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SELECTION OF THE AREA OF WINDOW OPENINGS OF RESIDENTIAL BUILDINGS IN CONDITIONS OF MONSOON CLIMATE OF THE FAR EAST OF THE RUSSIAN FEDERATION AND NORTHERN AREAS OF CHINA

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ABSTRACT

The term “window” in architecture usually stands for an opening in a wall or roof for penetration of natural light, sunrays and fresh air in premises. Recently, the requirement of contact with environment is added to this condition. It is especially relevant for residential buildings where rooms are considered residential if they have windows. The energy consumption of a building depends on sizes, form and location of windows. In winter, windows cause huge heat losses, in summer, on the other hand, large heat enters a building via the windows and is required to be removed by means of air conditioning. Moreover, windows are used for penetration of natural light in premises, which assists in saving of large amounts of power for artificial illumination. This article discusses partial solving the problem of the energy efficiency of residential buildings by determining the most efficient area of windows in terms of energy spending for compensation of heat losses via windows in winter, elimination of heat penetration through them in summer and energy losses for artificial lighting throughout the year. The analysis of the results of calculation of power consumption for residential premises in conditions of monsoon climate of the Russian Far East and Northern areas of China (PRC) is provided.

Keywords: window area, energy efficiency, natural and artificial illumination, heat losses, heat gain, critical illuminance, power consumption

1. INTRODUCTION

The area of windows of residential premises is set by means of standardised values of daylight factor (DLF). However, DLF characterises only physical conditions of natural illumination of premises. In Russia, it is considered that the premises is perceived as saturated with natural light with DLF of 0.5 % on the floor at a distance of 1 m from the wall opposite to the windows, but the standards in other countries may be different. For instance, in Germany it is considered that saturation of the premises with natural light is reached at DLF = 0.5 % in the middle of the premises on the level of working surface (i.e. 0.8 m above the floor) at distance of 1 m from the side wall of the premises [1]. In this article, the Russian standards are used [2].

Windows are the weakest point of the thermal envelope of a building. In winter, the largest heat losses are caused through them. For instance, the standards [3] require to reach the value of heat transmission resistance of about 3 ($m^2 \cdot °C$)/W in Moscow whereas ordinary windows do not even provide 1 ($m^2 \cdot °C$)/W. It means that three times as much heat is lost via windows as via blank walls in winter, which causes additional losses for heating. On the other hand, a lot of solar heat is gained through the windows in summer, which causes overheating of premises and increased losses of power for its cooling by means of air conditioning.

NIISF RAASN developed the method of energy evaluation of the system of natural illumi-

Table 1. Average Monthly Temperatures, Taken Temperatures and Some Data for Winter Period

City	Average ambient air temperature, °C												Annual indicators					
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average annual temperature, °C	Absolute minimum temperature, °C	Absolute maximum temperature, °C	t_1*, °C	$t_{\text{ОТ}}$**, °C	$Z_{\text{ОТ}}$, days
Khabarovsk	-22.3	-17.2	-8.5	3.1	11.1	17.4	21.1	20.0	13.9	4.7	-8.1	-18.5	1.4	-43	40	-34	-10.1	205
Harbin	-23.1	-18.7	-8.8	8.4	8.4	15	18.3	16.7	8.9	0.6	-9.6	-19.1	4.9	-38.1	36.8	-33	-10	176

* Taken minimal ambient temperature in the cold period.
** Average ambient temperature during the heating period.

nation of buildings with consideration of power consumption for electrical illumination, compensation of winter heat losses via the windows and energy losses for air conditioning in summer [4]. The authors of the article updated this method a little with consideration of the new types of air conditioners (split systems) by simplifying the calculation of air conditioner operational period and took the new provisions of energy efficiency of natural illumination according to SR (Set of Rules) [5] into account.

2. MONSOON CLIMATE CONDITIONS OF THE RUSSIAN FAR EAST AND NORTH-EASTERN AREAS OF PRC

Khabarovsk (Russia) and Harbin (PRC) are characteristic and similar cities of the Far East of Russia and the Northeastern part of PRC in terms of climate. Their climate is characterised by a large amount of clear and half-clear days with high solar radiation both in winter and in summer. For instance, in Khabarovsk, the diffuse and total illuminance are 13.8 klx and 28.6 klx at noon in January and 29.3 klx and 56.5 klx in July, whereas in Moscow the same values are 7.0 klx and 9.2 klx in January and 28.3 klx and 47.8 klx in July. Proportions of these values at noon in Khabarovsk: 1:2.07 in January and 1:1.92 in July and in Moscow: 1:1.31 in January and 1:1.69 in July. This means that there are twice as many sunny and half-clear days as dismal days in Khabarovsk and there are significantly less clear and half-clear days in Moscow, especially in winter. The number of clear and half-clear (with open Sun) days in Harbin is approximately the same as in Khabarovsk. The thermal cycle in both cities is approximately the same too (Table 1). Table 2 shows that both cities may be considered identical for summer period when artificial cooling of air by means of air conditioning is rather rarely but still required too.

There is data of temperature frequency for the cities of Russia [6] including Khabarovsk krai, where frequency of temperatures higher than 28 °C is just 16 hours per year (i.e. air conditioning (cooling) of premises oriented to the North is required for 16 hours per year). It is negligible and the power consumption for cooling of premises oriented to the South, West and East may be calculated only based on the conditions of overheating by solar radiation.

Table 2. Climatic Data for Summer Period in Khabarovsk and Harbin

City	Temperature, °C							Prevailing wind direction in July and August	Maximum rhumb wind velocity in June, m/s
	V	VI	VII	VIII	IX	Absolute maximum air temperature	Average maximum air temperature		
Khabarovsk	11.1	17.4	21.1	20.0	13.9	40.0	25.7	SW	4.6
Harbin	8.4	15	18.3	16.7	8.9	36.8	26.4		1.71

3. METHOD OF CALCULATION OF POWER CONSUMPTION FOR NATURAL ILLUMINATION

The systems of natural illumination may be assessed using two methods: 1) evaluation on the basis of reduced costs for installation of natural and artificial illumination and its operations (in roubles per m^2 of the area of premises per year); 2) evaluation of power consumption of illumination, compensation of heat losses via the lighting openings and elimination of heat gains through them (in kg of reference fuel per 1 m^2 of the area of premises per year). The first method is well suited for economical evaluation of a specific project in the course of cost calculation with consideration of corresponding current prices and tariffs but it is not well suited for common evaluation since it is almost impossible to account for future price changes. For this purpose, the second method suits better as it provides assessment of the system in terms of power consumption, more objective and long-term one.

Annual specific heat energy consumption for heating $W_{T.OT}$ (GJ/m^2/year) is determined as follows:

$$W_{\text{T.OT}} = 10^{-6} \cdot 1.1 \cdot 3.6 \cdot 1.3 \cdot \left(\frac{1}{R_{\text{ск}}} - \frac{1}{R_{\text{о}}}\right) \times$$
$$\times \; (t_{\text{в}} - t_{\text{от}}) \cdot 8760 \cdot Z_{\text{ОТ}} \cdot b \cdot \frac{A_{\text{ск}}}{365 \cdot A_{\text{п}}},$$

where 10^{-6} is J to GJ transfer ratio; 1.1 is the ratio considering useless heat losses of heating systems; 3.6 is the unit recalculation ratio, kG/W×h; 1.3 is the ratio considering heat losses for heating of external air by ventilation of the premises; $R_{\text{ск}}$ and $R_{\text{о}}$ are heat transmission resistance values of the window and the wall respectively, (m^2·°C)/W; 8760 is the number of hours per year; $t_{\text{ОТ}}$ and $Z_{\text{ОТ}}$ are average temperature, °C and duration of heating season, days; $t_{\text{в}}$ is the temperature of inner air of the building; b is the ratio of window area to the area of the translucent structure of the wall; $A_{\text{ск}}$ and $A_{\text{п}}$ is the area of the windows and the floor respectively, m^2; 365 is the number of days per year [4].

Power consumption for compensation of heat losses via windows with $R_{\text{ск}}$ of 0.7 (m^2 · °C)/W and $R_{\text{о}}$ of 2.12 (m^2 · °C)/W will be equal to 0.026 GJ/m^2/year. Calculated as 1 kg of reference fuel, it will be equal to 1.07 kg/m^2/year (41.2 kg/GJ×0.026 GJ/m^2/year).

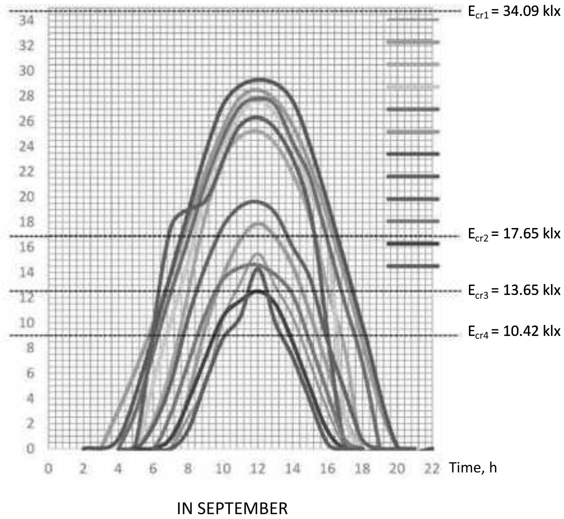

Fig. 1. The graphs of natural illuminance in Khabarovsk

Annual specific (per 1 m^2 of area) power consumption for artificial illumination of the premises $W_{s.p.c.}$ (kWh/m^2/year) is calculated in accordance with [4]:

$$W_{\text{spc}} = 10^{-3} \cdot E_i^{norm} \cdot Z \cdot \alpha \cdot P_l \cdot (1+\beta) \times \times T_p / [(u_{\text{св}} \cdot MF) \cdot \Phi_l], \quad (1)$$

where E_{i}^{norm} is the standardised artificial illuminance in residential rooms, equal to 150 lx; *MF* is the operating factor for artificial illumination luminaires [2] taken equal to 0.71; *Z* is the ratio considering irregularity of illuminance (rather high for residential premises, approximately equal to 1.3 [2]); α is the ratio considering power losses of control gear, which may be taken equal to 1.2 for FL and LED lamps; β is the ratio considering power losses in the grid (equal to 0.03 if IL, FL or LED lamps are used); P_l and Φ_{l} are total power and luminous flux of the lamps, W and lm; $u_{\text{св}}$ is the operation factor of the luminaire equal to 44 with the premises index i = 0.8 [7]; T_p is the period of using the artificial illumination determined on the basis of critical illuminance E_{cr} and the graphs of natural illuminance in Khabarovsk (Fig.1).

With the above-mentioned parameters of the premises and the window opening, the calculated value of DLF *e* is 0.84 % at distance of 1 m from the back wall, therefore

$$E_{cr} = \frac{E_i^{\text{norm}} \cdot 100}{e} = 17{,}65 \text{ [klx]}.$$

Fig. 1 shows that the standardised value of 150 lx is complied with in the design point for at least 105 h (3.5×30) in September, 186 h (6.0×31) in March, 217.6 h in April, 232.5 h in May, 240.0 h in June, 258.23 h in July and 217.0 h in August. Annual period of natural light use is equal to 1238.73 h. T_{p} is the difference between the total number of hours per year excluding 8 h of sleep per day and the period of natural light use: 4578.9 h [(16×30.3·12 = 5817.6) – 1238.7]. According to formula (1), $W_{s.p.c.}$ is equal to 8.586 kWh/m^2/year. Calculated as consumption of reference fuel, $W_{s.p.c.}^{eq}$ is the equivalent of 2.833 kg/m^2/year (0.33×8.586). We take that consumption of reference fuel in common use power plants per 1 GJ of heat energy A_1 is equal to 41.2 kg/GJ, and consumption of electric power A_2 is equal to 0.33 kg/kWh [4].

Therefore, consumption of reference fuel for compensation of heat losses through windows and for artificial illumination of the studied room W_{eq} calculated as

$$W_{eq} = W_{\text{T.OT}} \cdot A_1 + W_{\text{s.p.c.}} \cdot A_2,$$

is equal to 2.54 + 2.83 = 5.37 [kg/m^2/year].

Consumption of reference fuel for compensation of heat losses through the window in winter is directly proportional to the area of the window, i.e. the value of $W_{\text{T.OT}}$ of 2.54 kg/m^2 for windows with other dimensions may be changed proportionally to the area. Similar recalculation of consumption of reference fuel for artificial illumination cannot be done as it depends on T_p.

T_p depends on E_{cr} and is determined on the basis of Fig. 1. To determine E_{cr}, *e* should be calculated in design point of the premises with the above-men-

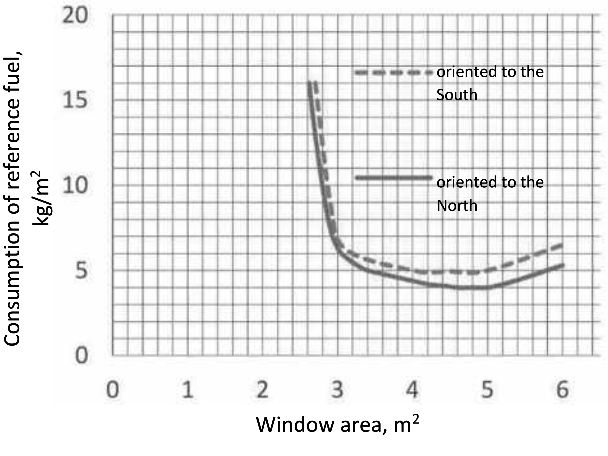

Fig. 2. The graphs of consumption of reference fuel for window operation (compensation of winter heat losses, artificial illumination and summer cooling)

Table 3. Consumption of reference fuel for operation of the windows per year

No.	Window type (dimensions), m	Window area, m^2	$W_{\text{т.от}}$, kg/m^2	$W_{\text{s.p.c.}}$, kg/m^2	$W_{eq} = W_{\text{т.от}} + W_{\text{s.p.c.}}$, kg/m^2
1	1.5 × 1.8	2.7	2.18	13.29	15.47
2	1.5 × 2.1	3.15	2.54	2.835	5.37
3	1.7 × 2.5	4.25	3.43	1.626	5.056
4	1.7 × 3.5	5.95	4.8	1.22	6.02

tioned dimensions of the premises and other considered size of the window.

4. STUDY OF ENERGY EFFICIENCY OF WINDOWS WITH DIFFERENT SIZES IN THE MONSOON CLIMATE OF THE SOUTHERN FAR EAST OF RUSSIA AND NORTH-EASTERN PART OF PRC

For this study, the residential premises with dimensions of (4×6) m and height between the floor and the ceiling of 3 m on one of the middle floors of a multi-floor building with no building located opposite to it were choosed. The type of glazing is described above.

Four types of windows were studied: a standard one with height of 1.5 m and width of 2.1 m; a large one with height of 1.7 m and width of 2.5 m; a small-size window, 1.5×1.8 m; a window with height of 1.7 m and width almost equal to the width of the room: 3.5 m.

The results of calculation are listed in Table 3 and shown in Fig. 2 which witnesses that the least power consumption for compensation of heat losses and for artificial illumination of the studied premises in kg of reference fuel occur with window area ranging between 3 and 5.0–5.5 m^2. With less dimensions of the windows, power consumption for electric illumination increases dramatically. In case of windows with area of 5.5 m^2, power consumption for compensation of heat losses via the windows will prevail increasing total power consumption.

It is worth noting that this conclusion is relevant only for the premises oriented to the North, North-North-West and North-North-East. For Southern orientations, heating of the premises by means of solar energy penetrating the windows should be taken into account. In this case, the premises may require air-cooling by means of air conditioners with high power consumption.

Specific power consumption for cooling $W_{s.p.c.c.}$ should be determined in accordance with [4] using the following formula

$$W_{s.p.c.c.} = L_{\text{o}} \cdot N_{\text{x}} \cdot T_{\text{x}}, \tag{2}$$

where N_{x} is power consumption for cooling of air by means of an air conditioner (kWh/m^3); T_{x} is duration of operation of the cooling system, h; L_{o} is performance of the conditioner ventilation system (m^3/h) per 1 m^2 of the floor area with consideration of average heat retention of the premises calculated as follows

$$L_{\text{o}} = \frac{3{,}6 \cdot 0{,}7 \cdot q_{rad}^{\max}}{c \cdot \rho \cdot (t_{\text{пр.А}} - t_{\text{р.А}})}, \tag{3}$$

where 3.6 is unit recalculation ratio, kJ/Wh; 0.7 is consideration of air heating in pipelines; $c = 1$ kJ/kg/°C is air specific heat; $\rho = 1.2$ kg/m^3 is air density; $t_{n\text{р.А}} - t_{\text{р.А}}$ is the difference between summer design input temperature of air and the temperature of air in the premises taken equal to 3 or 5 °C depending on heat load density of the premises [8]; $q_{rad}^{\max}$ is the largest value of radiant heat gain in the premises, W/m^2, determined by maximum value of heat gain by total solar radiation reaching the surface of the window during a day and calculated using the following formula

$$q_{rad}^{\max} = (Q_{\text{dir.h.g.}}^{\max} + Q_{\text{dif.h.g.}}^{\max}) \times \\ \times\ \tau_e \cdot \tau_2 \cdot MF \cdot \beta_{c.з} \cdot b \cdot A_{ск} / A_{\text{п}}, \tag{4}$$

where $Q_{\text{dir.h.g.}}^{\max}$ and $Q_{dif.h.g.}^{\max}$ are the maximum values of the direct and diffuse heat gains by solar radiation on the vertical surface of the window with relevant orientation (W/m^2) with clear sky defined in accordance with SNiP [6] (for Khabarovsk (N48°), with orientation to SE $Q_{\text{dir.h.g.}}^{\max} + Q_{dif.h.g.}^{\max} =$ 473 W/m^2); τ_{e} is the transmittance of translucent filler of the opening for solar radiation equal to 0.57 [5]; τ_2 is the ratio considering light losses on window sashes [2] taken equal to 0.9; MF is the ra-

Table 4. Consumption of Reference Fuel for Operation of Windows with Southern (SW) and, by Comparison, Northern Orientation of the Premises

No.	Window type (dimensions), m	Window area, m^2	W_{eq}, kg/m^2, northern side	W_{eq}, kg/m^{2,} southern side	$W_{s.p.c.c/}$, kg/m^2
1	1.5 × 1.8	2.7	15.47	16.042	0.0572
2	1.5 × 2.1	3.15	5.37	6.038	0.668
3	1.7 × 2.5	4.25	5.056	5.957	0.901
4	1.7 × 3.5	5.95	6.02	7.281	1.261

tio considering glass fouling in the course of operation [2] taken equal to 0.71; $\beta_{c3} = \tau_4 = 1$ (no solar protection is available); $b = 1$.

In the formula (2):

– T_x is determined in accordance with SNiP [6, table External air temperature frequency in hours] for external temperature of $t_н = 25$ °C, taken with a little reserve considering heat retention of the structures of the premises. For Khabarovsk, T_x=66 h;

– For determination of N_x (in accordance with [9]), it is necessary to calculate excess heat of the premises (Q) which comprises heat of the solar radiation penetrating the windows (Q_1), domestic appliances heat (Q_2) and heat generated by people (Q_3). $Q_1 = V \cdot q$ where V is the volume of the premises (in our case, 76 m^3, (4×6×3) m^3); q is specific heat gained by the premises via the South-West-oriented windows taken equal to 30 W/m^3; $Q_1 = 2160$ W; $Q_2 = 500$ W (TV set, PC); $Q_3 = (100$ W/person$)\times 3$ persons = 300 W; $Q = 2960$ W.

On the basis of these results, we are taking the contemporary household air conditioner by *Samsung* with refrigeration capacity of 3.2 kW. Its air capacity is $P = 900$ m^3/h. Then power consumption for cooling of air using this air conditioner is $N_x = Q/P = 3.23$ Wh/m^3.

Then the multiplier L_o in formula (2) is calculated using formulas (3) and (4) and reference data [6] for calculation of $W_{s.p.c.cool}$ and for its transformation into kilograms of reference fuel per 1 m^2, this value should be multiplied by conversion factor $A_2 = 0.33$ kg/kWh.

The consumption of reference fuel for compensation of fuel losses through the windows in winter, for artificial illumination and for cooling in summer for the studied windows of the room with the area of 4×6 m^2 oriented to the South-West (SW) with a household conditioner used for summer cooling is given in Table 4.

In Fig. 2, the graphs of changing of consumption of reference fuel for operation of light openings with different area in the residential premises oriented to the North and to the South are given provided that at $t_н > +25$ °C the *Samsung* household air conditioner is activated in the room oriented to the South. Heat gains through the window in winter are not considered.

It is worth noting once more that the least consumption of reference fuel occurs with window area ranging between 3 and 5.0–5.5 m^2 both with orientation to the South and to the North (Fig. 2).

We would also like to note that the values of Q_1, Q_2 and Q_3 were taken in accordance with [9] and although the specific power consumption for cooling may change after changing these values, it does not affect the results of this study.

CONCLUSIONS

The research for Khabarovsk climatic conditions has shown that the areas of windows ranging between 3 and 5.0–5.5 m^2 in residential rooms with dimensions of 6 m are the most energy-efficient. In Harbin, where the climatic conditions are similar, the windows of the same area are the most energy efficient. Of course, shadowing by surrounding buildings should be considered in each specific case but such recommendations may be considered common for typical development.

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9. Split systems data sheets (courtesy of *SAMSUNG*)

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