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MODERN APPROACHES TO NORMALIZING NATURAL LIGHTING OF RESIDENTIAL BUILDINGS: RESEARCH RESULTS

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ABSTRACT

In the premises of residential buildings, there are practically no requirements for the conditions of visual work. The light environment is evaluated by the criterion of the saturation of the premises with natural light. The required time of using natural light and providing natural lighting in space are also of great importance here. The task for residential buildings is to link these criteria to create an integrated method of rationing natural lighting in such rooms. The article discusses the modern trends in development of regulations of natural lighting from traditional, using Daylight Factor (*D*), to the modern ones, connected with dynamic evaluation of day lighting in time and space, necessarily taking into account real statistical brightness distribution on the sky. Evaluation of Daylight Factor method analyses its assessment, energy indicators and provides a comparison with the norms of Germany DIN. The results of research at MGSU on the evaluation of day lighting using the spatial criterion of the light field – cylindrical illuminance, which best describes the saturation of the light of the room are presented. It is noted that the full amount of natural light is not required over the entire area of the living room during the whole daylight hours. In this case, you can find the relationship between *D* and the coefficient of natural cylindrical illuminance (D_{ci}). This provides a link between traditional regulation and regulation on the saturation of rooms with natural light. The final assessment of the standardized parameters of natural lighting in residential premises is carried out using methods of psychophysics, which can connect the main and secondary factors affecting the comfort of the light environment.

Keywords: daylighting, light environment, visual work, light saturation of premises, daylight rationing, cylindrical illuminance, daylight climate, energy efficiency, static rationing, dynamic rationing, psychophysical assessment

1. INTRODUCTION

The twentieth century was the century when the science of daylight of buildings developed and flourished. All developments of this time were an attempt to determine as accurately as possible the conditions of day lighting in the rooms. Methods were developed for calculating the coefficients of daylight illuminance (*D*) [1, 2, 3], which with some degree of accuracy could determine the conditions of day lighting in the rooms. In order for the calculation results to be comparable with each other, we had to make the basic assumption about cloud conditions, which is the most unstable and uncertain characteristic. As a basic assumption, the International Lighting Commission (CIE) adopted the cloudy sky as the worst condition for daylight. Under this condition, the values of *D* in the premises for various purposes began to be compared with the norms. Relative values of *D* were included in the norms. However, these standards were based on the required conditions for visual work in artificial lighting. These conditions were determined by the methods of psychophysics in terms of speed and accuracy of distinguishing observers of conditional objects (Landolt rings test) and in the fatigue of observers in time. In residential buildings, the tasks of visual work are difficult to determine, therefore, for living rooms, the standardized level of general artificial illuminance is 150 lx, and the notes indicate that this value is recommended. The norms of natural lighting were obtained from the condition that the amount of lighting under artificial lighting for the year is equal to the amount of natural lighting for the year obtained by summing the integrals of the average hourly values of the outdoor daylight for each month during the daylight hours in the area where the building in question is located and multiplying by the number of days in a month. The ratio of the first value to the second as a percentage will be the value of the average *D*. The average *D* should be distinguished from the *D* value in the centre of the room. It is about 1.5 times larger. For example, standardized illuminance for the Moscow City according to conditions of visual work equal to 150 lx during single-shift work for 8 hours and at 226 working days a year, the amount of artificial lighting for the year $A_{artlight/year}$ is equal: $A_{artlight/year} = 150 \cdot 8 \cdot 226 = 271200$ lx·h/year.

At the beginning of work, at 9.00 a.m., and the end of work at 18:00 (1 hour lunch break) the amount of natural light in the open air will be the sum of the integrals of the functions of changing the total natural light for Moscow according to SP 367.1325800.2017 "Residential and public buildings: Rules for the design of natural and combined lighting". This value will be 36160000 lx·h/year. The average value of *D* will be: *D* norms. = (271200 / 36160000) ·100 % = 0.75 %. In the centre of the room, this value will be: *D* = 0.75 % / 1.5 = 0.5 %. This value is determined by the existing system of rationing of natural lighting in the Russian Federation. But is it satisfactory for the comfort of the internal light environment in terms of light saturation in the rooms? This was called into question in the article of the graduate student of the Department of Design of Buildings and Structures of the National Research University of Moscow State University Muravyova N.A. [4]. The studies were based on the work of M.M. Epaneshnikov and T.A. Sidorova [5] for artificial lighting of subway stations. It was found that the best characteristic that determines the saturation with room light is the spatial characteristic of the light field – cylindrical illuminance. At the same time, the saturation with light of the underground metro halls turned out to be acceptable for observers even at 200 lx of cylindrical illuminance.

2. THE RELATIONSHIP OF DAYLIGHT FACTOR *D* WITH THE SPATIAL CHARACTERISTIC OF THE LIGHT FIELD – CYLINDRICAL ILLUMINANCE

How to connect the traditional planar characteristic of the light field – *D* with the value, characterizing the cylindrical illuminance $D_{ci,}$ the coefficient of natural cylindrical illuminance. This value is the ratio of the internal cylindrical illuminance E_c to the simultaneous external horizontal illuminance E_n, taken in %. It makes no sense to take the ratio of internal and external cylindrical illumination as D_{ci}, since all data on the light climate around the world are tied to E_n, and data on external natural cylindrical illuminance simply do not exist. At the same time, the external horizontal illuminance characterizes well the change and the amount of natural illumination [6].

Experimental studies were conducted at the NRU MGSU under the guidance of the author, which showed that in rooms with ordinary windows with a windowsill at a height of 1 m from the floor, the *D* and D_{ci} graphs intersect almost exactly in the centre of the characteristic section of the room (*D* at the level of the working surface and D_{ci} at the observer's eye level at a height of 1.5 m from the floor) [4] for any room parameters. Thus, these studies have shown how the existing standardization system can be combined with standardization according to the light saturation of the room. Preliminary studies in the living quarters showed that observers considered acceptable saturation with room light at 120 lx cylindrical illumination. This means that in the centre of the room this value corresponds to a horizontal illumination of 120 lx. If we go to *D*, then with artificial illumination of 120 lx, included for 8 hours a day and at 30 days in a month, the annual amount of artificial lighting will be equal $A_{artlight/year} = 120 \times 8 \times 12 \times 30 = 345600$ lx·h/year. The value of the normalized *D* in the centre of the living room at the level of the working surface will be:

E_n = (345600 / 36160000) ·100 % = 0.956 %, i.e. approximately 1.0 %.

If compare the obtained value with the norms of the Federal Republic of Germany (DIN5034–1 Appendix A.1), the norms are indicating that, in rooms for long-term stays of people with windows for sufficient lightness, the value of *D* should be in half of the room depth at a height 0.85 m above the floor and at a distance 1 m from the side walls is not less than 0.9 % in the middle between these points and not less than 0.75 % in each of both points. Thus, the obtained value is approximately consistent with the norms of the Federal Republic of Germany, and an experimental justification has been obtained for this. Of course, the value obtained at MGSU requires additional verification by additional psychophysical studies, but the principles of rationing set forth in the article can be used.

It should be noted that in the scientific literature there is no justification for both the norms of the Federal Republic of Germany for residential buildings and the norms of the Russian Federation for residential buildings, which require one, two and three bedroom apartments in one of the rooms and four or more room apartments in two rooms apartments D equal to 0.5 % on the floor at a distance of 1 m from the wall opposite the windows. In other rooms, this value should be in the centre of the room.

3. CONSIDERATION OF THE REAL LIGHT CLIMATE OF THE AREA WHEN NORMALIZING DAYLIGHT

In the article of S. Darula [5], it was shown that there are two ways to standardize day lighting:

– Standardization of day lighting according to the simple "static" criterion of D in the sky, completely covered by clouds;

– The second way is based on the dynamic criterion of "autonomy of daylight", which is associated with the absolute values of daylight illuminance.

The last one method is currently being actively implemented by the British Institute for Building Research on Environmental Assessment (BREEAM). According to this method, the natural lighting of the premises should satisfy two indicators:

– The minimum value of the average D should be provided for 80 % of the room area at the height of the conditional working surface;

– The average daylight illuminance should be provided at a level of 200 lx or more for 2650 hours a year and at least 60 lx or more for 2650 hours a year in the worst places in terms of illuminance.

The average value of D in ordinary rooms depends on the latitude of the area, varying from 1.5 % for latitudes less than 40 degrees and up to 2.2 % for latitudes more than 60 degrees north latitude. For residential buildings, such regulatory data are not provided.

We see that, applying normalization according to the dynamic criterion of "autonomy of daylight", we take into account the change in daylight exposure by month and during the day. This can be considered as a higher level of standardization, for which, however, data are needed on the light climate of the area in dynamics by month of the year and time of day. Of course, a simple "static" criterion is easier to use, given the light climate by introducing light-climatic coefficients into the calculation formula. But its accuracy is low. In general, the concept of D is universal. The human eye cannot evaluate the absolute levels of illuminance and evaluates this only in comparison with the illuminance of something. In this case, it is outdoor natural light. Therefore, it is impossible to refuse relative values when evaluating natural lighting, and D or D_{ci} (or other relative spatial characteristics of the light field, referred to as external illuminance) are full-fledged estimated characteristics for natural lighting, which we will operate in the future. Linking the static and dynamic criteria for evaluating natural light is an important task that specialists in the field of daylighting will have to work on. And first of all it concerns the light climate of the area. The light climate depends on many factors such as the latitude of the terrain and, in connection with this, the height of the sun rising above the horizon, the duration of daylight hours, cloud statistics and its prevailing species. R. Kittler and S. Darula proposed in article [6] to classify 15 types of firmament according to the distribution of luminance from clear to cloudy sky, completely covered with 10-point cloud cover. At the same time, D, as a constant value for a given room point, makes sense only with a cloudy sky with a distribution of the luminance of the CIE according to the law of P. Moon and D. Spencer and with an equally bright sky, which is also sometimes found statistically, especially for upper natural lighting systems. In all other cases, the D value depends on the position of the sun in the sky, since an aura of increased brightness forms around the sun, which affects the D value. This halo during the day moves relative to the orientation of the window.

Accordingly, at this point the value of D changes. Therefore, it is necessary to choose a position of the sun relative to the orientation of the window, which is suitable for the purpose of calculating D. For example, comparing natural light in different rooms or determining the energy consumption for daylight devices.

Determining the type of firmament according to R. Kitterler and S. Darule is quite complicated. For this, there is not always enough data on the light climate in a particular area. At MGSU, another possibility was developed to determine the luminance distribution of the real sky by the value of the ratio of the total and diffuse horizontal illuminace by the hours of the day (for example, the 15th day of each month). In the absence of data on illuminance, data on the total and diffuse solar radiation, which are available at numerous actinometric stations in all cities of Russia, can be used. It is possible to construct charts of the hourly stroke of outdoor illuminance for any city using the light equivalent of solar radiation [7, 8, 9]. Thus, in MGSU were obtained graphs of the course of outdoor illuminance in real average sky for cities in Vietnam.

4. DEFINITION OF THE AREA OF LIGHT APERTURES AS A SIMPLIFICATION FOR DESIGNERS OF DAYLIGHTING

Until the end of the first half of the twentieth century, one of the methods of normalizing natural lighting was the normative determination of the ratio of the area of windows in a room to the area of a floor. Now this is called the "opening of the room." This method is simple and convenient for designers, but is not accurate. After that, the norms became more complicated, new indicators were introduced, the main of which was Daylight Factor *D*. Despite this, attempts to simplify calculations and design did not stop. This can be most simply represented by a characteristic expressed in terms of the ratio of the area of windows to the area of the floor. In the norms of SNiP P-4.79 "Daylight and Artificial Lighting" and in the subsequent Code of Rules, it was recommended that the design of daylighting systems has to be carried out in two stages. The first stage involved an approximate determination of the area of light apertures, which was based on formulas for lateral and upper daylight:

$$100 \cdot \frac{S_0}{S_f} = \frac{e_{norm} \cdot \eta_0}{\tau_0 \cdot r_0} \cdot K_{b.sh.} \cdot K_{sfactor}, \qquad (1)$$

$$100 \cdot \frac{S_{cl}}{S_f} = \frac{e_{norm} \cdot K_{sfactor} \cdot \eta_w}{\tau_0 \cdot r_2 \cdot K_{cl}}, \qquad (2)$$

where *So*, S_{cl} and S_f are the areas of windows, daylight ceiling, and floor respectively; e_{norm} – normalized *D*; τ_0 is the total light transmission coefficient of the openings; r_0 and r_2 are the coefficients that take into account the effect of reflected light from the internal surfaces of the room at the design point in lateral and upper natural light; $K_{b.sh.}$ is the coefficient, taking into account the shading of windows by opposing buildings; $K_{sfactor}$ is the safety factor, taking into account the pollution of openings; K_{cl} is the coefficient, taking into account the type of daylight ceiling; η_0 is the light characteristic of the window, showing the ratio of the windows area *So* to the floor area S_f in %, providing the value of *D* = 1 % at the calculated point in the depth of the room on the conditional working surface; η_w is the light characteristic of the daylight ceiling.

For the most common geometric and lighting parameters of the side and top light openings in the later Code of Rules SP 23–102–2003, graphs are given to determine the relative area of daylight openings, somewhat simplifying the calculation by equations (1) and (2). If we consider these graphs, it can be noted that for light apertures of the upper light, there is a direct proportionality between the values of *D* and the ratio of the openings area to the floor area, S_0/S_f. For light apertures of lateral daylight, the graphs are constructed according to a different principle. Here, as shown in Fig. 1, the aperture is determined depending on the ratio of the room depth d_r to the height of the top of the window above the working plane h_0. At the same time, there is no shading by opposing buildings. The graphs are represented by a series of curves. If we imagine the

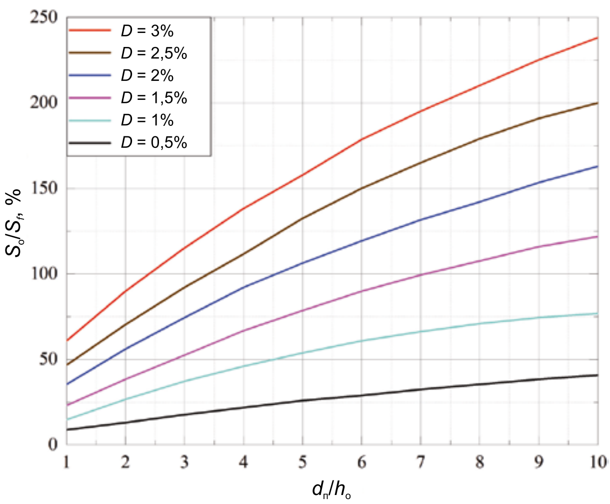

Fig. 1. Dependence of the opening on the ratio of the depth of the room to the height to the top of the window

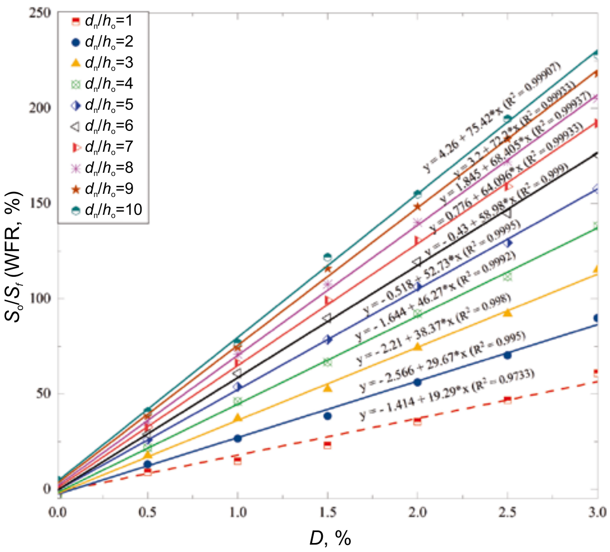

Fig. 2. The dependence of D from the magnitude of the opening

dependences of D on the S_0/S_f, they will also express direct proportionality between these values. To do this, you just need to select the characteristic ratio of the depth of the room to the height of the top of the window and build a series of graphs. In Fig. 2, such graphs constructed at MGSU are shown, for example, for the characteristic parameters of working rooms.

To normalize daylight, perhaps we should return to the definition of the "openness" of the premises, but at a higher level that increases accuracy and is most convenient for designers.

5. ENERGY EFFICIENCY OF WINDOW OPENINGS

The area of windows is closely related to the amount of energy spent on the device of light apertures in the building. There are more apertures for light transmission, the lower the cost of electricity for artificial lighting. This is confirmed by the above that the value of D is proportional to the ratio of the area of the windows to the area of the floor (i.e., the opening). But the larger the area of the windows, the greater the heat loss through them in winter, since the heat transfer resistance of good windows is about three times less than the heat transfer resistance of the blind parts of the walls. Of course, the heat transfer resistance for hygienic reasons in modern windows can reach similar values for walls, but based on the requirements of energy saving, this is not yet possible.

In summer, the larger the area of the windows, the greater the heat input into the premises through the windows of the south, west and south-east orientation. Less heat passes through the east-facing windows into the room, as the sun still does not have time to warm the air after night. However, nevertheless, solar thermal radiation in this case should also be taken into account in the heat balance of the room. Mostly only heat losses and daylighting of the rooms occur through the northern light paths. Therefore, on the north side should be located rooms with reduced requirements for natural lighting and, accordingly, reduced size of window openings.

Thus, energy costs for electric lighting, heating, ventilation and cooling in the summer should be minimal. To do this, you need to find the appropriate area of light apertures. This area may vary depending on the climatic conditions of the construction site. This energy-efficient glazing area should be compared with the required window area according to the lighting conditions from the conditions of saturation of the room with natural light, the conditions of visual work, the necessary time to provide it and the necessary area of the room on which it should be provided at this time.

The methodology for determining the energy costs for the device of light apertures was developed back in 1985 at the Research Institute of Building Physics [10]. It seems very reliable. But at present, it is slightly changed by us in connection with the advent of new air conditioners and is somewhat simplified [11]. We also developed a computer program "ECON", with the help of which the energy-efficient dimensions of daylight ceiling openings in the climatic conditions of Arkhangelsk were determined. It seems that a detailed presentation of this technique in this article would be interesting for designers.

The total energy costs should be calculated with the conversion to equivalent fuel costs, since the production of thermal energy and electric energy requires different costs. Therefore, they should be calculated by the formula:

$$W_{eq.fuel\cos t} = A_1 \cdot w_{hl} + A_2 \cdot (w_{heat} + w_{vent} + w_{coolair} + w_{artlight}), \quad (3)$$

where A_1 = 41.2 kg/GJ and A_2 = 0.33 kg/kW·h are specific consumptions of equivalent fuel in power plants of general use per 1GJ of thermal energy and

1kW·h of electricity; w_{hl} is the energy consumption for replenishing heat losses through light gaps GJ/m²/year; w_{heat} is the specific annual energy consumption for heating, adopted by the formula:

$$w_{heat} = 7.1 w_{hl}, \quad (4)$$

for air heating systems and equal to zero for other heating systems; w_{vent} is the specific amount of electricity for ventilation kW·h/m²; $w_{coolair}$ is the amount of electricity per year spent on cooling the supply air kW· h/m²; $w_{artlight}$ is the energy consumption for artificial lighting per year kW·h/m². The determination of energy costs for heating, ventilation, cooling and artificial lighting is carried out according to the formulas given in [10]. Values ω_{hl} determined by the formula:

$$w_{hl} = 10^{-6} \cdot 1.1 \cdot 3.6 \cdot (1.3 + \eta) \cdot (\frac{1}{R_{ts}} - \frac{1}{R_{ws}}) \times \times (t_{at} - t_{htt}) \cdot Z_{ht} \cdot 24 \cdot \frac{S_{lightopenning}}{S_f}. \quad (5)$$

Here 1.1 is the coefficient taking into account useless heat losses in the heating system; 3.6 is the conversion factor of units kJ/W·h; 1.3 is the coefficient taking into account heat losses due to heating of the outdoor air entering through light apertures by means of infiltration, which can approach 1.0 with high sealing of openings; η is the coefficient taking into account additional heat losses, its value should be taken according to SNiP "Heating and Ventilation "; R_{ts} and R_{ws} – heat transfer resistance of the translucent structure and the wall" on the surface "; t_{at} and t_{htt} are the calculated temperatures of the indoor air and in heating period too; Z_{ht} is the duration of the heating period (days); 24 is the hours in days; $S_{lightopening}$ and S_f are the areas of light apertures and floor indoors (m²).

The cost of electric energy for cooling with the help of air conditioners is determined if the air conditioners in the house exist. In this case, their value is determined by the formula:

$$w_{ec} = 10^{-3} \cdot (1.3 + \eta) \cdot (\frac{1}{R_{ts}} - \frac{1}{R_{ws}}) \cdot (t_{o.a.t} - t_{\max}) \times \times T_{28} \cdot \frac{S_{lightopenning}}{S_f} + 0.72 \cdot L_o \cdot N_o \cdot T_{28}, \quad (6)$$

where $t_{o.a.t}$ is the average outdoor temperature during the cooling period, determined by the reference SNiP P-A. 6–72 [12] in accordance with table of temperature repeatability in hours, in descending total hours at a temperature above 28 °C; t_{max} is the maximum permissible temperature of the internal air during the cooling period, taken for hygienic reasons (in Russia, there is no such standardized temperature, however, from the experience of application household air conditioners, it can be accepted as 24° C; T_{28} is the duration of cooling period in the days, taken in the same directory [12]; N_a is the specific consumption of electric energy for cooling, kW·h/m³; L_o is the performance of the ventilation system in the chilled air distribution devices ("fan coil") and in general in ventilation systems m³/h per 1 m² of flow area, calculated as:

$$L_0 = {3.6 \cdot q_{rad}^{\max}} \Big/ {c \cdot \rho \cdot (t_{avercool} - t_{\max})}, \quad (7)$$

where c = 1 kJ/kg/°C is the specific heat capacity of air; ρ = 1.2 kg /m³ is the air density; $q_{rad}^{\max}$ is the value of radiation entering the room in W/m², the main part of which is determined by the maximum value of the total solar radiation incident on the plane of the light openings of this orientation during the day and determined by the formula:

$$q_{rad}^{\max} = Q_B^{\max} \cdot \tau_e \cdot \tau_2 \cdot MF \cdot \beta_{sp} \cdot \frac{S_{lightopening}}{S_f}, \quad (8)$$

where $Q_B^{\max}$ is the maximum value of solar radiation arriving in a given area on a vertical surface of the most unfavourable – western orientation in July; τ_e is the heat transfer coefficient of windows; τ_2 is the light transmittance, depending on the type of binding (for single-chamber double-glazed windows in plastic binders τ_2 = 0.69, for double-chamber τ_2 = 0.57); MF is the operating factor taking into account pollution; β_{sp} is the heat transfer coefficient of sunscreens (if any), relative units. The corresponding coefficients are determined by SP 367.1325800.2017.

Energy costs for artificial lighting are calculated by the formula:

$$w_{eart} = 10^{-3} \cdot E \cdot K_{safe.art} \cdot Z \cdot \alpha \cdot P_l \times \times (1 + \beta) \cdot \frac{T_{art}}{\Phi_l \cdot K_{ld}}, \quad (9)$$

where E is the normalized value of artificial illumination, Φ_l is the luminous flux of artificial lighting lamps, T_{art} is the time of use of artificial lighting, P_l is the power of the lamps, and K_{ld} is the coefficient of use of the luminous flux of the lighting device [13], α is the coefficient taking into account energy losses in the ballast; β is the same in the network; Z is the coefficient taking into account the illuminance non uniformity (it is taken equal to 1.15 for spot lamps and 1.1 for fluorescent lamps).

To determine the time of use of artificial lighting, you can use the tables [10] or use the analytical method with approximation of the graphs of the course of outdoor natural illumination depending on the sinus of the height of the sun with small corrections for cloudiness.

Thus, using this technique, it is possible to determine the energy efficiency of the "opening" for a given construction site and, if necessary, adjust the size of the windows taking into account their orientation to the cardinal points.

6. CHECKING THE RATIONING OF NATURAL LIGHTING USING METHODS OF PSYCHOPHYSICS

Finally, all methods for determining regulatory requirements for daylighting in residential premises should be checked by the method of psychophysics. Indeed, we can calculate the physical parameters of natural light in a room, determine the requirements for daylight levels based on the conditions of some visual work with the determination of normalized values of D, but only the needs of residents, determined by the method of psychophysics, can give us the final answer.

At the Moscow State University of Psychology, psychophysical research was carried out at the end of the twentieth century in relation to the issues of the movement of human flows and the application of the spatial characteristics of the light field to improve the conditions of visual work with volumetric and relief objects of distinction. These studies were carried out in conjunction with existing at that time laboratory of psychophysics at Moscow State University, in accordance with methods developed in this laboratory and applied to our tasks. Currently, when conducting research, we used the work of the American scientist H. Helson [14], in which he proposes to consider any questions of sensation and perception associated with a subjective assessment by observers, as the sum of the main, secondary and background factors raised to a degree, the indicators of which show the significance of these factors in the assessment. The calculation formula of H. Helson is as follows:

$$A = X^p \cdot B^q \cdot P^r, \tag{10}$$

where X^p is the main factor. If this is the illuminance, then this is the quantity necessary to ensure that the main task. In rooms where the main is visual work, artificial lighting is normalized. In rooms where the basic requirements are imposed on the saturation of the room with natural light, this is cylindrical illuminance, determined according to the results of psychophysical studies conducted by a similar technique [15]. For residential premises, this factor A will be the main factor, and the normalized artificial lighting will be a secondary factor (B^q). Background factor P^r for residential premises may not be present at all. Values of weights coefficients, p, q, and r, may vary depending on the situations being evaluated. Moreover, in residential premises, the main and background factors can be estimated, for example, at $p = 0.7$ and $q = 0.3$. This should be determined by analysing the time of use by residents for different types of activity at home.

CONCLUSION

This article shows the results of scientific developments carried out at NRU MGSU and in many other research organizations of the world, which, with appropriate refinement, can be used as the basis for normalizing the daylighting of residential buildings. Based on these results, possible directions for further research in this field can be formulated. Briefly, for residential buildings these areas are as follows:

- Determination of the required average illuminance in lx, which must be provided in the living room during a certain period of daylight hours during the year, and determination of percentage of the area of the room on which it is necessary to provide the required amount of average illuminance during a certain period of daylight hours during the year;
- Determining the period of the year during which, at a given percentage of the room's area, it is necessary to provide the required average illuminance at time of the daylight hours;

• Determination of the average value of Daylight Factor *D,* which must be provided at a given percentage of the area of the room, and determination of the "openness" of the room;

• Checking the energy efficiency of the obtained glazing area for the equivalent fuel consumption for heating, cooling and artificial lighting per 1sq.m of the room; and it should be noted that the energy consumption for artificial ventilation for residential buildings may not be taken into account, since ventilation during the outdoor temperature period of more than 21 degrees in the housing, as a rule, is carried out by natural ventilation by opening the windows;

• Correct the "opening" according to the orientation of the openings to the cardinal points;

• Calculate the required illuminance according to the Helson's formula, depending on the requirements for the room according to the magnitude of the main factor, for example, the saturation with natural light of the room, and the value of the secondary factor, for example, the requirements for the conditions of visual work;

• Determine the normalized average value of *D* in the room from required luminance value.

Each of the topics can be an independent study, especially if we consider not only residential buildings, but also buildings and premises, where the conditions of visual work are determining. In the case of volumetric and relief objects of distinction, one should use such spatial characteristics of the light field as average spherical illuminance, average hemispherical illuminance, light vector, and their relationships [16]. Using the spatial characteristics of the light field only due to its own shadowing can significantly save energy costs for artificial lighting.

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