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ON METHODOLOGY FOR DESIGNING ARCHITECTURAL LIGHTING OF PRODUCTION SITE INTERIOR

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ABSTRACT

The article describes content of original and relevant but virtually forgotten thesis of V.V. Voronov on lighting of production site interiors by means of overhead natural (using three types of skylights) and artificial illumination, in order to elaborate scientific methodology for architectural design of more qualitative luminous environment on the basis of comprehensive approach and enhanced criteria framework of its evaluation using light engineering parameters.

The thesis is unique in terms of the scope and quality of field and laboratory observations which are reflected not only in the text but also in the graphical attachments, namely photos, figures, schemes, drawings, charts, nomograms, and diagrams accompanied by specific measured or calculated parameters. The first part of the thesis contains theoretical basics and results of field observations conducted by different methods.

This second part is the exposition of chapter 3 of the V.V. Voronov's candidate thesis (1985). It describes the methodology for and the results of the experiments by means of planar and volumetric light simulation using the architectural lighting simulating assembly (chamber) which were conducted in MARKHI in 1970–1985.

Keywords: design methodology, architectural lighting of interiors, daylighting and artificial lighting, luminance composition, overhead skylights, types of interior space experimental light simulation set, laboratory studies, luminance, interior light saturation

INTRODUCTION

Lighting engineering as applied science generalising prior empirical experience and proposing practical calculation techniques and then methods of standardisation and design of luminous environment parameters in interiors with natural and artificial lighting appeared and developed throughout the 20th century on the basis of problems of production site interior design to increase labour efficiency. Meanwhile, the issue of visual aesthetics of environment generated by space planning solutions, lighting and finishing of areas, i.e. by means of luminance composition, has not received due attention.

In Russia, the problem of daylighting of spaces has mostly been tackled by architects (N.M. Gusev, N.V. Obolenskiy, etc.) and construction engineers (A.M. Danilyuk, B.A. Dunaev, D.V. Bakharev, etc.) rather than by classical light engineers (V.V. Meshkov, M.M. Epaneshnikov, A.B. Matveev, etc.) as it is directly linked with architectural formation of buildings and selection of efficient daylighting systems. Unfortunately, this atavism is still noticeable in lighting engineering.

In 1967, V.V. Voronov (1939–2016), MARKHI postgraduate student and architect, attempted to solve this large-scale and relevant problem for production site interior with overhead daylighting under supervision of professor N.M. Gusev at the Construction Physics sub-department. Using his own design project, he made an artificial reflective sky model[1] with partly dimmable lighting by means of fluorescent lamps installed on the floor [1] and conducted a number of experimental statistic studies in 1971–1984 using models of production site interiors with three types of skylights: U-shaped (rectangular), saw-tooth skylights (shed) and roof lights. Previously and concurrently, he had conducted numerous field measurements and statistical evaluations of luminous environment of actual interiors of plants with the three above mentioned types of skylights in Uzbekistan and Moscow. All results of these comprehensive field and laboratory measurements performed by means of U-16 and U-17 illuminance meters (including self-made attachments for measurement of cylindrical illuminance (E_z) and hemispherical illuminance ($E_{2\pi}$) gauged using photometer bench in NIISF) and YaF-1 luminance meter (owned by the Leningrad Occupational Safety Institute) were thoroughly processed and presented in the form of original graphic schemes, formulas and conclusions.

As a result of many years of hard, thorough and exceptionally dedicated work, a convincing comprehensive method of designing synthetic lighting (daylighting with possible local and adjusting influence of additional artificial lighting during daytime) was born to ensure architectural aesthetics of production site interior. Not only the results of comprehensive analysis of interior lighting (it will just suffice to mention the butterfly-shaped nomogram for evaluation of lighting quality based on light distribution (Fig. 1)) using all methods available at that time but these methods themselves deserve attentive studying. Nobody else has ever done such large-scale and comprehensive work. So V.V. Voronov's forgotten thesis [2] may be an impulse, an example for new studies in this area with the modern level of science and technology.

And after defending successfully the thesis (1984), the author did not take care of familiarising the scientific community with its remarkable results

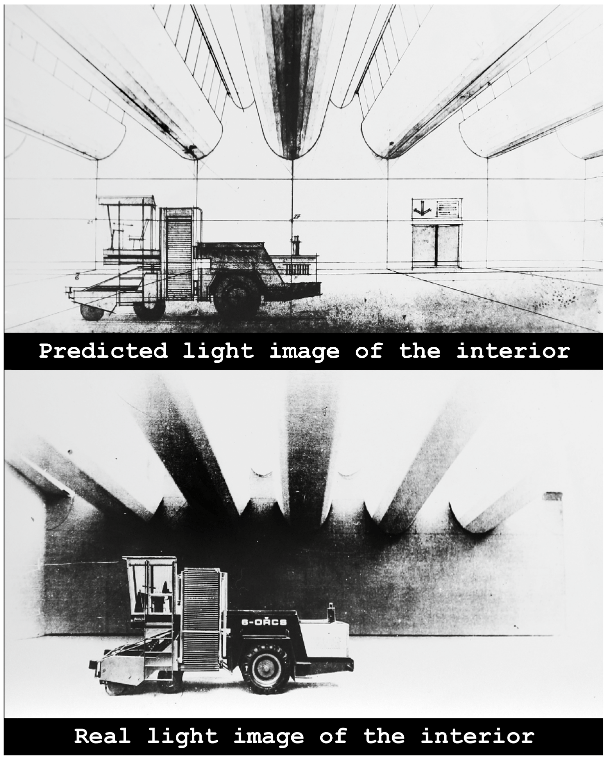

Fig. 1. Nomogram for evaluation of quality of interior architectural lighting based on luminance distribution

which were well in advance of their time. For some reason, today the thesis cannot even be found in the library of MARKHI, it is only stored in the Russian State Library[2]. In the meantime, candidate and master degree studies on daylighting in interior architecture which are sometimes conducted (though exceedingly rarely, for instance, in MGSU, NIISF, IFMO University, Samara GTU, etc.) start at much lower scientific levels and do not solve such problems with the same scope. As a friend, a colleague and a professional associate, I, N.I. Shchepetkov, feel it my duty to try to remedy this situation by exposing the content of V.V. Voronov's thesis in the Svetotekhnika/Light & Engineering Journals[3] and to publish their digital copy for free public access.

It seems that nowadays lighting of production site interiors in prefabricated buildings, which sprout like mushrooms after the summer rains, is not a subject of scientific studies from the point of

[1] Using this sky model, several postgraduate students (V.I. Zherdev, G.E. Chirkin, E.V. Shangina, etc.) made experiments and defended theses in MARKHI even before its creator did.

[2] In the Russian State Library, it is stored in the reading halls of the Theses Department (*Voronov, Vladimir Vasilievich*. Methodology for Designing Architectural Lighting of Production Site Interior: Thesis… by the Candidate in Architecture: 18.00.02. – Moscow, 1984. – 121 p. + Attachments (39 p.: ill.). Architecture of Buildings and Structures. Storage: OD61 86–18/14). Paid digital copy of the thesis is also available. – Ed. note.

[3] It turned out that it is not easy at all to expose very densely composed content of the thesis, especially its graphic attachment with its phenomenal level of scrupulosity (unfortunately, the quality of photographs is low).

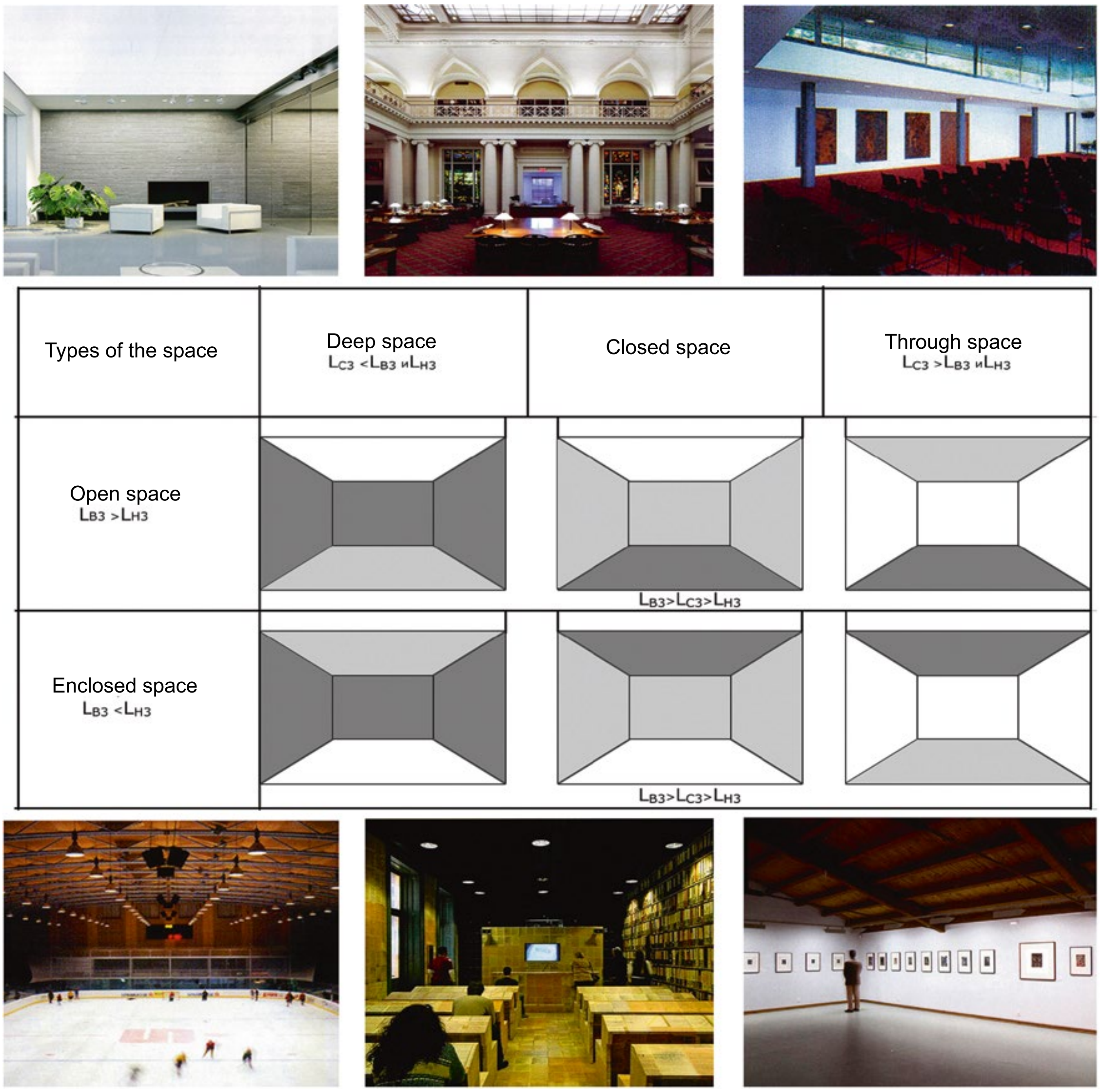

Fig. 2. Forecast concept of an interior with overhead daylighting (U-shape skylights) and its luminous image on a photo

view of their visual aesthetics. Using contemporary technologies and lighting materials, designers easily solve problems of daylighting, combined, artificial or mixed lighting on the basis of regulatory requirements and do not really care about interior aesthetics. From psychological, social and environmental points of view, it is a big mistake since, other things being equal, labour efficiency increases and the level of stress and the number of defects, sick leaves, etc. reduces in. And this is a top priority problem for interior of public and residential buildings. That is why the issue is still relevant. As the last section of the thesis shows, even additional means may be minimal and cost-effective with professional and proper design level.

It is planned to expose the content of the thesis in 3 parts, starting with this one, corresponding to the number of its parts: Theoretical Basics and Results of Field Observations; Experimental Laboratory Studies; Design Methodology.

PART I. THEORETICAL BASICS AND RESULTS OF FIELD OBSERVATIONS

1.1. Light and Spatial Arrangement of Production Site Interior with Overhead Lighting, Quantitative and Qualitative Evaluation of Interior Lighting in Field Conditions

In the 1st part of the thesis, the study subject is defined as “luminous environment of interiors of multi-span workshops with open roof structures and natural lighting through rectangular, saw-tooth skylights and roof lights”, and the goal of the study is defined as “development of scientifically substanti-

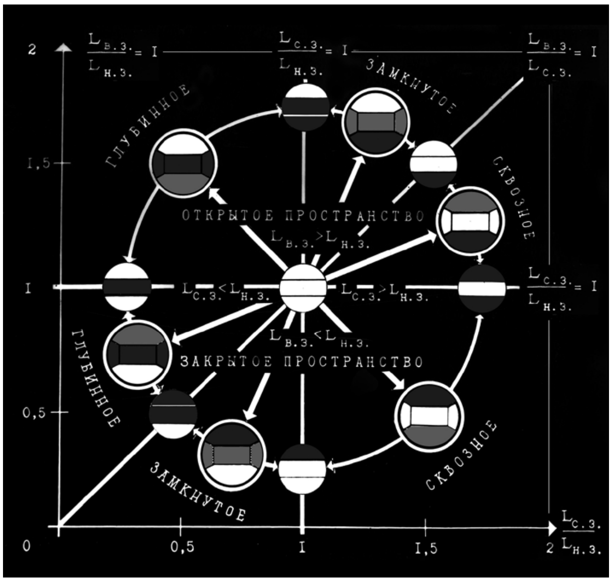

Fig. 3. Classification of interior space types based on perception of its luminance composition and their field analogues

ated methodology for design of architectural lighting for production interiors of industrial buildings with overhead lighting to ensure luminous comfort and artistic expression" [2].

Academic novelty is development of "methods of objective and subjective evaluation of interior lighting quality in laboratory and field conditions by means of graphic tests and questionnaires" as well as "graphic methods of evaluation of interior lighting quality on the basis of luminance distribution, lighting contrast and saturation." The concluding paragraph, which is (unfortunately) not included in thesis nowadays, describes the methodology for "economical evaluation of architectural lighting of interiors based on different schemes of their light and spatial arrangement" [2].

So, analysis of previous Russian and foreign studies and research of space-planning and light-engineering solutions of production site interiors with overhead daylighting which were contemporary at that time (1970–1980s) in terms of light and spatial arrangement as an aesthetic factor have shown that general evaluation of quality of luminous environment is defined by distribution and relation of average luminance values L_{uz}, L_{mz} and L_{lz} of three main interior zones respectively along the vertical access in the field of view: the upper zone (ceiling), the middle zone (wall) and the lower zone (the floor). This assumption is based on the first criterion of the classification of lighting quality: light distribution over the area as evaluated using a physical factor human eye directly reacts to luminance of surrounding elements.

At the design stage, luminous concept of an interior is a result of an architect's (designer's) professional visual imagination, which is formed in his/her mind in the course of project development and is presented in a perspective interior drawing by means of architectural (now computer) graphics in the form of luminance composition (colour composition was not taken into account in this work). Actual image of an implemented interior not often (maybe even exceedingly rarely) corresponds with the author's luminance distribution concept in any way (Fig. 2). The main reason is poorly considered distribution and level of lighting by primary reflective surfaces of the interior and their reflectivity. Nowadays, some computer programmes visualise such situations rather credibly allowing parameters of lighting installations (LI) to adjust and selection of finishing materials at the design stage, which was impossible 20 years ago and earlier.

The entire variety of these existing and possible compositions and luminance relations of the three zones of an interior constituted the author's specific classification of types of space in terms of the nature of its visual perception: i.e. the "open space" and the "closed space", each possible in three forms: "deep", "enclosed" and "through" (Fig. 3). This classification is inspired by associations and comparisons with daylight landscapes during different weather and with variable luminance distribution which are reflected in the graphic part of the thesis. It is described by the system of the types of interior space with approximate relative values of relations between average luminances of the three zones of the field of view (Fig. 3).

In these schemes, "open space" means interior space with $L_{uz} > L_{lz}$; "closed space" means interior with $L_{uz} < L_{lz}$; "deep space" means $L_{mz} < L_{uz,}$ and L_{lz}; "enclosed space" means $L_{uz} > L_{mz} > L_{lz}$; "through space" means $L_{mz} > L_{uz}$ and L_{lz}. Field analogues of interiors with different purposes and lighting systems are shown in Fig. 4.

In order to define quantitative relationship between objective (photometric) and subjective (visual) evaluations of the quality of interior lighting, field studies were performed with artificial and daylighting. For this purpose, the following set of photometric characteristics was taken: horizontal illuminance E_h, hemispherical illuminance $E_{2\pi}$ and cylindrical illuminance E_z, their daylight factors (D,

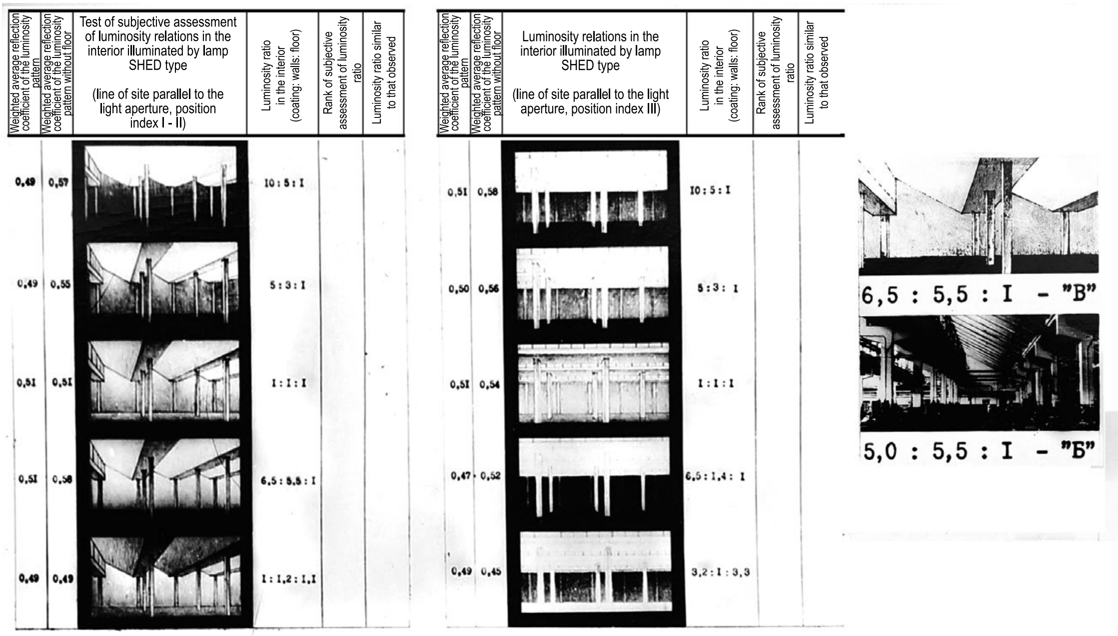

Fig. 4. System of interior luminous environment types

$D_{2\pi}$ and D_z respectively) as well as lighting contrast K[4], luminance level L and its distribution in the upper, middle and lower zones of the interior relative to the latter one.

Concurrently with objective (instrumental and photometric) evaluation of interior lighting quality, subjective evaluation was also performed using statistical methods of test-based and questionnaire-based surveys for all types of skylights.

The test-based survey was used for evaluation of interior lighting quality based on luminance distribution. The tests were perspective graphic images of the five variants of interior luminance composition with daylighting in the form of *A4*-format shots with different (recommended, designed and actually observed) relations $L_{uz}/L_{mz}/L_{lz}$ in mutually opposite directions of line of view: along and across the workshop structural span (Fig. 5). Seven tests were used: three, for interiors with saw-tooth skylights, two, for U-shaped skylights, and the last two, for roof-lights. The number of tests is different for the studied interiors due to specifics of skylight light by radiation distribution and structural distinctions of roofing systems.

For quantitative evaluation of relative preference of L distribution, the luminance compositions of the tests were ranked by the experts using five ranks. The experts were senior students and professors of MARKHI (410 persons who made 11,950 evaluations) as well as workers and employees of the workshops (125 persons from interiors with saw-tooth skylights, 109 persons from interiors with rectangular skylights and 96 persons from interiors with roof lights who made 3830 evaluations). Comparing the tests with the field observations, the experts who worked in the workshops marked those options where, in their opinions, the luminance distribution was visually similar to that observed in the interior. Thus, the L distribution was quantitatively evaluated using a rank of the test luminance composition marked by the observers.

Concurrently, during the questionnaire-based survey, the same observers evaluated saturation of the interior lighting in field (one of the most important characteristics of lighting quality which is not contained in recommendations for production site interiors) on a scale from one to five: I (low), II (normal), III (increased), IV (high), V (very high).

As a result of field observation of the luminous environment of the interiors with overhead lights in daylighting and artificial lighting, it was found that actual values of the regulated characteristics (D and E_h) were below standard values almost everywhere and characterised its quality absolutely insufficiently. Spatial characteristics of lighting ($D_{2\pi}$ and D_z for daylighting and $E_{2\pi}$ and E_z for artificial lighting) do not always correlate with judgemental evaluations

[4] Lighting contrast K in the interior space was defined using several methods: by relation between illumination vector and spherical illuminance $E_{4\pi}$ and by relations $E_{h,\max}/E_{2\pi}$, $E_h/E_{2\pi}$ and E_h/E_z.

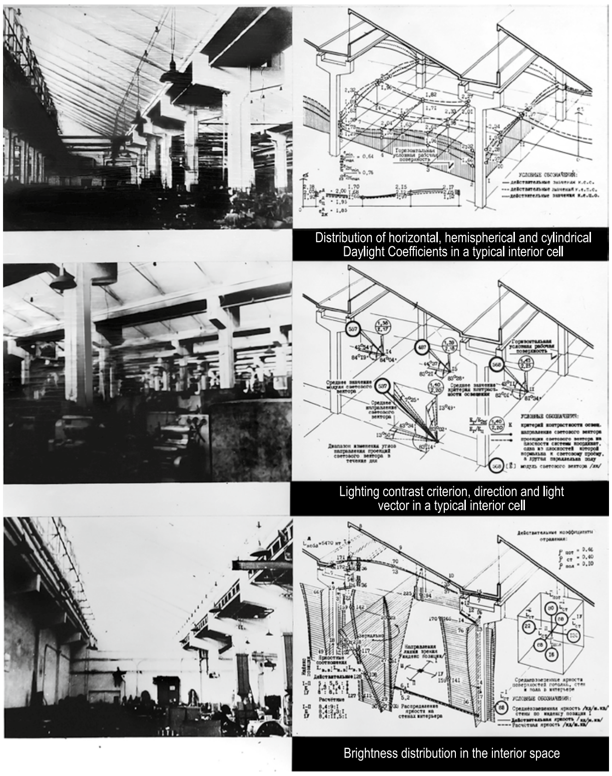

Fig. 5. Example of a test for subjective evaluation of the quality of interior daylighting and artificial lighting with saw-tooth skylights (graphic images and field photos)

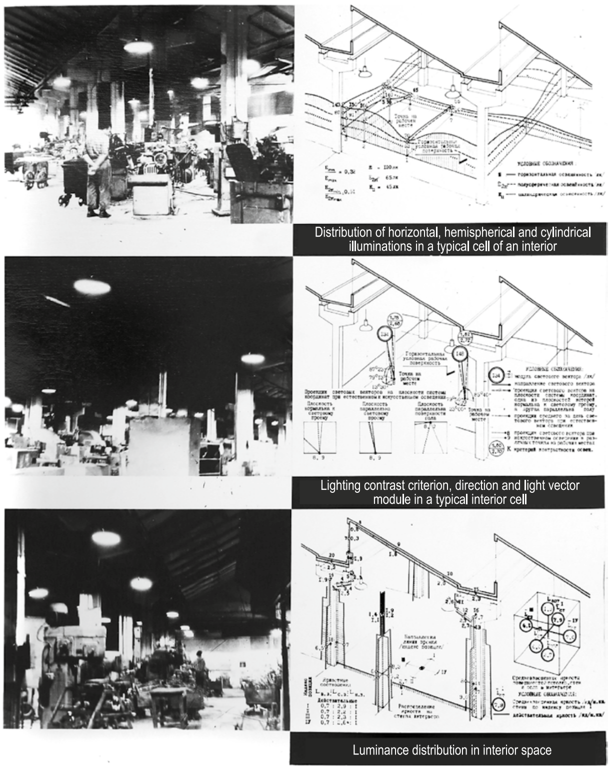

Fig. 6. Photometric evaluation of the quality of interior daylighting by saw-tooth skylights (methodological example, similar graphic evaluations for rectangular skylights and roof-lights are also presented in the thesis)

of lighting saturation (Figs. 6 and 7, as exemplified by saw-tooth skylights).

According to the data of the field observations, K in the interior space is an additional criterion for more complete photometric evaluation of the luminous environment. With values of the relations $E_h/E_{2\pi}$ and E_h/E_z exceeding 1.7 and 2.5 respectively, the observers evaluated lighting saturation as low even at relatively high levels of $E_{2\pi}$ (>100 lx) and E_z (>70 lx).

Daytime luminance composition in interiors with saw-tooth skylights which reminded relative luminance distribution over the field of view (sky/horizon/ground) on an overcast summer day under open sky in the central part of the Russian Federation (5:3:1 according to N.M. Gusev [3]) was evaluated by the experts as relatively high. In interiors with U-shape skylights and roof lights, the quality of natural lighting was evaluated as unsatisfactory, whereas the quality of artificial lighting was evaluated as unsatisfactory in all cases.

Comparative analysis of the quality of the visual environment in interiors with overhead daylighting and artificial lighting has demonstrated significant differences in levels of lighting, directions of luminous flux, lighting and shadow-formation contrast as well as in luminance distributions of such lighting modes, which is in contradiction with both practical and aesthetic requirements to production environment and indicates the necessity of a comprehensive approach, mutual arrangement and harmonisation of daylighting and artificial lighting systems. Aren't these problems convincing and relevant enough to continue scientific research in this field for the purpose of enhancement of norms, methods and practices of lighting design?

The results of statistical processing of ranking luminance composition on the basis of the field observations and the tests reflected in Figs. 8 and 9 have allowed correlation dependences to build of judgemental evaluations on relations L_{uz}/L_{lz}, L_{mz}/L_{lz}, L_{uz}/L_{mz}. They allowed the above mentioned butterfly-shaped nomogram to develop for evaluation of architectural lighting of an interior (Fig. 1). The results of the interior lighting quality evaluation based on luminance distribution conducted using the method of the test-based survey were compared to the evaluations obtained using this nomogram, which demonstrated their high convergence. This confirms reliability of the nomogram as an instrument of evaluation of luminous environment both at

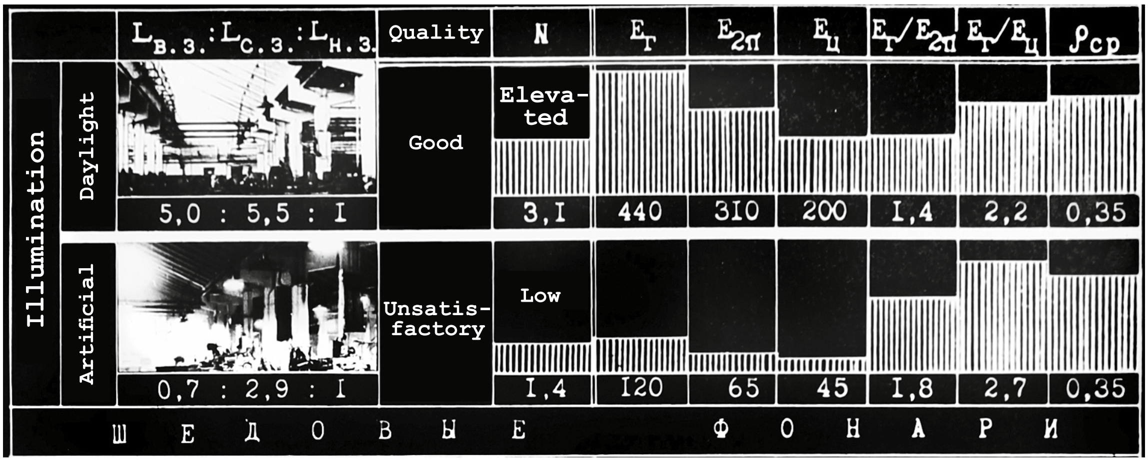

Fig. 7. Photometric evaluation of quality of artificial lighting in an interior with saw-tooth skylights (example)

the design stage and during project implementation. Today, with digital luminance meters available, it is possible to easily define necessary parameters of luminance composition for any lighting system using photographs.

The conducted comprehensive analysis of the results of field observations has shown that distribution of luminance over the interior and its light saturation are the main criteria of lighting quality evaluation and require to be further studied. Over the long term, this analysis should also include chromaticity and kinetics of primary light sources, colour and reflective characteristics of secondary light sources, i.e. material surfaces physically forming the space of the interior and in one way or other reflecting or transmitting the light from optical emitters incident on them. That is what V.V. Voronov dreamt of in his day.

PART II. EXPERIMENTAL LABORATORY STUDIES

The laboratory experimental studies of production site interior lighting with three types of skylights were caused by necessity of checking the results of analytical and field observations as well as of searching for criteria and methods of evaluation of interior luminous environment quality in comparable conditions of daylighting and artificial lighting, interior finishing and occupancy level. These studies of luminance distribution and evaluation of light saturation included two series of experiments. Their objectives were:

– To refine the data of instrumental photometric and statistical analysis evaluation of interior lighting obtained in field conditions;

– To develop criteria of qualitative evaluation of luminance distribution over interior space;

– To find an architectural way of transposition of luminance relations from a perspective architectural image of an interior into real interior;

– To define the most preferable values of reflectance ρ of finishing of structural elements and process equipment in workshops with the set value of ρ of background walls, ceiling and floor to provide visual comfort and architectural expression of interior.

The first series of experiments was conducted by means of planar graphic light simulation, the second

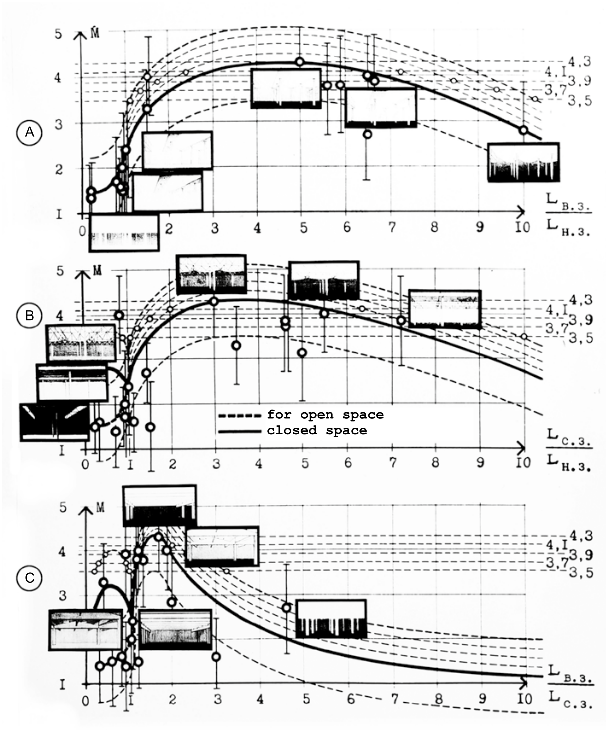

Fig. 8. Comparison of photometric evaluation and subjective evaluation of quality of natural lighting in an interior with sawtooth skylights (example)

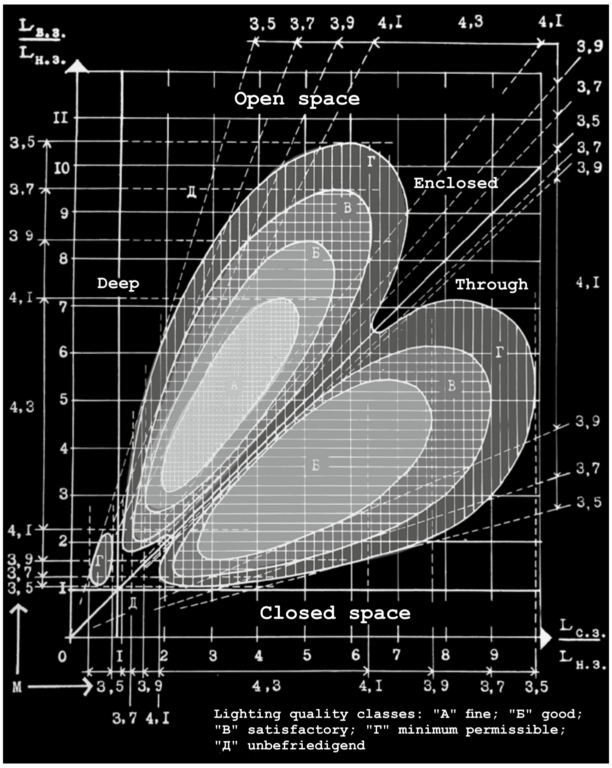

Fig. 9. Correlation dependence of subjective evaluation of lighting quality on relations of luminance in interiors with different types of skylight and space ("closed" and "open")

one was conducted by means of the method of volumetric light simulation using demountable models of interiors in a light simulating assembly (chamber) designed and built specially for these purposes (Fig. 10) [1].

81 experts took part in the first series of experiments (senior students and professors of MARKHI). Each expert was given a Whatman paper with an image of linear perspectives of the studied interiors and, on the instruction of the experimenter, had to draw the forecast luminance distribution over the three types of the "open" interior space (deep, enclosed, through) in daylighting and artificial lighting by stumping with a pencil (every expert could draw). In total, 486 drawings depicting variants of luminance (factually speaking, brightness) compositions were made and served as a material for statistical processing and analysis by means of the "brightness scale" with known ρ's of luminance relations of the three zones or, more precisely, the ceiling (L_{uz}) and the walls (L_{mz}) in relation to the floor (L_{lz}).

As a result, for each studied interior and type of "open" space (as the most preferable based on previous studies), the ranges of relations L_{uz}: l_{mz}: L_{lz} were defined as common for daylighting and artifi-

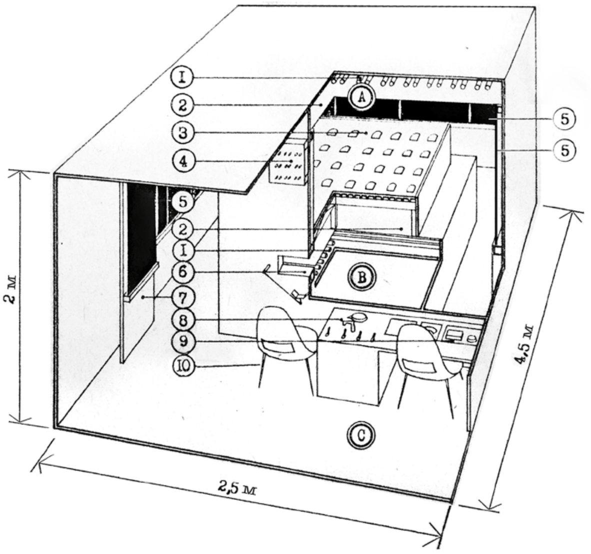

Fig. 10. Experimental assembly (chamber) for simulation of architectural lighting of interiors with overhead lighting: A – reflective artificial sky; B – transparent lighting and general artificial lighting simulator system; C – adaptation chamber (for an observer); 1 – fluorescent lamps with adjusted chromaticity, 30W and 40W; 2 – matted organic glass; 3 – model of an interior with overhead lighting skylights; 4 – artificial sky control board; 5 – reflectors; 6 – hole for observation of the interior; 7 – entrance of the reflective chamber; 8 – control board of the general artificial lighting simulator system; 9 – measuring equipment; 10 – observer's place

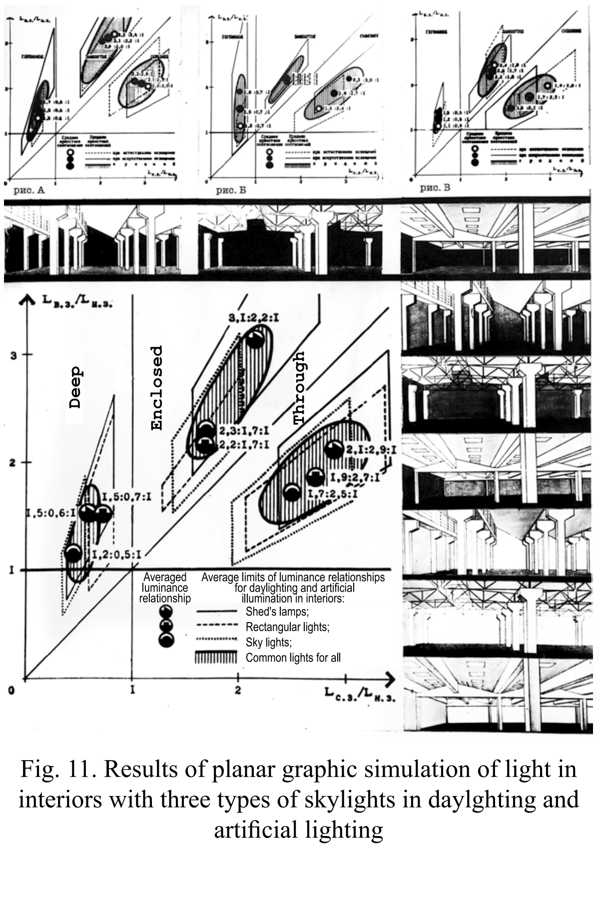

Fig. 11. Results of planar graphic simulation of light in interiors with three types of skylights in daylghting and artificial lighting

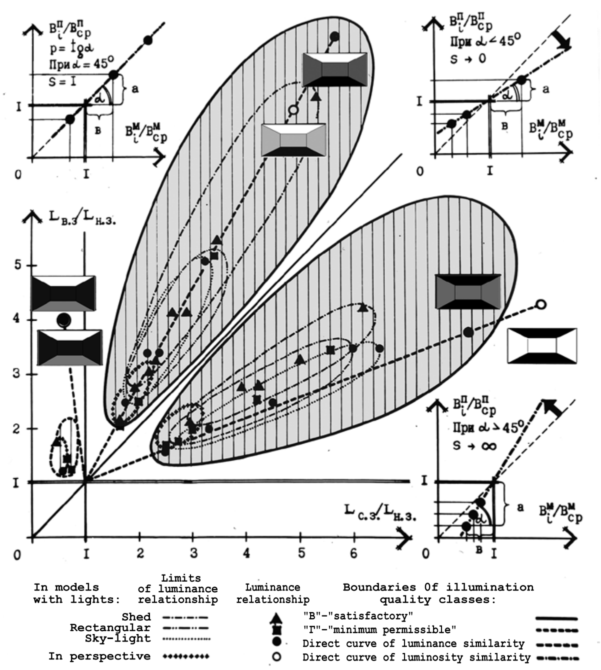

Fig. 12. Ranges of luminance relations of graphic and volumetric simulation of interior lighting

cial lighting. Mean values of these ranges are taken for light simulation using the models (Fig. 11).

Any graphic image has an irremovable disadvantage which makes it different from actual interiors: the range of luminance and even luminance contrasts depicted in images is incomparably smaller than in field as it is limited by reflecting capabilities of white paper: from $\rho = 0.8$ to $\rho = 0.05$ (black matt printing ink). Therefore, it is not possible to reproduce true luminance of sky area seen through a light opening and its contrast with, for instance, transoms or adjacent areas of the ceiling (of the sky and the external window in the case of windows).

To neutralise this disadvantage, the method of graphic light simulation was complicated: additionally, using perspectives of interiors with saw-tooth skylights, statistical experiments (17 participants) with use of transparent illumination of the light opening cut out in the images were conducted to define the effect of their luminance on the taken relations L_{uz}: l_{mz}: L_{lz}. These drawings were placed on the system of controlled lighting in the form of a matted-glass plane. Its luminance could be adjusted by means of fluorescent lamps installed under the glass. At different levels of light opening luminance (L_{lo}) and constant illuminance on the perspective image (E_h = 400 lx) and background luminance (64 cd/m^2), observers were asked to update their pencil stumping drawings if it seemed necessary to them in terms of visual perception in order to harmonise luminance composition of the interior.

The results of the experiments have shown that the relation L_{uz}: l_{mz}: L_{lz} remained relatively constant if L_{lo}: L_r was changed by the range of 1.1–33.7. With further increase in L_{lo}, the experts pointed at appearing visual discomfort (disability glare of the light opening) and associated feeling of lowered light saturation of the interior in the perspective image, which corresponded well with the data of [4].

In the course of the second series of experiments, luminance relations of the models of the studied interiors to three types of skylights similar or close to those depicted in the perspective images in terms of visual perception were defined.

The expert observers (92 persons) were invited in the light simulation chamber where they selected such luminance of the walls at the level of preset daylighting (daylight factor is equal to 4 %) and artificial lighting (E_h = 400 lx on the floor) with which they felt visual similarity between the luminance relations (luminance contrasts) of the model of the studied interior and perspective they had drawn. Luminance of the walls and the floors of the models were changed by means of exchangeable screens which transmitted and reflected light in different ways.

For the interiors being studied, ρ was constant for the ceiling (ρ_c=0.7) and varied for the walls and the floor within the ranges of ρ_{fl} = 0.1–0.5, ρ_w = 0.1–0.7.

The results of the experiments have shown that relations L_{uz}: L_{mz}: L_{lz} similar in terms of visual perception (luminance) are approximated in the system of Cartesian coordinates *x, y* by a line crossing the point with coordinates equal to one on a distance scale (luminance relations of these surfaces Bi on the model and on the perspective image are also approximated by means of a similar line but with other inclination in relation to the *X*-axis). The found conformity called luminance matching is of great importance since it allows an architect to determine the required (ideally harmonic) luminance relations for field conditions (for further light engineering calculation) which are visually similar to those depicted in a project using a simpler graphic method and avoiding the stage of difficult luminance calculation (based on the nomogram of N.M. Gusev and P.I. Khoroshilov [5]). In any case, luminance distribution and relations in interior images are indicative of the lighting quality class, from the "excellent" (A) to the "unsatisfactory" (D), which is reflected by the nomogram based on the results of light simulation using the two methods (Fig. 12). It corresponds to the butterfly-shaped nomogram built after field observations [Fig. 9] rather well.

The series of model experiments was supplemented by experiments aiming at clarification of the effect of structural elements and equipment on the general luminance composition of a production site interior. Optimal values of ρ in range (0.5–0.7) were defined statistically for these elements.

Based on the conducted experiments, the graph of quantitative evaluation of luminance distribution over interior based on luminance range, harmony and frequency was built, which allows to take account of not only the values of luminance but relative areas of luminance in interior visual image. In the series of experiments, 36 experts of MARKHI used seven sets of squares (4×4) cm consisting of 49 pieces each to build three luminance compositions: random, zoned and interior ones with dimensions of (28×28) cm. Luminance harmony ad range of the squares in the sets were defined by a uniform brightness row with ρ equal to 0.05–0.11–0.20–0.31–0.45–0.61–0.80. This experiment formed the basis of the author's method of manual depiction of zoned distribution of luminance in a photo of interior and determination of their mean ρ*'s* within each square (pixel) using the brightness scale and then calculation of total area of each uniform-luminance spot (Fig. 13). It is interesting that later such graphic method of brightness and geometrical formalisation of actual image was used in television for obscuring faces of persons under investigation: criminals, bureaucrats, etc.

During the following series of experiments, quantitative and qualitative evaluation of light saturation of the studied interiors was performed using their models in the experimental chamber under artificial and natural lighting. In the first case, the evaluation was first performed with gradual changing of E_h from 20 lx to 1200 lx and light saturation was determined using the "assembly method": more – equal – less. For each descriptive estimation (perception), observers set a level of illuminance (stimulus) corresponding to it for ten times. In the second case, evaluation was performed by its comparison with similar perception of light saturation under artificial lighting. With a set particular level of natural lighting in the interior model corresponding to a specific degree of its light saturation under artificial lighting, observers memorised it, turned off the artificial sky of the chamber and then immediately reproduced visually similar light saturation under artificial lighting for 10 times. The processed results of 23 experts (2300 evaluations) have shown that stimuli in daylighting lay within confidence ranges of stimuli in artificial lighting for similar visual perceptions with difference of up to 10 %.

Unbiased evaluation of light saturation was performed using the scale taken for field observations [1] for unbiased evaluation of E_h, $E_{2\pi}$ and E_z (Fig. 14).

As a result of this series of experiments, a stimulus (E_{lx}) versus perception (N) curve was obtained. It is approximated by a line in the system of Cartesian coordinates on a logarithmic scale and corresponds with the following equation: $N = aE^{0.5}$, where

N is the light saturation indicator, in points;

a is the taken illuminance criterion factor (for $E_h = 0.16$; $E_{2\pi} = 0.19$; $E_z = 0.22$);

E is the illuminance taken for calculation (E_h, $E_{2\pi}$, E_z), lx.

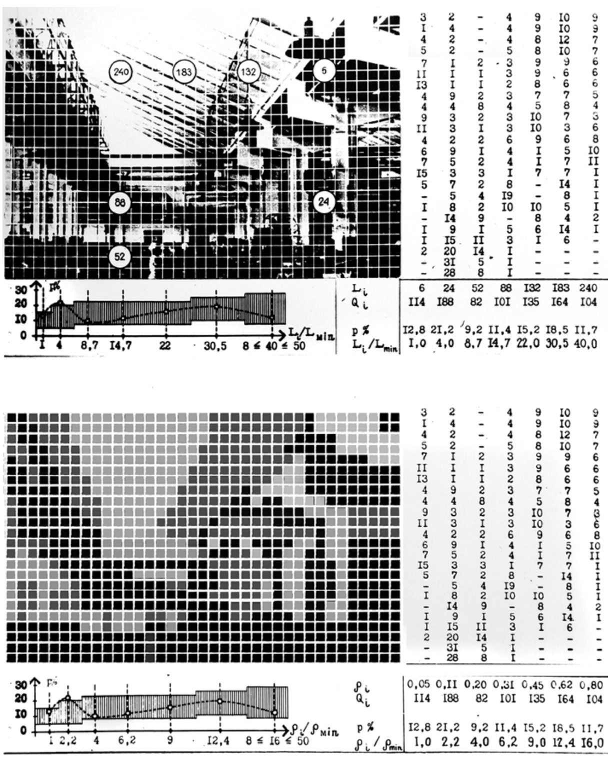

Fig. 13. Evaluation of lighting quality evaluation based on range, harmony and frequency of luminance distribution over an image of the interior with saw-tooth skylights in daylighting

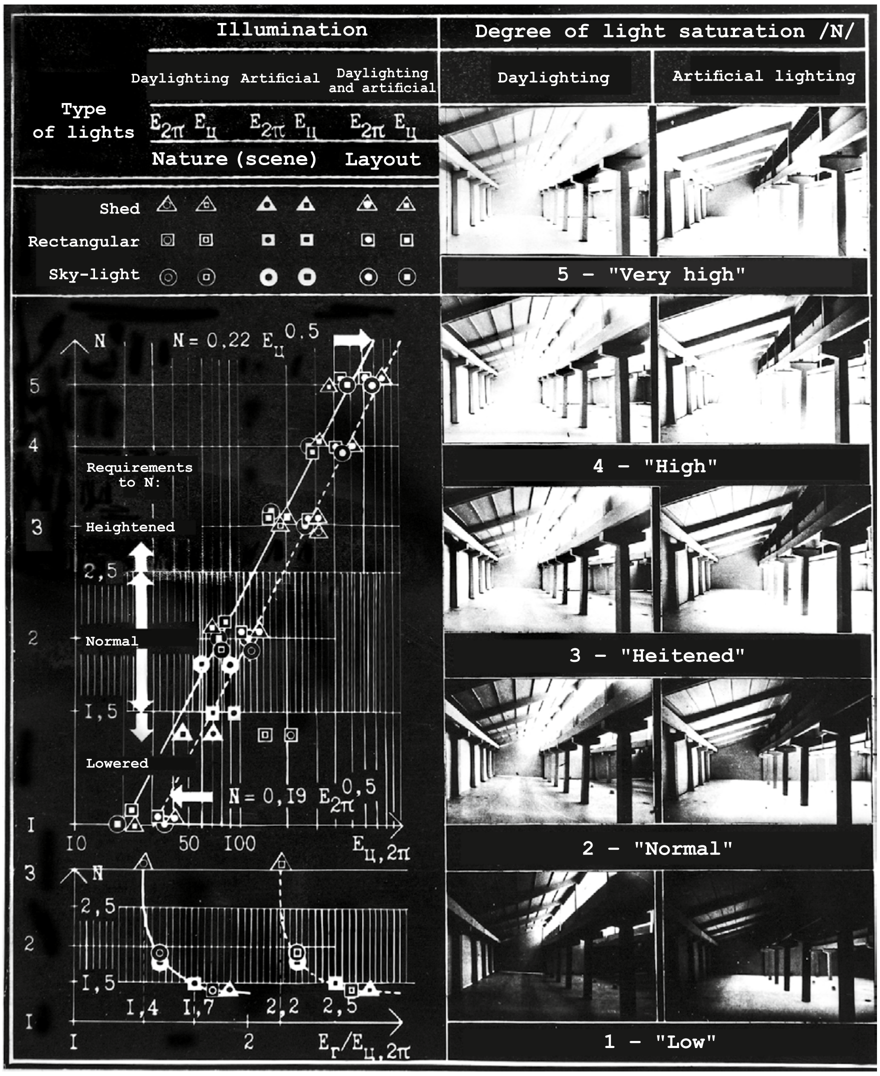

Fig. 14. Results of experiments for evaluation of the degree of light saturation of the interior with saw-tooth skylights

The values of lighting contrast $E_h/E_{2\pi}$ and E_h/E_z in the interiors did not exceed 1.4 and 2.2 respectively.

Required confidence and practical reliability of the results of subjective and objective evaluation of the quality of lighting of the studied interiors in terms of luminance and light saturation distribution obtained in field and laboratory conditions allowed to develop requirements and recommendations for qualitative evaluation of luminous environment of production site interiors in daylighting and artificial overhead lighting on the basis of the classification parameters of SNiP II-4–79, which develop and supplement the standards of lighting aesthetics (Table 1).

(See part 3 of this article in the next volume of the journal.)

P.S. Author's note: since these convincing results of comprehensive volumetric studies which will unlikely be repeated by anyone were not brought to attention of the scientific community and, above all, of research facilities and institutions issuing and revising corresponding standards (NIISF, VNISI, etc.) by V.V. Voronov (as contrasted with, for instance, T.N. Sidorova and M.M. Epaneshnikov), they have not been put into practice and embodied in standards. However, they have not become obsolete in any way. On the contrary, they have become even more relevant. Therefore, they should be used by the above mentioned organisations as well as young scientists in this field.

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Table 1. Classification Parameters

Requirements to quality of production site interior lighting	Visual performance characteristic as per SNiP II-4–79	Visual performance class as per SNiP II-4–79	Lighting quality class in terms of luminance distribution	Light saturation indicator (N)	Lighting contrast		Examples of interiors
					$E_h/E_{2\pi}$	E_h/E_z	
Heightened	The highest and very high precision	I–II	A Excellent B Good	More than 2.5	Less than 1.4	Less than 2.2	Workshops of electronic, radio-electronic and instrument-making plants.
Normal	High and medium precision	III – IV	B Good	2.5–1.5	1.4–1.7	2.2–2.5	Workshops of textile, consumer goods, instrument and metal processing industry plants
Lowered	Low precision and crude	V – VI	C Satisfactory	Less than 1.5	More than 1.7	More than 2.5	Workshops of construction industry plants, metallurgical facilities, storage facilities, etc.

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