HEAT INFLUX WHICH CAUSE DISCOMFORT WITHIN RESIDENTIAL PANEL BUILDINGS IN SOFIA

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Abstract

In this paper the heat influx, causing discomfort within the standard panel residential buildings is calculated by means of the equation of internal air thermal balance. A method is presented to determine the coefficient of self-shading for facades with different exposure. The beginning, end and duration of the discomfort space of time for rooms with different aspect are determined. The norms of the period of discomfort for the region of Sofia (Bulgaria) within rooms with South exposure is 66 days in year, for East/West exposure 106 days, and for this one with North exposure 0 days, as the discomfort in this rooms is observed only in single years. The concept "equivalent temperature" is used to account for the joined effect of air temperature and solar radiation on building walls. Maximum values for the equivalent temperature with given reliability are calculated. During the 9 hours in year the equivalent temperature for room with West exposure can reach to 51^{o}C and even exceed this value.

Key words

Building climatology, criptoclimate, radiation balance of buildings, thermal balance of internal air, discomfort period.

Preface

The basic part of residential buildings in the Bulgarian's capital Sofia is consisted of panel structures. A big part of them in next few years will be repaired with purpose to improve their thermal insulation and waterproofing. The overheating within rooms of residential panel buildings only, is investigated in this paper. Existence of overheating always is linked with decreasing of air relative humidity, that fact lead to additional increasing of sense of discomfort for inhabitants. For example at air temperature within the building higher than 30^{o}C, relative humidity can decrease below 30%. In such cases the air-conditioning or ventilation of internal air is necessary. The method of approach used in this paper can be used and for other type of buildings (not only panel structures), if we know theirs thermo-technical buildings parameters.

The equation of thermal balance of air within the building takes a shape (Anapolskaq L., L. Gandin. 1973):

$$\nu = \nu_1 + \nu_2 + \nu_3 + \nu_4 + \nu_5 + \nu_6 + \nu_7 + \nu_{int.} , \quad (1)$$

where the first member take into account heat fluxes caused by conduction through external building's walls and windows, ν_2 - conductive-infiltration heat exchange through the holes between walls and windows, ν_3 - penetrating through the windows into the rooms solar radiation, ν_4 and ν_5 - absorbed by the external walls and windows total solar radiation, ν_6 and ν_7 - long-wave emission of the walls, and the last member take into account the internal heat emissions caused by of live and biological origin.

The equation (1) can be written in the shape:

$$
V = \left[\frac{T_0 - T}{R}\right] + \left\{\frac{\sigma_2}{R_{0.}}.\left[A(\gamma.V) - 1\right].(T_0 - T)\right\} - \left[\sigma_1.\Sigma_{pr.}.(1-\xi_0).I_{pr.}\right] -
$$

$$
- \left[(1-\sigma_3).\frac{R_2}{R_c^{'}}.p_{pr.}.(1-\xi_c).I_{pr.}\right] - \left(\sigma_1.\Sigma_{dif.}.I_{dif.}\right) - \left[(1-\sigma_3).\frac{R_2}{R_c^{'}}.p_{dif.}.I_{dif.}\right] + \left[(1-\sigma_3).\frac{R_2}{R_c^{'}}.E\right] \qquad (2)
$$

where T_0 is air temperature within the rooms of building ,
T – temperature of external air,
R – total thermal resistance of external walls, which take into account thermal resistance of layers of external (R_2) and internal air (R_1) next to the walls,
R_0 – The windows' total thermal resistance, including layers of internal and external air next to them.
R'_c- thermal resistance only of external walls,
σ_1 – relative area of windows' glasses,
σ_2 – relative area of building's windows, through which is realize the penetration of external air ,
σ_3 – relative area of whole windows' woodwork,
$A(\gamma.V)$ – function which take into account air-exchange at wind velocity V and coefficient of air penetration through the windows γ,
$\Sigma_{pr.}$ – coefficient which take into account penetration of direct solar radiation through within the building's rooms,
$\Sigma_{dif.}$ – coefficient of penetration of diffuse and reflected solar radiation through the windows,
ξ_0- standard building's (many buildings are built using this technology) coefficient of self-shading for the windows,
ξ_c – typical building's coefficient of self-shading for external walls,
$I_{pr.}$ –The direct solar radiation intensity,
$I_{dif.}$ – The diffuse solar radiation intensity,
$p_{pr.}$ – The external walls' coefficient of absorption of direct solar radiation,
$p_{dif.}$ – The external walls' coefficient of absorption of diffuse solar radiation, and E – effective emission of external walls, which is calculated as difference between walls' own emission and this one of the atmosphere.

The fifth and seventh member from equation (1) do not taken into account in equation (2), as the internal heat emissions, too. Actually the fifth and seventh member of equation are taken into account the building's windows radiation balance. The radiation absorbed by building's windows is 10 times smaller than this one absorbed by the external walls. And the temperature of window's glasses (which is not measured) is almost equal to this one of external air, so those members can be neglected. The heat emissions by of live and biological origin within the building can be estimated too, but during the summer time rooms are often ventilated, some of them almost permanently, as this activity has accidental character. Because of that we do not take into account the internal heat emissions generally.

The coefficient of self-shading of buildings depend on theirs architecture-constructive peculiarity of theirs facades (external or internal balcony, broken up sections ant etc.). Introducing of this coefficient necessitate "cleavage" of total solar radiation on two parts – direct and diffuse solar radiation, because of the fact that this coefficient has influence only on direct solar radiation.

During the warm half-year Sun's altitude is relatively high, and residential districts in Sofia have enough wide space between blocks, so the shading over experimental building, caused by the neighboring buildings (so-called "urban influence") is observed only during sunrise or sunset periods of time. So the urban influence is taken into account only for facades with North exposure (the intensity of incoming solar radiation is decreased with 50%).

The period of discomfort duration

The sense of comfort and discomfort is quite subjective, and depend on physiological peculiarity of individual person. There are a lot of comfort indexes, which usually represent combination of meteorological factors temperature and relative humidity of the air, penetrated through windows into the rooms solar radiation, temperature of the walls and velocity of internal air motion. Usually is accepted that inhabitants are felt uncomfortably at temperature of indoor air above 24^{o}C, relative humidity below 40 or above 60% and velocity of air motion within the rooms higher than 0,2 m/s. According to The Bulgarian Standards for design of ventilation and air-conditioning installations (Ministry of architecture and constructions – Bulgaria, 1973), the cooling hour-degree is defined as a product of hours with air temperature above 23^{o}C and difference between mean air temperature of cooling room and 19^{o}C. That is way for the limit of temperature of discomfort we are accepted value 24^{o}C.

The equation of thermal balance of internal air is solved for building with next thermo-technical and constructive parameters:

Thermal resistance of external walls R'_c= 0,70 W/m^2 ^{o}C, thermal resistance of the windows R'_o= 0,35 W/m^2 ^{o}C, thermal resistance of the internal air 0,12 W/m^2 ^{o}C (Nikolov N. 1979), as the thermal resistance of external air is evaluated depending on wind velocity. The relative areas of glasses, area of air-penetration and of whole woodwork of external walls' windows are evaluated for section type BS-VIII 33-33 j within block 222 in district "Lulin" and they are respectively 0,25, 0,30 and 0,35.

The coefficient of penetrating of solar radiation through windows' glasses, albedo of the walls and windows (respectively the coefficients of absorption of solar radiation) are evaluated for the same type section (Moraliiski E. 1989). These coefficients are obtained for total solar radiation, but they are used in the members of thermal balance equation, which take into account intensity of direct solar radiation. This is admissible, because of the fact that the direct solar radiation is the main part of total solar radiation.

The coefficient of self-shading K of facades can be estimated through the model of building and model of "artificial Sun" (Voronov V. at all, 1987), by photometric and by planimetric way. In this paper the third method is used. The windows' shaded area for rooms and living room with external walls on the SW facade of experimental block 222 is measured every hour, in sunny days. All measurements are taken out around the middle of the months of warm half-year. The diurnal (Fig.1) and seasonal course (Table.1) of this coefficient are received in that way. A functional dependence between obtained mean monthly values of this coefficient and average monthly height of the Sun ($\overline{h}_{Sun}$), has been find out for SW aspected facade during the months of warm half-year:

$$K = 1{,}89.\ \overline{h}_{Sun} + 4{,}51\ . \qquad (3)$$

This dependence allow as when we know the mean height of the Sun for given wall orientation and month, to estimate value of respective coefficient of self-shading (Table.1). The coefficient of self-shading for walls is in average with 10% lower than this one for the windows.

Observations that were carry out, mainly in residential districts "Lulin" and "Mladost" in Sofia, shown that during the warm half-year on balconies there is a lot of things that shadow the windows (like awnings, sunshade parasols and same of windows are covered by persiennes). Those factors are added to values of coefficient of self-shading received for clear sky and unshaded building (Fig. 1). Therefore the values of coefficient of self-shading in living room are increased with a half of its complement up to 100% (Fig. 1, living room - correction). That means in practice, that for 10 days in month the windows are completely covered, in 10 days half of its area is covered and in other 10 days they are not covered generally.

Fig. 1 Diurnal course of the coefficient of self-shading K for SW aspected facade - 22.06.2002

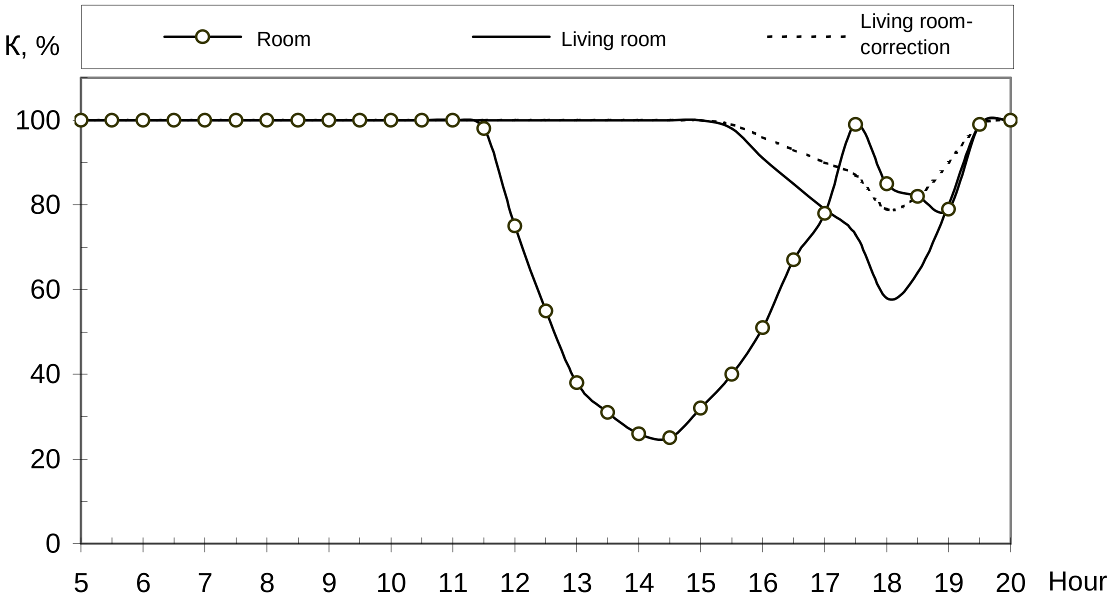


Table 1. Mean monthly values of the coefficient of self-shading (%) for windows with different exposure.

Aspect	V	VI	VII	VIII	IX	X
N	34	42	36	25	12	4
E, W	76	78	76	70	63	48
SW	83	85	83	78	63	48
SE	81	83	81	76	63	48
S	98	100	100	87	64	49

Such kind of problem is occurring during estimation of real area of windows (σ_1), too. On the values of this coefficient is added influence of curtain, internal and external persians, and etc., because of that the relative area of windows (σ_1) is decreased with 50%.

The radiation balance and effective emission of the walls with different exposure in its classical variant are investigated in details in (Moraliiski E., Cv. Dimitrov, 2002). In this paper the effective emission is evaluated for the case of tall building, i.e. without taking in consideration of Earth surface's own emission (Table. 2).

As was mentioned above, using of self-shading coefficient makes necessary dividing of total solar radiation intensity into two parts, direct and diffuse radiation, respectively. The diffuse radiation is obtained by experimental measurings in quarter "Lulin" over block 222 with orientation of main facades SW-NE. The hourly values have been used, when the facades are unshined by the Sun (there is not a direct radiation). For the other orientation of facades is used isotropy supposition.

Table 2. Average monthly values of effective emission (W/m^2) of walls with different orientation.

Exposure	V	VI	VII	VIII	IX	X
N	38	39	39	39	38	37
NE, NW	46	48	48	45	43	41
E, W	55	56	56	57	55	53
SE, SW	55	53	54	58	60	60
S	54	48	50	57	61	61

Its using is acceptable, because of the fact that the anisotropy is caused mainly by reflected radiation, but because of the high altitude of the Sun during summer time its influence is insignificant. After evaluation of diffuse solar radiation, as a part of total solar radiation, through subtraction from the total solar radiation is obtained the direct solar radiation. Inasmuch as, the measurements are carried out mainly at clear sky, a reduction of the value obtained in that way towards the real cloudiness conditions is made, too.

For the solving of the equation of thermal balance are used average monthly values of air temperature, total amount of cloudiness and wind velocity, for the period 1961-1990 [*]. The normative values of average monthly intensity of heat influx in the buildings during warm half-year are represented in Table. 3. The negative values means that the building receive heat from environment, as in this case that are heat influxes, causing increasing of indoor air temperature above 24^{o}C. The dates of beginning, ending and duration of period with discomfort are determined by passage of values through the zero. During the different years this period has various duration. For example the measurements carried out in Sofia shown that for the rooms with SW orientation during 1986 duration of this period is 84 days, while in 2001 its duration was 113 days. During some very hot summer periods discomfort can be observed within the rooms with N orientation, too. During other years the discomfort period can be torn to pieces of two or more periods. Their numbers depend on time step in our investigation, i.e. whether we use hourly, mean diurnal or as in this research, with average monthly values. The mean variability from year to year, of the moment of beginning, ending and duration of discomfort period for different aspected rooms, averaged for the period from 1971 till 1990 is shown in Table. 4.

Table 3. Intensity (W/m^2) of heat influxes causing discomfort within the rooms, and norms of dates of beginning, ending and duration of uncomfortable period (days) for area of Sofia.

Aspect	V	VI	VII	VIII	IX	X	Beginning	Ending	Duration
N	10	2	0	2	9	19	-	-	0
E, W	4	-4	-6	-5	3	11	1.VI	4.IX	96
SE, SW	5	-1	-3	-4	-1	3	10.VI	23.IX	106
S	8	3	1	-1	-2	1	1.VIII	5.X	66

Table 4. The norms of variation of dates of beginning, ending and duration of discomfort period (days) for area of Sofia.

Orientation	Beginning	Ending	Duration
N	18	13	13
E, W	12	12	19
SE, SW	14	20	26
S	25	14	30

[*] The World Meteorological Organization (WMO) is recommended this period in order to all measurements in different countries be comparable together.

The maximum heat influx causing discomfort, with different integral probability

The equation of thermal balance of internal air can be written into the shape:

$$\nu = \frac{T_0 - T_{ekv.}}{R} \qquad (4)$$

where

$$T_{ekv.} = T + R.\left[\sigma_1.\Sigma_{pr.}.(1-\xi_0).I_{pr.}\right] + +R.\left[(1-\sigma_3).\frac{R_2}{R_c^{'}}.p_{pr.}.(1-\xi_c).I_{pr.}\right] + R.\left(\sigma_1.\Sigma_{dif.}.I_{dif.}\right) +$$

$$+R.\left[(1-\sigma_3).\frac{R_2}{R_c^{'}}.p_{dif.}.I_{dif.}\right] - R.\left[(1-\sigma_3).\frac{R_2}{R_c^{'}}.E\right] \qquad (5)$$

The quantity $T_{екv.}$ has dimension of temperature and represent such imaginary temperature of external air at which the heat influxes into the buildings are the same as at real outdoor air temperature, wind velocity and intensity of total solar radiation. Usually maximum heat influxes into the buildings are received during conditions of anticyclonal weather – windlessness, cloudless and hot weather, at some optimum combination of air temperature and intensity of solar radiation on the external walls of building. Therefore during evaluation of the maximum heat influx in equation (4) the conductive-infiltration member is ignored.

When is known the appearance of equivalent temperature for different combination of air temperature and intensity of solar radiation, it is possible to obtain the integral function of distribution of T_{ekv}, and estimate the maximum heat influxes with different integral probability on the next step.

The values of equivalent temperature with precision up to 1 ^{o}C, evaluated for different combinations of air temperature and intensity of solar radiation on S exposured facade are shown in the Table. 5. All calculations are made for thermo-technical and construction parameters mentioned in previous paragraph.

The values of intensity of total solar radiation are taken separately for direct and diffuse radiation. The measurements that were carried out, shown that diffuse radiation over SW aspected wall represent from 24% (at clear sky) up to 30% (at mean cloudiness conditions) of total solar radiation.

To receive the differential distribution of $T_{ekv.}$, we need data for common distribution of external air temperature and total solar radiation intensity over facades with different aspect. In this paper the complex (T,I) is worked up using the 8-time in day (during every 3 hours) synoptic observations (at 02, 05, 08, 11, 14, 17, 20, 23 hour) for the hottest summer months in Sofia – July and August, for extremely hot and dry summer of year 2000 (Table.5). In the night hours there is not a solar radiation, and when the respective facade is not shined by the Sun the isotropy supposition is used, which is suppose that the facade receive a half of diffused and reflected solar radiation, measured on horizontal surface. In this paper are used the data obtained from the Central Meteorological Station in Sofia, too. In the cases of shining on the Sun over respective facade we used the intensity of solar radiation measured on respective aspected wall of experimental building (district “Lulin” and district “Mladost”) at clear sky, as a correction in purpose to take into account of influence of total amount of cloudiness is made.

Table 5. The equivalent temperature (above) and its relative frequencies (below) in percentage from the total number of observations through the year for the South exposured wall.

T, °C / I, W/m^2	10,1 12,0	12,1 14,0	14,1 16,0	16,1 18,0	18,1 20,0	20,1 22,0	22,1 24,0	24,1 26,0	26,1 28,0	28,1 30,0	30,1 32,0	32,1 34,0	34,1 36,0	36,1 38,0	38,1 40,0
0	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37
100	0.171	0.717	1.161	1.503	2.083	1.913	1.332	0.990	0.581	0.478	0.102	0.171	-	0.034	-
101	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38
200	-	-	-	-	-	-	0.102	0.068	0.068	0.034	0.034	0.068	-	-	-
201	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39
300	-	-	0.034	-	-	0.068	0.171	0.068	0.171	0.102	0.205	0.273	0.068	0.137	0.068
301	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
400	-	-	0.034	-	-	0.171	0.239	0.137	0.102	0.137	0.102	0.102	0.034	0.068	-
401	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41
500	-	-	-	-	-	0.239	0.068	0.137	0.137	0.205	0.307	0.137	0.102	0.068	-
501	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
600	-	-	-	-	0.068	0.034	0.102	0.137	0.376	0.342	0.205	0.137	0.034	-	-

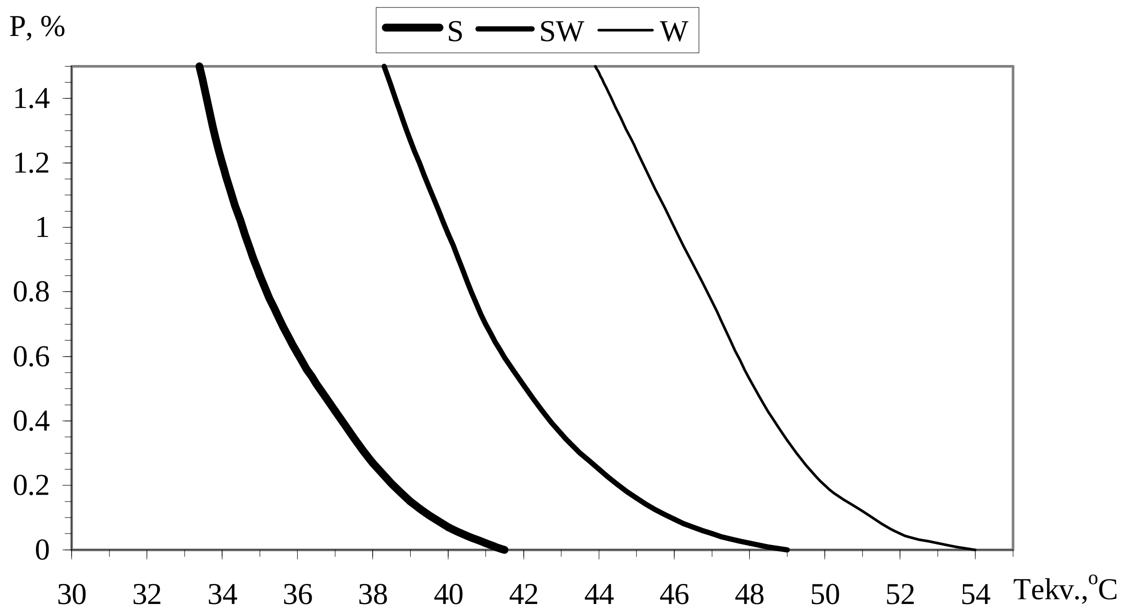
In the view of the fact that, the hourly values of effective emission of the walls in equation (5) are unknown, we find out an regression dependence between average monthly values of effective emission and intensity of total solar radiation for the months of warm half year, for the four cardinal points and intermediate orientations between them. The coefficient of correlation is higher than 0,95 (significant at level of importance 0,05), and this dependence allow as at given value of intensity of solar radiation to estimate respective value of wall’s effective emission.

Through directly putting of values of $T_{ekv.}$ on the relative frequency of the complex (T, I) we receive concept for frequency of $T_{ekv.}$ within the different gradations (Table. 5). By means of summarize of different frequencies for respective value of equivalent temperature we obtain the time of year (in %) during which it is possible to observe relevant T_{ekv} (Table. 6). After summarization of differential frequencies, from lower toward higher values of $T_{ekv.}$, we receive respective values of its function of distribution. The graphical modes of integral functions for the three orientations are represented on Fig. 2. From them we can read the values of maximum equivalent temperature with relevant integral probability. For example the integral probability 0,1% is corresponding with approximately 9 hours, this one of 0,4% - to 36 hours of the time during the year. For W orientation the equivalent temperature during 9 hours in the year can reach up to 51°C and even exceed this value.

Table 6. Differential frequency (%) of the equivalent temperature for the facades with different exposure.

$T_{ekv.}$, °C	36 37	38 39	40 41	42 43	44 45	46 47	48 49	50 51	52 53
SW	0.581	0.615	0.410	0.205	0.204	-	-	-	-
W	-	-	-	0.512	0.478	0.443	0.273	0.102	0.034

Fig. 2 Integral probability of equivalent temperature for facades with different exposure



Conclusion

The heat influx causing discomfort within the rooms of residential panel building are evaluated based on the equation of thermal balance of internal air. The dependences, that allow as to estimate mean monthly values of the coefficient of self-shading and albedo for the facades with different aspect, using the data for the average altitude of the Sun for relevant orientation, are find out. The diurnal and seasonal course of coefficient of self-shading for standard residential panel building is obtained from the carried out experiment. Introducing of this coefficient make necessary dividing into two parts of the total solar radiation intensity (diffuse and reflected one, respectively). The time of beginning, ending and duration of discomfort period within the rooms with different aspect are found out. The values of maximum equivalent temperature with different integral probability are evaluated, too. The results of this research will be found application in design of air-conditioners and ventilation systems.

Reference:

1. **Anapolskaq L. E., L. S. Gandin. 1973** Meteorological factors of thermal regime of buildings. *Publishing House "Gidrometoizdat", St. Petersburg*;
2. Thechnical Standards for Design of air-conditioning, ventilation and heating installations. *Ministry of architecture and constructions – Bulgaria, Sofia,* **1973**;
3. **Nikolov N. 1979** Regime of consumption of thermal energy and its control within the central heating systems. *The State Publishing House "Engineering", Sofia.*
4. **Moraliiski E. 1989** Sunshine duration and solar radiation on the facades with different exposure. *Sofia, "Building", book 8.*
5. **Voronov V.V., N. V. Obolenskii, N. I. Shepetkov. 1987** Estimation of shading ability characteristics of sun-protected equipments. *Publishing House "Energatomizdat", Moskow, "Luminous technics", vol. 4.*
6. **Moraliiski E., Cv. Dimitrov. 2002** Radiation balance of residential panel buildings in Sofia during the warm half-year. *Sofia, "Building", book 2.*

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