \sum_i w_i x_i + \theta. \quad (2)$$

In addition, the neuron output value is:

$$o = f\left(\sum_i w_i x_i + \theta\right). \quad (3)$$

The neural network used in this paper has multiple layers of hidden layers. This is because different goals are had in remote monitoring and fault detection of solar photovoltaic power generation equipment. If only one hidden layer is used, not only the efficiency of calculation, but also the efficiency of calculation will be greatly reduced, the calculation accuracy cannot meet our use requirements. The special hidden layer calculation of special data is used in order to meet the calculation needs of this article. For example, an *n*-layer neural network, the first layer is the input layer, the last layer is the output layer, and the middle layer is all hidden layer. In the forward propagation process of the network, all the activation values of all the neurons of the layer *1* are calculated first, and then as the input to the next layer, calculate the activation value of all neurons in this layer, and so on, until the last layer.

The information transfer process of the IoT technology used in this paper is different from the transmission of neural network algorithms. In addition, certain deviations and noises sometimes appear in the process of information transmission. In order to increase the computational accuracy of this new type of computer algorithm, in the process of information transmission, the calculation form of the back propagation algorithm is combined. By using the reverse, the calculation of the propagation algorithm reduces the error in the algorithm calculation information transfer to a minimum. Since the neural network used in this paper uses the sigmoid function as the activation function, the Sigmoid function has a good computational advantage, and its derivative can be expressed by its output value:

$$\frac{df(o)}{do} = f(o)\left(1 - f(o)\right). \quad (4)$$

In fact, when performing network training, the error function is usually calculated using the mean square error. For a multi-class problem with *s* categories and *N* training samples, the error function is defined as follows

$$E = \frac{1}{2}\sum_{n=1}^{N}\sum_{k=1}^{s}\left(y_k^n - o_k^n\right)^2. \quad (5)$$

Where y_k^n represents the *k-th* note value and o_k^n represents the *k-th* output value.

The error for a single sample can be expressed as:

$$E^n = \frac{1}{2}\sum_{k=1}^{s}\left(y_k^n - o_k^n\right)^2 = \frac{1}{2}\left\| y^n - o^n \right\|_2^2. \quad (6)$$

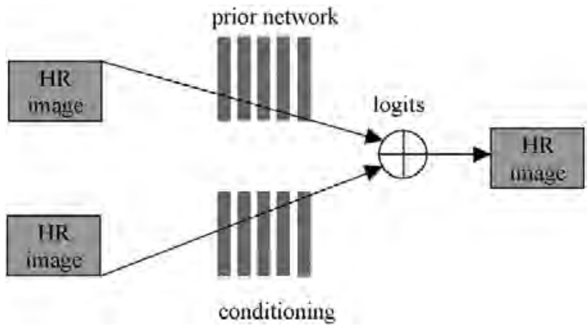

Fig.1. Artificial neuron unit model

According to the above method, the computational optimization research of the IoT technology is finally realized. Through the optimization research of the IoT technology, it provides a theoretical basis for the establishment of the following wireless monitoring model. Through our optimization analysis, the IoT technology can analyze different information without affecting the efficiency and accuracy of the algorithm calculation.

3.2. Solar Photovoltaic Power Generation Wireless Monitoring Model Based on IoT Technology

In the above research, the calculation form and calculation steps of the IoT technology is optimized. The remote control and wireless monitoring model of solar photovoltaic power generation equipment is analyzed based on IoT technology. First, the coding form of the model is studied. Nowadays, the rapid development of computer technology has brought many coding forms. Different coding forms have different features and functions. The model coding of this paper adopts the sparse de-noising automatic encoder. The sparse auto-coder implemented by the unsupervised feature learning algorithm completes the initialization of the deep neural network, and then uses the sparse feature expression learned by the encoder to train the last layer of neural network classifier, and finally completes the training and fine tuning of the entire deep neural network. In fact, this sparse de-noising auto-encoder is also the encoder after optimization. The traditional sparse de-noising auto-encoder cannot automatically reduce noise. In order to show the most realistic computing power of the computation model established in this paper, noise reduction processing is an indispensable form. An encoder incorporating noise reduction processing can minimize the noise impact of the model calculation data. The calculation model established in this paper can make more accurate judgments on fault handling, which is also determined by the use function of this paper. When the solar photovoltaic power generation equipment fails, many faults are not independent. It is likely, some information different and fault would appear at the same time. These fault information are interlaced, which brings huge impact on the wireless monitoring and remote control of the model. Challenge, although this paper uses different hidden layers for computational analysis in the optimization of model calculation algorithms, there will be some data cross-impact. Since the sparse de-noising auto-encoder is an unsupervised feature learning method, the deep neural network constructed by it can mine the intrinsic characteristics of the data from a large number of unlabeled data during the training process, greatly expanding the number of training samples, and is very suitable. The realization of big data mining of induction motor equipment is of great significance for the condition monitoring and fault diagnosis of induction motors.

After the analysis of the advantages of using this form of coding, it is also needed to study the coding process. According to the calculation form of this paper, the coding steps are mainly divided into three major steps, which are analyzed one by one below.

The first step is to use the data XI for coding training studies. Before coding the model in this paper, an automatic encoder model needs to be built in advance for encoding. Here, various parameters used in the encoding need to be set, the learning rate is represented by ε; the sparse parameter is ρ; the connection weight is *W*; and the offset is *b*. After setting these parameters, the various training numbers, iterations are analyzed, and the average activation amount ρ_j is calculated. And the sparse cost function of this paper is established:

$$C(W,b)=\left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{2}\left\|h\left(x(i)-y(i)\right)\right\|^{2}\right)\right]+ +\beta\sum_{j=1}^{32}KL\left(\rho|\rho_{J}\right) \quad . \quad (7)$$

This completes the preparatory work for the coding form. The next step is to construct a deep neural network corresponding to the hierarchy, and use the parameters such as the sparse de-noising encoder weight ring and the offset *b* obtained in the previous step to initialize the first layer parameters of the deep neural network; learning rate, batch training number and iteration number, dropout parameter, etc., training network, extracting features and classifying; calculating the cost function and mean square error of deep neural network according to formula 7; performing the same back-propagation algorithm process as before (only the sparse item is set to zero). The network iteratively updates the weight once and fine-tunes the entire network. The model parameters of the remote control and wireless monitoring model of solar photovoltaic power generation equipment based on the IoT technology established in this paper are shown in Table 1.

According to the coding form above and the optimization of the IoT technology, the calculation steps of the remote control and wireless monitoring model of the solar photovoltaic power generation equipment based on the IoT technology are as shown in Fig. 2.

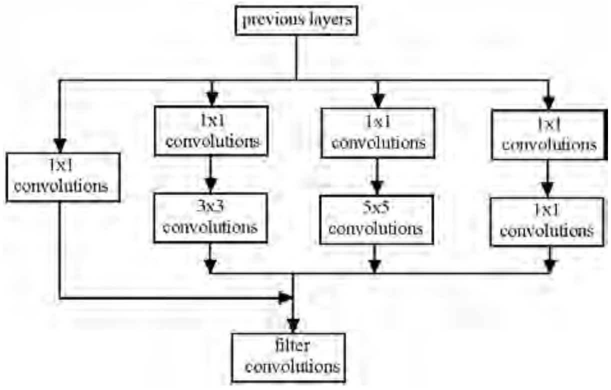

Fig.2. Steps for calculating the remote monitoring and fault detection model of machinery manufacturing equipment based on deep learning algorithm

4. RESULT ANALYSIS AND DISCUSSION

In order to verify the detection effect of the remote control and wireless monitoring model of the solar photovoltaic power generation equipment based on the IoT technology established in this paper, a set of tests are established to prove the practicability of the test model established by testing the calculation effect of the model. The NI-PCI6259 data acquisition system is used to collect the vibration signals of the induction motor in six different operating states. The signal sampling frequency is 20 kHz. The vibration signal of the motor in the *Y*-axis direction at the SOHz speed is selected as the experimental processing signal. The types

Table 1. Model Parameters of Remote Monitoring and Fault Detection Model of Mechanical Manufacturing Equipment Based on Deep Learning Algorithm

Tpe	Patch size/stride	Output size	Depth
Convolution	7×7/2	112×112×64	1
Max pool	3×3/2	56×56×64	0
Convolution	3×3/1	56×56×192	2
Max pool	3×3/2	28×28×192	0
Max pool	3×3/2	14×14×480	1
Max pool	3×3/2	7×7×832	0
Avg pool	7×7/2	1×1×1024	0

Table 2. Types of Faults Involved in the Induction Motor in the Experiment

	Species	Description
HEA	Normal motor	Health status, no failure
SSTM	Stator winding failure	Short circuit of stator winding
UBM	Rotor imbalance	3 washers on the rotor cause imbalance
RMAM	Bearing failure	Fault in the bearing inner ring of the shaft end
BRB	Rotor broken bar	Rotor 3 spoke breaks
BRM	Spindle deflection	Spindle centre bend 0.01”

Table 3. Parameter Settings Used in the Calculation

DSAE			DNN		
M	2000	The number of input layer nodes	M	2000	The number of input layer nodes
Sz	600	Hidden layer nodes	S	600	Hidden layer nodes
out	2000	Output layer node number	out	6	Output layer node number
ρ	0.08	Sparse target	Dropout	0.3	Dropout rate
β	0.4	Sparse weight	ε	1	Learning rate

of faults included in the induction motor are shown in Table 2.

The wireless monitoring model for power generation based on sparse denoising auto-encoder proposed in this chapter, the input layer, the hidden layer and the output layer of the encoder are set to 2000, 600 and 2000 respectively, because the effect of one layer of encoder is mainly studied, and there are 6 kinds of motor running states to be classified, so the corresponding deep neural network structure is 2000–600–6. Through the test of this paper, it is hoped to analyze the denoising parameters and dropout rate of the model to achieve the test purpose of this paper. The parameter settings used in the calculation are shown in Table 3.

Through the preparation of the above data, the wireless monitoring model established in this paper can be tested. First of all, the calculation dispersion of the data in the calculation is analyzed. For the analysis of the dispersion, the calculated data is divided into five nodes for research, and the relationship between the data points of the model analysis and the actual curve is established, which is shown in Fig. 3.

As can be seen from the analysis of the model calculation dispersion in the above figure, the cal-

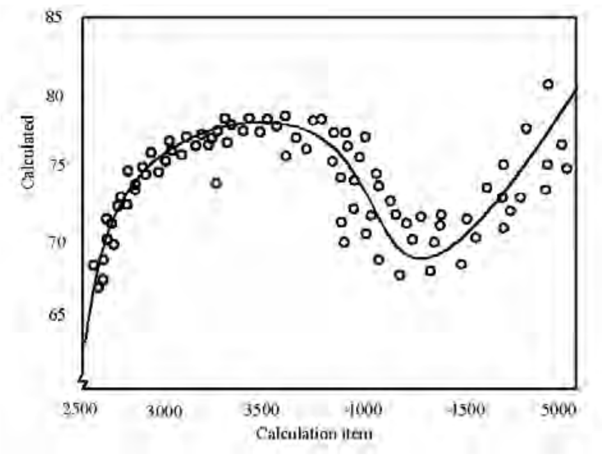

Fig.3. Dispersion analysis diagram of fault detection model

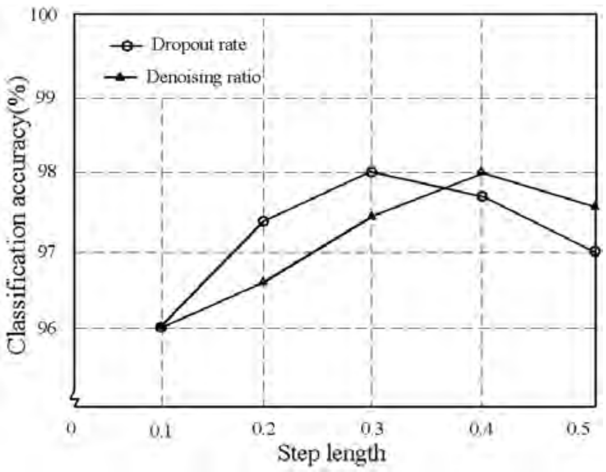

Fig.4. The model's de-noising ratio and model's dropout rate

culation of the model increases with the increase of the calculation items, and the dispersion of the model is the highest when the calculation term is between 4500 and 5000, which can be analyzed from the distance between the calculated data point and the actual curve. However, in terms of overall dispersion, the data analysis capability of the wireless monitoring model established in this paper is strong, which indicates that the model has higher calculation accuracy for the wireless monitoring model of solar photovoltaic power generation equipment, and the calculation results meet the requirements of this paper. The relationship between the calculation result and the exact value is relatively close.

Next, the model test is based on the de-noising ratio of the model and the dropout rate of the model. In the overall model calculation, the calculation ratio is used as the calculation variable in the test, and then the classification accuracy of the two ratios is tested and analyzed. The test results are shown in Fig. 4 below.

The experimental results directly prove the excellent performance of the wireless monitoring model established in this paper. Among the tests for dropout rate, in the range of 0~0.5, the classification accuracy rate of the model is increasing before 0.3, and it reaches 98 % correctly at 0.3, and the initial classification accuracy is 96 %. It can be seen that the dropout rate is well calculated in the detection model established in this paper. The calculation of the model is not calculation for the single information, so the increase of the classification accuracy rate is of great significance to the accuracy of the magic calculation. In addition, the calculation accuracy of the model for the de-noising ratio is also gradually increased from 0 to 0.5, reaching the apex at 0.4, and also achieving 98 % of the calculation accuracy. The test from these two aspects proves that the remote control and wireless monitoring model of solar photovoltaic power generation equipment based on IoT technology is in full compliance with the calculation requirements of this paper, and the calculation accuracy has been above 96 %. And the calculation of multiple hidden layers also ensures the computational efficiency.

5. CONCLUSION

With the gradual deepening of the application of computer technology, the detection and monitoring of power plant equipment failures are gradually using computers for research. A remote control and wireless monitoring model of solar photovoltaic power generation equipment based on IoT technology is established by studying computer technology. Through the test research of the model in this paper, it is found that the wireless monitoring model has low dispersion of data calculation when calculating and analyzing the data, and basically the calculated data is near the exact value. In addition, the de-noising ratio and the dropout rate of the model is also tested and analyzed. It is found that the classification accuracy of the model and the calculation accuracy of the model are all stable above 96 %. This kind of precision calculation can already meet the monitoring and wireless monitoring of solar photovoltaic power generation equipment at this stage. In addition, the model of this paper draws on the calculation of neural network algorithm, and uses a variety of hidden layers to classify and calculate the data. The calculation accuracy is improved and the calculation efficiency is also high. This parallel form of computational model has great advantages for the calculation and analysis of multiple data. The research in this paper will further improve the application in the future progress of solar power generation technology.

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Erhua SUN, Master of Business Administration, Associate Professor. Graduated from the Chongqing communication college in 2001. Worked in Chongqing real estate college. Her research interests are data analysis and data mining

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EXPERIMENTAL RESEARCH INTO THE INFLUENCE OF PHOTODECTECTOR TYPES ON CHARACTERISTICS OF OPTICAL MINI-STICKS OF UNIFIED HUMAN-MACHINE INTERFACES

Sergei A. Golubin, Alexei N. Lomanov, Vladimir S. Nikitin, and Valery M. Komarov

Research, Development and Manufacturing Enterprise "TENSOSENSOR"
E-mail: 507z@mail.ru

ABSTRACT

The article provides the results of the experimental research into the influence of different types of photo detectors of digital optical mini-sticks on their transformation function – the useful mini-stick signal as a function of the mini-stick control lever deviation value. The set problem was solved using experimental research methods. Circuits with a photodiode (PIN photodiode PD15–21B/TR8 manufactured by Everlight company) and circuits with a phototransistor (phototransistor KP-2012P3C manufactured by Kingbright company) were studied. An automated test bench was used for the research. The test bench allows setting the mini-stick rotation angle and the value of mini-stick lever deviation from the central position to the left or to the right. The influence on mini-sticks was set by the test bench software. Based on the test results the test bench software plotted a ray path diagram. The mini-stick signal quality was assessed in terms of resolution, accuracy, non-linearity and hysteresis. The following results were obtained in the research. The mini-stick using a photo transistor as a photo detector ensures the output signal amplitude and resolution which exceed those of mini-stick with a photodiode by factor of 3.5 to 4. It allows using mini-sticks with a phototransistor for high-precision control of complex robotic systems, manipulators and aircraft, and for designing joysticks and unified human-machine interfaces on their basis. The indices of precision, non-linearity and hysteresis of both mini-stick types are comparable and meet the basic requirements applied to control devices.

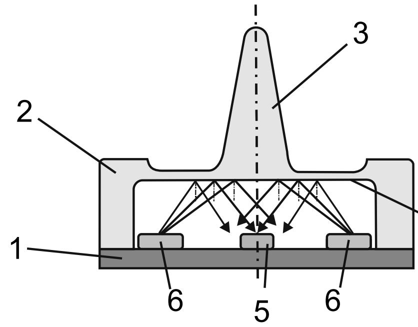
Thus, mini-sticks based on phototransistors can be regarded as the best in terms of the signal quality. Taking into consideration the circuitry, overall dimensions and the cost of hardware components which are identical for both photo detectors, mini-sticks based on phototransistors shall be considered to be more advanced switching devices.

Keywords: optical mini-stick, robotics control, switching device, elastic deformation polymer element, photodiode, phototransistor, experimental research

1. INTRODUCTION

Now the robotization is gradually approaching the stage where robotic systems consisting of numerous diverse robots remotely controlled by operators are applied. An example is a robotic system for forest fire extinguishing developed by Research, Development and Manufacturing enterprise "Tensosensor" LLC [1]. It contains three different specialized ground robots and a drone for aircraft reconnaissance. Compact, multi-purpose and unified input devices are necessary for efficient control of robots of such systems. Digital optical mini-sticks meet such requirements. A mini-stick is a two-coordinate mini-joystick, which is operated using a hand finger or thumb. Finger movement is 5 to 7 faster than hand movement, which allows performing control actions much quicker. Small size of mini-sticks

Fig. 1. Appearance of optical mini-stick



Fig, 2. Optical mini-stick: 1 – printed circuit board; 2 – elastic deformation element; 3 – control lever; 4 – light-reflective surface; 5 – photo detector; 6 – LED

allows deploying several of them on the panel or control lever.

Research, Development and Manufacturing enterprise "Tensosensor" LLC in cooperation with Rybinsk P.A. Solovyov State Aviation Technical University has developed the design of the optical mini-stick considered in [2–7] and detailed in patent [10]. As compared with their equivalents, the optical mini-sticks feature design simplicity, constructability and high reliability. They are low-noise, fire- and explosion safe, injury free, lightweight and multi-purpose due to reprogram ability of executed functions [11, 12].

The appearance of the optical mini-stick is shown in Fig. 1.

The optical mini-stick consists of printed circuit board 1 and elastic deformation element 2. Control lever 3 is located on elastic deformation element 2. The elastic deformation element made of an elastic polymer contains light-reflective surface 4 facing printed circuit board 1. Photo detector 5 and several light sources 6 are installed on circuit board 1. They are connected to the control microprocessor and face light-reflective surface 4, Fig.2.

The optical mini-stick operating principle is based on the effect of light reflection from the light-reflective surface of the elastic deformation element. When the control lever is pressed, the light-reflective surface is deformed depending on the press direction and magnitude. The light-reflective surface deformation changes the reflected light distribution, which is detected by photoelectric transducers. Based on readings of photoelectric transducers, the mini-stick microprocessor calculates the current position of the control lever.

Since the photoelectric transducer type influences the mini-stick performance greatly, it was very important to determine the influence of different photo detector type on the optical mini-stick characteristics.

2. RESEARCH METHODS

2.1. The scientific task of the research was determining the influence of a type of mini-stick photo detector on its transformation function – useful mini-stick signal as a function of mini-stick control lever deviation value.

The set problem was solved using experimental research methods.

The useful signal of the mini-stick is two numerical values which correspond to the values of mini-stick control lever deviation on X and Y coordinates. The unit of measurement of the output signal is the mini-stick control microcontroller ADC counts which correspond to the ratio of voltage on the photoelectric transducer to ADC reference voltage. The voltage on the photoelectric transducer is determined by the intensity of the reflected light impinging onto it which depends on the mini-stick control lever deviation value.

The experiment method was the method of logging readings along axes X and Y in the points with set value of deviation of the mini-stick control lever from the central position and the deviation direction, which is set by the mini-stick housing rotation angle.

The mini-stick transformation function was studied using a special test bench for automated research into the mini-stick characteristics. The test bench allowed setting the mini-stick rotation angle and the value of mini-stick lever deviation from the central position to the left or to the right. The influence on the mini-stick under study was set by the test bench software. The test bench is described in more detail in [3–4, 6–7, 9].

To ensure the adequacy of the experiment for study of the influence of the photo detector type on the mini-stick readings the experimental specimens were manufactured with other general parameters:

– Elastic deformation element – with identical dimensions and shape;

– Light emitter type – infrared light emitting diodes KP-3216F3C manufactured by Kingbright company;

– Measurement device type – 10-digit analog-digital converter integrated into microcontroller PIC16F1704-I/ML manufactured by Microchip company.

The following devices were used as photoelectric transducers:

– In the circuit with a photodiode – PIN photo diode PD15–21B/TR8 manufactured by Everlight company;

– In the circuit with a photo transistor – photo transistor KP2012P3C manufactured by Kingbright company.

The mini-stick readings were measured in the following conditions:

– Limits of deviation of the mini-stick lever from the centre: –5..+5 mm, with 0.5 mm pitch;

– Deviation direction: to the left (from +5 mm to –5 mm), to the right (from –5 mm to +5 mm);

– Mini-stick rotation angle: from 0° to 157.5° with 22.5° pitch;

– Number of reading measurements: 5 with subsequent averaging of the obtained values.

Based on the test results the test bench software plotted a ray path diagram. In the ray path diagram the useful mini-stick signal measurement results are represented as points with coordinates *X* and *Y*, corresponding to numerical values of the mini-stick output signal. The measurement results obtained during deviation of the lever are shown as the points shift, Fig. 3. The ray path diagram allows assessing the mini-stick output signal quality visually: signal amplitude, resolution, precision, non-linearity, hysteresis.

The quality of the useful mini-stick signal was assessed based on the following indices:

1. Resolution is the parameter characterizing the mini-stick sensitivity;

2. Precision is the parameter characterizing the spread of values of the useful signal at a particular lever deviation;

3. Non-linearity is the parameter characterizing the transfer function curve deviation of the mini-stick under study from the straight line;

4. Hysteresis is the parameter characterizing the difference of the output signal values at identical value of the lever deviation but different directions of the signal change.

Resolution is the change of the number of the useful signal values per unit lever deviation magnitude. The resolution determines the mini-stick sensitivity, the higher resolution allows determining the mini-stick control lever position more precisely.

The mini-stick resolution is determined using the formula

$$R = | \Delta x / \Delta L |, \quad (1)$$

where R is the mini-stick resolution, ΔL is the mini-stick lever deviation value change pitch, Δx is the value of change of mini-stick readings at change of mini-stick lever deviation value by ΔL.

To assess the precision of the readings, the value of root mean square deviation of measured values from the measured readings in the point with the set lever deviation was used. Relative value δ was calculated using the formula

$$\delta = |RMS/ \Delta X |, \quad (2)$$

where δ is the relative deviation of mini-stick readings on the set coordinate, *RMS* is the root mean square deviation of the mini-stick readings on the set coordinate, ΔX is the value range (amplitude) of the transfer function on the particular coordinate.

To assess non-linearity using the least-squares method, $X=kx+b$ approximating function was plotted for the straight line. Then non-linearity N_L was calculated using the formula

$$N_L = |X–Xcalc|/\Delta X, \quad (3)$$

where X is the actual value of the mini-stick readings for the particular coordinate in the particular point; *Xcalc* is the value calculated using the approximating function; ΔX is the value range (amplitude) of the transfer function for the particular coordinate.

Hysteresis of readings G is assessed using the formula:

$$G=|Xr-Xl|/ \Delta X, \quad (4)$$

where X_r is the value of the mini-stick readings for the particular coordinate in the particular point

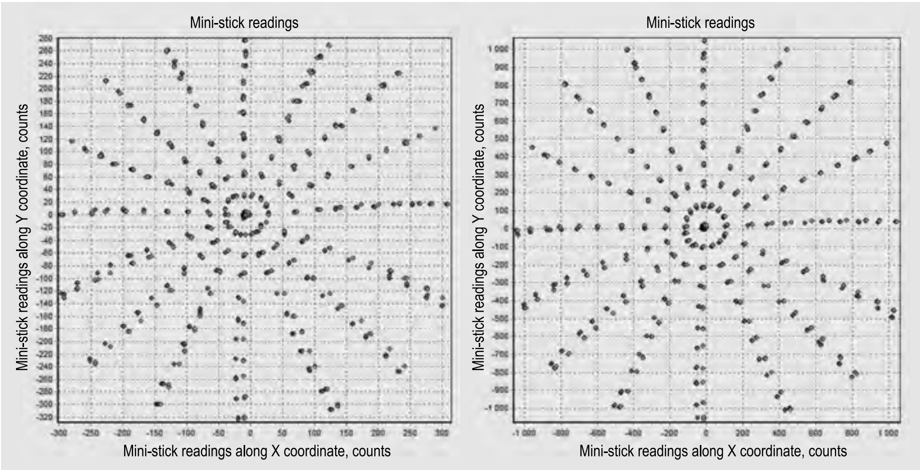


Fig. 3. Ray path diagrams of mini-stick readings

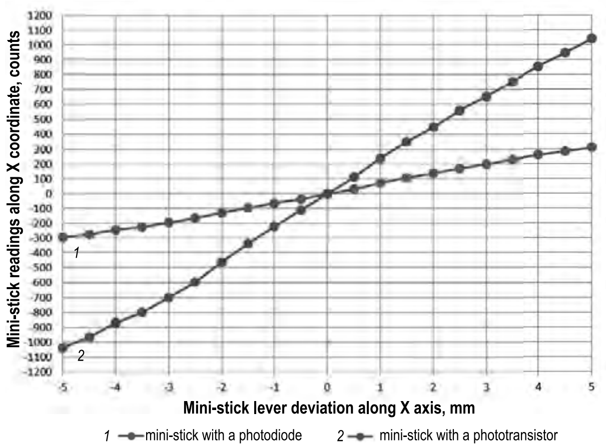


Fig. 4. Transformation function of mini-sticks of different circuits on coordinate X (at 0° mini-stick rotation angle)

when the lever moves to the right; Xl – for movement to the left; ΔX is the value range (amplitude) of the transfer function for the particular coordinate.

3. EXPERIMENTAL RESEARCH RESULTS

Ray path diagrams of the studied mini-sticks are shown in Fig. 3.

Graphs of mini-stick transformation function along X axis (rotation angle 0°) are shown in Fig.4. Graphs of mini-stick transformation function along Y axis (rotation angle 90°) are shown in Fig. 5.

To make it possible to compare, graphs of functions of different mini-sticks are superimposed on each other.

The calculation results are provided in Table 1.

4. CONCLUSIONS AND RECOMMENDATION

1. The selected circuits of mini-sticks on the basis of elastic deformation element, infrared chip LEDs and photodetectors on the basis of a photodiode and a photoresistor allow creating operable devices ensuring acceptable performance for their use in controls. The use of the mini-stick output signal in controls does not require any mathematically complex and resource-hungry processing, which simplifies the implementation and increases the response rate.

2. The mini-stick using a phototransistor as a photo detector ensures the output signal amplitude and resolution which exceed those of mini-stick with a photodiode by factor of 3.5 to 4. The minimum resolution of a mini-stick with a phototransistor is much more than 100 counts per millimetre, which is much greater that all existing equivalents and it ensures the guaranteed mini-stick sensitivity of 0.01 mm. It allows using mini-sticks with a phototransistor for high-precision control of complex robotic systems, manipulators and aircraft, and for designing joysticks and unified human-machine interfaces on their basis.

3. The indices of precision, non-linearity and hysteresis of both mini-stick types are comparable and meet the basic requirements applied to control devices. The mini-sticks based on phototransistors ensure several times as large indices.

4. A traditionally recognized drawback of phototransistors as compared with photo diodes is lower speed of the former. Build-up time and fall time for the phototransistors used in the experiment

Table 1. Parameters of Mini-stick Signal Quality

Mini-stick photodetector type	Mini-stick with a photodiode	Mini-stick with a photoresistor
Value range (amplitude) along X axis, counts	602	2078
Value range (amplitude) along Y axis, counts	599	2106
Min. resolution along X axis, counts/mm	37	142
Min. resolution along Y axis, counts/mm	39	162
Max. spread of values	<0.5 %	<0.5 %
Max. non-linearity along X axis	3.24 %	2.58 %
Max. non-linearity along Y axis	4.25 %	2.64 %
Max. hysteresis along X axis	1.83 %	2.02 %
Max. hysteresis along Y axis	2.34 %	1.66 %

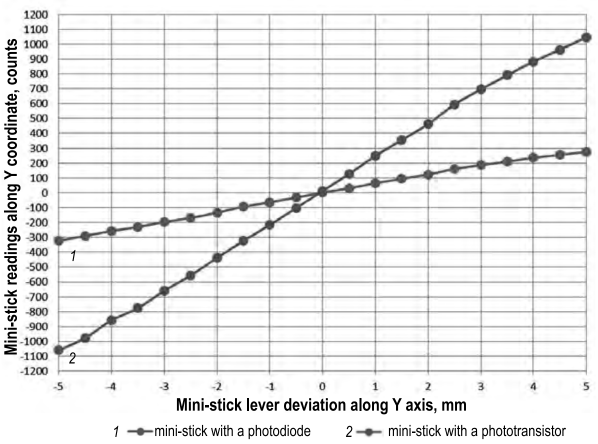


Fig. 5. Transformation function of mini-sticks of different circuits on coordinate *Y* (at 90° mini-stick rotation angle)

is no more than 15 microseconds. However, the human response time is on average no less than 100 milliseconds, which is 6.6 thousand times as longer, and for use in mini-sticks the delay ion phototransistor operation is negligible.

Thus, mini-sticks based on phototransistor can be regarded as the best in terms of the signal quality. Taking into consideration the circuitry, overall dimensions and the cost of hardware components which are identical for both photodetectors, mini-sticks based on phototransistors shall be considered to be more advanced switching devices.

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Sergei A. Golubin,
post-graduate of Federal State-Financed Educational Institution of Higher Professional Education «P.A. Solovyov Rybinsk State Aviation Technical University» (RSATU). He is graduated from RSATU in 2013. At present he is a systems engineer in Teuzosensor LLC

Alexei N. Lomanov,
Ph D. and associate professor in Federal State-Financed Educational Institution of Higher Professional Education (RSATU). He is graduated from Rybinsk State Aviation Technological Academy (now RSATU) in 2003. He has much experience in electrical engineering, microcontroller systems, industrial control and thin-film technologies, works in RSATU since 2003. At present, he is the dean of Faculty of radioelectronics and computer science

Vladimir S. Nikitin,
Ph.D. and CEO&founder of Tenzosensor LLC. Inventor and idea man, leading expert in the field of R&D organization and performance strategy development, organization of project team work. Miscellaneous expert in the field of physics, chemistry. electronics, material sciences, highly qualified designer and programmer, possesses a great experience of working at executive positions. He has 24 patents. 5 certificates for PC software products, 100+ published works in scientific and popular editions; author of the book Technologies of the Future (Tekhnosfera publishing house, 2010)

Valery M. Komarov,
Ph.D. and Full Professor of Federal State-Financed Educational Institution of Higher Professional Education «P.A. Solovyov Rybinsk State Aviation Technical University» (RSATU). Graduated from Rybinsk Aviation Technological Institute (now RSATU) in 1972, got an academic degree in 1980. He has more than 40 years' experience in designing microprocessor systems and technological control systems. Works in RSATU from 1977.
He has 49 author's certificates. 6+ published works

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CLASSROOM LIGHTING ENERGY SAVING CONTROL SYSTEM BASED ON MACHINE VISION TECHNOLOGY

Ruijie CHENG

Ulanqab Vocational College, Wulanchabu City in Inner Mongolia, 012000 China
E-mail: pwktuzc0@sina.com

ABSTRACT

In order to further improve the energy efficiency of classroom lighting, a classroom lighting energy saving control system based on machine vision technology is proposed. Firstly, according to the characteristics of machine vision design technology, a quantum image storage model algorithm is proposed, and the Back Propagation neural network algorithm is used to analyze the technology, and a multi-feedback model for energy-saving control of classroom lighting is constructed. Finally, the algorithm and lighting model are simulated. The test results show that the design of this paper can achieve the optimization of the classroom lighting control system, different number of signals can comprehensively control the light and dark degree of the classroom lights, reduce the waste of resources of classroom lighting, and achieve the purpose of energy saving and emission reduction. Technology is worth further popularizing in practice.

Keywords: machine vision technology, classroom lighting, energy saving, a control system, conventional lighting control (lc)

1. INTRODUCTION

School is a major power user, whose electricity consumption accounts for more than 30 % of the total electricity consumption of the society, while the classroom electricity consumption accounts for a large proportion of the total electricity consumption. To solve the problem of classroom lighting waste, the energy conservation measures adopted by the teaching unit mainly include: strengthening publicity on energy conservation, standardizing rules and regulations on classroom electricity consumption, reducing the number of open classrooms and arranging regular inspections [1]. Although the above measures save lighting energy consumption to a certain extent, it limits the number of available classrooms, which is not conducive to mobilizing students' enthusiasm for learning. Open classrooms usually turn on all lighting equipment, but lighting fixtures are not automatically controlled and intelligent based on the conditions of the room and the intensity of the light, resulting in severe power wastage. With the development of computer and image processing technology, machine vision and video detection technology has been applied in the field of traffic monitoring and fabric inspection [2]. Controlling energy conservation based upon existing video surveillance equipment is a new research direction emerging in recent years. The monitoring equipment automatically turns on or off the air conditioning, lighting, and ventilation equipment according to personnel conditions, light intensity, air temperature, humidity, and other information. Since this technology can improve the utilization rate of monitoring equipment and reduce energy consumption with small input, it was applied to air conditioning energy saving and city road lighting control [3]. Therefore, studies the energy-saving control system of classroom lighting based on machine vision technology was studied in this thesis, which has important practical significance.

2. STATE OF THE ART

Colleges and universities are a densely populated area which integrates teaching, scientific research and life. Therefore, it is inevitable that the power consumption of colleges and universities remains high. At present, most colleges and universities have begun to attach importance to energy conservation and environmental protection, and have taken corresponding actions and measures [4]. Many researchers have also turned to the research field of university lighting energy conservation and have achieved a lot of research results. Some scholars have conducted energy-saving experiments on different types of lamps used in college classrooms and found that replacing the existing classroom fluorescent lamps with energy-saving lamps can save 52.8 % of electricity. Besides, scholars have also adopted household metering and energy conservation in colleges and universities, centralized control through telephone lines, and limited power supply for the limited time and limited power supply [5]. University lighting power-saving technology has changed from the overall control of all lighting equipment in the classroom to the fine control of the classroom lighting equipment division; also, many new projects for energy-saving control in classrooms have expanded from lighting equipment to electrical products such as electric fans and air conditioners. Some scholars have proposed energy-saving schemes for classroom lighting: the classroom was divided into four areas, and light intensity detectors and pyroelectric infrared sensors were installed above different areas. The light intensity detector is used to detect the average light intensity in the corresponding partition, and the pyroelectric infrared sensor detects the corresponding segmentation personnel signal and then passes it to the single-chip microcomputer to independently control the illumination of each zone [6]. More importantly, using the existing monitoring camera network classroom, through the controller processing and decision-making to collect images in the classroom, determine the number of classroom staff, in order to control the classroom lighting equipment. This technology has broad application prospects in safety and monitoring [7].

3. METHODOLOGY

3.1. Quantum Image Storage Model Algorithm Based on Machine Vision Design Technology

To further improve the design of the classroom lighting energy-saving system, machine vision design technology is applied to achieve accurate system design, while this technology is the main system image processing part, usually adopting the method of frame difference and background difference superposition to separate the background and identify the indoor personnel [8]. The frame difference method uses the previous frame image as the background model of the current frame. It has the advantages of short interval between adjacent frames, strong real-time performance, no background accumulation, fast update speed, simple algorithm and small calculation [9]. However, the disadvantage of the frame difference method was that it was sensitive to the choice of ambient noise and noise. For example, for a more uniform moving target, the frame difference method was likely to create gaps in the target and affect the effect of background separation. Background subtraction method uses the parametric model of the background to approximate the background image, and compares the current frame with the background image to realize the detection of the target area. The pixel region with large difference was regarded as the target region, and a pixel region with small difference was regarded as the background region. The key to the background difference method is background reconstruction and its real-time update algorithm with changes in illumination or external environment; therefore, the quantum image storage model algorithm is used to analyze machine vision technology. The quantum matrix model was proposed by S.E. Venegas Anemia in the literature, in which each pixel in the image was represented by a qubit, so when the size of the classical digital image is N×M, its representation is as in Equation (1):

$$I = \phi_{ij}, i \in \{0,1,\dots,N-1\}, j \in \{0,1,\dots,M-1\}. \quad (1)$$

When performing quantum image processing, improvement cannot be achieved. Moreover, the colour information of the image pixels we noted in this model was preserved in the quantum amplitude of the ground state of the qubit. And we have no way to obtain this kind of probability information by quantum measurement, which means that when we save the image information in the quantum model, there is no way to recover the classic digital image. For images with a size of N * N, the model will iteratively divide the image into 1/4. This state is equivalent to the ground state of the n-bit 4-dimensional quantum bit sequence representing each image pixel, and the colour information of the pixel is stored in the quantum amplitude of the ground state I. N the entire quantum superposition state, where n = 21 OG 4 N. The representation of the model is shown in equation (3).

$$I = \sum_{i_1,\ldots i_n=0,1,2,3} c_{i_n,\ldots i_1} \, . \tag{2}$$

For an image of size 2n×2n, the representation of the two-dimensional superposition state model is as follow:

$$I = \frac{1}{2}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}(\cos\theta_{YX} + \sin\theta_{YX}). \tag{3}$$

This model can maintain the adjacent relationship between the pixels of the classic image; meanwhile, the performance of the quantum image processing can also be improved by using the quantum superposition state to store the pixels. The two-dimensional coordinates of the image pixels were still determined by two quantum sequences of Y and X, and the colour information of the corresponding pixels was determined by the quantum amplitude θ_{YX} of a single qubit entangled with YX. In the superposition state of the quantum image, the base vector terms corresponding to all the pixels are equally weighted. Fig. 1 shows a schematic diagram of a quantum image based on a two-dimensional superposition state model with a size of 4 × 4. It could be known that for image of size, the model needs to use 2logN+1 2D qubits to store the complete image information by analyzing the expression of the model.

3.2. Design of Classroom Lighting Energy-saving Control System Based on Back Propagation Neural Network Algorithm

Combining the analysis above, the classroom lighting energy-saving control system is mainly composed of the image acquisition module, monitoring computer, and electrical control module and classroom circuit. The image acquisition module is a camera monitoring device and a video transmission line installed in the classroom, and the monitoring computer was located in the teaching building or the main monitoring room of the school. In addition to the traditional video surveillance and recording functions, the monitoring computer of the system also completes the personnel identification and electrical control decision tasks in the classroom. The electrical control module is designed based on a microcontroller that can receive control information from the monitoring computer and turn the lighting on or off in the classroom. The classroom electrical circuit can be controlled by the electronic control module and manually. The working process of the system determines the working status and goals of the system. A correct and reasonable workflow is also very important for the normal and stable operation of the system. The work flow chart clearly reflects the designer's design ideas and objectives for entity operation. According to the sequence of the system flow chart, the working mode and process of the system software can be determined. The design of this paper explores and chooses the hardware of the system in detail, which requires that the design of the workflow diagram should be as accurate as possible. Only if these hardware functions can be played, the smooth operation of the hardware can be guaranteed, or can the intelligent control requirements of the lighting system be realized.

The basic Back Propagation algorithm contains two processes of forwarding propagation of signals and back propagation of errors. That is, the calculation of the error output is performed in the direction from the input to the output, and the adjustment weight and the threshold were performed from the

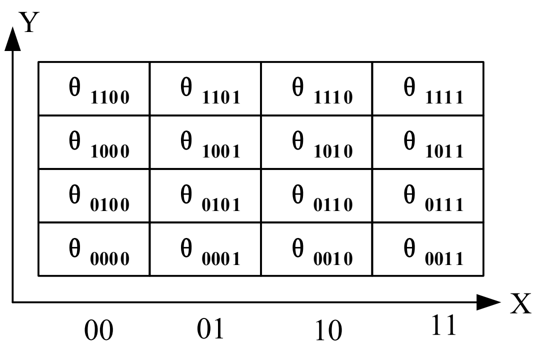

Fig.1. Schematic diagram of 4×4 pixel two-dimensional superposition quantum image model

output to the input. In the case of forwarding propagation, the input signal acts on the output node through the hidden layer and undergoes a nonlinear transformation to generate an output signal. But if the actual output does not match the expected output, it is transferred to the back propagation process of the error. Error back propagation is to pass the output error back to the input layer through the hidden layer one by one and distribute the error to all the units in each layer, and then use the error signal obtained from each layer as the basis for adjusting the weight of each unit. By adjusting the connection strength between the input node and the hidden layer node, and the connection strength between the hidden layer node and the threshold value of the output node, and reducing the error along the gradient direction, after repeated training, the final network parameters to the minimum response error is determined (weight and threshold), the training will stop. Therefore, Back Propagation neural network algorithm is applied to analyze and evaluate the effectiveness of its design. The basic learning algorithm of Back Propagation neural network is called gradient steepest descent method, which is defined as adjusting weights to minimize the total error of the network. Using the gradient search technique, the mean square error of the actual output value of the network is minimizing. The network learning process can be seen as a correction of weight coefficients and a process of error propagation. In the Back Propagation neural network structure, the three-layer network structure is made up of the input layer, the hidden layer and the output layer, among which there is no direct connection between the hidden layer (middle layer) and the outside world, but the neuron state of the hidden layer can influence and change the input and output. The idea of the algorithm is to continuously correct the network weight (ω_{ij}, T_{li}) and the enthalpy (θ), so that the error can continue to decline along the direction of the negative gradient, thus finally we get the satisfactory results. The learning formula of Back Propagation neural network has designations as follows: ω_{ij} is the network weight between the input node and the hidden layer node, T_{li} is the network weight between the hidden node and the output node, t_1 is the expected value of the input node, t_1 is the input node, and the output node is O_l. Where x_1—x_n represents the input signal of the neuron, ω_{ij} represents the connection weight between the neuron *j* and the neuron *i*, and *e* represents the threshold, also called the bias, and the input and output relational expression of the neuron *i* is:

$$net_i = \sum_{j=1}^{n} w_{ij} x_j - \theta \qquad y_i = f\left(net_i\right). \tag{4}$$

The output of neuron *i* is y_1, the net is called net activation, and function *f* is called activation function. If the threshold has been used as the weight w_{i0} of certain input x_0 of neuron i, then Equation 1 can be simplified as:

$$net_i = \sum_{j=1}^{n} w_{ij} x_j \qquad y_i = f\left(net_i\right). \tag{5}$$

If *X* has been defined as the input vector and *W* as the weight vector, then:

$$X = \left[x_0, x_1, x_2, ..., x_n\right]. \tag{6}$$

$$\omega = \begin{bmatrix} \omega_{i0} \\ \omega_{i1} \\ \omega_{i2} \\ \cdot \\ \cdot \\ \cdot \\ \omega_{in} \end{bmatrix}. \tag{7}$$

Then the output of the neuron can be converted into the product of the vector:

$$net_i = X\omega \qquad y_i = f\left(net_i\right) = f\left(X\omega\right). \tag{8}$$

If the net value of the neuron is positive, it could be defined that the neuron is in an active state or an excited state; but if the neuron net value is negative, it can be defined that the neuron in a suppressed state. Such a neuron model embodied in the form of a “threshold weighted sum” is called McCulloch-Pitts Model, which is also known as the processing unit in the neural network. The network topology was divided into two types of feedforward type network and feedback type network in the neural network, including the structure of the network and the connection mode between the neurons. The feedforward type network means that when there is no feedback in the middle, each neuron outputs the input operation of the previous layer to the next layer; the feedback network refers to the feedback loop

Table 1. Classroom Lighting Monitoring Data

Input quantity		Output	
Standard of illumination (h)	Luminaire power (W)	X axis coordinates (cm)	Y axis coordinates (cm)
150	40	282	225
	30	233	280
	20	200	250
	25	92	82
300	40	282	229
	30	200	229
	20	80	200
	25	50	82

between the neurons. The training algorithm (also called learning algorithm) refers to the method of adjusting the weight during the training process determining the initial weight of each connected neuron and satisfying the performance of the network, which could be broadly divided into supervised and unsupervised learning methods. Supervised learning provides input mode and desired output mode to the network while training; by continuously inputting different training modes to adjust the weight, the output mode gradually approaches the expected pattern. Unsupervised learning is to adjust the parameters according to the input value, and the output value can accurately reflect the characteristics of the input training samples.

4. RESULT ANALYSIS AND DISCUSSION

When the light is turned on and off, the difference between the current frame and the previous frame is large. At this time, the model will improve the convergence speed of the reconstructed background, so that the image acquisition system can get better background adaptability. At the same time, the convergence speed of background reconstruction will also be adjusted adaptively according to the difference. For designing the most energy-saving luminaire installation scheme under the premise of meeting the standard illuminance value, the simulation experiment can be carried out through the Back Propagation neural network. Generally, in different environments, the installation position and power of the luminaire have a certain influence on the lighting effect establishing the model by the Back Propagation neural network, and defining the illuminance standard and the luminaire power as the input quantity, and the installation position of the luminaire as the output quantity, and training it. The experiment selects a classroom in the teaching building as the experimental object and normalizes the input data of the Back Propagation algorithm to determine the input and output parameters of the network, which were selected according to the actual situation. The distribution and measured data of the lamps in the classroom are shown in Tables 1, 2.

First, a composite dataset is generated consisting of two graphs: the Delaunay Triangulation Graph and the Random Join Graph. Graph Differential thermal gravity is commonly used in the field of computer vision and pattern recognition because of some quite good properties, such as sparseness, locality, and no singular angles. When generating the data set, the nodes of the graph can be randomly generated in a two-dimensional space by using a literature method, and then the Differential thermal gravity graph is constructed. Scale from 5 to 50,

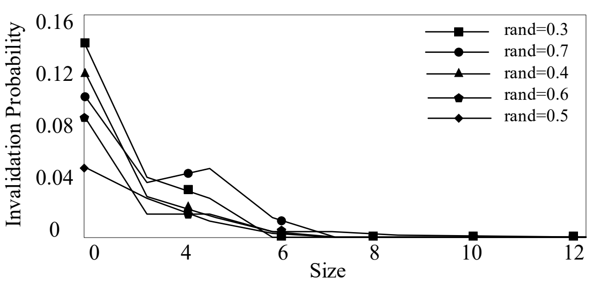

Fig.2. Failure probability distribution for random connection graph data set in running Qwalk algorithm

Table 2. The Sample Data Table

Input sample									Output sample	
H(10m)	φ (1041m)	A(102m^2)	η	K	P_c	P_f	P_w	E_{av} (103lx)	N(10)	E_{av} (103lx)
0.36	0.3112	1.08	0.7	1.3	0.55	0.26	0.35	0.35	28	0.304
0.36	0.2865	1.08	0.7	1.3	0.36	0.33	0.36	0.39	35	0.350
0.36	0.2553	1.08	0.7	1.3	0.39	0.36	0.37	0.299	36	0.318
0.36	0.2006	1.08	0.7	1.3	0.12	0.41	0.61	0.15	28	0.196

randomly generating 100 sets of test chart pairs for each scale. Fig. 2 shows the accuracy comparison of these approximate quantum model algorithms for different scale Differential thermal gravity plots. Lu is an algorithm designed specifically for Differential thermal gravity diagrams, but it can be found that when the scale of the graph is large, the accuracy of the algorithm is poor. Also, from the results, it can be implied that as the scale of the graph increases, the quantum model algorithm has a smaller standard deviation and better accuracy.

Fig. 2 displays the probability distribution of the algorithm failures caused by the random connection graph generated for us leading to two trends in the results. Firstly, the larger the scale of the graph is, the more the probability of failure can be. When the scale of the graph exceeds 10, basically no more failures occur. Secondly, the data used in the test shows that the input is the illumination brightness (lc) and the lamp power (W), and the output is the minimum horizontal and vertical interval (in cm) of the installed fixtures in a given classroom, and the size is 12m × 9m, which can be tested by modifying the data for classrooms of different sizes. The fluorescent lamp is used as the test luminaire in the test since the 16 W LED tube selected in this design is the same as for 40 W fluorescent lamp, so the simulation result of the 40W luminaire under test can be used as the basis for the installation position of the luminaire in the design. The total error of the training obtained by running multiple times is shown in Fig. 3. The error of the algorithm is graphically displayed and displayed every ten iterations.

Furthermore, it can be calculated through the test results that to meet the illumination requirements, 40W lamps can be chosen in the 12m × 9m classroom, for five lamps in the X-axis range, six lamps within the Y-axis range, and 30 lamps throughout the whole classroom. In order to achieve better background difference, this research proposes a background reconstruction algorithm for segmentation convergence: the video image processing program uses the pre-acquired empty classroom image as the first frame of background reconstruction, and the first 10 frames converge at 1 % rate to make the initial reconstruction background similar to the real-time background.

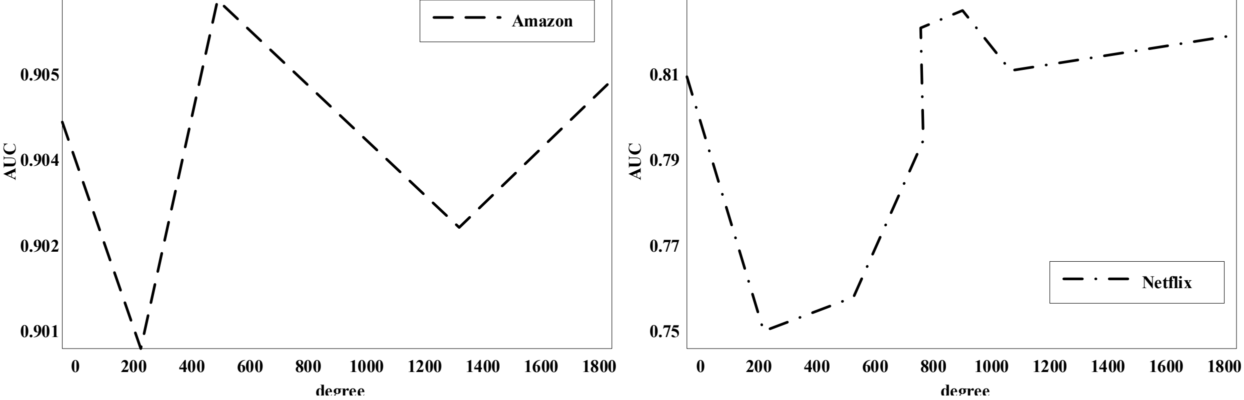

Fig.3. Back Propagation neural network algorithm

5. CONCLUSION

To solve the problem of energy waste in classroom lighting, this paper studies the energy-saving control system of classroom lighting based on machine vision. The system captures indoor surveillance video by monitoring equipment installed in the classroom, and uses frame difference and BA technology, neural network algorithm Back Propagation and quantum image storage technology to segment and identify indoor personnel in surveillance video. On this basis, the opening and closing of lighting in the classroom is controlled according to the personnel situation. The model algorithm is used to analyze and simulate the experiment. The system can perform real-time indoor personnel identification of the illumination video, and the detection accuracy of the frame containing no and including indoor personnel is 100 % and 93 % respectively. With the increasing popularity of public space monitoring equipment, machine vision-based energy consumption control applies its monitoring system to improve the utilization of monitoring equipment while reducing energy consumption, which has a popular application prospect.

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Ruijie CHENG,
Associate Professor, graduated from Jianghan University in 2005. Mainly engaged in computer application field of teaching and research. Since the work, with solid professional skills and theoretical knowledge, she published more than 10 professional papers

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INTELLIGENT LIGHTING SYSTEM OF URBAN ROAD BASED ON INTERNET OF THINGS

Lulu HAO and Jing GAO*

School of General Education, Wuhan Business University, Wuhan, 430056 China
**E-mail: 441691661@qq.com*

ABSTRACT

Aiming to solve the problems of energy waste, management confusion and poor flexibility in urban road lighting control system, an intelligent lighting system of urban road was designed based on the internet of things technology. The intelligent lighting system included hardware system composed of street lamp control terminal, main controller, software platform server, and software system composed of communication interface software, data processing software and operation management software. The lighting energy-saving control strategy and system characteristics were analyzed. The results show that the intelligent lighting system of urban road can realize the functions of remote street lamp switch, power regulation and timing operation, so as to meet the realistic demand of urban road intellectualized lighting control.

Keywords*:* internet of things (IoT), urban road, intelligent lighting, system design, ZigBee technology

1. INTRODUCTION

With the rapid development of society and economy, the street lamps and landscape lighting construction in modern cities are developing synchronously and rapidly. The total street lamps in large cities are several hundred thousand, and the annual street lamp growth rate is (15–20) %. In 2012, China's urban lighting (functional lighting, such as landscape lighting and street light) accounted for about 4 % to 5 % of China's total power generation, equivalent to the annual capacity of the Three Gorges Hydroelectric Project [1]. The rapid development of street lamp construction, the improve quality of road lighting, because of in recent years LED light sources are in the attempt to update the existing road-pass lighting products, but some shortcomings greatly limited further promotion and improvement. At the same time, there are some problems in the existing street lamp management and control system, such as energy waste, management confusion, high maintenance cost, and poor flexibility [2]. The intelligent urban lighting system with independent control is the most potential modern energy-saving research field. By reasonably planning the layout of the street lamp, reasonably controlling the switching time of the street lamp, and incorporating intelligent street lamp management methods, such as light control, flow control and scene analysis, further adjusting the lighting strategy of the street lamp can save more than 30 % of the energy consumption of the street lamp [3].

In recent years, with the rapid development and application of cloud computing technology, the Internet of Things technology has been rapidly popularized. The concept of smart city has been gradually developed from the theoretical stage to the realization stage, and the demand for smart lighting has emerged [4]. Therefore, it is decided by the development of urban construction and the development level of new technology to bring urban street light into the new urban Internet of Things, and to realize the development route of intelligent lighting control by using advanced cloud computing technology. The standard of street lighting Internet of Things for smart lighting is not clear, the technology developed is not comprehensive, and the application is not yet extensive. Therefore, it is necessary to conduct in-depth research on this emerging technology field.

Based on the development of new light source and sensor wireless networking technology and the background of data communication and processing technology of Internet of Things, this study designed an intelligent lighting system of urban road. Street lamp controller achieved short-range wireless networking by means of ZigBee technology. GPRS wireless transmission technology realized communication and interaction between control and state data acquisition. Because the control terminal has an open control interface, it provides a technical basis for the realization of remote street light switch, power regulation, timing operation and other functions.

2. STATE OF ART

The development of road lighting management and control system can be roughly divided into three stages: manual control stage, mechanical control stage and computer control stage. Modern street lamp monitoring system can realize data acquisition and monitoring of remote measurement, remote control and remote communication by means of existing communication service platform [5]. Since the 1990s, developed countries have been engaged in the research and development of intelligent lighting systems for generations, and have accumulated rich construction experience and successful cases. The technical characteristics in the field of street lamp monitoring are mainly embodied in the following aspects: the modernization of monitoring strategy, the modernization of information carrying mode, and the modernization of management system. The modernization of monitoring strategy is reflected in the development from centralized control mode to the precise scene and behaviour analysis stage. The "three remote" mode of street lamp control has been mature in developed countries, and many countries have formulated industrial standards for street lamp. On the basis of centralized control, modern streetlight control strategies pay more attention to the function of the scene and behaviour analysis. For example: the adaptive light perception function, according to the sunrise and sunset time automatic switch and dimming function, traffic flow and flow analysis function, and for busy streets, remote streets and highways have different monitoring strategies, on the one hand, the street lamp control is more humane, on the other hand, further saving energy [6].

The progress of information carrying mode is reflected in the continuous progress of information carrying mode from "wired – wireless – wired". A wired communication method similar to fixed telephone is used to solve the problem of the transmission of street lamp status and control information. But this method needs to be reconstructed, and the cost is high. On the other hand, there is a bottleneck problem of information transmission. Later, with the development of wireless communication technology, the transmission of street lamp status and control information can be easily accomplished by wireless communication technology. For example, ZigBee is used to communicate with the central control unit in a local area, and GPRS module is used to complete the remote communication. This multi-layer wireless communication mode can effectively save the construction cost on the one hand, and improve the flexibility and reliability of the system configuration on the other hand. The latest way of information carrying in street lamp monitoring is mainly embodied in the application of power carrier technology, which modulates information into power carrier signal and transmits it simultaneously. It can be put into use almost without revamping the existing equipment. However, this new technology is not mature enough, and the stability and reliability of information transmission cannot meet the needs of practical application.

The modernization of the management system is reflected in two aspects: management mode and management method. The management model is a comprehensive business management platform, from the beginning of planning and design to the maintenance of the later period, all business information are used to manage the integrated business management platform, so that the efficiency of communication between the various departments is significantly improved, mutual supervision mechanism is also easy to establish; meanwhile, mobile media and communication service equipment are also widely used in the management and maintenance of street lights, where the street lights have trouble, as long as the fault equipment pictures uploaded to the business platform, can be timely processed [10].

3. DESIGN OF INTELLIGENT LIGHTING SYSTEM FOR URBAN ROADS

3.1. Related Technology

3.1.1. Intelligent lighting

Following the electrification and informatization, intellectualization has become the inevitable development of the scientific and technological revolution, and the development of intelligent cities conforms to the trend of urbanization. Intelligent city is based on the Internet, using information and communication sensing technology to solve intelligent sensing, communication, computing, analysis, judgment and control of the key technologies of urban operation, to build a smart environment for urban development [11]. The development of intelligent city requires that lighting is also intelligent lighting, and intelligent lighting is to use the Internet of Things technology to build intelligent lighting system to achieve intelligent management of lighting. The key of intelligent lighting is to make full use of the external effect of each subsystem through multi-source perception, depth integration and intelligent decision-making, and connect the systems vertically and horizontally to form a network, so as to enhance the density of knowledge sharing among the systems and improve the intelligence of the whole system.

3.1.2. Internet of Things

Internet of Things is the way to realize road intelligent lighting. The concept of Internet of Things was put forward in 1999. In 2005, the International Telecommunication Union (ITU) formally put forward the concept of the Internet of Things, which is defined as: through radio frequency identification (RFID) infrared sensors, global positioning systems, laser scanners and other information sensing equipment, according to the agreed agreement, any article and the Internet connected, information exchange and communication to achieve intelligence.

The architecture of the Internet of Things includes three aspects: perception, network and application [12]. The perception function is composed of sensor and transmission gateway. It is embedded in the "Things" of the Internet of Things. The network functions of receiving, sending and controlling information of "Things" are responsible for transmitting the "Things" information in the Internet of Things in different networks, connecting the application layer and the Internet of Things. The perception layer and the application function are the analysis and expression of wisdom. The data are analyzed and mined by the application layer, and any "things" in the Internet of Things are fed back, commands are issued, and management and control are implemented.

3.2. Structure of Road Intelligent Lighting System

The intelligent lighting system consists of two parts: software system and hardware system. The hardware system is mainly composed of the street lamp control terminal, the main controller and the software platform server. The street lamp control terminal is installed on the street lamp column, which is responsible for data acquisition and independent control of the street lamp unit. The main controller is installed in the street lamp distribution box, and a main controller manages multiple control terminals and is responsible for them. Monitor the total circuit of the distribution box and communicate with the platform server. The software system is mainly embodied in the software platform system of the control centre, which consists of communication interface software, data processing software and operation management software. The overall structure of the system is shown in Fig. 1.

The road lighting control equipment is the basic guarantee to realize the street lamp detection and control function. In order to realize the networking and data acquisition and transmission of street lamps [13], the terminal equipment requires the following functions: (1) a ballast with adjustable power; (2) the control unit needs to be able to output adjustable analogue for connecting the ballast control power output; (3) the control unit needs to be able to collect the data of the running state indicators of the street lamps. It includes: current, voltage, power factors, etc.; (4) the control unit needs to be able to set up a network, and the main unit for control and scheduling within the subnet; (5) the control unit needs to have wireless communication capabilities, the main unit needs to be able to carry out data transmission and instruction communication through the mobile Internet; (6) the control unit needs to be able to set the ability to send packets on time.

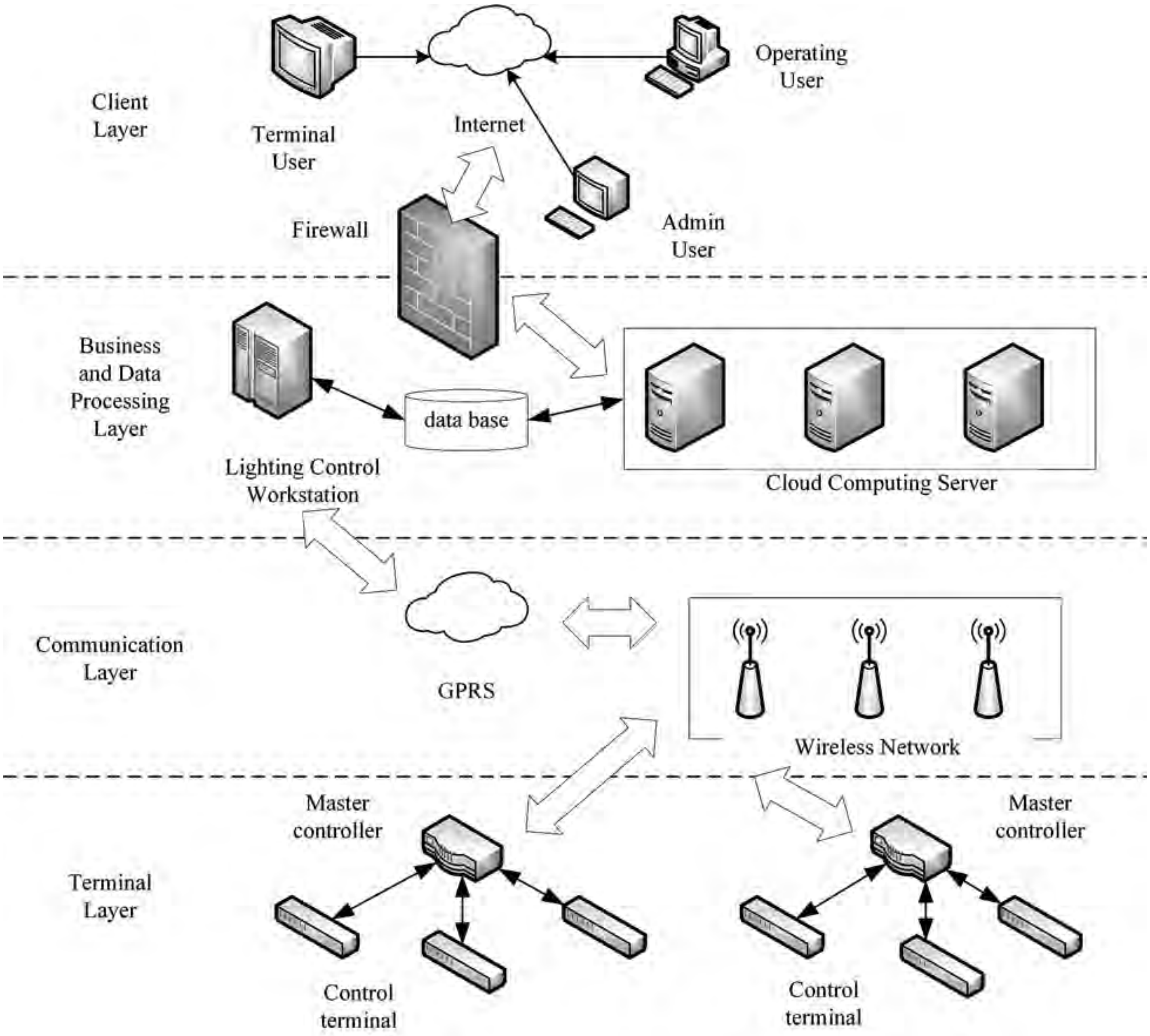

Fig.1. Architecture of a road intelligent lighting system

The control system is composed of two levels of network structure. ZigBee technology is used between the control terminal and the main controller to realize the close wireless network, and the GRPS network is used between the main controller and the server to realize the remote network transmission. This kind of network structure design, on the one hand has played the ZigBee network low cost superiority. Simultaneously solved the ZigBee wireless network transmission distance limited question. Based on the Two-level Network structure, the urban streetlights are divided into several ZigBee regional networks, each of which controls dozens of streetlights and covers several streets.

The terminal control node installed on the lamppost is connected with the master controller node through ZigBee communication mode. A master controller is connected to a plurality of control terminals. The main controller transmits control signal data to the control terminal through wireless connection, and the control terminal transmits status data and alarm data to the main controller through wireless connection. The control center server is connected with the main controller through GPRS communication mode. The master controller acts as an intermediate node layer in the network, passing data up and down, and the overall network structure is shown in Fig.2.

3.2.1. Energy-saving Control Strategy Analysis

The main objective of smart lighting system is to achieve energy-saving optimization of urban street lighting system, while reducing maintenance

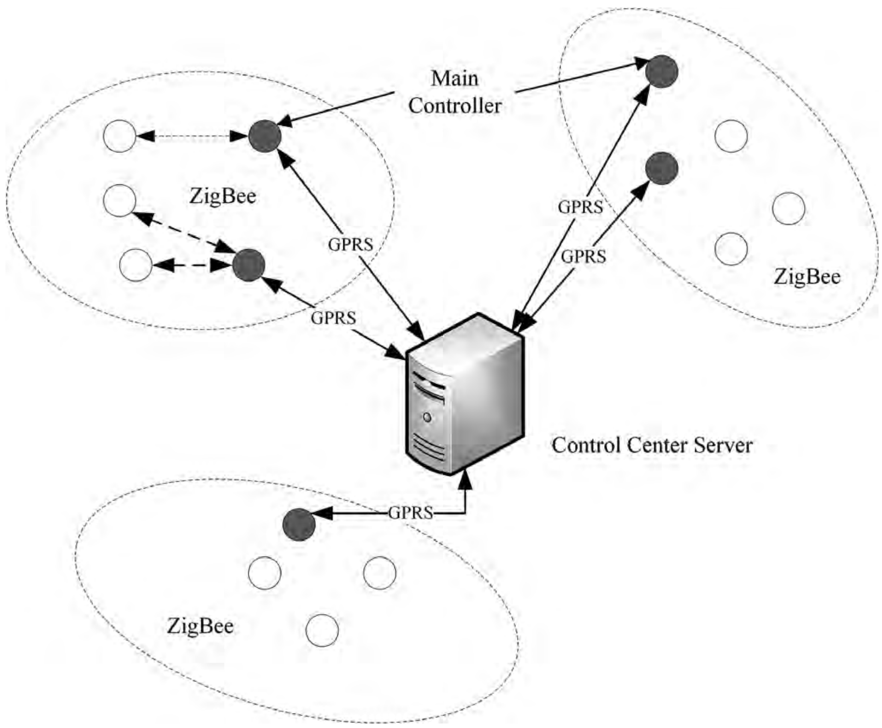

Fig. 2. The network architecture of control terminal

workload and overall system operation and maintenance costs. Intelligent control of street lighting cannot only realize energy-saving control based on time and brightness for a single street lamp, but also implement energy-saving strategy algorithm for a group of lamps in a region to achieve the purpose of energy saving. Realize the fault detection and alarm, make the street lamp fault or damage automatically send out information promptly, and can provide accurate positioning for the inspectors, so no longer need manual road patrol for repair, greatly reducing the daily maintenance costs. The parameters of current, voltage, and power are collected in real-time, and transmitted to the server through wireless communication for real-time processing and data storage. The data base is established for energy-saving effect analysis, lighting project planning and intelligent city construction.

Street lighting control strategy is the core part of intelligent street lamp system. Through control of street lamp nodes about 6 control modes are realized.

1. Odd-even operation mode. The odd-even operation mode is based on the number of light only to turn odd numbered light or even numbered light. When the street lamp control terminal is set to even and odd operation mode, it is judged to turn on or off according to the street lamp number. Generally used in the evening when visibility is high or bad weather leads to low visibility. In the even-odd operation mode, the even-odd lamp group is usually turned on in turn, so that the working time is balanced to prolong lamp life.

2. Full power operation mode. When the street lamp control terminal is set to full power operation mode, the street lamp starts to work immediately, and with full power output, the illumination brightness reaches the maximum. It is usually used for night time traffic and holiday time interval.

3. Half power mode. When the street lamp control terminal is set to the half power mode, the street lamp starts to work immediately. Through the PWM dimming function of the controllable ballast, the output power of the street lamp is controlled at 50 % of the rated value or the specified power value. It is generally used in small sections of people's traffic flow or after midnight.

4. Random alternate operation mode. The random alternate operation mode is one of the effective ways to save electricity and prolong the life of street lamps. Street lamp control terminal is set to random alternate operation mode, and the street lamp is turned on alternately with a certain probability distribution. It is generally used in small sections of people's traffic flow or after midnight.

5. Time control mode. According to the current longitude and latitude of the city, the system automatically calculates the time of sunrise and sunset every day in a year. Based on this time data, the system can realize the automatic control of dynamic switching light.

6. Power abnormal alarm mode. When the lamp control terminal detects the lamp power failure (such as too small power, short circuit, etc.), it will trigger an alarm event and upload the alarm information to the server. When the power is too large, the circuit will cut off the lighting power at the same time.

4. CHARACTERISTICS OF ROAD INTELLIGENT LIGHTING SYSTEM

Compared with the traditional road lighting system, the intelligent road lighting system based on the Internet of Things has the definite distinct characteristics.

1. Dynamic perception. The perception of the physical object state is the basis of intelligent road lighting system, which has a wide range of spatial distribution and continuous time requirements. It is because of the dynamic changes of perceptual data (such as traffic flow, weather conditions, etc.) that the lighting demand changes, thus laying the foundation for the optimal control of the lighting system.

2. Effective feedback. The state of the perceptual physical object must be processed in the information system. Lighting system operation is related to road traffic safety, especially when there is a fault alarm. It will highlight the importance and necessity of real-time information feedback.

3. Deep integration. Through the deep fusion of all kinds of perceptual information, the information world can accurately analyze the situation of the physical world, and make control decisions in time. The control decisions can be implemented through the network control system to control the behaviour of the physical world in real time and scientifically.

4. Accurate cognition. Through the analysis and mining of the massive data acquired, the accurate cognition of the characteristics of urban road lighting can be achieved, which lays the foundation for the scientific grasp of the changing law of lighting demand and evaluation of lighting energy-saving effect. For example, the benefit of energy-saving and emission-reduction can be evaluated by comparing and analyzing the unit vehicle/km power consumption, and the luminance index of lighting can be analyzed. And traffic accident rate to analyze the impact of lighting on urban road lighting management, through the analysis of luminaire light attenuation to develop lighting maintenance program.

5. Reliable control. The information system controls the physical system dynamically, and the physical system has the feedback function to the information system, that is, the physical system can influence the control effect of the information system through the information feedback. For example, intelligent road lighting system can be reliably controlled dynamically according to the actual distribution of vehicles in the road and the weather environment. Step-less dimming and graded dimming avoid ineffective lighting and over lighting.

5. CONCLUSIONS

1. Intelligent road lighting system is a typical application of Internet of Things technology in traffic field. It cannot only realize dynamic dimming according to perceptual information, reduce ineffective lighting and excessive lighting of urban roads, but also analyze and excavate massive data, accurately recognize the characteristics of urban road lighting, and scientifically grasp the lighting requirements. Change law and evaluation of lighting energy saving and emission reduction effect lay the foundation for significant economic, social and ecological benefits.

2. Internet of Things is the key strategic technology and means to lead the innovation of the future information industry. Through the construction of intelligent road lighting system based on Internet of Things technology, the digitalization and intellectualization of urban road lighting management can be realized, and the limited control of energy consumption of highway tunnel lighting can be achieved.

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Lulu HAO,
Ph.D. in Economics, Lecturer. Graduated from Wuhan University of Technology. The research area is industrial economics and Internet of Things

Jing GAO,
Professor. Graduated from the Central China Normal University. The research area is tourism economy and smart tourism

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DEVELOPMENT OF EXPRESS-METHODS FOR DESIGN OF SKI SLOPES ILLUMINATION SISTEMS

Sergei A. Alexandrov

Spector Lab. Ltd., Moscow.
E-mail: alexandrov@spector-lab.com

ABSTRACT

The article is devoted to the creation of methods of accelerated lighting design of ski slopes for competitions with a television broadcast.

Keywords: sports lighting, ski track, TV – broadcast, design method, reflected glare

1. INTRODUCTION

Currently, both in Russia and abroad winter sports are actively developing, there are new modern route, competitions of international level with TV broadcasting are held. Thus, there is a demand for high-quality lighting of the ski slopes, which would meet the standards of lighting for high-definition television (HDTV).

If we look on the ski slopes as on objects of the lighting design, then we see that they differ from many other sports facilities by its complex volume structure, in which the surfaces of these slopes are located not only at an angle to the horizon, but also have a complex of shapes with many faces. The reflective properties of the illuminated surface of snow cover with high reflectance (from 60 to 95 % for different snow conditions) are of significant importance [1, 2]. Accounting of the reflected component of the vertical illumination allows significantly reduce the number of lighting devices. In addition, snow has a pronounced mirror effect that can have a blinding effect on athletes. The author's analysis of modern lighting computer programs showed that none of them has full functionality for the calculation of the illuminating of ski slopes. And only the "DIALux" program is applicable there, because it allows calculation of direct and reflected lighting components of inclined planes for which the calculation is made. However, there are several serious limitations for the using of this program. First, it is impossible to build a continuous track of complex shape, and the calculation has to be carried out on a set of flat fragments, what reduces the accuracy of the calculations, because for each fragment they are displayed on a separate sheet. Secondly, "DIALux" does not allow calculate the indicator of blindness – one of the most important indicators of quality in sports lighting – for inclined surfaces. The reflected brilliance is not taken into account. Finally, the calculation for complex scenes with a large number of lighting fixtures is too long to allow anybody to quickly assess the results of the changes, made him (for large tracks it takes tens of minutes). At the same time, the specifics of the calculation of sports lighting is such that to achieve a good uniformity of lighting in several directions, it is necessary to make multiple iterations to change the angle of targeting and types of light distribution of each one of several hundreds of searchlights, so the design process of lighting of one track can take several weeks. In addition to these shortcomings of the software, there is an apparent lack of methodological material for the lighting design of such complex objects. In addition to this disadvantage of the software, there is a clear lack of methodological material for the lighting design of such complex objects. Both in domestic and foreign literature, there are only General recommendations on sports lighting, in which only a few lines are given to ski slopes, and often the features of lighting for television broadcasts are not taken into account. The aim of this work was to develop a method of illumination installations designing for competitions with TV- broadcasting, creating high quality coverage of ski slopes with minimal time spent on design. To achieve this goal, it was necessary to develop a program that takes into account the features of illuminated objects, expanding the capabilities of the designer and serving as the basis for the creation of this technique.

2. THE DESIGN METHOD

When starting to design of lighting systems, you must first determine the requirements for lighting. In our country, departmental standards apply to these objects [3] (the regulation of lighting for filming was carried out in addition before the 1980 Olympics [4]), and in European countries (standard [5]) the relevant recommendations of the ICO are also applied [6]. At the same time, the customer usually prepares a task for the lighting of a particular object together with representatives of the sport Federation and of the organization – performer of filming and broadcasting of competitions.

Next step is the determination of the installation locations of lighting devices. To illuminate the ski slopes, a classic "top-side" lighting scheme typical for many sports facilities is used. Batteries of spotlights are installed on the supports located on both sides of the track. As for the height and pitch of the supports, this parameter is entirely determined by the geometry of the route, by its width and angle of inclination. Minimum height and number of supports are laid in the project, taking into account the high costs of supports and their installation on the mountainous areas. This minimum is limited by the requirements to exclude increased blinding action of spot lights and the need to create a uniform illumination of the snow surface. Based on the width of the ski slope, the maximum angle of elevation of the spotlight, under which its blinding action will be within the permissible limits, determines the height of the support. As a rule, this angle should be no more than 70° from the vertical. The support itself should deviate from the track so that the angle between the vertical and the light flux direction from the battery of the searchlights to the near border of the track would be no less than 30°, otherwise it will not be possible to create the necessary vertical illumination in the zone near the support. Thus, we have a very narrow range of geometric parameters, in which the coordinates of the locations of searchlight batteries installed on the supports should be get. Further, a similar method is determined by the step of the supports – the basis is the maximum angle at which the spotlight can be aimed up or down relative to the plane of the route, i.e., as a rule, the same 70°. The camera targeting lines and the line of view of observers are inclined to horizon, the angles of targeting of the searchlights are not postponed from the vertical, but from the perpendicular to the surface of the track at the installation site of the light device. The pitch of the supports should be such that the light spots from the searchlights on the adjacent supports border each other without dark dips. To create uniform illumination of the track, the step of the supports in the projection onto the track plane should not exceed 1.6 length of the perpendicular lowered from the battery of the searchlights on the track plane. This ratio is subject to specification for each specific route during the lighting calculations. After determination of the geometric parameters of the lighting system, further design is carried out using the lighting calculation program. The main stages of design are listed below:

– Setting the design planes and the reflecting surface;
– Placement of television cameras;
– Selection and placement of light batteries;
– The primary target, the adjustment quantity of searchlights;
– Optimization of the light system parameters.

Optimization is the process of selecting the angles of targeting and light distribution of searchlights to achieve the required parameters, and this item takes the bulk of the design time.

The author offers the corresponding design algorithm, presented in Fig. 1. Further consideration of this algorithm is made on the example of its implementation in the experimental calculation program created by the author.

It has the following features: – Display the scene in the graphical window with navigation;
– Upload to the project graph of the light force of the searchlights in space in *ies*- and *ldt*- formats;
– The table view of the lighting devices used in the scene and their characteristics;
– Setting the coordinates of the cameras in the corresponding table;

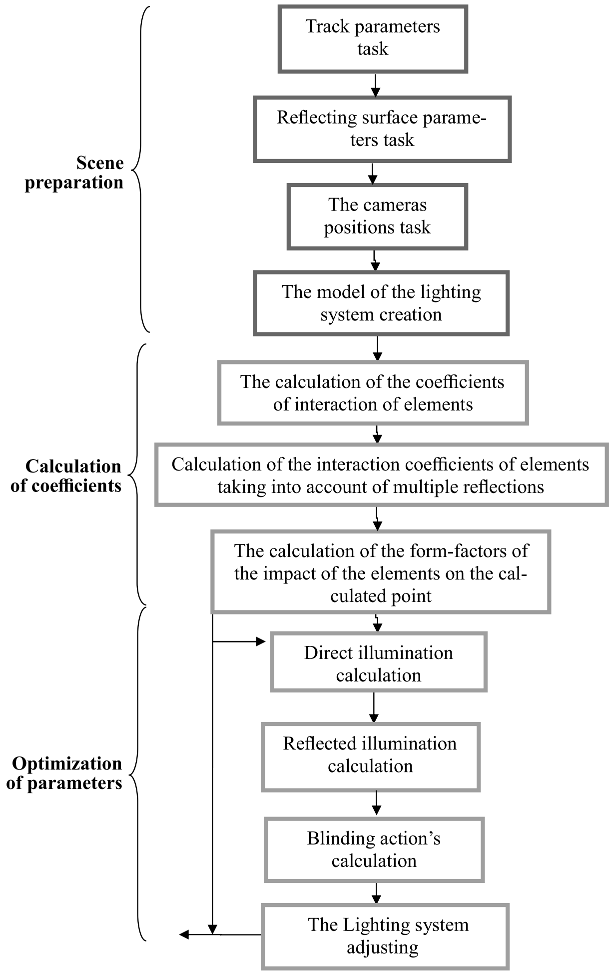

Fig. 1. Algorithm of the ski slopes lighting design

– Calculation of illumination both in the plane of the route and at a given height in the direction of the cameras;

– Calculation of the blinding action on inclined surfaces;

– Display of the calculated values.

3. THE CONSTRUCTION OF THE ROAD AND THE SLOPE

Since the ski track in the plan constitutes a complex polygonal figure, for its construction is used graphic method using the construction plan. This plan, which is given to the developers of the sports track, is the task for the design of engineering systems on the slopes. It shows the route of the isohypsum (lines of equal height), passing there. The user marks on the screen reference points with known heights on the boundaries of the route, using this plan as a substrate. When this process is completed, the program automatically distributes the calculated points for illumination and glare with a given step along the surface of the track (Fig. 2).

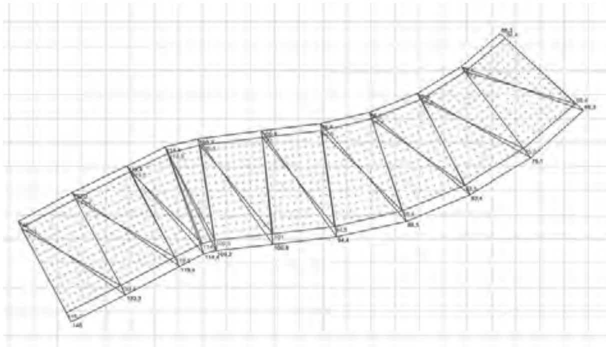

Fig. 2. The route with the calculated points and the surface slope

Similarly, the reflecting surface, which can be larger than the trace, is specified and thereafter it is automatically divided into elementary triangular planes of a given maximum size (Fig. 3).

4. CALCULATION OF THE BLINDING INDICATOR

For installations of outdoor sports lighting and lighting of outdoor the areas of glare are determined in accordance with publication CIE112–1994 [7]. This method has been developed on an extensive experimental basis and has proved its applicability in various lighting systems. Studies have shown that the following two parameters best correlate with the evaluation of glare for outdoor installations:

L_{vl} is the veiling luminance created by the lamps;

L_{ve} is the veiling luminance created by the environment.

The blinding action can be different for different points of the observer's location and for different directions of his gaze. The following formula defines the equivalent veiling luminance L_v (cd / m^2):

$$L_v = 10\sum_{i=1}^{n}(E_{eyei} / \Theta_i^2), \quad (1)$$

where E_{eyei} is the light intensity of the observer's eye in the plane perpendicular to the line of view created by the *i-th* light source (lx),

Θi is the angle between the line of view of the observer and the direction from the eye to the *i-th* light source, degrees (1.5°<Θi< 60 °),

n is the total number of light sources.

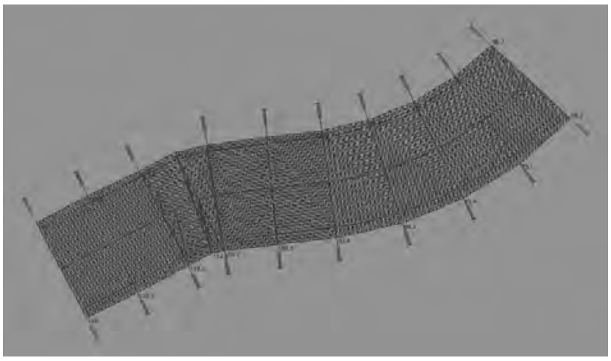

Fig. 3. Slope divided into elements on the background of the substrate

For the L_v calculation, the illuminated area appears illuminated by an infinite number of small light sources. The condition $\Theta > 1,5°$ to about L_{vi} automatically will be performed when the observer's gaze direction is no less than 2° from the horizon.

For L_{ve} this limitation means that a part of the illuminated area that falls into the centre of the field of view within the angle of 2×1,5°, will not be taken into account. The value of GR (Glare Rating), characterizing the blinding action, is calculated by the formula:

$$GR = 27 + 24 \cdot \lg(L_{vl} / L_{ve}^{0,9}). \quad (2)$$

A lower *GR*-value determines lower glare and better observation conditions.

The calculation of the blinding action is performed at points evenly distributed along the entire track. The step between these points may be less than the step of the points used for the calculation of illumination. Based on the formula (1), an important parameter is the direction of the observer's line of view. At the same time neither domestic, nor foreign standards offer the direction, which need to choose for the sportsmen or the viewer on the ski slope. It is clear that when you look directly at the floodlight battery, the glare index will be unacceptably large even in a properly designed lighting system, so to obtain data useful the direction of the observer's view must be limited. When calculating the planar sports facilities line of view of the observer, height must be limited to an angle of 2 ° down from the horizon, with the position of the eye at a height of 1.5 m from the level of the sports ground. In azimuth covers all directions with a step of 15°.

Returning to the ski slopes, we can be sure that the line of view in most cases will be directed along the track. A mountain skier looks to the track, and viewers, who stand on the same ski slopes, looks to the skier.

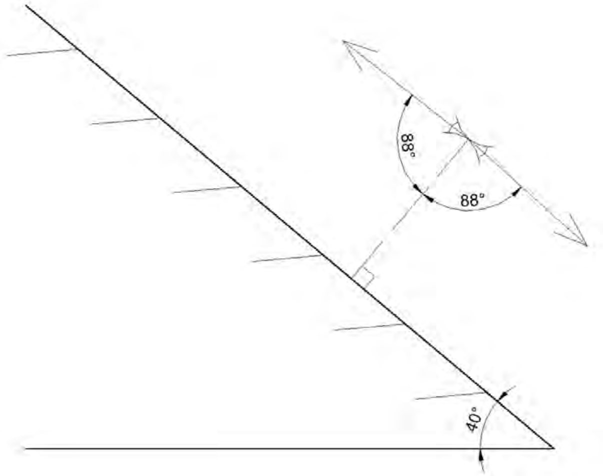

Fig. 4. The directions of the observer's view line on a section inclined of the track

In 2013 during the world junior's championship in freestyle in Sochi, the author of this work made a survey of competing athletes on the subject of blinding action during the jump from the springboard in the discipline "ski acrobatics".

The survey of viewers showed that, when the skier approaches to the springboard, he looks practically at his feet, and during the jump, searchlight lighting, made on the upper-side scheme, does not prevent him from concentrating and controlling his actions. Thus, for practical application, you can take a view angle of 2° below the plane of the route, while the rotation of the line of view in azimuth will be in the plane of this section of the route, which can be tilted to the horizon (Fig. 4).

5. THE ALGORITHM OF EXPRESS CALCULATION

The first distinctive feature of the rapid calculation method is the preservation of constant, earlier calculated parameters in the memory and recalculation of the effect on the light distribution only the current changes in the position and targeting of a particular device. The calculation of the direct illuminations of the track and snow is made according to the law of the squares of the distances when the parameters of the spotlights (targeting, location, type, number) are changing. The method is based on the fact that each of the searchlights contributes to the illumination of each calculated point of

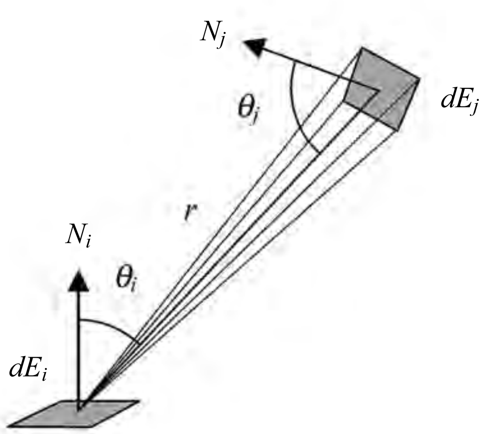

Fig. 5. The geometry of the two elements interaction

the considered slope section. For each searchlight on the considered slope area, this contribution is considered and stored separately. When a searchlight will be replaced with an another one, the previously calculated contribution of the changed searchlight is first deducted from the illumination of each calculated point of the track or snow element, then the light contribution of the new one is calculated and added.

The second idea of saving working time provides that the calculations of the coefficients (form factors) of single and multiple interaction of elements, as well as coefficients that relate the illumination of the calculated points to the illumination of snow elements, are taken from the calculation of the reflected light and are made only once after the creation of the scene geometry. In this regard, the process of rapid calculation can be divided into two main stages: **the initial stage**, at which all coefficients are calculated once and stored in memory **and the optimization stage**, at which the individual light devices are created, removed or changed. Herewith we accept the condition when geometry of the route is constant, it is set once and its change entails the re-conduct of the initial stage of the calculation with the recalculation of all the coefficients. The coefficient of interaction of element *i* with element *j* (Fig. 5) is calculating in accordance with the law of squares of distances:

$$k_{i-j} = \frac{E_j}{E_i} = \frac{\rho \cdot S_i \cos\theta_i \cdot \cos\theta_j}{\pi \cdot r^2}, \quad (3)$$

where: E_i is the illuminance obtained by the element *i* from searchlights,

E_j is the illumination of element *j* as a result of the light reflection from element *i*,

ρ is the reflection coefficient of the element *i*,

S_i is the area of element *i*,

θ_i is the radiation angle of light in the direction of the element *j* with respect to the normal to surface element *i*, θ_j is the angle of incidence of light on the element *j* relative to the normal to its surface,

r is the distance between the centres of the elements.

Similarly, coefficients that relate the illumination of this element of the reflecting surface and this calculated point of the trace are calculated and stored in the memory.

Further, in the process of optimization, the calculated values of snow illumination will be multiplied by the stored coefficients. The coefficients are calculated according to the above formula, where the calculated point on the plane acts instead of the element *j*.

To calculate the coefficients of interaction of elements taking into account multiple reflections in the cycle, the beam passage from one element to an-

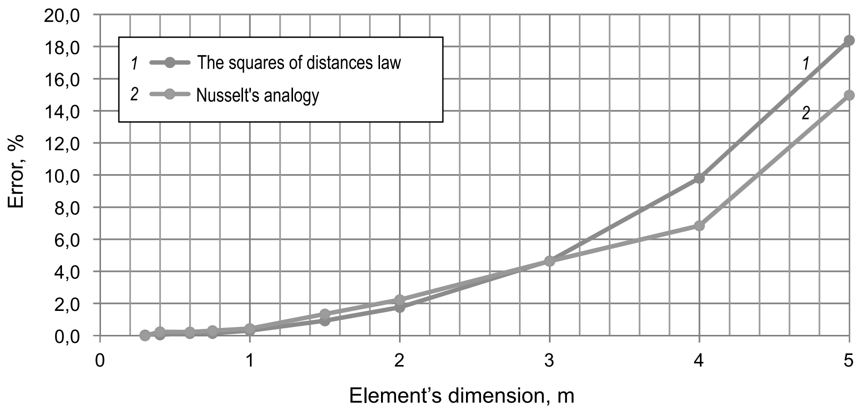

Fig.6. Error dependence on element size

other through all possible options is simulated (for two reflections, the passage through one intermediate element, for three through two intermediate elements, etc.). As a result, the formula for accounting for the contribution to the illumination of the *n-th* iteration looks like

$$E_j = E_i \cdot \sum_{p1,p2,\ldots pn} (k_{i-p1} \cdot k_{p1-p2} \cdot \ldots \cdot k_{pn-j}), \qquad (4)$$

where intermediate elements $p1, p2, \ldots p_n$ iterates through all elements of the scene.

The contributions from all iterations taken into account in the calculation must be folded to obtain the final reflected light component of element *j*.

It is known that the law of squared distances gives a significant error when the ratio of the element size to the distance to it is increased. Mathematical modelling made on the basis of the created calculation program showed that for two adjacent triangles the error of calculation of illumination of the centre of mass of one triangle reflected from the centre of mass another triangle light is 60 %, regardless of the angle between them.

Despite the significant error, it should be taken into account that the illumination of the snow element is influenced not only by the adjacent element, but also by many more distant elements, and the direct light from the searchlights creates the main part of the illumination. In addition, the illumination of snow is only an intermediate link in the chain of calculations. To reveal the real influence of this error, it was decided to consider as an alternative the calculation of the interaction coefficients by Nusselts analogy [8], which has an analytically accurate value. The analogy of the Nusselts is that the form factor of a face with respect to a point is a projection of the vector of the solid angle of a face on the calculated plane, which is similar to the projection of a part of the hemisphere of a single radius on the plane of its base. Mathematical modelling with the calculation of vertical illumination on the areas of real tracks showed that the error in the calculation of illumination using the Nusselts analogy becomes significantly lower than the error when the law of squares of distances is used only on large sizes of elements, when the error itself reaches ten percent or more (Fig. 6). At the same time, the calculation of coefficients by the Nusselts analogy takes about twice as much time. Based on this, it is more appropriate to use the law of the squares of distances.

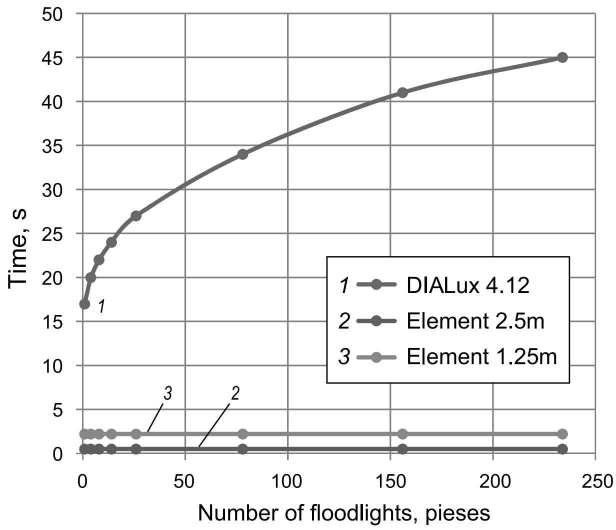

Fig.7. A comparison of the calculation times

Also, a series of calculations with different parameters for two types of tracks was carried out within the framework of the above-described mathematical modelling in the experimental calculation program – a section of the straight line with a break 37° and a section of the half-pipe track, which is a half of the pipe and, therefore, was considered separately. The aim was to determine the maximum size of the elements at which the error does not exceed the specified limits. The following conclusions are drawn from the results: up to the element size of 1.5 m on a straight track and up to 1.25 m on the half-pipe track, the error does not exceed 1 %, with the element size up to 3 m on a straight track and up to 2.5 m on the half-pipe track, the error does not exceed 5 %.

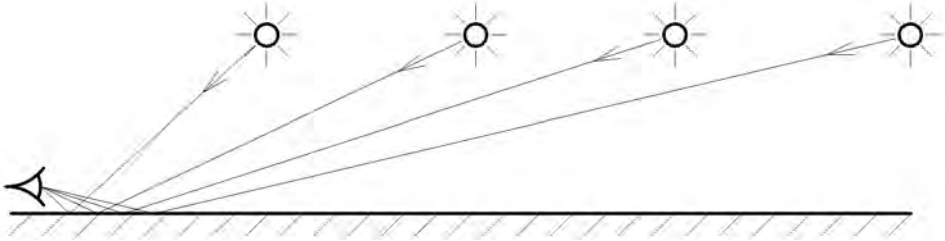

Fig.8. The scheme of the searchlight targeting and moving

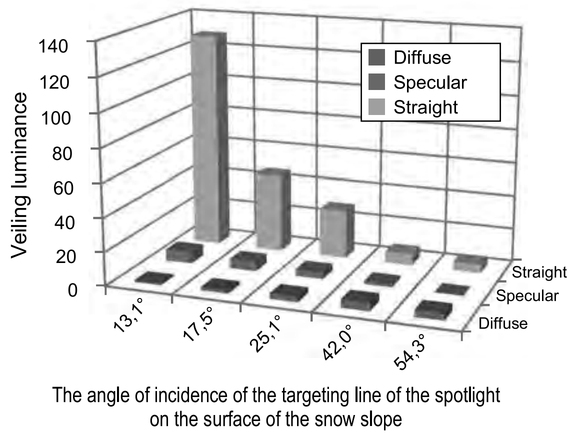

Fig. 9. A comparison of the cover luminance for the searchlights having narrow luminous intensity curve

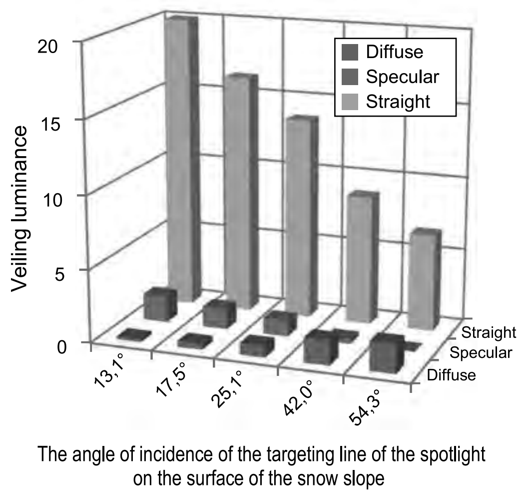

Fig.10. A comparison of the cover luminance for the searchlights having wide luminous intensity curve

Since the rate of coefficients calculation in the proposed method is critically dependent on the number of iterations of multiple reflections taken into account, the next task was to find out the minimum number of iterations that would be sufficient for this type of objects. Using mathematical modelling it was found out that for the section of the half-pipe route, the contribution of the third and further iterations to the vertical illumination does not exceed a tenth of a percent and, accordingly, they cannot be taken into account in the calculation. For a direct plot of the slope of the fracture 37^{o} the contribution of the second and further iterations does not exceed a few tenths of a percent. Also, the contribution of the second iteration in the half-pipe does not exceed 1 %, and the contribution of the first iteration on direct routes – 3 %. Taking into account such small values can be left to the designer's discretion.

6. CONTROL OF THE ACCURACY AND SPEED OF CALCULATION

After the development and implementation of the above algorithm of Express calculation in the experimental calculation program, it was tested for the accuracy of the calculation in two different ways. The first way is the solution of the Sobolev's problem [9], which is a calculation of illumination from a point light source located between two infinite parallel planes, and has an accurate analytical solution. The second way is a comparison with the program "DIALux" on the test section of the track. Comparison of the data obtained in the program of Express-calculation with the analytical solution of the Sobolev's problem and the output data from the program "DIALux" showed good convergence of the results.

In addition, a comparison of the calculation time with the program "DIALux" was made. As already it was mentioned above, for the calculation of sports lighting it is important that the recalculation of the scene after making changes to it is made "in real time", i.e. no more than a few seconds. The comparison was carried out on the test track for two variants of the size of the elements: 1.25 and 2.5 m. For one iteration, the calculation of the coefficients of the interaction were considered as 123 and 25 seconds. The results of the comparison depending on the number of floodlights in the scene is shown in Fig. 7. From the above chart it is clear that, the program of Express calculation allows to calculate the changes several times faster than the program "DIALux" when it optimize the solution and when the settings of only one of all the light devices participating in the scene are changed sequentially.

In this scene, the difference for a single spotlight is 8 to 34 times, depends on the selected element size. With the increase of the number of spotlights, this difference increases many times and ranges from 20 to 90 times.

7. REFLECTED GLARE

Mathematical modelling was carried out on the basis of available literature data on the mirror reflection of snow with ice crust (infusion) [10] in order to assess the blinding effect of the mirror component of snow reflection. A scene with a straight section of the track was created in the program. The observer was located in the middle of the end side of the site, and the spotlight, located on the longitudinal axis of the route, moved along this axis (Fig. 8). The light axis of the spotlight was inclined in a vertical plane passing through the longitudinal axis of the track, so that the reflected beam fell into the eye of the observer, i.e. the worst case from the point of view of blindness was chosen. The observer's view line remained unchanged and was 2° from the horizon accordingly to the existing method of the *GR*-calculation.

It's a pity, but this technique does not allow taking into account the bright distributed spots. Therefore, it was decided to compare veiling luminance for a straight line from the spotlight, diffuse from snow and snow-specula component of illumination in order to assess the effect of reflected glare. The results obtained for the two types of luminous intensity curve are shown in Figs. 9 and 10.

The data obtained clearly demonstrate that the direct component creates a veiling luminance much greater than the specula reflected. Therefore, the contribution of the latter to the blinding effect will not be decisive.

8. CONCLUSION

The method presented in the article allows you to provide qualitative calculations of the ski slopes lighting taking into account the light reflected, while the shape of the track is as close as possible to its real form, and the calculation speed allows display the results within a few seconds. The identified optimal initial data for the calculation, namely the number of multiple reflections and the size of the elements of the partition allow optimize the time spent on the design. The mathematical modelling has shown that the reflected glare from snow is relatively small. In itself, the question of the impact of bright distributed spots on the blinding effect remains open, but the effect of snow reflection can be neglected for practical use in the calculation of ski slopes. The created experimental calculation method has all the necessary functionality for the calculation of ski slopes illumination and, after a small revision, can be used as a full-fledged calculation program.

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Sergei A. Alexandrov,
Ms. Dr. He graduated from MPEI in 2003. At present, he is aTechnical Director of "Spector lab", Ltd

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APPLICATION OF INTELLIGENT LIGHTING CONTROL SYSTEM IN DIFFERENT SPORTS EVENTS IN SPORTS VENUES

Peng DONG

Dalian Maritime University, Dalian City, Liaoning Province, 16032 China
E-mail: zhmyu599@sina.com

ABSTRACT

This paper analyzes the application of intelligent lighting control system in different sports events in sports venues, which is based on the perspective of computer technology. Firstly, this paper analyzes the characteristics of different sports events lighting system in stadiums, proposes a lighting demand analysis algorithm based on gray-scale modulation model, and designs a control algorithm based on neural network for intelligent lighting control system. Finally, the paper tests the designed algorithm and the results show that the intelligent lighting control system is effective. The application can play an important role in the optimization of lighting systems in different sports venues, with the value of further promotion in practice.

Keywords: intelligent lighting, control system, stadium, sports events, application

1. INTRODUCTION

With the continuous development of intelligent building technology, more and more intelligent systems were applied to various buildings. The intelligent sports system has also been widely used in sports venues as a place for sports events and sports activities. As an important part of the intelligent stadium system, the intelligent lighting control system has the advantages of intelligent control, efficient management, integration, energy saving, and environmental protection. Therefore, it is widely used in different sports programs in sports venues [1]. With the increasing attention and participation of sports, large-scale comprehensive gymnasiums have emerged nationwide. Unlike the small gymnasiums in the past, modern large stadiums are more functional, intelligent and user-friendly [2]. The modern comprehensive gymnasium not only provides basic sports venues, but also conferences, cultural events, exhibitions were held, which greatly improves the comprehensive utilization rate and economic utility of the stadium. At the same time, it also provides a more comfortable and modern sports venue [3]. As an important embodiment of the function of the stadium, lighting is an important part of the design of the stadium. The lighting of the stadium has different design requirements depending on the occasion. Since the main function of the stadium is to hold various sports events, the lighting of the competition, that is, the lighting of the stadium is an important part of the lighting design. The requirements for intelligent lighting system control are different for different sports [4]. Therefore, the application of intelligent lighting control system in different sports events in sports venues are studied and analyzed.

2. STATE OF THE ART

Stadium lighting is not only one of the prerequisites for the successful holding of sports events, but also one of the prerequisites for other functions of the stadium. It mainly illuminates the stadium, also known as sports lighting; of course, sports lighting also includes venue maintenance lighting, emergency lighting, auditorium lighting, etc. [5]. Some scholars believe that the choice of different lamps, different light sources, and the most appropriate intelligent lighting control system can make the lighting evaluation indicators such as colour temperature, glare index, horizontal and vertical illumination, illumination uniformity, colour rendering and other parameters of the stadium meet the required standards [6]. Some scholars believe that the application of an intelligent lighting control system is the basic requirement of modern comprehensive sports stadiums. Due to the diversity of sports venues, venues cannot only host different sports events but also perform entertainment activities such as evening performances, so lighting needs to meet a variety of uses. In most cases, the venue will was divided into multiple sub-sites for simultaneous activities [7]. Therefore, according to the different needs of the site, the lighting is divided into various scene modes, and the control was realized by the intelligent lighting control system. In recent years, with the continuous development and mutual promotion of computer technology, automatic control technology, network communication technology, and microelectronic technology, the development of intelligent lighting control systems is also deepening [8]. According to different environments, users can use the intelligent lighting control system to set different requirements according to their actual conditions, collect environmental information through the automatic acquisition system, and form feedback signals through the system to achieve the best lighting control effect [9].

3. METHODOLOGY

3.1. Gray-Scale Modulation Model Algorithm Based On Different Projects of Stadiums

For different sports events in sports venues, the application requirements of intelligent lighting control systems are also different. The design of the lighting control system should was based on the characteristics of the different operating items. The intelligent lighting control system consists of three parts: input, output, and system unit. The input section converts external control signals into system signals, including a control panel, an LCD (Liquid Crystal Display) touch screen, a smart sensor, and remote control; the output section receives control signals on the bus to implement lighting control, including a dimming controller, a switch controller, and an output. The system was powered by system power, PC (Personal computer) interface and monitoring to control computers and other components. Most lighting systems use a bus structure and communicate according to certain protocols. The Distributed mode was usually used, all components were connected by bus, and communication between components was performed in a peer-to-peer manner. At present, intelligent lighting control systems of different manufacturers use their bus protocol products, such as DyNet bus. Outdoor venue lighting systems require high brightness. In direct sunlight, the audience needs to see the above. Similarly, it should have strong windproof, protective, anticorrosive and lightning protection capabilities. The size should was determined according to the size of the venue, the size of the space and the capacity of the audience. Also, the venue is brighter and has a larger field of view [10]. Therefore, according to the specifications of different sports items, the intelligent lighting system should be determined according to the actual situation. The conclusion is clear that if the LED display in the intelligent lighting system was taken as an example, the specific settings can was referred to Table 1.

Table 1. Determination of the Size of the Frame of the Stadium LED Display

Stadium audience capacity	LED display frame size
1,0000 seats or less	3000 mm (height) × 10000 mm (length)
2000~3000 seats	5000 mm (height) × 15000mm(length)
3000~4000 seats	7000(height) × 20000mm(length)
More than 8,000 seats	8000(height) × 25000mm(length)

The pixel count N_{LEF} of the intelligent lighting control system can be calculated from the width and height of the lighting equipment. It is:

$$N_{LEF} = N_w \times N_h. \quad (1)$$

Where N_w represents the width of the lighting equipment in the model and N_h represents the height of the lighting equipment in the model. The number of pixels of the intelligent lighting control system is calculated from the perspective of the driver chip. It can also be expressed as:

Table 2. Proportion of Brightness Loss Within the Reference Time

ΔN_{latch} / N_{latch}	1	2	3	4	5
32	3.03	5.88	8.57	11.11	13.51
64	1.54	3.03	4.48	5.88	5.88
96	1.03	2.04	3.03	4.00	7.25
128	0.78	1.54	2.29	3.03	4.95
192	0.52	1.03	1.54	2.04	3.76
256	0.39	0.77	1.16	1.54	1.91

$$N_{LEF} = N_{ic} \times N_{ch}. \quad (2)$$

Where N_{ic} represents the number of driver chips used for one channel of data, and N_{ch} represents the number of channels included in each driver chip. If the latch length is defined as N_{Iatch}, obviously:

$$N_{Iatch} = N_{ic} \times N_{ch}. \quad (3)$$

For the data link with a length of N_{Iatch}, the time required for the transfer is τ_{Iatch}.

$$\tau_{Iatch} = \frac{1}{f_{clk}} \times N_{Iatch}. \quad (4)$$

In actual engineering use, there will be some idle clocks in the gap between each two transfer operations. The shift gap is used for timing adjustment, denoted as ΔN_{Iatch}, and then the time τ_0 required to transfer data once is expressed as:

$$\tau_0 = \frac{1}{f_{clk}}(N_{Iatch} + \Delta N_{Iatch}). \quad (5)$$

τ_0 is defined as the reference time of the scan, also known as a time slice, which is an important parameter based on time slice gray modulation. As can be seen from the above data, the reference time is increasing with the increase of the shift length, when the scan clock is constant. If the reference time is kept constant, the scan clock needs to increase as the shift length increases. The latch signal is a very narrow level signal, and the number of scan clocks is recorded as NLE, which is part of ΔN_{Iatch}. During the benchmark time, the bandwidth utilization and bandwidth loss rates are:

$$\begin{cases} \eta_{BL} = \dfrac{N_{latch}}{N_{latch} + \Delta N_{latch}} \times 100\% \\ \eta_{\Delta BL} = \dfrac{N_{latch}}{N_{latch} + \Delta N_{latch}} \times 100\% \end{cases}. \quad (6)$$

Table 2 shows the ratio of luminance loss in reference time. The first behaviour is the clearance of movement, which ranges from 1 to 5. The first column of the form is a shift length, with a length ranging from 32 to 256. The other part of the form is the luminance loss in reference time. The first column is the shifting length. The range is from 32 to 256. The other parts are the luminance loss during the reference time. It can be seen that when the transfer length is constant, the brightness loss in the reference time increases with the increase of the transfer gap; when the transfer gap is constant, the brightness loss decreases as the transfer length increases. In actual engineering applications, the transfer gap is generally set to be adjustable, in order to obtain better bandwidth utilization, if there is no special explanation about the calculation of the transfer gap mentioned later, taking $N_{Iatch} = 3$, if the transfer length is 256, the bandwidth loss rate is 1.16 % within the reference time. If the gradation level of the lighting equipment is *n* bit, the single primary colour image data is represented as *D* [(n-1): 0], and each bit of data is represented as *D* [n-1], *D* [n-2] … *D* [1], *D* [0]. During the reference time, the relationship between the stored serial data sequence *D*[x] and the data bits can be expressed as:

$$D[x] = \bigcup_{i=0}^{N_{LED}-1} D_i[x], (0 \le x < n). \quad (7)$$

From Equation 7, when x = 0, $D[0] = \{D_0[0], D_1[0],..., D_{N_{LED-1}}[0]\}$ it indicates serial data that is sequentially transferred in a time slice.

3.2. Design of Intelligent Lighting Control System for Different Sports Events in Stadiums Based on BP Neural Network Algorithm

The lighting control requirements of the stadiums are characterized by large venues, large number of circuits, a large number of lamps, scattered distribution of lighting distribution boxes, and usually need to achieve centralized control and locking. The comprehensive sports arena is not only used for formal sports competitions, but also for training, gatherings, exhibitions and other activities. Different areas and occasions have different requirements for lighting, and different lighting control schemes should be adopted according to different functions and occasions. It plays a key role in the overall environment, so in order to create a variety of lighting effects, changing the different spaces, the dimming and scene preset function need to be set. With the improvement of the intellectualization and integration of the stadium, it is necessary to integrate the stadium with other systems because of the higher and higher requirements for the linkage control and remote control of the lighting system. The overall design of the sports lighting system introduces a rotating light into the existing sports lighting system, and adds an input unit, a control panel, a wireless RF remote control, an output unit, and a luminaire rotary drive. The input unit and the output unit together form a luminaire rotation control system, which may also be referred to as a luminaire rotation controller. The unit is connected to the bus system via a standard communication interface. The introduced lamps and units can set the address code through software to establish the corresponding control relationship and realize the control function of the rotating lamps. The wireless remote control panel is mounted on the wall according to the site conditions, the wireless RF remote control is detachable and hand-held, and the rotary drive of the lamp is mounted in the rotating light.

BP network is a multi-layer forward network trained by error back propagation algorithm. This network consists of two processes: forward propagation of information and back propagation of error. The basic learning algorithm of BP neural network is called gradient steepest descent method. It is defined as adjusting the weight to minimize the total network error; that is, using gradient search technology to minimize the error mean square value of the actual output value of the network and the desired output value. The process of network learning can be seen as a process of correcting the weight coefficient while spreading. In the BP neural network structure, the three-layer network structure is composed of the input layer, the hidden layer and the output layer. There is no direct connection between the hidden layer (middle layer) and the outside world, but the neuron state of the hidden layer can influence and change the input and output. The idea of the algorithm is to continuously correct the network weight (ω_{ij}, T_{li}) and the enthalpy value (θ), so that the error can continue to decline along the direction of the negative gradient, and finally the satisfactory result can be obtained. The learning formula of BP neural network is as follows: where ω_{ij} is the network weight between the input node and the hidden layer node, T_{li} is the network weight between the hidden node and the output node, t_1 is the expected value of the input node, and t_1 is the input node and the output node is O_l. x_j is entered at the input node, the output of the intermediate node:

$$y_i = f\left(\sum \omega_{ij} x_j - \theta_i\right). \tag{8}$$

Output node:

$$O_l = f\left(\sum_i T_{ij} - \theta_l\right). \tag{9}$$

The connection weight is ω_{ij} and the node domain value is θ_l. For the output layer, the expected output of the output node is t_1, and then the error formula is:

$$\delta_1 = (t_1 - o_1)(1 - o_1)o_1. \tag{10}$$

Error control:

$$E = \sum_{k=1}^{p} e_k < \in. \tag{11}$$

$$e_k = \sum_{l=1}^{n}\left[t_1^{(k)} - o_1^{(k)}\right]. \tag{12}$$

Weight correction:

$$T_{li}(k+1) = T_{li}(k) + \eta\delta_1 y_i. \tag{13}$$

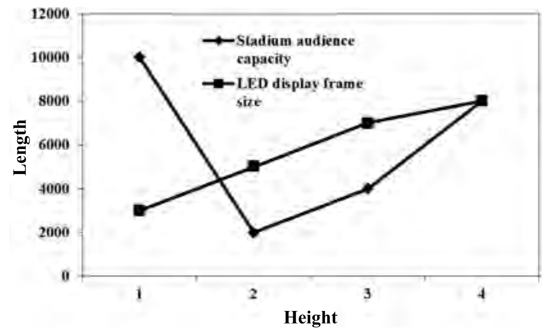

Fig.1. Determination of the size of the frame of the stadium LED display

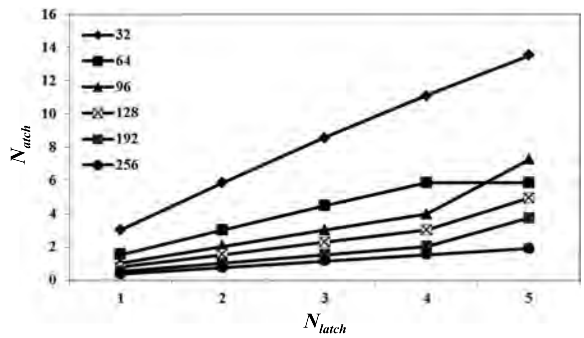

Fig.2. Proportion of brightness loss within the reference time

K is the number of iterations. For the devaluation correction:

$$\theta_l\left(k+1\right)=\theta_i\left(k\right)+\eta\delta_1 y_i. \quad (14)$$

4. RESULT ANALYSIS AND DISCUSSION

Based on the previous algorithm analysis, the application requirements of the illumination gradation display of the intelligent lighting control system in different sports events in the stadium are first analyzed. When the minimum pulse width is selected to be 40 ns and the refresh rate is 600 Hz, the relationship among the gray level, the shift length, and the scan clocks is as shown in Fig. 1, in which the scan clock is varied between 1 and 30 MHz. The storage length varies between 16 and 512, taking the LED intelligent lighting system as an example.

As can be seen from Fig. 1, its gray value varies between 14 and 15 bits, of which 14 bits are the most, 15 bits are less, are distributed in a few bands. The upper right picture shows the amplification of the low-speed clock area. It can be seen that when the transfer length is less than 200, the fluctuation of the gray level distribution fluctuates greatly. In the area above 200, the gray level changes relatively smoothly.

Fig.2 is a state in which the gradation level exhibits disordered fluctuations in the low-speed clock region where the transfer length is small. During the whole modulation period, the time slice matching algorithm realizes that the LED lighting control system illuminates according to a certain rule, so that the LED lighting fixture does not appear bright or off for a long time, thereby achieving the purpose of reducing the flickering of the display screen. According to the characteristics of LED lamp gray modulation, not only the evaluation strategy based on flash frequency factor is proposed, but also the qualitative evaluation of screen flicker is carried out. This method evaluates different time slice combinations and belongs to the category of gray modulation algorithms. The human eye produces a flickering effect on the rapidly changing light signal. Since the LED lighting fixture is intermittent, when the LED lighting fixture changes frequency is not fast enough, the human eye can perceive a noticeable flickering feeling. When the frequency of change is high, due to the visual inertia of the human eye, the observer will no longer feel flicker, the frequency that would normally not cause flicker, that is, the picture that the human eye can feel stable, is called the critical flicker frequency. The critical flicker frequency of the human eye is related to many factors: the brightness of the flickering picture: the higher the brightness, the higher the critical flicker frequency, the amplitude of the flicker: the larger the amplitude, the more obvious the flicker is perceived by the human eye. When the amplitude is less than the brightness that can be resolved by the human eye, the observer will not feel the flicker. Observation time, short-term observation is not obvious to the flicker, and it is easier to feel the flicker when observed for a long time.

Fig. 3 reflects the subjective evaluation of the display effect of the display screens of different

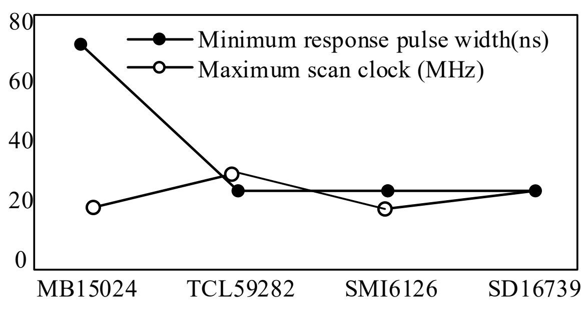

Fig.3. Little driver chip parameters

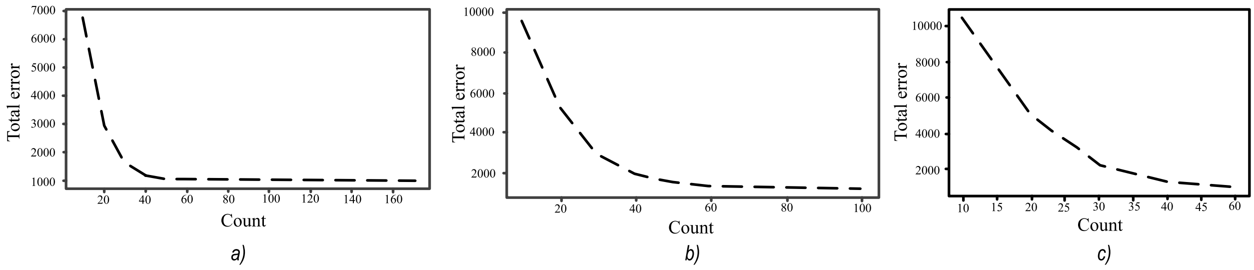

Fig.4. The BP neural network algorithm

Table 3. Classroom Lighting Monitoring Data

Input quantity		Output	
Standard of illumination (lx)	**Luminaire power (W)**	***X* axis coordinates (cm)**	***Y* axis coordinates (cm)**
150	39	169	214
	52	131	177
	18	99	149
	14	89	79
200	33	188	159
	35	98	189
	22	68	141
	51	79	71
300	61	120	117
	44	111	139
	37	89	201
	24	56	91

types of lighting control systems under different conditions. The observation results show that when the outdoor display brightness is greater than 4000 cd/m^2, it is better to use a refresh rate above 400 Hz; when the brightness is less than 4000 cd/m^2, it is better to use a refresh rate above 240 Hz. The degree of flicker is not enough to measure by the refresh rate, because in the case of the same refresh rate. The gray scale modulation algorithm is different, and the results are different. Therefore, for different sports in the stadium, the design of the display in the intelligent lighting system of each sports venue should be designed and applied according to the characteristics of the sports itself.

In order to design the most energy-saving luminaire installation scheme under the premise of meeting the illuminance standard value, the simulation experiment can be carried out through BP neural network. Generally, in different environments, the installation position and power of the luminaire have certain influence on the lighting effect. The model can be established by BP neural network, and the illuminance standard and the luminaire power are defined as the input quantity, and the installation position of the luminaire is defined as the output quantity, and they are trained. The experiment selects a classroom in the teaching building as the experimental object, and normalizes the input data of the BP algorithm to determine the input and output parameters of the network. The selection and determination of the parameters are selected according to the actual situation. The distribution and measured data of the lamps in the classroom are shown in Table 3.

The data used in the test indicates that the input is the illumination brightness and the lamp power. The output is the minimum horizontal and vertical spacing (in cm) of the fixtures installed in a given classroom. The default size of the schoolroom is 12m × 9m, for classrooms of different sizes; they can be tested by modifying the data. The fluorescent lamp is used as the test luminaire in the experiment. Since the 16W LED tube selected in this design is the same as the 40 W fluorescent lamp, the simulation result of the 40 W luminaire under test was used as the basis for the installation position of the luminaire in the design. The total error of the training obtained by running multiple times was shown in Figs. 4 (a), (b), and (c), and the error of the algorithm is graphically displayed, and is displayed every ten iterations.

Then the test results are obtained, it can was calculated through the test results that, to meet the illumination requirements, if a 40 W luminaire was used, in the 12m×9m classroom, 5 luminaires can be installed in the X-axis range, 6 luminaires can was installed in the Y-axis range, and 30 luminaires need to was installed in the entire classroom.

5. CONCLUSION

With the development of the stadium intelligent, the function of the clever lighting control system will be perfect. The wise lighting control system not only satisfies the complex lighting control requirements of the stadium but also chiefly reduces the maintenance management workload and improves the management level, which is unmatched by traditional lighting methods. Therefore, the intelligent lighting control system will become an indispensable part of the intelligent stadium system and has a very wide application prospect. A smart lighting control system suitable for modern stadiums was introduced. In the overall design of the system, according to the gray-scale modulation model, the gray-scale modulation is divided into central gray-scale modulation and extended gray-scale modulation, the optimal scanning clock selection method was given. The design algorithm of an intelligent lighting control system based on neural network is designed, with the conceived algorithm tested. The test results show that the design of this paper can play a perfect role in optimizing the lighting system of different sports events in the stadium.

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Peng DONG
studied in the Northeast Normal University and received his bachelor degree in 2004, and then obtained a master degree in the Liaoning Normal University in 2009. Now Mr. Dong is employed in the Dalia Maritime University as an associate professor, whose research fields are fitness and bodybuilding guide and the kendo development in the university students' group

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INTELLIGENT LIGHTING CONTROL SYSTEM IN LARGE-SCALE SPORTS COMPETITION VENUES

Shengmin CAO

Physical Education Department of Northeastern University, Shenyang, Liaoning, 110819 China
E-mail: 651010564@qq.com

ABSTRACT

This paper mainly studies the application of intelligent lighting control system in different sports events in large sports competition venues. We take the Xiantao Stadium, a large-scale sports competition venue in Zaozhuang City, Shandong Province as an example, to study its intelligent lighting control system. In this paper, the PID (proportion – integral – derivative) incremental control model and the Karatsuba multiplication model are used, and the intelligent lighting control system is designed and implemented by multi-level fuzzy comprehensive evaluation model. Finally, the paper evaluates the actual effect of the intelligent lighting control system. The research shows that the intelligent lighting control system designed in this paper can accurately control the lighting of different sports in large stadiums. The research in this paper has important practical significance for the planning and design of large-scale sports competition venues.

Keywords: intelligent lighting, control system, large sports venues

1. INTRODUCTION

With the development of the society, there are various kinds of sports events in the society and most of them need to be held in the stadium [1]. During the competition, the lighting management in the stadium is undoubtedly the top priority in the event management. At the same time, with the breakthrough of modern intelligent building technology, more and more buildings are beginning to integrate into various intelligent management systems [2]. As a place with huge human traffic, large sports venues will not only consume very high human resource cost, but also restrict the space for large stadiums to play their functions [3]. Therefore, an intelligent lighting control system must be introduced in it, and a more intelligent lighting management system can provide more humanized management methods and high management efficiency for the management staff of large stadiums, making the venue more energy-efficient and stable [4]. However, as the intelligent lighting control system is a new thing, the research work on it is not very rich, and the actual usage rate in the stadium of large sports is relatively low [5]. Therefore, it is necessary to carry out more and more in-depth research on the application of optical intelligent lighting control systems in different sports venues in large sports venues in order to realize the upgrade of stadium competition services [6]. Good lighting conditions are provided for the stadium to ensure that the future venue event service can be carried out normally.

2. STATE OF THE ART

The application of intelligent lighting control system in large-scale sports competition venues originated from the United States in the early 1980s. At that time, the United States was in the period of rapid development of information technology. Enterprises with advanced information technology at that time were not satisfied with their own fields. The development of the industry began to penetrate into other fields. The construction industry is one of the areas where the lighting in the building is effectively controlled by computer systems, which not only enhances the lighting effect, but also reduces the power consumed by actual lighting [7]. Subsequently, Western Europe and Japan introduced such technology and developed their own lighting control system. In the 1990s, with the further improvement of technology, the technology began to transform from experimental technology to commercial technology, and Western Europe began to adopt this technology on a large scale. At that time, China's economic level was relatively backward, and did not carry out research in time [8]. In the late 1990s, with the deepening of reform and opening up and the development of social economy, it began to be studied. It was more applied in office buildings and other places, and there were few applications for large-scale sports competitions. In the 21st century, with the increase of large-scale sports venues, more and more venues have adopted this technology. Especially during the construction of Beijing Olympic Games, it is the peak of the development of intelligent lighting control system research and application [9].

3. METHODOLOGY

3.1. PID Incremental Control Model

As early as the 1930s, researchers proposed the PID (proportion – integral – derivative) incremental control model. After years of development, its practical application in the field of industrial control has been quite rich. In the industrial control process, there are many factors that affect the control process and need to be adjusted in real time. The supporting control parameters are also constantly changing, so it is very suitable to use the PID incremental control model to control it [10]. Moreover, the development process of PID is relatively easy. In the process of being able to send, the parameters can be changed at any time according to the actual situation. It has excellent flexibility and can adapt to any actual situation. The PID incremental control model is shown in Figs. 1,3.

The PID incremental control model is a linear regulator that is the ratio (P), integral (I), and derivative (D) of the control deviation $c = r - y$ formed by the given value r of the system and the actual

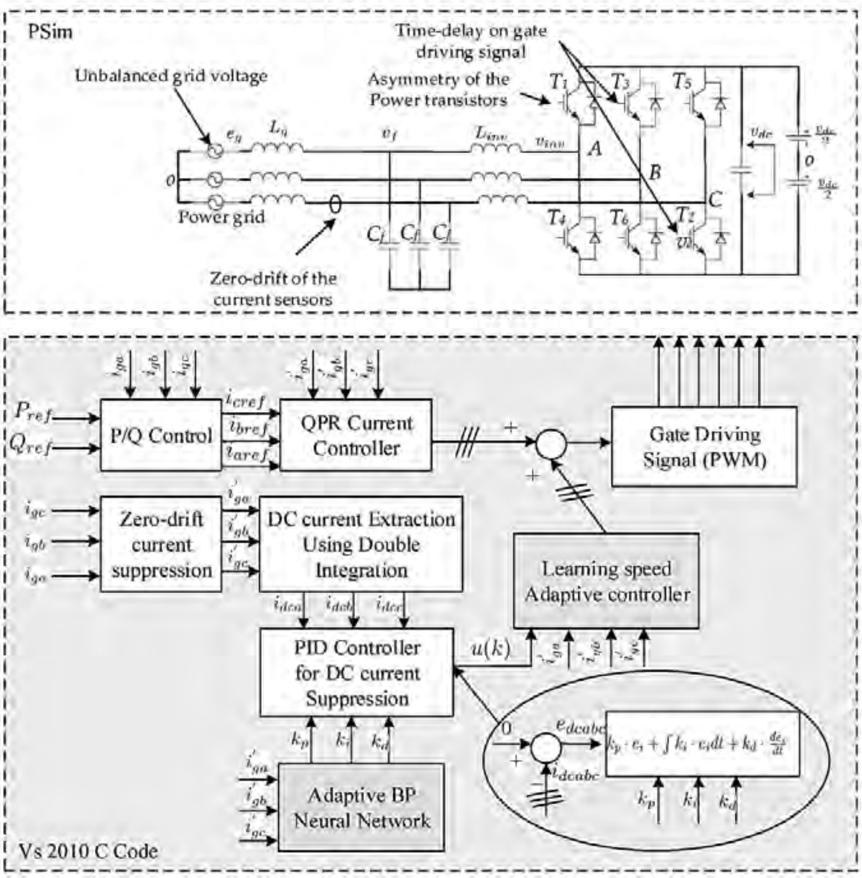

Fig.1. PID control model diagram

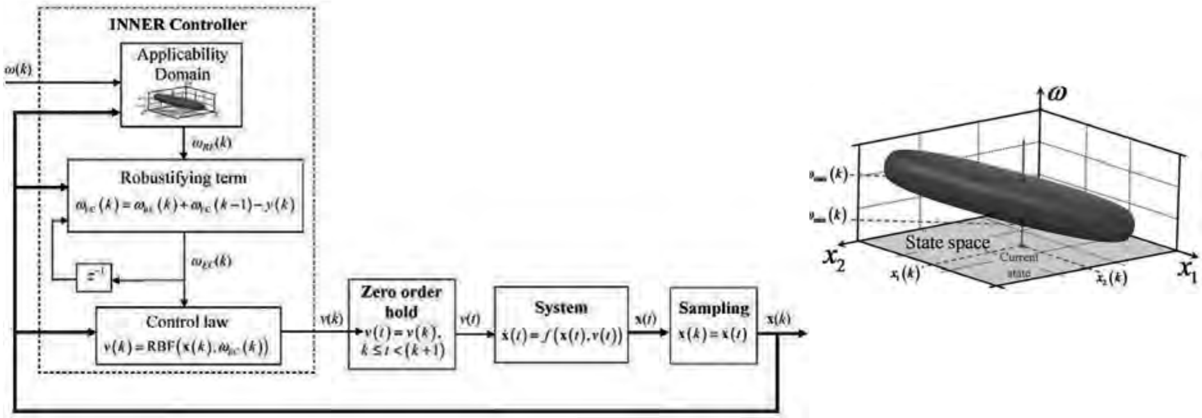

Fig.2. PID control model amplitude adjustment

output value *y*. The control quantity is formed by linear combination, so the PID incremental control model is abbreviated. The analogue PID control law in the continuous control system is:

$$u(t) = K_p[e(t) + \frac{1}{T_I}\int_0^t e(t)dt + T_D\frac{de(t)}{dt}], \quad (1)$$

where $u(t)$ is the output of the algorithm, $e(t)$ is the deviation between the system's given amount and output, K_P is the proportional coefficient, T_I is the integral time constant, and T_D is the differential time constant. Its corresponding transfer function is:

$$G(s) = K_p(1 + \frac{1}{T_I s} + T_D s). \quad (2)$$

The functions of the proportional regulator, the integral regulator and the differential regulator. The proportional regulator is used to prevent the deviation of various control parameters during the control process, which leads to the occurrence of control errors. If a control error occurs during the actual control process, the proportional regulator adjusts the control according to the corresponding principle to minimize the deviation. Proportional integral regulator: Static difference will occur during the process of proportional adjustment. In order to compensate for the control effect caused by static difference, it needs to be adjusted by proportional integral regulator. It adjusts the amount of control by deviation, and the deviation can also be accumulated. That is to say, as long as the deviation is not zero, there is adjustment. The larger the deviation, the larger the integral, the larger the adjustment, and the adjustment process is completed when the deviation is zero. In the actual adjustment process, in order to ensure the stability of the control, the adjustment range can be reduced by a small amount. Proportional integral differential regulators: It exists in order to make the control process complete in the shortest time. When there is a deviation in the control process, it is analyzed, and the control is adjusted according to the predicted deviation. It can minimize the adjustment range and ensure the normal operation of the system, as shown in Fig. 2.

Because of the control characteristics of the computer system itself, the deviation analysis should be carried out according to the sampling condition of the system at the time of operation. Therefore, the numerical interpolation is performed by the circumscribed rectangle method, and the first-order backward difference is numerically differentiated. When the sampling period is T,

$$u_i = K_p[e_i + \frac{T}{T_I}\sum_{j=0}^{i} e_j + \frac{T_D}{T}(e_i - e_{i-1})]. \quad (3)$$

This discrete approximation is quite accurate if the sampling period is small enough. In the above formula, u_i is the full output, which corresponds to the position that the actuator of the controlled object should reach at the *i* sampling time. Therefore, the above formula is called the PID position type control algorithm.

It can be seen that when u_i is calculated as above, the output value is related to all past states. When the actuator does not need the absolute value of the control quantity, but the increment, the following formula can be derived:

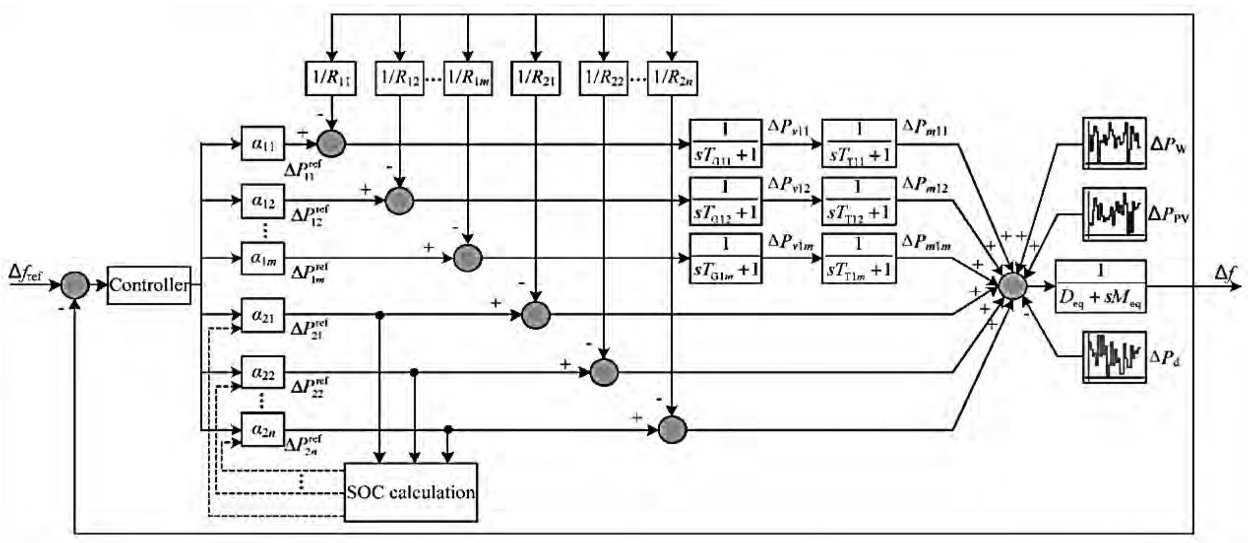

Fig.3. Incremental PID control model circuit schematic

$$\Delta u_i = u_i - u_{i-1} = K_p[e_i - e_{i-1} + \\ + \frac{T}{T_I} e_i + \frac{T_D}{T}(e_i - 2e_{i-1} + e_{i-2})]. \quad (4)$$

$$u_i = u_{i-1} + K_p[e_i - e_{i-1} + \frac{T}{T_I} e_i + \\ + \frac{T_D}{T}(e_i - 2e_{i-1} + e_{i-2})]. \quad (5)$$

Formula (4) is called incremental PID control formula. Formula (5) is called recursive PID control formula. The quantitative control equation has the following advantages:

– The computer only outputs the control increment, that is, the change part of the actuator position, so the influence of the malfunction is small;

– The output u_i at the time i only needs to use the deviation at this moment, and the deviation e_{i-1} of the previous two moments at the previous moment, e_{i-2} and the previous output value u_{i-1}, which greatly saves memory and calculation time;

– When manual-automatic switching, the control volume impact is small, and the transition can be smoother.

The computer requirements of the control process are highly real-time. When using a microcomputer as a digital algorithm, due to the limitation of word length and operation speed, necessary methods must be adopted to speed up the calculation. The method of simplifying the formula is described below.

According to the recursive PID formula represented by the equation (6), each time the computer outputs, four additions, two subtractions, four multiplications, and two divisions are performed. If the formula is slightly combined, it is written as follows:

$$u_i = u_{i-1} + K_p(1 + \frac{T}{T_I} + \frac{T_D}{T})e_i - \\ - K_p(1 + \frac{2T_D}{T})e_{i-1} + K_p \frac{T_D}{T} e_{i-2} = \\ = u_{i-1} + a_0 e_i - a_1 e_{i-1} + a_2 e_{i-2}. \quad (6)$$

In the formula, the coefficients a_0, a_1, and a_2 can be calculated discretely, which speeds up the operation speed of the algorithm program.

3.2. Karatsuba Multiplication Model

In the process of multiplying large integers, it is often encountered that the operation result overflows or the accuracy of the operation result cannot meet the requirements, as shown in Fig. 4. This also makes many fields that have stringent requirements on computational accuracy often have a variety of problems due to the operation of large integer multiplications. Therefore, how to effectively improve the calculation accuracy of large integer multiplication has become an urgent problem to be solved. In response to this problem, scholars at home and abroad have injected a lot of research energy and carried out corresponding research work.

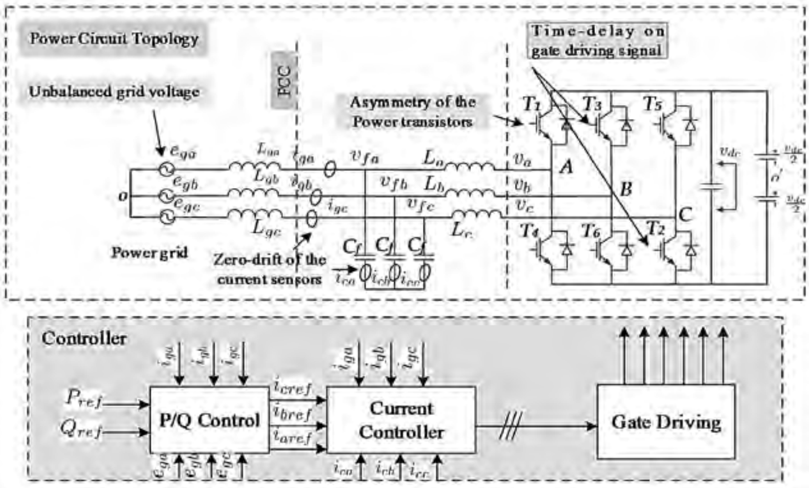

Fig.4. Big integer multiplication

In these research works, the more common methods of large integer arithmetic mainly include superposition method and divide and conquer method. The principle of the superposition method is to separate large integers and calculate them in pairs, and finally superimpose the calculated results according to different weights. The calculation idea of divide and conquer is the opposite of the superposition method. It first decomposes large integers into different small integers, then multiplies the small integers, and combines the obtained results to obtain the result of the original formula. Although the large integer arithmetic method can obtain the final result of the formula, its operation efficiency is relatively low, so it is generally not used in engineering applications. For the moment, the Karatsuba multiplication model is the most widely used and most effective computational model in the process of large integer multiplication. The model mainly uses a special method of recursive method for large integer multiplication calculation, which ensures the accuracy of calculation. Under the premise, the time complexity of large integer multiplication is greatly reduced, and the operating efficiency of the al-

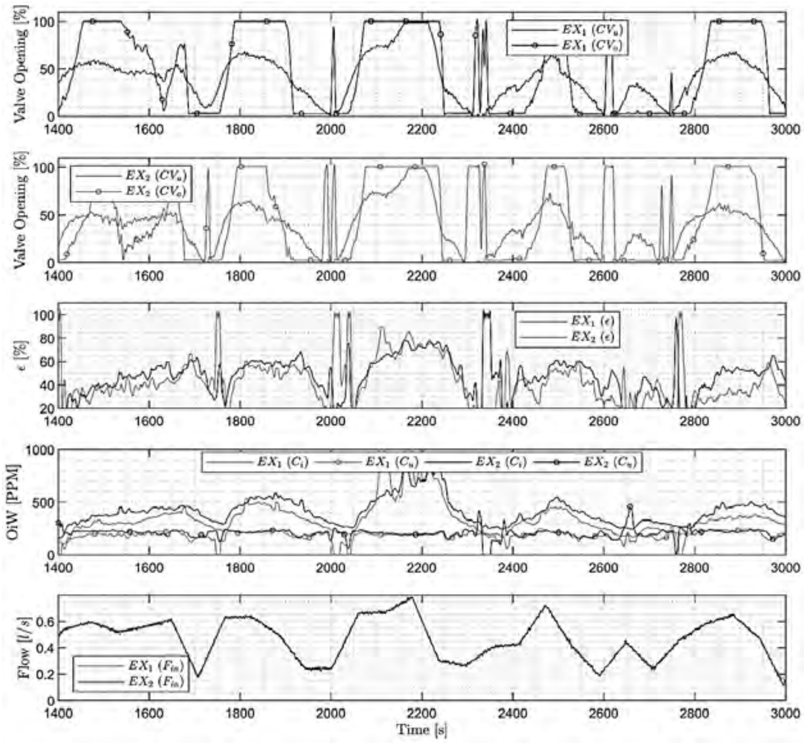

Fig.5. Karatsuba multiplication mathematical model

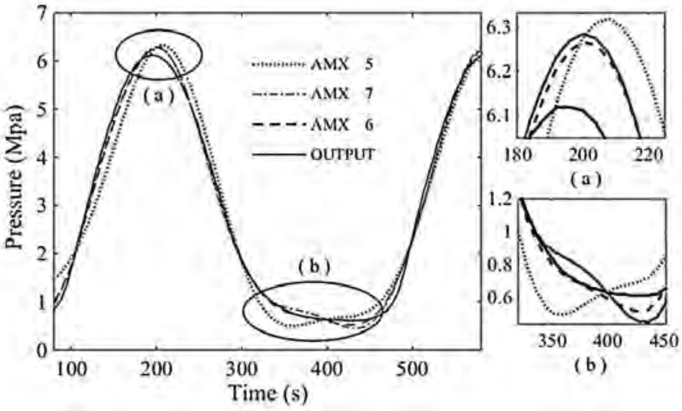

Fig.6. Karatsuba multiplication model function distribution map

gorithm is effectively improved. The mathematical implementation of the Karatsuba multiplication mathematical model (Figs. 5,6) is as follows:

According to the electromagnetic field theory, the effective value E_0 of the electric field intensity from the radiation source is

$$E_0 = \frac{\sqrt{30P_T}}{d}(\text{V/m}). \quad (7)$$

The effective value of the magnetic field strength is

$$H_0 = \frac{\sqrt{30P_T}}{12\pi d}(\text{A/m}). \quad (8)$$

The electric wave power density per unit area S is

$$S = \frac{P_T}{4\pi d^2}(\text{W/m}^2). \quad (9)$$

If a directional antenna with a transmit antenna gain of G_T is used instead of an isotropic antenna, the above formulas should be written as

$$E_0 = \frac{\sqrt{30P_T G_T}}{d}(\text{V/m}). \quad (10)$$

$$H_0 = \frac{\sqrt{30P_T G_T}}{12\pi d}(\text{A/m}). \quad (11)$$

$$S = \frac{P_T G_T}{4\pi d^2}(W/m^2). \quad (12)$$

The power of the wave obtained by the receiving antenna is equal to the power density of the wave at this point multiplied by the effective area of the receiving antenna, so

$$P_R = SA_R. \quad (13)$$

Where A_R is the effective area of the receiving antenna, which satisfies the following relationship with the receiving antenna gain G_R:

$$A_R = \frac{\lambda^2}{4\pi}G_R. \quad (14)$$

In this formula, $\lambda^2/4\pi$ is the effective area of the isotropic antenna.

Available from the above formula

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2. \quad (15)$$

When the gain of the receiving and transmitting antenna is 0 dB, that is, when $G_T = G_R = 1$, the power obtained on the receiving antenna is

$$P_R = P_T \left(\frac{\lambda}{4\pi d}\right)^2. \quad (16)$$

As can be seen from the above equation, the free space propagation loss L_{fs} can be defined as

$$L_{fs} = \frac{P_T}{P_R} = \left(\frac{4\pi d}{\lambda}\right)^2. \quad (17)$$

In dB, we can know,

$$\left[L_{fs}\right](dB) = 10\lg\left(\frac{4\pi d}{\lambda}\right)^2 (dB) = \\ = 20\lg\frac{4\pi d}{\lambda}(dB). \quad (18)$$

Or,

$$\left[L_{fs}\right](dB) = 32.44 + 20\lg d\,(km) + \\ + 20\lg f\,(MHz). \quad (19)$$

In the formula, the unit of d is km, and the frequency unit is in MHz.

At this point, suppose that there are r integers whose variable X and variable Y belong to n bits, and then you need to calculate the product XY of them. Then you need to segment the variable X and the variable Y first. In order to facilitate the calculation into two segments, the length of each segment is more suitable for the n/2 position, as shown in the following formula.

$$X = \underbrace{A}_{n/2}\ \underbrace{B}_{n/2},\ Y = \underbrace{C}_{n/2}\ \underbrace{D}_{n/2}. \quad (20)$$

Thus, $X = A\,r^{n/2} + B$ and $Y = C\,r^{n/2} + D$. From this it can be concluded that the product of variable X and variable Y is:

$$XY = (Ar^{n/2} + B)(Cr^{n/2} + D) = \\ = ACr^n + (AD + CB)r^{n/2} + BD. \quad (21)$$

It is not difficult to know from the above formula (21) that if wanting to obtain the calculation result of XY, the n/2 -bit integer must be multiplied by 4 times and the integer addition of 3 times without exceeding the n-bit. In addition to this, two completely different carry processing is required.

At this point, variable X and variable Y can be expressed by the following formula:

$$X = x_{n-1}x_{n-2}.....x_1x_0. \quad (22)$$

$$Y = y_{n-1}y_{n-2}.....y_1y_0. \quad (23)$$

In order to facilitate the calculation, it can be obtained after simplification:

$$X = \sum_{i=0}^{n-1} x_{[i]} \cdot r^i. \quad (24)$$

$$Y = \sum_{j=0}^{n-1} y_{[j]} \cdot r^j. \quad (25)$$

Therefore, the calculation formula for large integer multiplication is:

$$XY = \sum_{i=0}^{2n-1} R_{[i]} \cdot r^i = \sum_{i=0}^{n-1}\sum_{j=0}^{n-1} x_{[i]} \cdot y_{[j]} \cdot r^{i+j}. \quad (26)$$

If there are constants $C > 0, p > 0$ and $h_0 > 0$ then,

$$T(\varphi) = \left|(L - L_h)\varphi\right| \le \\ \le Ch^p, \forall \varphi \in C^m,\ \forall h < h_0. \quad (27)$$

Then L_h has a truncation error of $O\left(h^p\right)$.

Find the limit values for any smooth f and sufficiently small h in equation (27):

$$\lim_{h\to 0} T(f) = h\left|\frac{f''}{2}\right|. \quad (28)$$

After completing its approximation, the average of the forward and backward differential approximations can be found.

$$f'(x) = \frac{1}{2}\left(\frac{f(x+h) - f(x)}{h} + \frac{f(x) - f(x-h)}{h}\right) + O\left(h^2\right). \quad (29)$$

Suppose $T(n)$ is the total number of operations required to multiply two n-bit integers. The result inferred from the above formula yields the following expression:

$$T(n) = \begin{cases} O(1) & \text{n} = 1 \\ 4T(n/2) + O(n) & \text{n} > 1 \end{cases}. \quad (30)$$

This gives,

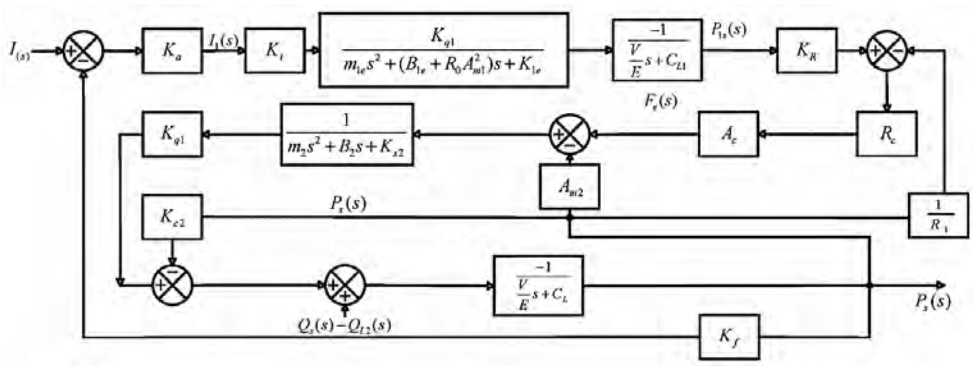

Fig.7. Lighting circuit diagram of Xiantao stadium

$$T(n) = O(n^2) \qquad (31)$$

In order to further improve the efficiency of the operation, it is necessary to further simplify the operation process. The product of the variable *X* and the variable *Y* obtained after simplification is calculated as follows:

$$XY = ACr^n + [(A-B)(D-C) + AC + BD]r^{n/2} + BD \qquad (32)$$

4. RESULT ANALYSIS AND DISCUSSION

With the rapid development of the IoT technology, intelligent lighting control systems have been widely used in the field of industrial control. The control principle is mainly to control different lighting sensors through smart chips to achieve the purpose of intelligent control of the lighting system. Since the real-time communication between the smart chip and different sensors needs to be ensured in the whole control process, the smart bus and the sensor are generally connected by field bus technology to achieve the effect of decentralized intelligent control (the circuit diagram is shown in Fig.7). This paper takes the Xian Tao Stadium, a large-

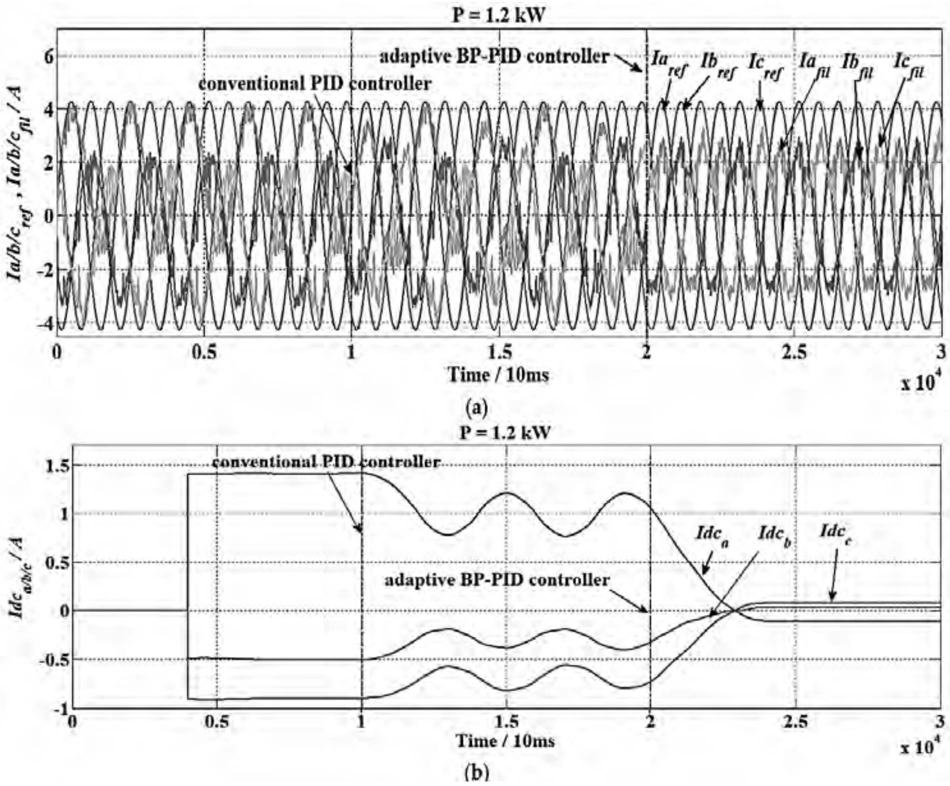

Fig.8. Intelligent lighting control system light adjustment

scale sports competition venue in Zaozhuang City, Shandong Province as a research example, and uses the PID incremental control model and the Karatsuba multiplication model to design and implement an intelligent lighting control system for different sports in large sports venues, effectively improving the quality of lighting services in large competition venues.

Xiantao Stadium is a large-scale sports competition venue newly built in Zaozhuang City, Shandong Province. It is mainly used to hold some relatively large-scale competitions. There are a number of different types of competitions in the stadium to meet a variety of competition purposes. In most cases, the venues in the stadium are multi-distributed and different competitions are carried out at the same time. This means that different types of competitions in the stadium also have different requirements for the lighting mode. The traditional lighting control mode is difficult to meet the needs of such lighting control. For this reason, using intelligent chips to design an intelligent lighting control system for centralized real-time control of the lighting of sports venues has become a future development trend.

The intelligent lighting control system designed in this paper mainly uses AT89S52 chip as the core control chip of the system. The main stadium lighting of the stadium uses 200 sets of 650W metal halide lamps for lighting control. The auditorium of the main stadium uses 36 sets of 500W iodine tungsten lamps for lighting control. The AT89S52 chip will adjust the illuminance according to the actual requirements of the different types of games. For some games with higher light perception requirements, such as table tennis competition, all the metal halide lamps will be illuminated at the same time to enhance the indoor luminosity. For some games that require an atmosphere, such as a football game, the brightness of the room light will be reduced accordingly, as shown in Fig. 8.

AT89S52 chip is a high performance and low power consumption small chip launched by STC. The chip USES key features of flash memory technology, reduces production costs, and its software and hardware are fully compatible with McS-51 related manufacturing technology, making development and testing easier and providing intelligent flexibility and cheap solutions for many embedded control systems.

Finally, the multi-level fuzzy comprehensive evaluation model is used to evaluate the actual effect of the intelligent lighting control system. The multi-level fuzzy comprehensive evaluation model is an evaluation method based on cognitive science and fuzzy mathematics. The specific form is as follows:

$$\begin{pmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,n} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,n} \\ . & . & . & . \\ a_{n,1} & a_{n,1} & & a_{n,n} \end{pmatrix}. \quad (33)$$

In the formula, $a_{i,j}$ represents the relative weight of indicator a_i relative to indicator a_j.

Calculate the product of each row element of the judgment matrix *R*,

$$M_i = \prod_{j=1}^{n} B_{ij}, i = 1,2,\ldots,n. \quad (34)$$

Calculate the *n* root of M_i,

$$\overline{w_i} = \left(M_i\right)^{\frac{1}{n}}, i = 1,2,\ldots,n. \quad (35)$$

Normalize $\overline{w_i}$, so,

$$w_i - \frac{\overline{w_i}}{\sum_{i=1}^{n}\overline{w_i}}, i = 1,2,\ldots,n. \quad (36)$$

Then the weight vector,

$$w = \left[w_1, w_2, \ldots, w_4\right]^T. \quad (37)$$

Calculate the maximum eigen value $\lambda_{\max}$ of the judgment matrix R, where $\left[Rw\right]_i$ is the element of *i* in the Rw vector.

Let the target criterion layer weight vector obtained according to the above method be:

$$W = \left(w_1, w_2, w_3, \ldots, w_k\right), \quad (38)$$

where w_i is the relative weight of the criterion layer indicator *i* in the criterion layer.

For the *k* criteria level indicators, the weights of the measures level indicators under each criterion are:

$$W_k = \left(w_{k1}, w_{k2}, w_{k3}, \ldots, w_{kp}\right). \quad (39)$$

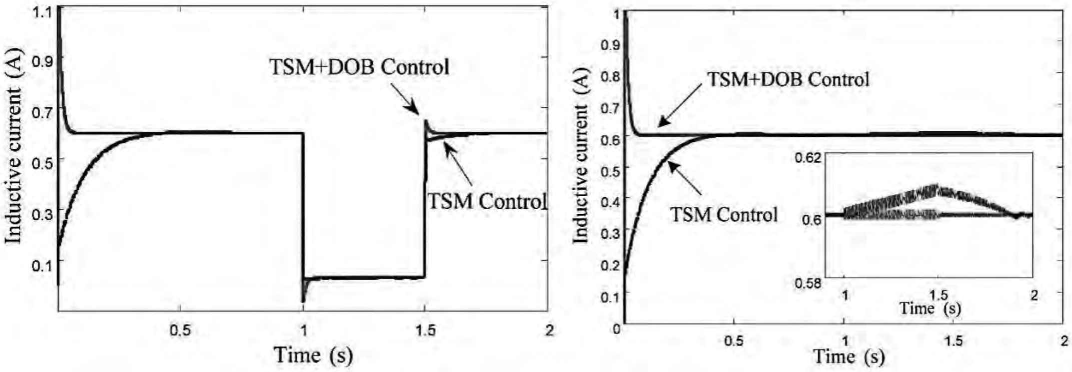

Fig.9. The program evaluation results of ocean folk sports function and development dynamic mechanism

In the hierarchical structure, the comprehensive weight calculation operator of the measure *j* indicator under criterion *i* is:

$$w_{i,j} = w_i \cdot w_j. \quad (40)$$

After obtaining the weights of the respective indicators, the evaluation score can be finally calculated by multiplying the evaluation values. The calculation operator is:

$$Ea = \left(w_{p,1}, w_{p,2}, \ldots, w_{p,n}\right)\left(v_{p,1}, v_{p,2}, \ldots v_{p,n}\right)^T, \quad (41)$$

where $w_{p,i}$ is the comprehensive weight of the lowest level indicator *i*, and $w_{p,i}$ is its evaluation score.

According to the content represented by the formula (41), the collected related data is substituted and the evaluation result is obtained, as shown in Fig 9. It is not difficult to see from the results that the intelligent lighting control system designed in this paper can accurately control the lighting between different sports in large sports venues.

5. CONCLUSION

With the development of society, there are different types of sports events in the current society and most of these events need to be carried out in large sports venues. In the course of the game, good lighting conditions are the basic guarantee for the normal operation of the game. However, unfortunately, at present, there is little research on the application of intelligent lighting control systems in sports venues. Based on the above reasons, this paper takes the Xiantao Stadium, a large-scale sports competition venue in Zaozhuang City, Shandong Province as a research example, and uses PID incremental control model and Karatsuba multiplication model to design and realize an intelligent lighting control for different sports in large sports venues. System to effectively improve the quality of lighting services in large competition venues. The intelligent lighting control system mainly uses the AT89S52 chip as the core control chip of the system, and performs photometric control according to the actual requirements of the lighting according to different types of games. In order to verify the application effect after completing the intelligent lighting control system, this paper uses the multi-level fuzzy comprehensive evaluation model to evaluate the actual effect of the intelligent lighting control system. The results show that it is not difficult to see from the results that the intelligent lighting control system designed in this paper can accurately control the lighting between different sports in large sports venues.

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Shengmin CAO,
Doctor, Associate Professor. Graduated from the Shenyang Sport University in 1997. Worked in North – Eastern University. His research direction is the sports policy of higher education and the training of sports education

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LIGHTING AND CONTROL DESIGN OF LARGE-SCALE STADIUM SKATING COMPETITION

Qi ZOU

Jilin Sport University, Changchun, Jilin, 130022 China
E-mail: yaj29377@sina.com

ABSTRACT

In order to further improve the synchronicity of stadium lighting, this paper puts forward a design and analysis model of lighting and control for large-scale stadium skating competition. In this paper, the development and mode analysis of lighting system based on micro-grid control are introduced. Then, in the process of analysis, the research model of circuit automatic control for micro-grid control is designed, and the algorithm is used to assist it. Finally, the simulation system is used to test the synchronization of the micro-grid controlled lighting system. The results show that virtual synchronous machine technology can significantly improve the coordination and synchronization of lighting system, and further reduce circuit failures, ensure the smooth lighting of stadiums, and have a good development prospects.

Keywords: micro-grid control, stadium, lighting, control design, system simulation

1. INTRODUCTION

With the continuous progress of social production, people's lives are more and more inseparable from the power industry. People's dependence on electricity is also getting stronger and stronger [1]. However, the complexity of the stadium lighting micro grid system makes people pay more attention to the synchronization of power consumption. According to the voltage of electricity consumption: medium voltage line, between the high and low pressure, the general voltage amplitude between 10 KV to 30 KV [2]. Compared with the high voltage line, the distance between the medium voltage line and the high voltage line is shorter, mainly for the large industrial area; low voltage lines, which mainly use stadium facilities themselves, generally do not exceed 500V. Most of them are controlled by micro-grid [3]. In the micro-grid control mode, the normal operation of venues and facilities is affected because of the numerous and miscellaneous facilities, and the corresponding circuit and system mode often appear. Therefore, in recent years, with the continuous development of micro-grid controlled lighting engineering system, people realize the importance of lighting engineering system based on micro-grid control, and the development of automatic control system has achieved initial results [4]. But on a large scale, the lighting engineering mode controlled by micro-grid is still in the exploratory stage in our country. In many places, there are still unreasonable electricity consumption and high mode rate. Therefore, the lighting and control design analysis system of large-scale skating stadium has been put forward, which has a positive role in reducing the mode rate of power consumption, improving the synchronization of power supply and enhancing the overall service capacity [5].

2. STATE OF THE ART

Although the development of illuminated mode detection system in China started late, after more than 10 years of exploration and development, the gap between the mode detection and inspection technology of high voltage line system and

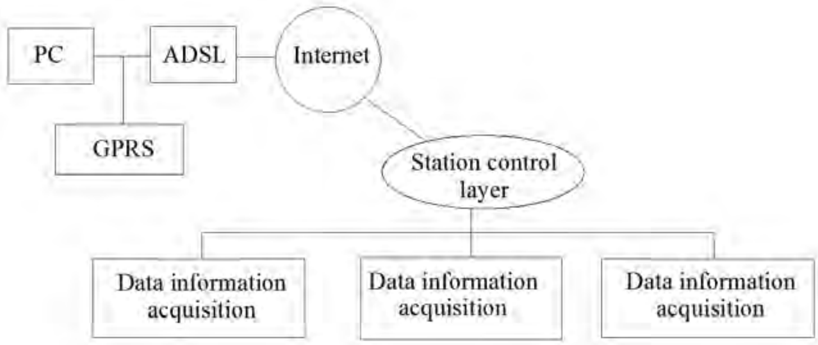

Fig.1. Structure diagram of photovoltaic monitoring system

foreign countries has been narrowed. However, it should be recognized that the research on lighting system mode controlled by micro-grid is still in a backward state, based on the huge population base and relatively backward scientific and technological level in China [6]. Many individual venues and facilities in the process of automatic control, which is rely basically on simple meters, and it is difficult to find control mode effectively [7]. In the overseas automatic control of lighting system, the more advanced intelligent mode is combined, which can give a certain warning to the appearance of the mode. After the appearance of the mode, the source of the mode can be found in the first time. It has greatly facilitated the operation of venues and facilities [8]. In recent years, the national government has also realized that besides the high voltage system, the improvement and construction of the medium and low voltage system is the fundamental to improve the satisfaction of venues and facilities and to solve the problem of high mode rate [9] China's Beijing, Shanghai, Shenzhen and other developed areas, advanced computer technology has been used in the management of low-voltage lines, greatly improving the management efficiency and reducing the occurrence of the mode. However, due to the imbalance of regional development in China, the lighting engineering system model based on micro-grid control in China is not perfect and mature [10]. There are still some problems, such as low automation, inadequate real-time supervision of electricity consumption, inadequate supervision and investigation of modes. Therefore, it is necessary to explore the mode of lighting system in sports venues controlled by micro-grid [11].

3. METHODOLOGY

3.1. Design Concept and Principle of Lighting System for Stadium Skating Competition

In sports venues, the demand for electricity is high and widely distributed [12]. Firstly, the object of study is micro-grid control [13], so from the point of view of virtual synchronization, a real-time control and detection system is designed based on General Packet Radio Service technology. With the development of modern communication technology, the transmission and analysis of power consumption data can be accelerated. After the information collection is completed, the data in the process of power consumption can be detected in real time by using the powerful information processing capability of the terminal. The equipment mainly includes plug-in box, transformer and power output switch lamp. The twisted pair transmits the centralized data of the equipment to the field trunk line, then the fibre ring network receives the data of the communication unit, which is pre-processed and the

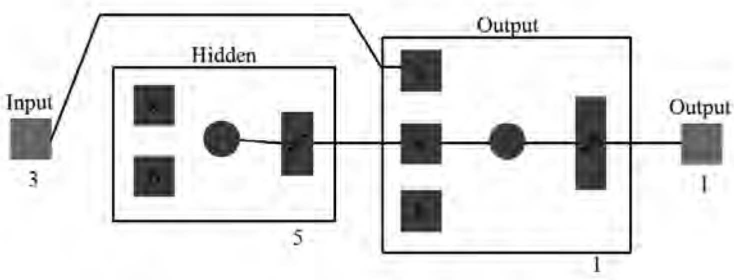

Fig.2. Monitoring system of Lighting Power Generation system

multidimensional conversion. The system is composed of three parts, as shown in Fig. 1.

As shown in Fig. 1, the top layer is the central layer, the brain of the entire system, which is responsible for regulating the entire system. The supervision of the whole lighting system is mainly applied in the central layer. The lowest layer is the equipment layer, which is mainly for data acquisition. For example, the current temperature of the line and the amount of power generated need real-time measurement of the equipment layer. According to the relevant data analysis of the most intermediate station control layer, it is mainly a data transmission centre, similar to the construction of the Broker. The information collected at the device layer can be fed back to the central layer through simple processing, or the commands placed at the central level can be transferred to the device Layer. Among them, the central layer and the station control layer use optical fibre lines. Because of a large amount of information transmission, Personal Computer intelligent instructions can be applied to the central layer, the central layer as the core of data processing. Through the application of the system, human and material resources will be greatly saved, and the relevant personnel only need to control the central level of data management. In the research process of the system, the design of the system contains three important steps. The first is the information collection phase. Since the design of the system is aimed at controlling and checking the power consumption of venues and facilities, the management requirements of venues and facilities should be collected and analyzed in the process of information collection. In addition, it is a functional analysis of products, which involves research and analysis of classic venues and facilities. The third stage is the integration stage, which mainly integrates the collected information and reflects the implementation of the feedback mechanism. The preliminary process design is as shown in Fig.2.

In the process of running the system, the corresponding principles must be met: First, the principle of real-time, facilities on the monitoring of electricity consumption, the transmission of electricity in a state of change at all times, which requires the establishment of a regulatory system should contain a large number of data analysis plates. Secondly, the principle of accuracy is different from the complexity of other multi-functional systems. From the point of view of venues and facilities, venues and facilities are sure to want to control the more accurate the detection of the better, can quickly take the right measures for control. Thirdly, the principle of rapidity is that the feedback mechanism of the system should start to operate as soon as the control is detected. Because the system is cyclic, regulation is a continuous process, if there is no timely data transmission, it is likely to lead to a link can't be carried out.

3.2. Design of Synchronization System for Lighting Engineering Based on Micro-grid Control

In sports venues, the system needs to collect basic data, and it needs to measure the effective value of data. Using the system, the direct ratio between *U* and *I* is adopted in the measurement of voltage and current in the line, where *U* represents the real-time RMS of voltage, *I* is the RMS of current, i is the instantaneous value of current, u is the instantaneous value of voltage. The stability of *U* and *I* is verified by substitution of corresponding formulas. After the valid voltage and current values are obtained, the data should be converted into corresponding digital signals for data processing. It can be seen that in order to maintain the accuracy and accuracy of data conversion, it is necessary to synchronize the acquisition information to prevent the mutual change of current and voltage from affecting the accuracy of detection. According to the sampling theorem, the higher the sampling frequency is, the more complete the analogue signal can be restored. However, in practical design, the sampling frequency will be affected by capture time, A / D conversion accuracy, Central Processing Unit speed, the sampling frequency can't be too high. The rationalization frequency should be worked out according to the actual needs of the line, rather than the pursuit of sampling frequency. The following formula is for the calculation of charge amount for large stadium power supply technology, as shown in the following formula:

$$\sum_{i \in A} P_{Gi} - \sum_{j \in A} P_{Li} - P_{loss} > \varepsilon. \qquad (1)$$

Dijkstra algorithm is used to calculate the quantity of charge with negative weight. For solving the problem of negative weight in the model, the defi-

Table 1. Computer Aided Lighting System Design Hardware

Project	Hardware constitution	The main influencing factors of the system energy
Graphics workstation	Professional graphics cards	Memory, hard disk
Collaborative design system	Data transmission line	Network status
VR system	Excellent integrated display	Data acquisition
Microcomputer	A central processor	Graphics accelerator card

nition of safety factor shows that it is advantageous to the safety factor F_s.

$$F_s = \sum \tau_f / \sum \tau. \tag{2}$$

Since all anti-sliding forces are positive, if one sliding force is negative, it is equivalent to making the denominator smaller, so the safety factor will increase. So for module overlap, it is beneficial to deal with it. Define the size relationship as follows:

$$F_s(P) - F_s(P') = \frac{a+c}{b+d} - \frac{a+e}{b+f}. \tag{3}$$

If the formula holds, then $\left(P'\left(v_s, v_j\right)\right)$ can be deduced as the shortest path by the method of counter-proof, and the problem can be transformed into a mathematical expression as follows:

$$F_s\left(P'\left(v_s, v_j\right)\right) = \frac{\tau_f(Q) + \tau_f\left(v_i, v_j\right)}{\tau(Q) + \tau\left(v_i, v_j\right)}. \tag{4}$$

It is very difficult to satisfy the power supply, because if there is an edge, its safety factor is relatively small, but its position is far from the shortest path, the shortest path will not pass.

$$F_s\left(P\left(v_s, v_j\right)\right) = \frac{\tau_f(Q) + \tau_f\left(v_i, v_j\right)}{\tau(Q) + \tau\left(v_i, v_j\right)}. \tag{5}$$

Second, the hardware and software requirements of the Personal Computer terminal should also be taken into account. The application of new technology requires a certain degree of detection performance. Because the system has the corresponding graphics, video and other integration and output functions, its configuration as is shown in Table 1.

In Table 1, it can be seen that the operation of a good system improves the configuration of the computer to a certain extent, which not only has a certain technical advantage in the graphics processor, but also in the coordination of network patency. In the aspect of regulating system, higher configuration requirements are put forward to the computer, which not only considering the accuracy of data processing, but also considering the surrounding environment. Finally, based on the addition of General Packet Radio Service module technology, a benign system cycle requires timely information exchange between facilities and systems. The first is the control and monitoring of the whole line. Before the Internet has been put into practice, many electric facilities can only receive rated power. Once the control occurs, it is impossible to adjust the voltage quickly and autonomously, resulting in further expansion of the control. Secondly, due to the lack of a corresponding rapid adjustment range, so many times there will be an embarrassing situation of power failure. Under such circumstances, it is urgent to deal with the intellectualization of power generation and supply. Based on the above design ideas, for the power generation system, the following

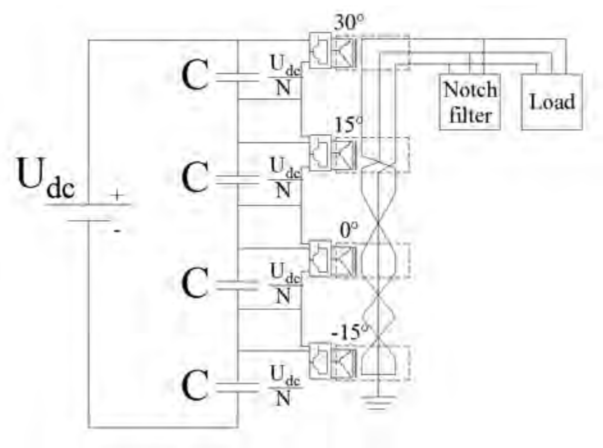

Fig.3. Optimization of communication structure of monitoring system for stadium lighting

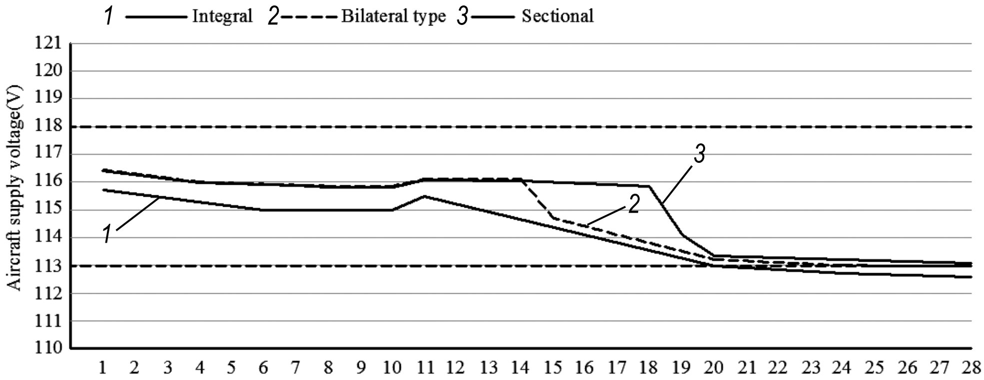

Fig.4. Comparing experimental results versus graphs

is the main idea, as shown in Fig. 3, In this mode, it is found that the line appears to be controlled, the order is issued through the venues and facilities, the General Packet Radio Service touch-board is used to reach the service terminal on the spot, the simple information processing is interrupted, the line is fed back to the multi-function meter, and the multi-function meter influences the transmission of the transformer to complete the control of the power generation system. This transmission mechanism is bidirectional, so in the process of venue facilities to manage the power generation system, the data will be updated in real time, greatly reducing the possibility of control. The detailed drawing is shown in Fig.3.

With the continuous development of intelligent detection, its data processing ability in the circuit system is no longer the same. After the process of the whole system is clear, it is necessary to perfect the control data model with the corresponding auxiliary technology, so that the venues and facilities can participate in the actual control improvement. In the previous article, the establishment of the feedback system of the whole line is improved, and then through the development of wireless technology and Internet technology, venues and facilities can be managed by themselves using the Internet. This model is mainly related to the establishment of facilities and the central level between the relevant links. The original line system monitoring is transmitted to the Internet in real time, and then the Internet is used to directly provide feedback to the monitoring. Each facility has an independent account that can be monitored remotely. The facility then has the right to supervise on-site and in-station monitoring. It can use its own needs to change the mode of power consumption at any time and enable intelligent self-regulating circuit control.

4. RESULT ANALYSIS AND DISCUSSION

After the completion of the research and design, in order to verify the feasibility of the theoretical design, the corresponding experimental tests are carried out on the system. In the exploration of specific applications, a real lighting micro net system is selected for performance testing. In the control and detection system of the original venue lighting micro-grid system, because most of them are manual investigation, the work efficiency is low, and each time the control and inspection can't be completely improved, and the actual effect is quite different.

Table 2. Steady-state Experimental Data of Lighting System Control for Stadiums

Reference value /V	Actual output value /V	Steady difference /V	Steady-state error/%
200	241	3	1.45 %
300	423	5	4.33 %
400	124	4	6.75 %
500	566	9	7.2 %
600	133	14	4.87 %
700	556	15	7.57 %

Table 3. List of Common Emotion Research Directions

Project	Total survey	Number of failures	Other factors interference	Failure rate
Experience group	1000	2	0	0.2 %
Control group	1000	20	0	2 %

After using this system, the system first collects the data of the whole venue lighting micro-grid system. According to the real-time power consumption status provided by each venue facility, the corresponding stadium lighting balance adjustment is made, the voltage and current and the adjustable amplitude are normalized, and the possible control according to the abnormal processing of the circuit. With the introduction of this system, the company's control, investigation and testing system has been on the road of automation and information in a relatively short period of time.

As shown in Fig. 4, this is the real-time operation of the line after the completion of the information collection. In the past, the line statistics can only be distinguished by normal and abnormal. In this line statistics, both the overall operation of the line, as well as the real-time voltage, current maximum and minimum fluctuation range, the traditional line detection is difficult to achieve comprehensive coverage. In the analysis of the system, the possible risks are estimated, which indicates that there is a strong early warning capability. When the control occurs, even the fastest remedy will affect the normal operation of the whole line, but the early warning mechanism will reduce the possibility of runaway, while ensuring the continuous and stable operation of the whole line. In addition, based on its huge database function, every real-time data can be saved in time. The investigation of historical control can greatly reduce the likelihood that the same control will occur again and greatly reduce the difficulty of work. Traditional workers often need a few days to check and control. After the application of the lighting engineering system control system controlled by micro-grid, the accuracy and efficiency of the control check-up have been greatly improved. The result data of the power system using the algorithm are shown in Table 2.

The Table 2 shows the power supply technology using the new algorithm. The data show that the efficiency of power transmission has been significantly improved and the efficiency of oil resources exploitation has also been significantly improved after the application of the new algorithm.

In order to prove the specific performance of the system, through the application of the lighting engineering system controlled by micro-grid in large stadium, the feasibility of the system is explored in detail. A comparative study of traditional lighting engineering system control and exploration system based on micro-grid control is organized. A total of 2000 venues and facilities controlled by micro-grid in a large stadium are selected as the experimental subjects and divided into control group and experimental group according to the situation. 1000 people in the experimental group adopted the control and management mode of lighting engineering sys-

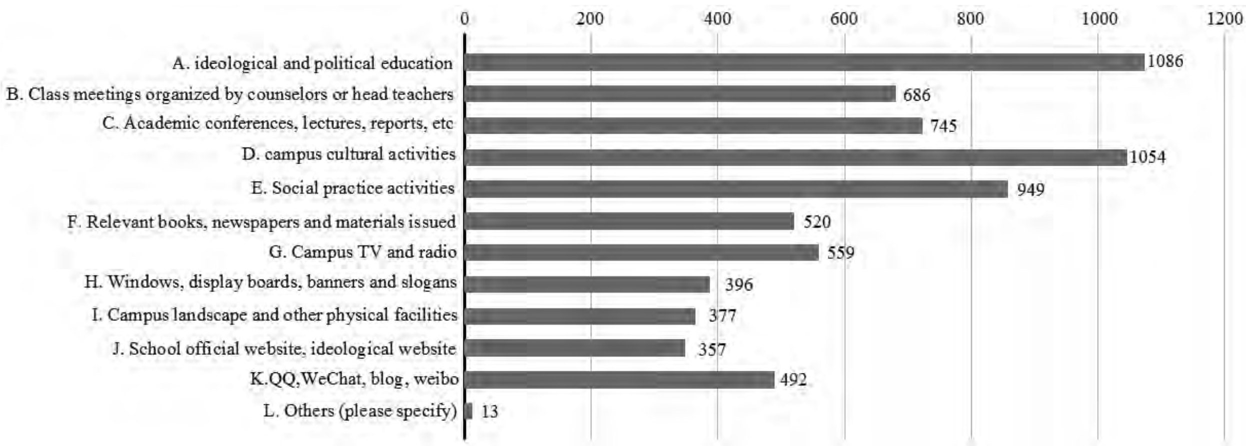

Fig.5. Synchronization test of lighting system controlled by micro-grid circuit system

tem proposed by this time, and 1000 venues and facilities in the control group adopted the traditional control and management mode. In order to study the stability and practicability of the system, it is decided to take the control in the process of power consumption of venues and facilities as the object of study. In order to improve the accuracy of the experimental data, the investigation time is set at the peak of electricity consumption. The control occurrence rate of the experimental group and the control group is compared between 7:00 and 9:00 in 10 days. The findings are shown in Table 3.

Through the detailed analysis of Table 2, it can be seen that the control rate of the experimental group is 0.2 % and that of the control group is 2 % after adding the computer supervision mode and excluding other interference factors. By comparison, the control rate of the venues and facilities in the process of power consumption is significantly reduced, which also shows that the system has a strong function of adapting to the environment and can play a good role in different environments. The whole research shows that the control of lighting engineering system based on micro grid has strong feasibility, Fig. 5.

The system can find out the control of the circuit more easily and quickly, and make the early warning and the corresponding investigation at the first time when the control occurs. The application of this system makes the whole regulation only need 3–5 cycles of coordination work, the number of cycles is greatly reduced, thus improving the work efficiency and speeding up the repair time of the line. In addition, the speed of each coordination work is also increased, saving money and reducing rework. However, this survey did not involve the application in a special environment, so there is a certain flaw in the comprehensive investigation. In future tests and research, emphasis will be placed on the application of the system in special environments.

5. CONCLUSION

With the development and application of information technology in gymnasium lighting system in China, the lighting engineering system controlled by micro-grid has a great prospect in large-scale skating competition. Therefore, the application of virtual synchronization technology in micro-grid control of stadium lighting micro grid system is put forward. The proposed system model is conducive to the realization of the optimization of lighting power lines, the safety of lighting power is improved, and the ability to check the synchronous control of lighting is increased. Considerable results have been achieved in the actual stadium lighting system test. In order to further verify the feasibility of the system, the effect of the application of the control system in lighting engineering system is explored. In order to further verify the performance of the system, the synchronous control processing of large stadium circuit is studied. By comparing the synchronization control rate of the traditional mode, it is found that the synchronization control rate of the large-scale stadium is only 0.2 % after adopting the control system, but in the traditional mode, the synchronization control rate of the line is 2 %. By comparing, it is found that the lighting and control system of the large-scale stadium skating competition has very strong function. However, this test has some flaws in the comprehensive investigation. In future tests and research, emphasis will be placed on the application of the system in special environments.

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Qi ZOU,
Master Dr., Associate Professor. Graduated from North-east Normal University in 2007 and now working in Jilin Sport University. The research interests include physical education

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DESIGN & DEVELOPMENT OF A SOLAR POWERED, CCT CHANGING R-B-W LED BASED ARTIFICIAL WINDOW

Basudeb Das, Asit Kumar Sur, and Saswati Mazumdar

Electrical Engineering Departmentt, Jadavpur University, Kolkata, India
E-mails: basudebdas.1991@gmail.com; saswati.mazumdar@gmail.com

ABSTRACT

The concept of Artificial Window is being applied in indoor lighting design since couple of years and is easily available in market, but the main drawback of these artificial windows is their constant CCT (Correlated Colour Temperature) light output. The developed artificial window is a CCT changing system, which follows the preset pattern of daylight CCT throughout the day. It will very effective for those, who stay in a window-less room or a closed room. It is known that light not only has the visual effects but also has photo-biological effects. A dynamic light is very helpful in well being, positive mood, increased concentration, alertness consequently increased productivity. The developed system is solar powered at daytime; this window is powered by the SPV module directly without using battery. A small battery is being charged simultaneously which powers the system at night time. The window is made using two types of coloured LEDs: Red and Blue and Warm White LED. The new concept of dynamic lighting provides a very wide CCT range from 2300 K to 10800 K.

Keywords: artificial window, human centric lighting, CCT changing lighting, solar powered based system, dynamic lighting, dynamic lighting controller

I. INTRODUCTION

Window is a very important part of any building. It has a psychological effect on people. Daylight can enter inside the room through the window; this is the main purpose of a window. Daylight is a natural light source, which varies over time in quantity (illuminance) and quality (colour) [1,2]. A room can be illuminated using daylight and it has several good effects on mankind [3]. Daylight has a great impact on the human circadian system [4], influencing our metabolism and controlling the hormone balance [5,6]. Many modern urban multi-storeyed buildings, even many village huts do not have the windows. People inside those rooms always stay under the artificial light and many of them suffer from seasonal affective disorder (SAD) caused by lack of daylight [7,8].

In such buildings and rooms artificial windows may be used, serving the same purpose, giving the illusion of a natural window. The artificial windows available in Indian market have the constant CCT. Such types of windows do not fulfil the requirement of a real window; they do not give the dynamic light effect of daylight. This designed and developed artificial window produces the dynamic light effect throughout the day. This dynamic light resembles to the daylight, i.e. the window follows the preset pattern of daylight CCT all the day. At night time, it produces a constant CCT (2900 K). The CCT of daylight can varies from 2000 K at sunrise to 5000 K at noon in clear sky conditions. Sometimes it exceeds 10,000 K in overcast conditions [9,10]. Using the combination of Warm White (2840 K) and Cool White (5750 K) LEDs [11] it was not possible to get the CCT of 10,000 K of overcast conditions. Many experiments were done to get the wide range of CCT using red-yellow-green-blue (RYGB) LEDs [9,12,13]. To get that wide range of CCT very easi-

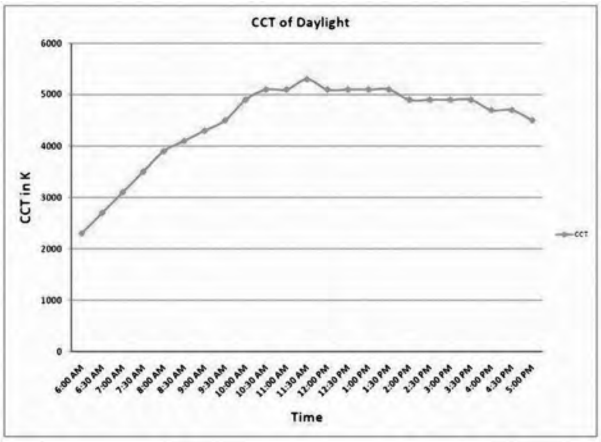

Fig.1. CCT of Daylight in the month of March'2017

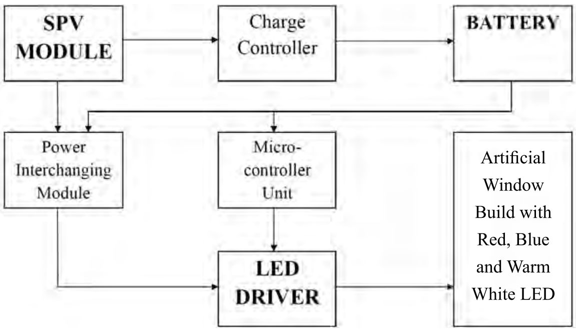

Fig.2. Block diagram of the system

ly, red, blue and warm white LED having CCT 2900 K was used in the window prototype and this combination of LEDs achieved up to 10,800 K CCT.

This window is powered by the solar photo voltaic (SPV) module directly at daytime and at night time it gets power from a battery, which will charged during daytime by the SPV module at daytime simultaneously. When the insolation is less, light level of the artificial window falls down. In the cloudy condition or in the evening time when there is no sunlight, this window provides a constant CCT of 2900 K. The design of the artificial window is described in the following sections.

2. MEASUREMENT OF DAYLIGHT CCT

As daylight is dynamic in quality and quantity, spectral power distribution (SPD) and light level of daylight varies with time [1,2], CCT of daylight cannot be standardized for a particular day or season. For the artificial window a daylight pattern is needed. The measurement of daylight CCT is done in the month of March'2017 on the rooftop of Electrical Engineering Department, Jadavpur University, Kolkata, India, in clear sky condition. This experiment was performed for 15 days. CL200A colorimeter (Konica Minolta Measuring Instrument, Japan) was used to measure the CCT of daylight. It is seen that during sunrise the CCT is around 2300 K, at noon around 5400 K and during sunset it falls to 4500 K. Collecting all the data of 15 days, a CCT pattern is made for the artificial window, which is shown in Fig.1.

3. CONCEPT OF VARIABLE CCT USING LED

In this system, the colour mixing follows the Grassmann's law of colour. According to Grassmann's law, colour mixtures obey the law of addition. If the tristimulus values (*X, Y, Z*) of two colours are known, they can be added to obtain the tristimulus values of the resultant. Usually, a colour can be specified in terms of its chromaticity coordinates (*x, y*) and its luminance (*L*), which is proportional to the tristimulus value *Y* [14,16]. Chromaticity of the resultant colour can be obtained using (1):

$$x = \frac{\sum_1^n \left(xk \frac{Yk}{yk} \right)}{\sum_1^n \frac{Yk}{yk}} \text{ and } y = \frac{\sum_1^n \left(yk \frac{Yk}{yk} \right)}{\sum_1^n \frac{Yk}{yk}}. \quad (1)$$

The chromaticity coordinates (*x*, *y*) of this blended colour will be somewhere on the straight line connecting the chromaticity coordinates of two colours on CIE1931 chromaticity diagram. The tristimulus distribution function $\overline{y}(\lambda)$ is exactly similar to the relative spectral luminous efficiency curve V (λ). Hence any photometric parameter like luminous flux (*Φ*), luminance (*L*) or illuminance (*E*) is proportional to tristimulus value *Y* [14]. Therefore, colour can be specified by chromaticity coordinates (*x, y)* and any photometric parameter [11]. In this work, the colour is specified by chromaticity coordinates (*x*, *y*) and the illuminance (*E*). Equation (1) can be rewritten as

$$x = \frac{\sum_1^n \left(xk \frac{Ek}{yk} \right)}{\sum_1^n \frac{Ek}{yk}} \text{ and } y = \frac{\sum_1^n \left(yk \frac{Ek}{yk} \right)}{\sum_1^n \frac{Ek}{yk}}. \quad (2)$$

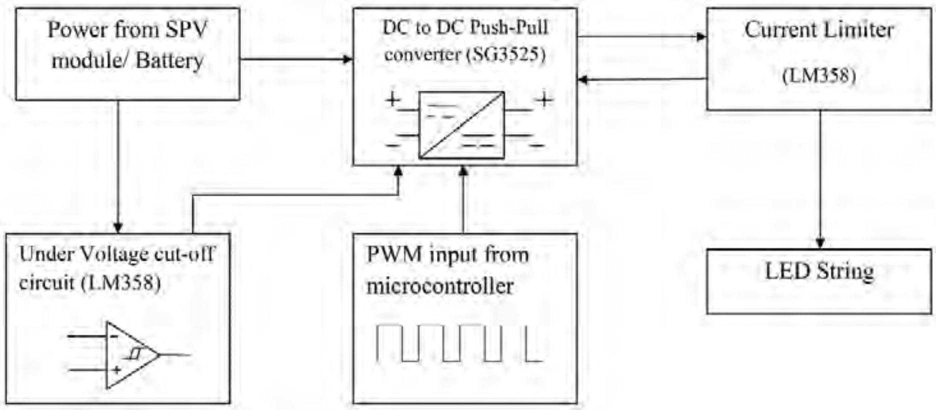

Fig.3. Block diagram of LED driver

4. DESIGN OF THE CONTROLLER CIRCUIT

4.1. Block Diagram of the System

Block diagram of the system is shown in Fig.2.

There are three individual LED drivers for three colours of LED. This driver includes the under voltage cut-off circuit, DC-DC converter circuit and current limit circuit etc. A charge controller charges the battery and consists of a DC- DC converter, under voltage cut-off circuit, current limit circuit, overcharging protection module and deep discharge protection module. Due to low insolation, when SPV module's voltage falls below 10V, whole system gets disconnected from the SPV module and this is done by the under voltage cut-off circuit and the window (at 2900K CCT) is powered by the battery instantly, which is done by the interchanging module. The overcharging protection module protects the battery from excess charging and the deep discharge protection module protects the battery from deep discharging. There is a microcontroller (ATMEGA 32 microcontroller from ATMEL) unit in this system, which generates the PWM signal for three different colours of LEDs for a particular CCT. The CCT changing throughout the day is controlled by this unit.

4.2. Description of LED Driver and the Charge Controller

Three LED drivers are used for three different colours of LED. Design and construction of three drivers are similar. In this section one LED driver is discussed. Block diagram of LED driver is shown in Fig.3.

The LED driver consists of a DC-DC converter, a current limiter, an under voltage cut-off circuit and a push-pull switching circuit for dimming the LED. For any LED driver it is necessary to make it constant current and constant voltage configuration (CC/CV). To make the CV configuration DC to DC Push-Pull converter is designed using SG3525 IC. It is a dual output SMPS IC and it is operated at the frequency of 100 KHz. In current limiter circuit a LM 358 op-amp is used as a comparator, which compares the voltage across current sensing resistor with a reference voltage. When the voltage across the resistor exceeds the reference voltage, a high signal is sent to the IC SG3525 and the output voltage will be reduced, as well as the current will also be reduced. The under voltage cut-off circuit is a comparator too. LM 358 op-amp is used as a comparator, which compares the input voltage with a reference voltage of 10 V. Whenever the input voltage falls below 10 V, it will generate a high signal. The high signal is given to the pin 10 (shut down pin) of SG3525 IC. As long as the pin 10 is in high state, circuit will be shut down completely and output voltage will remain zero. When a low signal is applied to that pin, circuit will be in operating condition. The microcontroller (ATMEGA 32) is programmed in that way, it will give different PWM signal for different CCT. The PWM signal controls the illuminance level of Red LED and Blue LED. The on time and off time of the control signal depends upon the duty cycle of the PWM signal. If the duty cycle of the PWM signal is higher, on time will be high and LED will glow brighter, illuminance will be higher. If the duty cycle is less, on time will be less, LED will be dimmed and the illuminance will be less. The on and off cycle is opera-

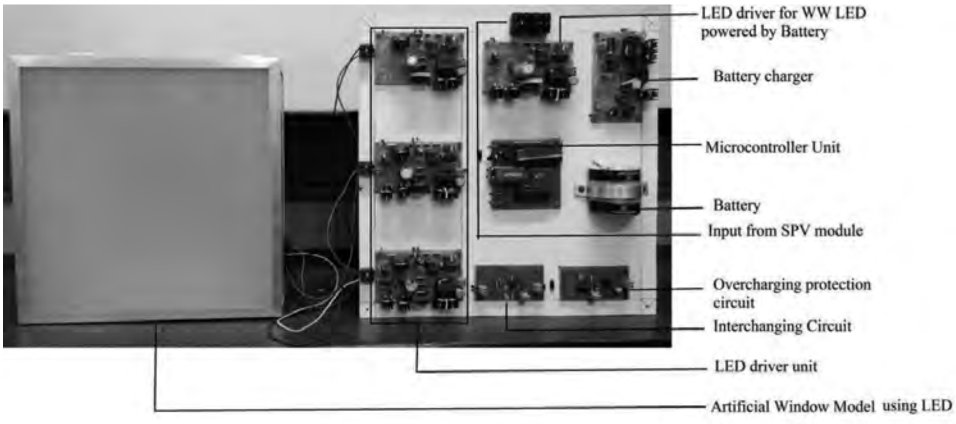

Fig.4. Developed System

ted in very high frequency, so that one cannot see it in bare eye.

The circuit operation of the charge controller is same as the LED driver. It consists of a DC-DC push-pull converter, a current limiter and the under voltage cut off circuit. Beside that an overcharging protection circuit and a deep-discharge protection circuit is also incorporated with the charge controller to protect the battery from damage, which increases the battery life.

5. DEVELOPED SYSTEM

The window has been developed with 24 numbers red LEDs, 24 numbers of blue LEDs and 24 numbers of WW LEDs. When it is covered with a good diffuser and fitted on wall, it resembles opaque glass covered window. The developed system is shown in the Fig.4.

6. COLOUR MIXING EXPERIMENT FOR VARIABLE CCT

To get the variable CCT by mixing the colour, it is necessary to use the suitable light source with appropriate colour. Many works were done in past to get the wide range of CCT using two or more colour sources. By mixing the red-blue-green (RGB) LEDs [15] or red-yellow-green-blue (RYGB) LEDs [9,12,13], variable CCTs were generated, but the mixing algorithm is difficult and the control circuit is costly. Using the mixture of cool white (6000 K) and warm white (2700 K) LEDs [11] wide range of CCT cannot be generated. In this developed system two types of LED, red and blue have been mixed with Warm White LED with 2900 K CCT. WW LED is taken as a reference. Here CCT below 2900 K is achieved by the mixture of WW LEDs and the red LEDs and the CCT above 2900 K is achieved using WW LEDs and blue LEDs. The mixing algorithm is quite easy and a wide range of CCT, starting from 2300K to 10800K has been achieved here.

The resultant CCT is obtained when two or more colours are mixed by changing the input currents of the LEDs and ultimately changing the illuminance (*E*) of the individual light sources (Equation 2).The input current can be changed by the pulse width modulation (PWM) technique. If the width of the current pulse increases, current will increase, as well as the illuminance of the light source also increases.

The colour mixing experiment was performed in the Illumination Engineering Laboratory, Electrical Engineering Department, Jadavpur University, India. A luminaire used in this experiment consists of three WW LEDs, three blue LEDs and three red LEDs (total nine LEDs). A dome shaped P4 type LED of 1watt has been used. Dimension of the luminaire is 6”x6”x3”. Three control circuits are used for each colour of LEDs, the PWM duty cycle is controlled by these control circuit. The WW LED

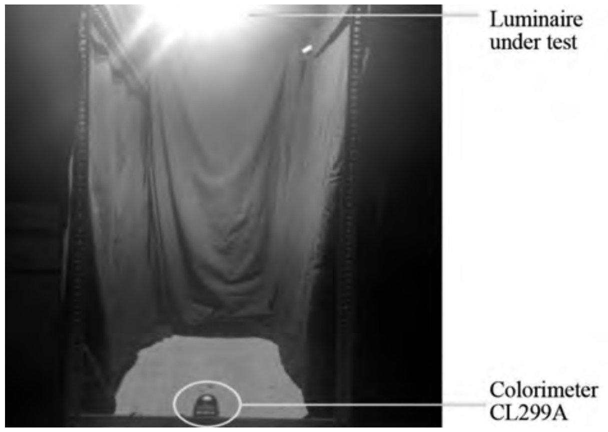

Fig.5. Experimental setup of the colour mixing experiment

Table 1. Experimental Results of Colour Mixing Experiment

PWM duty cycle, %			Illuminance, E_v, lx	Coordinate		CCT, K
Red LED	WW LED	Blue LED		*X*	*y*	
10.2	100	0	27	0.4727	0.3834	2300
2.5	100	0	25.8	0.4122	0.3299	2700
0	100	0	25.6	0.3967	0.3170	2900
0	100	1.9	25.6	0.3736	0.2937	3300
0	100	2.8	25.8	0.3606	0.2838	3700
0	100	4.1	26.1	0.3445	0.2750	4500
0	100	4.5	26.3	0.3369	0.2704	4900
0	100	5.3	26.6	0.3272	0.2630	5700
0	100	5.4	26.6	0.3253	0.2606	6000
0	100	5.8	26.8	0.3204	0.2548	6600
0	100	6.2	27	0.3164	0.2500	7200
0	100	6.5	27.1	0.3132	0.2460	7800
0	100	6.8	27.2	0.3105	0.2429	8400
0	100	7.2	27.2	0.3076	0.2394	9200
0	100	7.5	27.2	0.3058	0.2372	9800
0	100	7.7	27.2	0.3047	0.2359	10200
0	100	8.0	27.3	0.3033	0.2342	10800

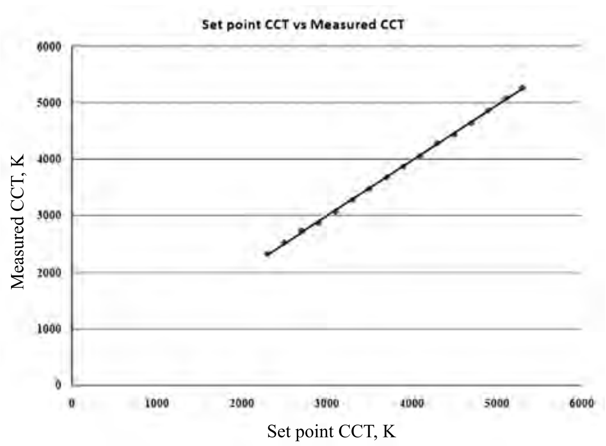

Fig.6. Set point CCT vs Measured CCT

duty cycle has been kept fixed at 100 %. The colorimeter CL200A is used for measuring the resultant CCT. It is placed vertically at 6 ft distance from the luminaire. The experimental set up is shown in Fig.5.

In this experiment varying PWM duty cycle for red and blue, the data of illuminance at a fixed point,

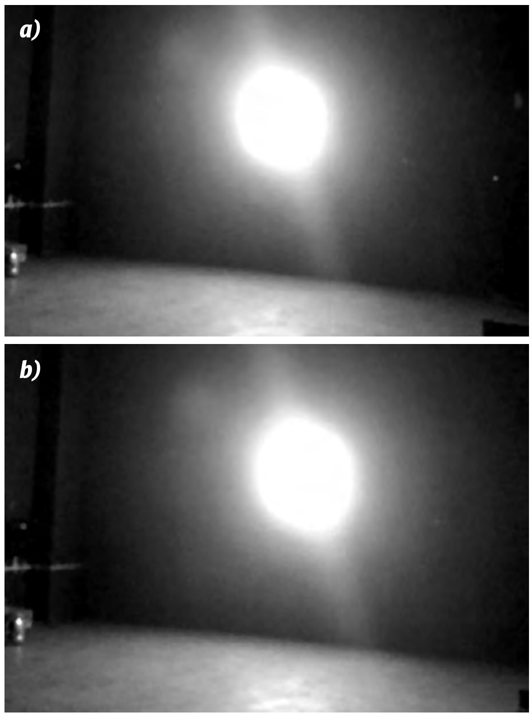

Fig.7. Artificial window model at different CCT: a) CCT 2500 K, b) CCT 5300 K

Table 2. Photometric and Colorimetric Data of the Designed Artificial Window

CCT, K		Illuminance, lx							
		1m		2m		3m		4m	
Set point	Measured	Ver.	Horiz.	Ver.	Horiz	Ver.	Horiz.	Ver.	Horiz
2300	2328	310	106.3	110.4	38	45.6	16.3	27.6	8.5
2500	2530	270	103	106	37.6	45.3	16.2	27.5	8.5
2700	2727	250.2	99	99	37.2	44.2	15	25.9	7.9
2900	2867	225.5	95	97.2	36	43	14.7	25.8	7.9
3100	3069	228.7	95.4	97.3	36.2	43.8	14.7	26.2	8.0
3300	3280	230	95.5	97.7	36.8	44.3	14.7	26.8	8.1
3500	3474	240.6	95.9	97.1	35.8	45.2	14.7	26.3	8.0
3700	3675	255.9	96	97.3	36.1	44.1	15	26.9	8.1
3900	3868	260.2	96.2	99.2	37.5	43.9	14.8	26.9	8.1
4100	4059	262.5	96.9	97.5	36.6	43.6	15	26.9	8.2
4300	4280	255.3	96.2	97.9	37.1	44.1	14.7	26.9	8.2
4500	4436	258.2	97.1	101.2	37.5	45.3	15.5	27	8.2
4700	4639	263.7	97.4	98.2	37	45.4	14.8	27	8.3
4900	4865	265.6	97.4	98	36.8	46	14.6	27.1	8.2
5100	5076	260.3	96.6	98.1	36.7	46.7	14.6	27.3	8.3
5300	5261	267.2	97.5	98.2	36.9	46.6	14.5	27.3	8.4

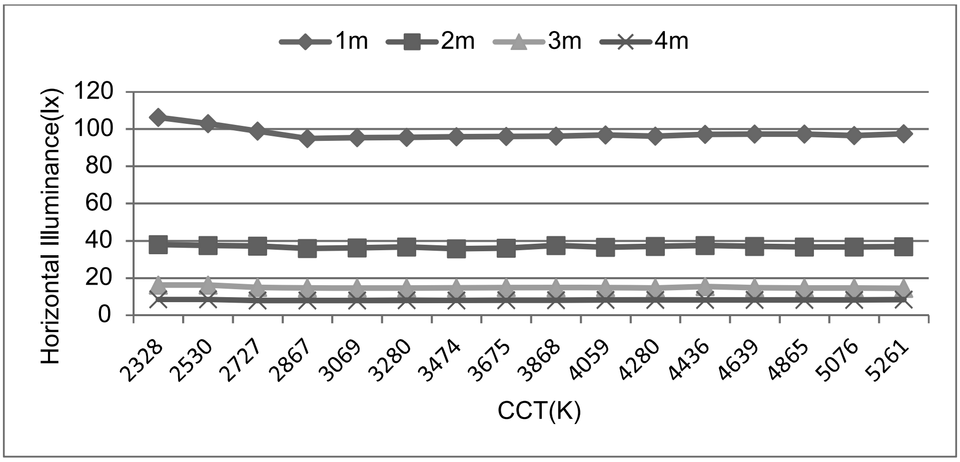

Fig.8. Horizontal illuminance with distance for different CCT of the Source

coordinate (x, y) and the resultant CCT has been taken. The experimental result of colour mixing experiment to get variable CCT is given in Table 1.

7. PHOTOMETRIC AND COLORIMETRIC PARAMETERS OF THE SYSTEM

The colorimetric and photometric data of the artificial window is taken. For the dynamic lighting, initially the CCT is decided and accordingly the microcontroller is programmed. It is necessary to observe the CCTs of artificial window and compare the observed CCTs with the preset CCTs. CCTs are measured with the colorimeter CL200A with proper experimental set up. Horizontal and vertical illuminance is also measured at 1m, 2m, 3m and 4 m distances from the artificial window. The measured data are given in Table 2.

Set point CCT vs measured CCT is shown in the Fig.6.

It is seen that CCTs of the artificial window are very close to the desired CCTs. Fig.7 shows artificial window at different CCTs.

The measured CCTs vs illuminance graphs are given in Fig.8.

From the graph given in Fig.8, it is seen that when the CCT is 2328 K the horizontal Illuminance is maximum, the red colour is mixed with the warm white colour here. With decreasing value of red content, CCT is increasing and the illuminance is decreasing. When CCT is measured as 2867 K, there is no red or blue colour mixed; only the warm white is present. At that time illuminance is less than any other values. When the CCT is increasing with the increasing value of blue, the illuminance is also increasing. As the change of amount of blue is very less, the illuminance increases very slightly.

8. CONCLUSIONS AND FUTURE SCOPE

Our country India is located close to the equator where sun light with high intensity and long shining hour is available. To meet up the increasing demand of electrical energy, solar energy can play a vital role. Solar energy has some drawbacks, in cloudy days it cannot produce the required energy. This developed system is completely based upon solar energy. In cloudy weather this system will not work properly.

The developed dynamic lighting artificial window follows the preset pattern of day light CCTs for clear sky condition. The system will be more realistic and more practical if the CCT of artificial window varies with the present available daylight CCT instantly considering a feedback system. If the daylight CCT varies, CCT of the artificial will also vary instantly. In that way one may get the exact outer sun conditions (CCT and illuminance) sitting in a closed room where sunlight is not available.

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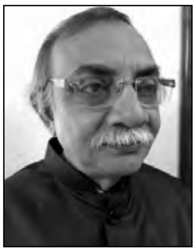
Basudeb Das

received the B. Tech. degree in Electronics & Communication Engineering from Guru Nanak Institute of Technology, Kolkata, India and M.E. degree in Illumination Engineering from Jadavpur University, Kolkata, India in 2017. His research interest includes optical communication, dynamic lighting, Solar powered based lighting systems



Asit Kumar Sur

is a Visiting Demonstrator for Master's courses on Illumination Engineering course, Jadavpur University since 2004, consultant engineer in designing of various digital electronic projects for 35 years in different companies. His research interest includes electronics, power electronics and solar system based lighting technology

Saswati Mazumdar,

Ph.D., Professor in Electrical Engineering at Jadavpur University (JU), Kolkata, India. She has 30 years of experience in lighting research and teaching, developed a modernized Illumination Engineering laboratory in Electrical Engineering Department, Jadavpur University, has founded two Masters' Courses on Illumination Engineering (Daytime) and Illumination Technology & Design (evening) in JU, executed a large number of R&D and Consultancy Projects on Illumination and allied fields

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PHYSICAL EXERCISE BEHAVIOUR AND EFFECT OF PHOTOVOLTAIC ENTERPRISE EMPLOYEES

Jinghua LI

School of Physical Education, Xianyang Normal University, Xianyang, Shaanxi, 712000 China
E-mail: n8353881@sina.com

ABSTRACT

In order to improve the physical health of employees in high-pressure working environment, this paper investigates the behaviour and effects of physical exercise of photovoltaic companies. Firstly, the article expounds the physical health status of employees in China's photovoltaic enterprises, then enumerates the research results of the physical exercise behaviour and effects of employees at home and abroad, and uses the mixed Gaussian model to study the behaviour and effect of photovoltaic employees' physical exercise. Specific measures to promote active physical exercise for employees are proposed. Finally, the article uses the multi-level fuzzy comprehensive evaluation model to evaluate the rationality of the measures. The results of the evaluation show that the measures proposed in the paper have positive effects on the health of photovoltaic employees.

Keywords: photovoltaic enterprise, employees, physical exercise

1. INTRODUCTION

Photovoltaic lighting is a relatively popular industry in China at present, and both the industry's gross domestic product and industry-related practitioners have a large scale [1]. However, due to the imperfect development system of the industry, although the photovoltaic enterprises have developed very prosperously, the physical exercise of their employees has not received enough attention. The physical health of photovoltaic companies' employees is not satisfactory, which seriously restricts the further development of photovoltaic companies [2]. Only in-depth investigation and research on the behaviour and effects of photovoltaic employees can be used to develop practical solutions within the industry, so that targeted solutions can be developed [3]. Reasonable physical exercise can effectively maintain people's physical and mental health, promote blood circulation, improve blood supply to the brain, maintain normal brain function, and maintain efficient and clear thinking [4].

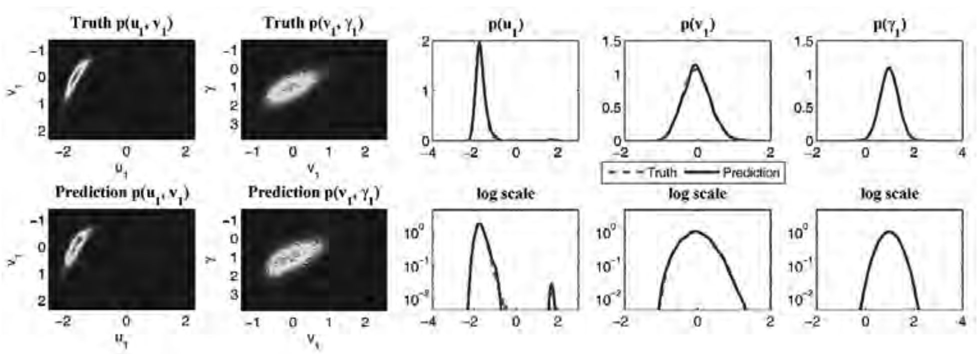

Fig.1. Fuzzy comprehensive evaluation mathematical model

In addition to maintaining the health of the body, the mentality of the person is also in a state of steady health and maintaining a healthy personality [5]. However, due to the existence of many deficiencies in the research on the physical exercise behaviour and effect of photovoltaic enterprise employees in China, the guidance exercise opinions cannot fully meet the actual exercise demand [6]. The backwardness of theoretical research will inevitably lead to the backwardness of physical exercise behaviour and effects of photovoltaic companies [7]. This is very detrimental to the healthy and sustainable development of the photovoltaic lighting industry, and is even more detrimental to the personal and physical development of the relevant practitioners. How to improve the physical and mental health of employees through better physical exercise planning has long been a research topic for relevant practitioners. The investigation and research on the physical exercise behaviours of photovoltaic employees and their effects are carried out, and the improvement direction is discussed [8].

2. STATE OF THE ART

In developed countries where the relevant employees of foreign companies are more perfect, they attach great importance to the physical exercise behaviour of employees, and regard it as a kind of human capital investment behaviour for employees. It is also an important method for enterprises to protect their own labour resources [9]. In the 1950s, with the development of the corporate system, enterprises have become more and more valued about their own labour resources, and began to protect through a variety of ways, strengthening the physical exercise of employees is one of the methods. After years of development, the relevant systems have been perfected and the coverage is very broad. For example, in the United States, more than 60 % of companies have their own physical exercise facilities and develop a very perfect sports club model. The Swedish National Sports Club is more affluent, with nearly 30,000 sports clubs, and an average of three residents will have one to participate in sports clubs. In China, due to the late start of the enterprise system, the research on the behaviour and effect of employees' physical exercise is lagging behind the developed countries, and more is still in the initial stage of establishment of the physical exercise system. Some scholars have studied the current situation of the employee sports management system of large enterprises in China, and proposed to implement the enterprise management of employee sports, and further enrich and complete it through the market mechanism.

3. METHODOLOGY

3.1. Multi-Level Fuzzy Comprehensive Evaluation Model

The multi-level fuzzy comprehensive evaluation model is an evaluation model based on fuzzy mathematics. Based on the qualitative evaluation theory, the fuzzy mathematics comprehensive evaluation method uses fuzzy mathematics to quantitatively evaluate various factors of things or objects, and then comprehensively evaluates them [10]. The mathematical model is shown in Fig. 1. The multi-level fuzzy comprehensive evaluation model has certain advantages in solving some nonlinear fuzzy problems. If this evaluation method is used to evaluate, the clear results can be gotten. Therefore, it is widely used and expresses the uncertainty of things. The basic implementation principle of the fuzzy comprehensive risk assessment method is as follows:

Let $V=\{v_1,v_2,\cdots,v_m\}$ be the factor of the research object, called the factor set. $V=\{v_1,v_2,\cdots,v_m\}$ are the set of judgments composed of m factors of various factors, and their number and name can be subjectively determined according to the needs of actual problems and decision makers. In real life, most of the criteria for consideration have no clear criteria, so the comprehensive judgment should be a fuzzy subset $B=(b_1,b_2,\cdots,b_m)\in F(V)$ on V.

b_k is the degree of membership of the v_k on fuzzy subset B: $\mu_B(v_k)=b_k(k=1,2,\cdots,m)$, which reflects the role of the k-th evaluation v_k in the comprehensive evaluation. The comprehensive evaluation B depends on the weight of each factor, i.e. it should be a fuzzy subset $A=(a_1,a_2,\cdots,a_n)\in F(U)$ on U, and $\sum_{i=1}^{n}a_i=1$, where a_i represents the weight of the i^{th} factor.

Thus, when the weight A is given, a comprehensive evaluation B can be given accordingly. The ba-

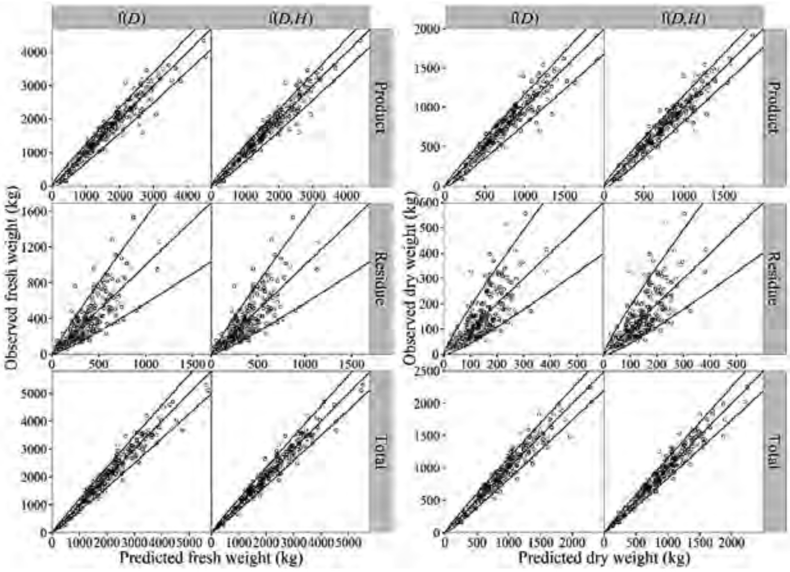

Fig.2. Truncation error represents linear operator function

sic steps are as follows: (1) determine the factor set $U=\{u_1,u_2,\cdots,u_n\}$; (2) determine the evaluation set $V=\{v_1,v_2,\cdots,v_m\}$; (3) determine the fuzzy evaluation matrix $R=(r_{ij})_{n\times m}$.

First, by making a judgment $f(u_i)\ (i=1,2,\cdots,n)$ for each factor u_i, a fuzzy map f from U to V can be gotten, i.e.:

$$\begin{aligned} &f: U \to F(U) \\ &u_i \mapsto f(u_i)=(r_{i1},r_{i2},\cdots,r_{im})\in F(V). \end{aligned} \qquad (1)$$

Then, the fuzzy relation $R_f \in F(U\times V)$ can be induced by the fuzzy map f, i.e.:

$$\begin{aligned} &R_f(u_i,v_j)=f(u_i)(v_j)= \\ &=r_{ij}(i=1,2,\cdots,n;\, j=1,2,\cdots,m). \end{aligned} \qquad (2)$$

Therefore, the fuzzy evaluation matrix $R=(r_{ij})_{n\times m}$ can be determined. Moreover, (U,V,R) is called fuzzy comprehensive evaluation model, and (U,V,R) is called the three elements of the model.

(4) Comprehensive evaluation: For the weight $A=(a_1,a_2,\cdots,a_n)\in F(U)$, the maximum-minimum synthesis operation can be obtained by using the model $M(\wedge,\vee)$, and a comprehensive evaluation can be obtained:

$$B=A\circ R \quad (\Leftrightarrow b_j=\bigvee_{i=1}^{n}(a_i\wedge r_{ij}),\, j=1,2,\cdots,m). \qquad (3)$$

At this time, it is assumed that the fuzzy comprehensive evaluation model is the (U,V,R). For the weight $A=(a_1,a_2,\cdots,a_n)\in F(U)$, the fuzzy evaluation matrix is the $R=(r_{ij})_{n\times m}$, and the comprehensive evaluation of the model $M(\wedge,\vee)$ is $B=A\circ R=(b_1,b_2,\cdots,b_m)\in F(V)$, and $b_j=\vee_{i=1}^{n}(a_i\wedge r_{ij})\quad (j=1,2,\cdots,m)$. In fact, due to $\sum_{i=1}^{n}a_i=1$, $a_i\le r_{ij}$ may appear for some cases, i.e. $a_i\wedge r_{ij}=a_i$. The result of doing so will make it possible to let many of the information in the fuzzy evaluation matrix R be lost, that is to say, the judgment information made by some factors u_i cannot be effectively used in the decision making.

The result of this is that the result of the judgment is no longer accurate, Fig. 2. Therefore, the model $M(\wedge,\vee)$ can be improved in practice. To this end, the following four computational models are proposed: (1) Multi-level fuzzy comprehensive evaluation model Non-Local Means (NLM) calculation method; (2) Multi-level fuzzy comprehensive evaluation model Transmission-Line Matrix Method (TLM) calculation method; (3) Multi-level fuzzy comprehensive evaluation model Reads Per Kilobase of exon model (RPM) calculation method; (4) Multi-level fuzzy comprehensive evaluation mo-

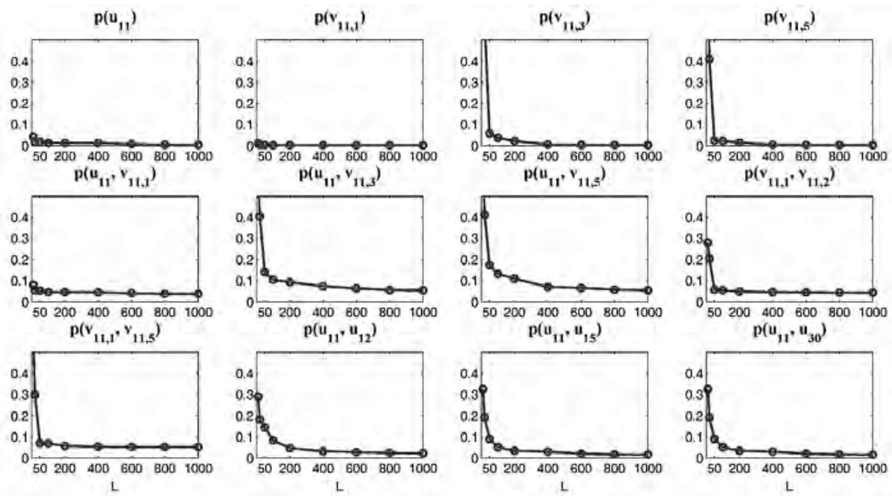

Fig.3. The mathematical function of membrane control equation of ROMS (Regional Ocean Modelling System) ocean model

del is the new adaptive delta modulation (ADM) calculation method.

These four different types of computational models can effectively solve the various problems encountered in the multi-level fuzzy comprehensive evaluation model in the operation process. The combined use of these models can also effectively solve some complex real-world problems. The multi-level fuzzy comprehensive evaluation model mainly includes the intimate control equation and the outer membrane control equation Fig.3. The intimate control equation of the multi-level fuzzy comprehensive evaluation model is as follows:

$$\begin{aligned}&\frac{\partial(H_z u)}{\partial t}+\frac{\partial(uH_z u)}{\partial x}+\frac{\partial(vH_z u)}{\partial y}+\\&+\frac{\partial(\Omega H_z u)}{\partial s}-fH_z v=-\frac{H_z}{\rho_0}\frac{\partial p}{\partial x}-\\&-H_z g\frac{\partial \eta}{\partial x}-\frac{\partial}{\partial s}\left(\overline{u'w'}-\frac{v}{H_z}\frac{\partial u}{\partial s}\right)-\\&-\frac{\partial\left(H_z S_{xx}\right)}{\partial x}-\frac{\partial\left(H_z S_{xy}\right)}{\partial y}+\frac{\partial S_{px}}{\partial s}.\end{aligned}\qquad(4)$$

$$\begin{aligned}&\frac{\partial(H_z v)}{\partial t}+\frac{\partial(vH_z v)}{\partial x}+\frac{\partial(vH_z v)}{\partial y}+\\&+\frac{\partial(\Omega H_z v)}{\partial s}-fH_z u=-\frac{H_z}{\rho_0}\frac{\partial p}{\partial y}-\\&-H_z g\frac{\partial \eta}{\partial y}-\frac{\partial}{\partial s}\left(\overline{v'w'}-\frac{v}{H_z}\frac{\partial v}{\partial s}\right)-\\&-\frac{\partial\left(H_z S_{yx}\right)}{\partial x}-\frac{\partial\left(H_z S_{yy}\right)}{\partial y}+\frac{\partial S_{py}}{\partial s}.\end{aligned}\qquad(5)$$

$$0=-\frac{1}{\rho_0}\frac{\partial p}{\partial s}-\frac{g}{\rho_0}H_z\rho.\qquad(6)$$

$$\frac{\partial \eta}{\partial t}+\frac{\partial(H_z u)}{\partial x}+\frac{\partial(H_z v)}{\partial y}+\frac{\partial(H_z\Omega)}{\partial s}=0.\qquad(7)$$

$$\begin{aligned}&\frac{\partial(H_z C)}{\partial t}+\frac{\partial(uH_z C)}{\partial x}+\frac{\partial(vH_z C)}{\partial y}+\\&+\frac{\partial(\Omega H_z C)}{\partial s}=-\frac{\partial}{\partial s}\left(\overline{c'w'}-\frac{v_\theta}{H_z}\frac{\partial C}{\partial s}\right)+\\&+C_{source}.\end{aligned}\qquad(8)$$

In the above formula, the variable *u* and the variable *v* represent the mean median of the Cartesian coordinates of the *x*-axis and the *y*-axis, respectively, and the variable *U* mainly represents a constant. The outer membrane governing equation of the multi-level fuzzy comprehensive evaluation model is as follows:

$$\begin{aligned}&\frac{\partial(D\bar{u})}{\partial t}+\frac{\partial(\bar{u}D\bar{u})}{\partial x}+\frac{\partial(\bar{v}D\bar{v})}{\partial y}-fD\bar{v}=\\&-D\frac{\partial p}{\partial x}+\tau_{sx}-\tau_{bx}-\frac{\partial\overline{S_{xx}}}{\partial x}-\frac{\partial\overline{S_{xy}}}{\partial y}.\end{aligned}\qquad(9)$$

$$\begin{aligned}&\frac{\partial(D\bar{v})}{\partial t}+\frac{\partial(\bar{v}D\bar{u})}{\partial x}+\frac{\partial(\bar{v}D\bar{v})}{\partial y}-fD\bar{u}=\\&-D\frac{\partial p}{\partial y}+\tau_{sy}-\tau_{by}-\frac{\partial\overline{S_{xy}}}{\partial x}-\frac{\partial\overline{S_{yy}}}{\partial y}.\end{aligned}\qquad(10)$$

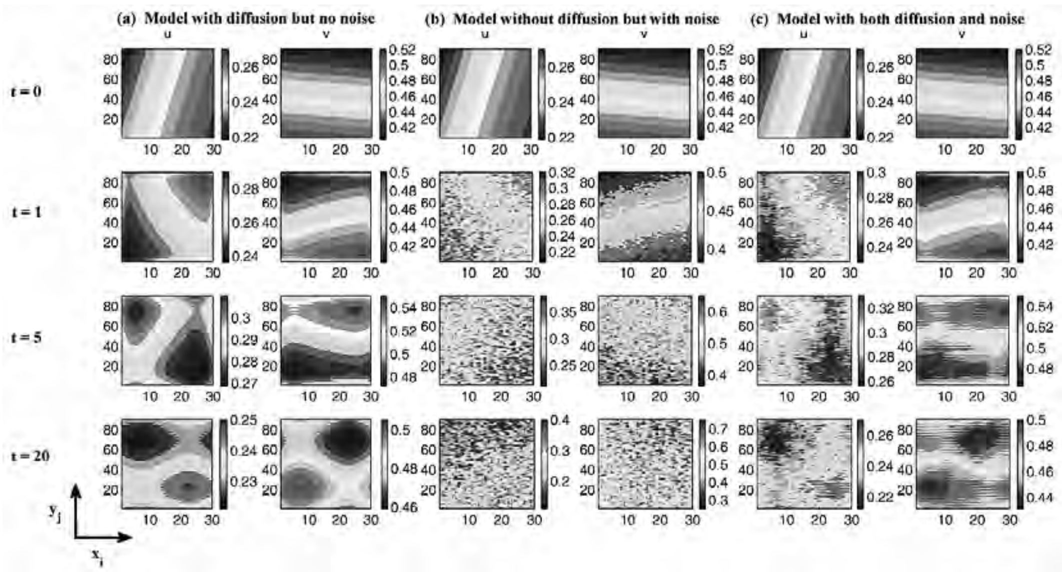

Fig.4. Second order fuzzy mapping set

$$\overline{S_{xx}} = E\frac{c_g}{c}\frac{k_x k_x}{k^2} + E\left(\frac{c_g}{c}-\frac{1}{2}\right) + \frac{k_x k_x}{k^2}\frac{c^2 A_R}{L}. \quad (11)$$

$$\overline{S_{xy}} = \overline{S_{yx}} = E\frac{c_g}{c}\frac{k_x k_y}{k^2} + \frac{k_x k_y}{k^2}\frac{c^2 A_R}{L}. \quad (12)$$

$$\overline{S_{yy}} = E\frac{c_g}{c}\frac{k_y k_y}{k^2} + E\left(\frac{c_g}{c}-\frac{1}{2}\right) + \frac{k_y k_y}{k^2}\frac{c^2 A_R}{L}. \quad (13)$$

$$c_g = \frac{\partial\sigma}{\partial k} = \frac{c}{2}\left(1+\frac{2kD}{\sinh(2kD)}\right). \quad (14)$$

$$\frac{\partial ç}{\partial t} + \frac{\partial(D\bar{u})}{\partial x} + \frac{\partial(D\bar{v})}{\partial y} = 0. \quad (15)$$

The multi-level fuzzy comprehensive evaluation model often uses the ADSEN function to constrain different functions in the process of operation. The ADSEN function is divided into two types, one is a strong constraint type S4DVAR (Strong 4DVAR) function, and the other is a weak constraint type W4DVAR (Weak 4DVAR) function. The strong constraint function mainly focuses on the strong constraints on the initialization conditions of the function and the variable factors of the function to ensure that the finally obtained operation solves the requirements. The weak constraint function, on the other hand, is mainly to perturb the final result of the function along the most unstable direction of the state space. The combined use of the S4DVAR (Strong 4DVAR) function and the W4DVAR (Weak 4DVAR) function can effectively improve the operational precision of the multi-level fuzzy comprehensive evaluation model. The simplification process of the intimate control equation of the multi-level fuzzy comprehensive evaluation model is as follows:

$$\begin{aligned}&\frac{\partial(H_z u)}{\partial t} + \frac{\partial(uH_z u)}{\partial x} + \frac{\partial(vH_z u)}{\partial y} + \\ &+\frac{\partial(\Omega H_z u)}{\partial s} - fH_z v = -\frac{H_z}{\rho_0}\frac{\partial p}{\partial x} - \\ &-H_z g\frac{\partial\eta}{\partial x} - \frac{\partial}{\partial s}\left(\overline{uw} - \frac{v}{H_z}\frac{\partial u}{\partial s}\right) - \\ &-\frac{\partial(H_z S_{xx})}{\partial x} - \frac{\partial(H_z S_{xy})}{\partial y} + \frac{\partial S_{px}}{\partial s}.\end{aligned} \quad (16)$$

In the above formula, the variables parameters $D_{T,ij}$, G_{ij}, φ_{ij}, ε_{ij} need to establish the corresponding mode to close the aspect, and the variables $-C_{ij}$, $D_{L,ij}$, P_{ij}, F_{ij} do not need to be closed.

In addition to the above mentioned problems, the multi-level fuzzy comprehensive evaluation model also has the intersection of the model and many factors in the actual operation process, but the weight distribution of each factor is not balanced. At this time, these factors can be divided into several levels to analyze them. The first is to judge each factor separately, and then make a comprehensive judgment on all factors. The detailed operation is as follows:

The factor set $U=\{u_1,u_2,\cdots,u_n\}$ is divided into several groups $U_1,U_2,\cdots,U_K$ $(1\le k\le n)$ such that $U=\bigcup_{i=1}^{k}U_i$, and $U_i \cap U_j = \Phi (i \neq j)$, called $U=\{U_1,U_2,\cdots,U_k\}$ is the set of first order factors.

Let's set

$$U_i=\{u_1^{(i)},u_2^{(i)},\cdots,u_{n_i}^{(i)}\}\ (i=1,2,\cdots,k;\sum_{i=1}^{k}n_i=n),$$

which is called the secondary factor set.

Set the judgment $V=\{v_1,v_2,\cdots,v_m\}$, and make a single factor evaluation on the n_i factors of the second factor set $U_i=\{u_1^{(i)},u_2^{(i)},\cdots,u_{n_i}^{(i)}\}$, that is, establish a fuzzy map, as shown in Fig. 4.

$$\begin{aligned} &f_i:U_i \to F(V)u_j^{(i)} \mapsto f_i(u_j^{(i)})= \\ &=(r_{j1}^{(i)},r_{j2}^{(i)},\cdots,r_{jm}^{(i)})(j=1,2,\cdots,n_i) \end{aligned}. \quad (17)$$

Then the evaluation matrix is:

$$R_i=\begin{bmatrix} r_{11}^{(i)} & r_{12}^{(i)} & \cdots & r_{1m}^{(i)} \\ r_{21}^{(i)} & r_{22}^{(i)} & \cdots & r_{2m}^{(i)} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n_i1}^{(i)} & r_{n_i2}^{(i)} & \cdots & r_{n_im}^{(i)} \end{bmatrix}. \quad (18)$$

Let the weight of $U_i=\{u_1^{(i)},u_2^{(i)},\cdots,u_{n_i}^{(i)}\}$ is $A=(a_1^{(i)},a_2^{(i)},\cdots,a_{n_i}^{(i)})$, and the comprehensive evaluation can be obtained as:

$$B_i=A_i \circ R_i=(b_1^{(i)},b_2^{(i)},\cdots,b_m^{(i)})(i=1,2,\cdots,k). \quad (19)$$

$b_j^{(i)}$ is determined by the model $M(\wedge,\vee)$, or $M(\bullet,\vee)$, $M(\wedge,+)$, $M(\bullet,+)$.

For the comprehensive evaluation of the first-order factor set $U=\{U_1,U_2,\cdots,U_k\}$, it is possible to set its weight $A=(a_1,a_2,\cdots,a_k)$, and the total evaluation matrix is $R=[B_1,B_2,\cdots,B_k]^T$. According to the models $M(\wedge,\vee)$, $M(\bullet,\vee)$, $M(\wedge,+)$, $M(\bullet,+)$

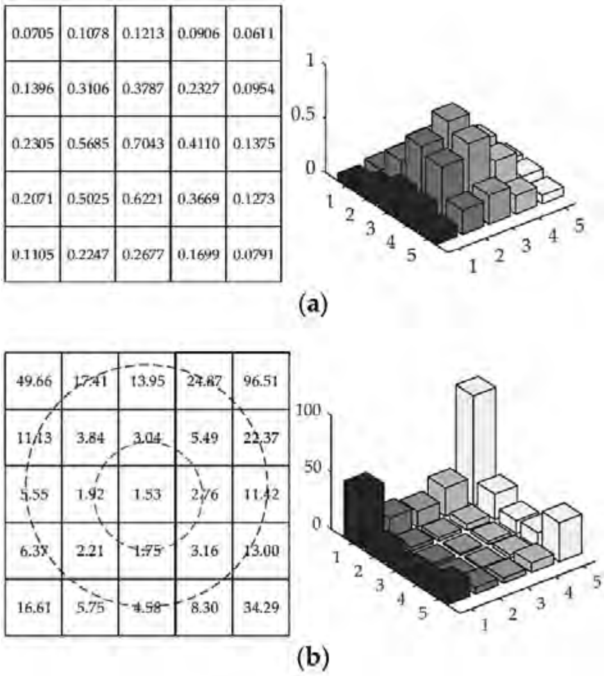

Fig.5. Mathematical model of discrete differential arithmetic

and operation, the comprehensive evaluation model is obtained.

$$B=A\bullet R=(b_1,b_2,\cdots,b_m)\in F(V). \quad (20)$$

3.2. Mixed Gaussian Model

The mixed Gaussian model is mainly to convert the high-order equation into multiple Gaussian equations, and then use the Gaussian equation to calculate the equation results to achieve the purpose of simplifying the calculation. The mathematical model is shown in Fig. 5. The solution process is generally divided into two parts: first, by establishing a function that is related to the approximation, it produces an approximation, its derivative, and the use or application of the algorithm will eventually release the associated value. The most straightforward method of the Gaussian equation is to construct a functional differential equation using the derivative of the finite difference approximation instead of the differential equation. After the discretization is completed, an appropriate calculation method can be constructed to solve the functional differential equation. This is a challenging problem, and it may indeed have a significant impact on the discretization of the derivative. In the numerical solution process for solving differential equations, a numerical solution is needed to judge the accuracy. Also, it needs to be tested and evaluated by better calculation methods and other new parallel algorithms. The detailed implementation steps are as follows in the Fig. 5:

The derivative of a function f is generally obtained by quadratic polynomial:

$$p_2(x) = a_0 + a_1 x^1 + a_2 x^2. \quad (21)$$

The difference f is at points x_0, x_1 and x_2, i.e., using a local coordinate system, let $x_i = 0, x_{i+1} = h$ and $x_{i+2} = 2h$, then,

$$f(x_i) = a_0 + a_1 x_i + a_2 x_i^2 = a_0. \quad (22)$$

$$f(x_{i+1}) = a_0 + a_1 x_{i+1} + a_2 x_{i+1}^2 = a_0 + a_1 h + a_2 h^2. \quad (23)$$

$$f(x_{i+2}) = a_0 + a_1 x_{i+2} + a_2 x_{i+2}^2 = = a_0 + a_1(2h) + a_2(2h)^2. \quad (24)$$

This three equations with three unknowns can be turned into:

$$a_0 = f(x_i) = f(0). \quad (25)$$

$$a_1 = \frac{-f(x_{i+2}) + 4f(x_{i+1}) - 3f(x_i)}{2h} = + \frac{-f(2h) + 4f(h) - 3f(0)}{2h}. \quad (26)$$

$$a_2 = \frac{f(x_{i+2}) - 2f(x_{i+1}) + f(x_i)}{2h^2} = = \frac{f(2h) - 2f(h) + f(0)}{2h^2}. \quad (27)$$

Solve $a_i, i = 1,2,3$ and derive the formula (1):

$$f'(x) = a_1 + 2a_2 x,. \quad (28)$$

Then calculate the expression in $x_i = 0$,

$$f'(x) = \frac{-f(x_{i+2}) + 4f(x_{i+1}) - 3f(x_i)}{2h}. \quad (29)$$

Regarding the point x, f is sufficiently smooth, then the Taylor series expansion of f can be expressed as:

$$f(x+h) = f(x) + h\frac{d}{dx}f(x) + + \frac{h^2}{2!}\frac{d^2}{dx^2}f(x) + \frac{h^3}{3!}\frac{d^3}{dx^3} + \ldots \ . \quad (30)$$

Move the function $f(x)$ on the right side of (28) to the left and then divide by h to get the standard deviation quotient:

$$\frac{f(x+h) - f(x)}{h} = \frac{df(x)}{dx} + + \left\{\frac{h}{2!}\frac{d^2 f(x)}{dx^2} + \frac{h^2}{3!}\frac{d^3 f(x)}{dx^3} + \ldots\right\}. \quad (31)$$

Let $h \to 0$, the item in the braces disappear, defined by the derivative:

$$f'(x) \approx \frac{f(x+h) - f(x)}{h}. \quad (32)$$

At this point, the difference quotient $(f(x+h) - f(x))/h$ is used instead of $f'(x)$:

$$\left|f'(x) - \frac{f(x+h) - f(x)}{h}\right| = = \left|\frac{h}{2!}\frac{d^2 f(x)}{dx^2} + \frac{h^2}{3!}\frac{d^3 f(x)}{dx^3} + \ldots\right|. \quad (33)$$

Extract a linear operator from equation (31):

$$T(f) = \left(\frac{h}{2!}\frac{d^2}{dx^2} + \frac{h^2}{3!}\frac{d^3}{dx^3} + \ldots\right) f(x). \quad (34)$$

The error between the corresponding differential operator $\mathrm{D}f = df/dx$ and the approximate linear operator $D_h f = (f(x+h) - f(x))/h$ is constructed

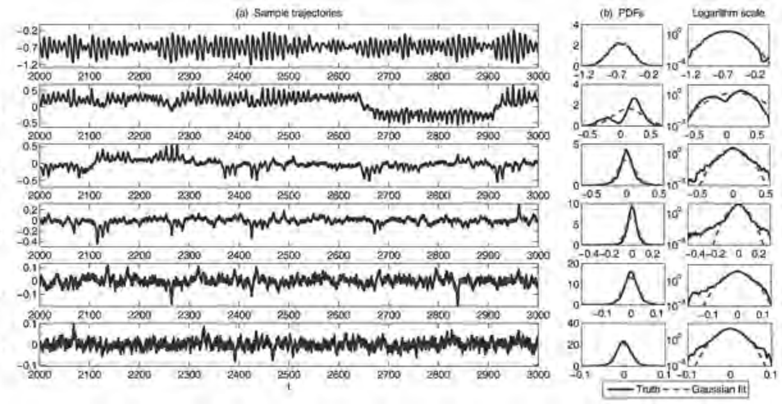

Fig.6. Truncation error of linear differential operators

according to different representatives. The truncation error can be found according to the formula (32), and the truncation error obtained at this time represents the error in the linear operator L.

Let L_h be a discrete approximation h on the neighbourhood with the largest value defined by the linear differential operator L; If there are constant $C>0, p>0$ and w, then:

$$T(\varphi)=\left|(L-L_h)\varphi\right|\le Ch^p, \forall\varphi\in C^m,\ \forall h<h_0. \quad (35)$$

Then L_h has a truncation error of $O\left(h^p\right)$.

Find the limit values for any smooth f and sufficiently small h in equation (35):

$$\lim_{h\to 0}T(f)=h\left|\frac{f''}{2}\right|. \quad (36)$$

Because of this, the truncation error $T(f)$, when the variable h infinitely approaches zero, $O(h)$ can be defined by the method given by (36), as shown in Fig. 6.

When $h^3 f^{(4)}/6+...$ is much smaller than $hf''/2$. At this point, the f' calculation is approximated. If the second derivative of the function f is far less than the other derivatives in the effective range, when,

$$0<\left|f''(x)\right|\ll\left|f^{(n)}(x)\right|, n>2. \quad (37)$$

Solving the Taylor series of the function f at point x:

$$f(x+h)=f(x)+hf'(x)+\frac{h^2}{2!}f''(x)+ +\frac{h^3}{3!}f'''(x)+\frac{h^4}{4!}f^{(4)}(x)+\dots . \quad (38)$$

At this point, re-provide a forward difference approximation for f', that is:

$$f'(x)=\frac{f(x+h)-f(x)}{h}-\frac{h^2}{2!}f''(x)- -\frac{h^3}{3!}f'''(x)-\frac{h^4}{4!}f^{(4)}(x)+\dots . \quad (39)$$

A forward difference approximation formula for $f'(x)$ is obtained from the truncation error of the command h, that is:

$$f'(x)=\frac{f(x+h)-f(x)}{h}+O(h). \quad (40)$$

Similarly, the Taylor series of f can be expanded around the point x in the -h direction, that is:

$$f(x-h)=f(x)-hf'(x)+ +\frac{h^2}{2!}f''(x)-\frac{h^3}{3!}f'''(x)+\dots . \quad (41)$$

The backward differential approximation of f' at point x:

Fig.7. Physical exercise chart of photovoltaic employees

$$f'(x)=\frac{f(x)-f(x-h)}{h}+O(h). \quad (42)$$

Subtracting the formula (40) from the formula (42):

$$f(x+h)-f(x-h)= \\ =0+2hf'(x)+0+2\frac{h^3}{3!}f'''(x)+\dots . \quad (43)$$

Solving the centre difference approximation of $f'(x)$:

$$f'(x)=\frac{f(x+h)-f(x-h)}{2h}+O(h^2). \quad (44)$$

After the approximate solution is completed, the average of the forward and backward differential approximations can be found, which the final result is.

$$f'(x)=\frac{1}{2}\left(\frac{f(x+h)-f(x)}{h}+ +\frac{f(x)-f(x-h)}{h}\right)+O(h^2). \quad (45)$$

4. RESULT ANALYSIS AND DISCUSSION

At present, the health conditions of the employees in the photovoltaic industry are not satisfactory, which seriously restricts the further development of the industry. In order to further explore the specific reasons for the lack of physical exercise for photovoltaic companies, the questionnaire survey method was used to explore 450 front-line employees working in photovoltaic companies. Finally, 288 copies were recovered, of which 268 were valid questionnaires. Among the 268 valid questionnaires, there were 114 questionnaires for female employees and 154 questionnaires for male employees.

According to the contents reflected in the questionnaire, it is not difficult to know that there are two major factors that cause the lack of exercise for photovoltaic companies:

– The competitive pressure in the industry market has led to the employees of photovoltaic companies having a greater sense of exhaustion both physically and psychologically after work. Physically exhausted employees lack the motivation to exercise;

– Employees of photovoltaic companies lack a clear and clear understanding of physical exercise, and also lack the necessary technical guidance for physical exercise. This also makes the photovoltaic company's employees less motivated to exercise.

In this survey, less than 5 % of photovoltaic company employees said they were completely uninterested in physical exercise and did not want to waste time on exercise. It is not difficult to know that, in fact, most of the photovoltaic company employees are still willing to exercise. It was only because of the lack of certain conditions that they eventually failed to do so.

Based on the above reasons, China's photovoltaic enterprises will be used as a research example, and the mixed Gaussian model will be used to conduct in-depth research and analysis on the behaviour and effects of photovoltaic employees' physical exercise. The research results show that photovoltaic companies can take effective measures to promote employees' active physical training from the following aspects. The specific measures are as follows:

– Photovoltaic enterprises should regularly carry out corresponding training courses in physical exercise, actively help their employees to establish a sound physical education knowledge system and improve their interest in physical exercise, Fig. 7;

– Photovoltaic enterprises should also increase investment in sports funds, improve the internal sports facilities, and provide an excellent physical exercise environment for employees to meet the fitness needs of employees.

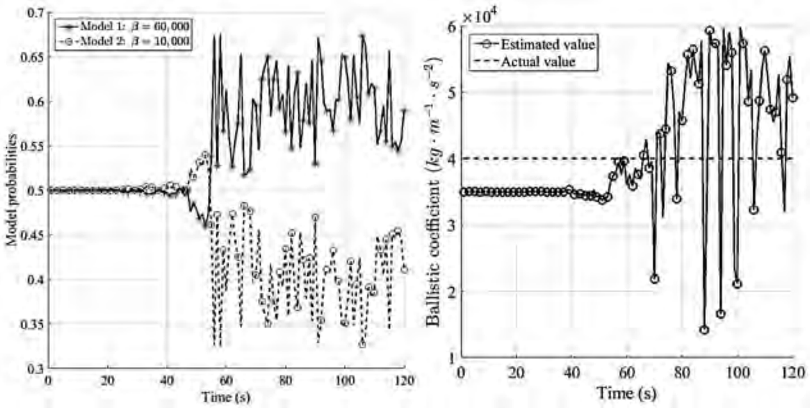

Fig.8. Square root summation method of multilevel fuzzy comprehensive evaluation model

After the corresponding development measures are drawn, the multi-level fuzzy comprehensive evaluation model is used to evaluate its rationality. The multi-level fuzzy comprehensive evaluation model is an evaluation method based on cognitive science and fuzzy mathematics. The specific form is as follows:

$$\begin{pmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,n} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,n} \\ \cdot & \cdot & \cdot & \cdot \\ a_{n,1} & a_{n,1} & & a_{n,n} \end{pmatrix}. \quad (46)$$

In the formula, $a_{i,j}$ represents the relative weight of the indicator a_i relative to the indicator a_j.

In view of the fact that the weight of the multi-level fuzzy comprehensive evaluation model has a great influence on the overall accuracy of the results obtained by the scoring calculation, it is necessary to analyze the weight of the multi-level fuzzy comprehensive evaluation model, which can be understood as the analysis of the largest eigen value in the judgment matrix. The most widely used calculation method is the square root method, as shown in Fig. 8. The calculation steps are as follows:

Calculate the product of each row element of the judgment matrix R,

$$M_i = \prod\nolimits_{j=1}^{n} B_{ij}, i = 1,2,\ldots,n. \quad (47)$$

Calculate the M_i root of n,

$$\overline{w_i} = (M_i)^{\frac{1}{n}}, i = 1,2,\ldots,n. \quad (48)$$

Normalize $\overline{w_i}$, i.e.

$$w_i - \frac{\overline{w_i}}{\sum_{i=1}^{n} \overline{w_i}}, i = 1,2,\ldots,n. \quad (49)$$

Then the weight vector is,

$$w = [w_1, w_2, \ldots, w_4]^T. \quad (50)$$

Let the target criterion layer weight vector obtained according to the above method be:

$$W = (w_1, w_2, w_3, \ldots, w_k). \quad (51)$$

w_i is the relative weight of the criterion layer indicator i in the criteria layer.

For the k-th criterion level indicators, the weights of the measures level indicators under each criterion are:

$$W_k = (w_{k1}, w_{k2}, w_{k3}, \ldots, w_{kp}). \quad (52)$$

In the hierarchical structure, the comprehensive weight calculation operator of the measure j indicator under criterion i is:

$$w_{i,j} = w_i \cdot w_j. \quad (53)$$

Finally, sort by each indicator, and the results are calculated. After obtaining the weights of the respective indicators, the evaluation score can be finally calculated by multiplying the evaluation values. The calculation operator is:

$$Ea = (w_{p,1}, w_{p,2}, \ldots, w_{p,n})(v_{p,1}, v_{p,2}, \ldots v_{p,n})^T. \quad (54)$$

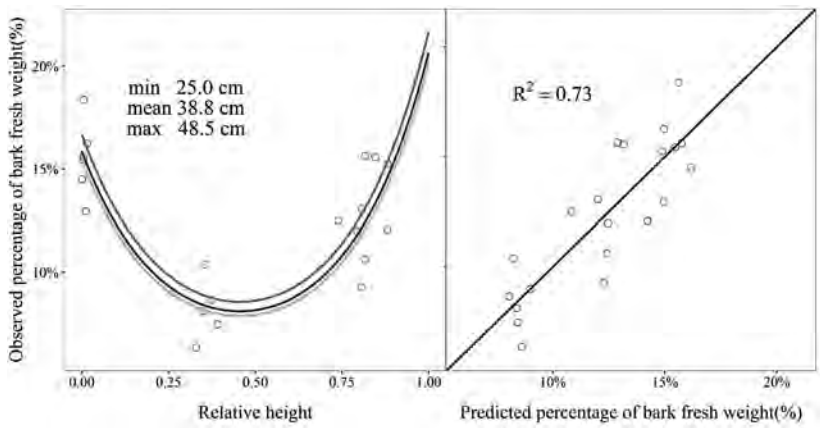

Fig.9. The program evaluation results of ocean folk sports function and development dynamic mechanism

$w_{p,i}$ is the combined weight of the lowest level indicator i, and $w_{p,i}$ is its evaluation score.

According to the content represented by the formula (54), the collected related data is substituted and the evaluation result is obtained, as shown in Fig 9. It is not difficult to see from the results that the above measures have positive effects on the physical exercise behaviour of photovoltaic company employees.

5. CONCLUSION

At present, the health conditions of the employees in the photovoltaic industry are not satisfactory, which seriously restricts the further development of the industry. The main reason is that industry scholars have many shortcomings in the research on the physical exercise behaviour and effect of photovoltaic enterprise employees, which leads to their guidance and exercise opinion cannot fully meet the actual exercise demand. Based on the above reasons, the hybrid Gaussian model is used to study the behaviour and effect of photovoltaic employees' physical exercise, and two main factors are obtained:

– Employees work under competitive pressure and lack the motivation to exercise;

– Employees lack the necessary technical guidance for physical exercise, and in view of the above reasons, the following solutions are proposed: the first is that company regularly conducts training courses on physical exercise to improve employees' interest in physical exercise and the second is that enterprises should also increase investment in sports funding and improve the corporate fitness environment.

At the end of the paper, the multi-level fuzzy comprehensive evaluation model is used to evaluate the rationality of the measures, and the conclusions are drawn that the proposed measures can positively promote the physical exercise behaviour of photovoltaic employees.

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Jinghua LI,
graduated from the school of physical education of Shaanxi normal university in 2004. He currently works at the institute of physical education of Xianyang normal university in Shaanxi province. Master’s degree, associate professor. Research Orientation: School Physical Education

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great work to reach your
fondest goals, and when you're
done, sweet rest.

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when all your dreams come true!

Warmest wishes for
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and a wonderful New Year!

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