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ENERGY ANALYSIS OF AN OFFICE BUILDING – STUDY OF THE SHADING DEVICES IMPACT ON BUILDING ENVELOPE

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European Directives require a continuous reduction of energy consumption in buildings. In Romania ((Köppen climate type D - temperate continental) the climate is characterized by cold winters and hot summers. In this paper the summer shading devices impact on building envelope is studied. For this purpose an office building with curtain walls, located in Bucharest, was chosen. The curtain wall on South façade is shaded with an exterior louvers metallic system. The cooling energy load decreasing realized by the shading devices was determined. Also, in terms of energy efficiency, the optimal distance between two louvers was calculated.

Keywords: shading device, metallic louvers, Romanian climate, office building, curtain walls

1. Introduction

2010 Energy Performance of Buildings Directive [1] and 2012 Energy Efficiency Directive [2] represent EU's main legislation when it comes to reducing the energy consumption of buildings. It can be found from [2] that buildings represent 40% of the Union's final energy consumption. Moreover, buildings are crucial to achieving the Union objective of reducing greenhouse gas emissions by 80-95 % by 2050, as compared to 1990.

To this purpose architecture strategies has been proposed [3, 4, 5, 6, 7] but in general some fashion counter-pressure like widespread use of glass-and-metal building walls is strong. Glass facade represents an overheating risk in summer. In [8] the authors explain that the cooling demand rises significantly in buildings with curtain walls and depends on the climate changes. From [9] it can be found that conventional window technologies tend to have poor U-values, which cause significant heat losses during the winter season and undesired heat gain in summer. In [10] the authors remark that nowadays, curtain wall is the norm, due to which there is an increase in direct solar gain and heat loss through the window

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inside the building, causing massive thermal load. Use of shading devices both for low-rise and high-rise residential and nonresidential buildings is away to mitigate this trend [11, 12].

Romanian climate (Köppen climate type D - temperate continental), [13], is characterized by cold winters and quite dry hot summers. Although the highest percentage of building consumption is generated by the heating, the cooling consumption and the overheating risk in Romanian climate are very important [14, 15]. In the last years in Romania a lot of office buildings with glass facades have been built. Therefore, the shading devices may be considered as interesting solutions to improve thermal comfort and to reduce the cooling consumption in summer.

The Romania legislation lacks at this moment a unitary approach regarding building energy efficiency and specifically the possible savings due to shading devices. For an approved building design, an allowable value of the traditional G quantity [16] is required, G being rather a measure of the thermal insulation of the building. The Building Energy Performance Certificate [17], where the solar gains are considered in more detail, has only to be delivered to the local authority by the building owner after its envelope has been built.

Window shading systems can be classified as interior and exterior [18]. The interior ones (blinds, shades drapes) are all operable and very easily accessible while the exterior ones (overhangs, louvers, Venetian blinds, shades, sun screens, meshes) are more energy efficient [19, 11] but some of them are fixed and they may not be very accessible.

An office building with curtain walls, located in Bucharest was chosen for this purpose. The South facade of the building is a glazing one and is shaded with exterior metallic louvers. The decreasing of the cooling energy load caused by the shading devices was determined. The optimal distance for mounting two louvers was calculated.

2. Method and procedure

2.1. Building description

INCD-ECOIND is a building owned by a research institute in chemical field. It is an office and laboratory building and it is located in the North-West side of Bucharest, Romania. The building height regime is represented by: semi-basement, ground floor, other 5 levels and a technical room on top of the building. The building subdivision is composed of two staircases, located on building extremities, on East and West sides, connected with a corridor from which offices and laboratory rooms start. The year of construction is 2011. The building is oriented North-South and, excepting the semi-basement and ground floor, an important part of North and South facades are realized by curtains walls, figure 1 a). The constructive system of the building is realized by reinforced concrete and the exterior walls are made of Porotherm bricks, 30 centimeters thick. The exterior wall insulation is made of expanded polystyrene EPS, 5 centimeters thick. Excepting curtain walls, the building is provided with low-emissivity double-pane glazing windows. Among the building systems one can mention a boiler type SIME, model 2R13 with a burner and two storage tanks for heating, that is located at semi-basement. The cooling is realized by a chiller type CLINT, model 13010-P located on the building roof.

In 2015 the building has been modernized, a shading device composed of metallic louvers was mounted on the South façade. In the modernization project also, the building was provided with six air handling units (AHU) served by three systems type VRV.

At the moment of the study the building was free all around (completely detached), so the received solar radiation wasn't shaded by the neighboring buildings.

a) b)

Fig. 1. INCD-ECOIND building: a) South façade; b) exterior metallic louvers, view from indoor

2.2. Shading devices description

The building is provided with metallic louvers on south façade, over the curtain wall, fig. 2 a), b). The producer of the louvers system is Hunter Douglas Europe BV. The louvers are fixed on a light metallic frame, connected to the building structure or to the vertical elements of the curtain wall. This kind of solution was chosen, on the one hand, due to the fact that it is an exterior shading device and as it is known to be more efficient than an interior one, and on the other hand, because its mounting system is located only on the building exterior and thus didn't interfere with the working process in the building in the mounting period. As one can see in fig. 2, the louvers are positioned at a rather small distance, mounted at 220 mm from one another. The distance between louvers extremities is of 88 mm.

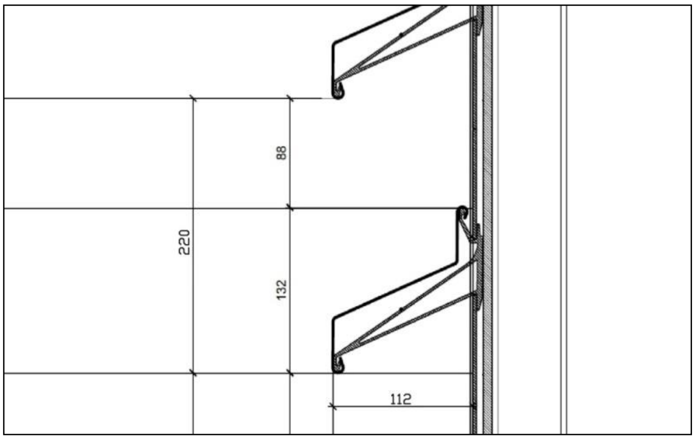

Fig. 2 Exterior metallic louvers system – transversal section, mm

2.3. Shading calculation method

The horizon plane is a flat plane tangent to the earth's surface where the observer is standing, fig. 3. In order to describe sun (or other star) position, the Horizon Coordinate system is defined. Thus, in fig. 4, the observer plane is N-S-E-V diameter of the sphere. Azimuth (AZ) is the coordinate defining directions parallel to the horizon. It goes from 0 to 360° starting with north = 0° and increasing towards the east. Altitude (ALT) is the coordinate defining directions above or below the horizon plane, how high an object is in the sky, fig. 4. It measures the position of a star on a particular vertical circle. The horizon is altitude = 0°. Straight up is the zenith point, corresponding to altitude 90°.

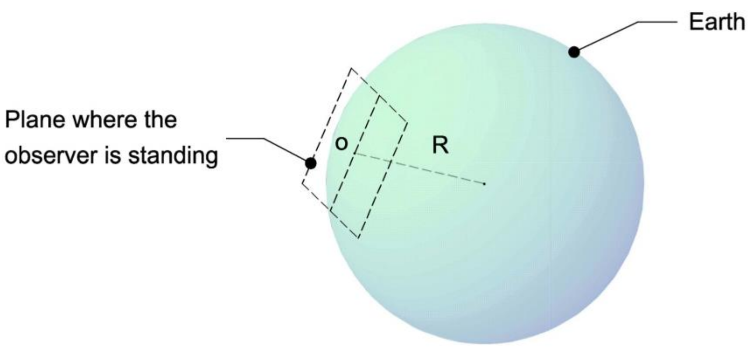

Fig. 3 Earth and the plane where the observer is standing

In fig. 5 the south façade of the building plane is represented. In the shadings calculation procedure the shading device could be assimilated with its horizontal projection. The same effect in building shading is obtained by its horizontal projection, as can be seen in fig. 5.

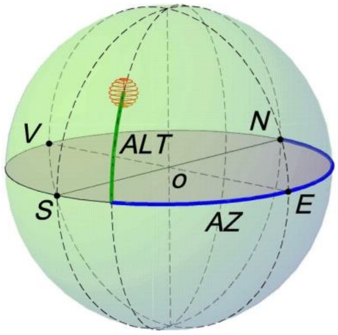

Fig. 4 Azimuth (AZ) and altitude (ALT) in the Horizon Coordinate system

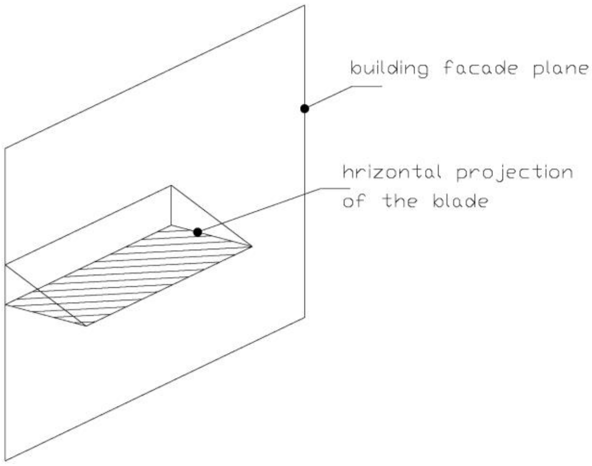

Fig. 5 Horizontal projection of the metallic louver

In figure 5 one can notice the façade plan is perpendicular to the N-S plane. In the point "o" the observer is standing and the sun position, located in a current plane has position established by azimuth (AZ) and altitude (ALT) angles. In this case azimuth is measured relatively to South direction, but you will see in Table 1 the conversion from South to North direction. The solar beam is represented passing by the intersection point between current plane and horizontal louver projection plane. It is known that all solar beams at a moment of time reach the Earth after the same direction.

AZ angle can be found in the ABC triangle. This triangle represents the intersection of the horizontal projection of the metallic slat plane with current sun plane and N-S plane. The "L" distance can be expressed by "l" (the distance from slat to wall as can be seen from fig. 2), equation 1.

$$\boldsymbol{L = l/cosAZ} \tag{1}$$

$$\boldsymbol{d = L/tg(90° - ALT)} \tag{2}$$

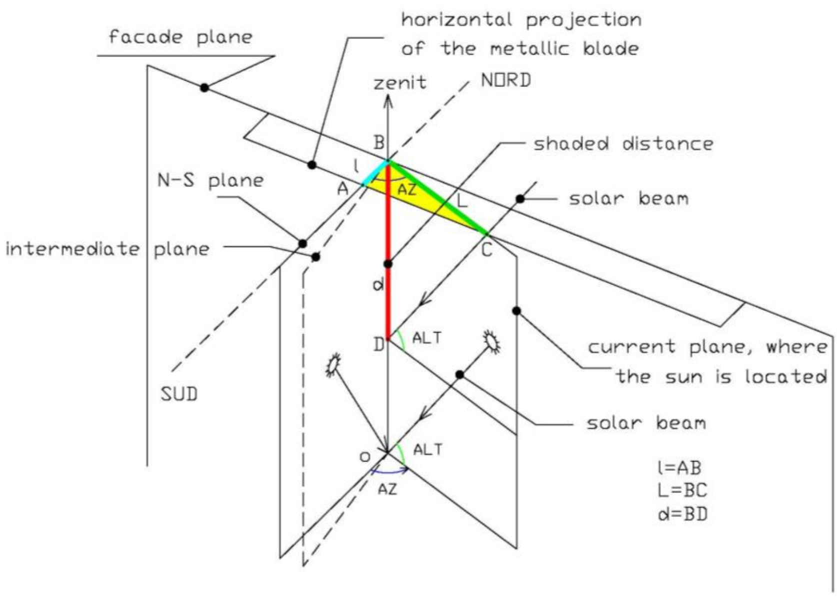

Fig. 5 Geometrical elements used in the shading distance computation

The shading distance "d" can be computed from BCD triangle using equation 2. The shading distance, expressed by "l" results from equations 1 and 2 and is presented in equation 3.

$$\boldsymbol{d} = \frac{\boldsymbol{l}}{\boldsymbol{cosAZ} \cdot \boldsymbol{tg}(\boldsymbol{90}° - \boldsymbol{ALT})} = \frac{\boldsymbol{0.112}}{\boldsymbol{cosAZ} \cdot \boldsymbol{tg}(\boldsymbol{90}° - \boldsymbol{ALT})} \quad (3)$$

3. Results and discussions

3.1. Optimal positioning distance between two louvers

It is wanted to compute the hourly variation of shading distance for a relevant day positioned at the middle distance between spring equinox and summer solstice. For the period between summer solstice and autumn equinox the sun position on the sky is symmetrical and so the hourly variation of shading distance is the same. In 2015 the spring solstice is on March 20 (the 79th day of the year) and summer solstice is on June 21 (the 172nd day of the year). The 125th day of the year is located in the middle of the interval and represents May 5th.

For a more precise computation, we choose another two days, positioned at one month distance from May 5, April 5 and June 5. These days divide spring equinox - summer solstice interval in equal parts.

NOAA Solar Position Calculator was used to obtain the hourly variation of the solar azimuth and altitude [20].

In summer, the sun rises north from east and sets south from west. We study only the south façade shading and thus, the angles between 90 and 270 (between east and west) are of interest. The computation for the hourly shading distance for May 5 date is presented in table 1. For each hour its middle was considered: 5:30, 6:30 and so on. At the beginning and the end of the period in which the south façade is sunlit (for AZ angles between 80 and 90 degree or -80 and -90 degree) the d value shown in the table is irrelevant because at large incidence angles (close to 90 degrees), the reflectance of the glazing becomes very high (and its transmittance very low) for incidence angles close to 90. So it does not matter then, the louver shadow on the vertical facade can no longer be approximated as a rectangle of vertical edge d whose upper corners are those of the respective louver.

Table 1

Shading distance computation for May 5, 2015

May 5, 2015

hour	azimuth North [degree]	altitude [degree]	hour	azimuth North [degree]	azimuth South [degree]	altitude [degree]	azimuth [rad]	altitude [rad]	d [mm]
5:30	60.58	-5.74							
6:30	71.19	4.16							
7:30	81.32	14.42	7:56:30	90.57	89.43	26.64	1.56	0.46	5648
8:30	91.61	25.07	8:30	91.61	88.39	25.07	1.54	0.44	1865
9:30	102.94	35.66	9:30	102.94	77.06	35.66	1.34	0.62	359
10:30	134.58	54.45	10:30	134.58	45.42	54.45	0.79	0.95	223
11:30	159.18	60.35	11:30	159.18	20.82	60.35	0.36	1.05	211
12:30	188.97	61.48	12:30	188.97	-8.97	61.48	-0.16	1.07	209
13:30	216.3	57.33	13:30	216.3	-36.30	57.33	-0.63	1.00	217
14:30	236.8	49.55	14:30	236.8	-56.80	49.55	-0.99	0.86	240
15:30	251.95	39.91	15:30	251.95	-71.95	39.91	-1.26	0.70	302
16:30	264.04	29.48	16:30	264.04	-84.04	29.48	-1.47	0.51	610
17:30	274.65	18.82	17:04:15	269.31	-89.31	26.96	-1.56	0.47	4731
18:30	284.77	8.36							

7:53:00	90.01	25.97
Middle of the interval 7:53:00 and 8:00		
7:56:30	90.57	26.64
17:08:30	270	26.15
Middle of the interval 17:00 and 17:08:30		
17:04:15	269.31	26.96

The same computation was done for April 5th and June 5th and the data is systemized in table 2. The possible distance to be shaded (distance between louvers extremities) is of 88 mm, see figure 2. In table 2 it is noticed that all

computed distances are bigger than 88 mm. In conclusion, it can be said that for all summer period the building south façade is completely shaded.
It is observed that the smallest distances are obtained for April 5, with a minimum value of 141 at 12:30. It is normal that the smallest distances are obtained for April, when the sun position in the sky is lower.
A distance of about 140 mm between metallic louvers extremities have the same effect as the current one and so it realizes a total shading of the building in the summer period. The optimal positioning distance between two louvers is 140 + 132 = 272 mm.

Table 2

Shading distance for April 5, May 5, and June 5, 2015

April 5		May 5		June 5	
hour	d [mm]	hour	d [mm]	hour	d [mm]
6:51:30	742				
7:30	233	7:56:30	5648	7:57:00	7262
8:30	169	8:30	1865	8:30	800
9:30	152	9:30	359	9:30	398
10:30	145	10:30	223	10:30	312
11:30	142	11:30	211	11:30	283
12:30	141	12:30	209	12:30	278
13:30	143	13:30	217	13:30	295
14:30	147	14:30	240	14:30	347
15:30	157	15:30	302	15:30	520
16:30	185	16:30	610	16:17:00	1552
17:26:30	328	17:04:15	4731		

3.2. Shading device effect on the building need for cooling

It is wanted to establish the building annual energy need for cooling. For this purpose a calculation according to European norms [21], using monthly method, was done. For each month the energy need for cooling is given by the equation 4.

$$Q_{C,n} = Q_{C,gn} - \eta_{C,ls} \cdot Q_{C,ls} \quad Q_{C,n} \geq 0 \qquad \text{[kWh]} \tag{4}$$

where:

$Q_{C,n}$ [kWh] is the building energy need for cooling;

$Q_{C,ls}$ [kWh] is the total heat transferred in the cooling mode, between indoor and outdoor;

$Q_{C,gn}$ [kWh] are the total heat sources for the cooling mode;

$\eta_{C,ls}$ is the dimensionless utilization factor for heat losses through the building envelope;

$$Q_{C,gn} = Q_{\text{int}} + Q_{sol} \quad \text{[kWh]} \tag{5}$$

Q_{int} is the sum of internal heat sources over the given period;
Q_{sol} is the sum of solar heat sources over the given period;

$$Q_{C,ls} = Q_{tr} + Q_{ve} \quad [\text{kWh}] \tag{6}$$

Q_{tr} is the total heat transfer by transmission through the envelope;
Q_{ve} is the total heat transfer by ventilation through the envelope.

Table 3

Total heat gain and total heat transfer in cooling mode

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Q_{int} [kWh]	11651	10583	11762	11422	11831	11471	11835	11849	11447	11757	11283	11637
spec. q_{int} [kWh/m^2]	4.8	4.4	4.9	4.7	4.9	4.7	4.9	4.9	4.7	4.9	4.7	4.8
Q_{sol} [kWh]	7275	9627	11687	11944	14399	15333	14947	18241	15812	12738	7040	6451
spec. q_{sol} [kWh/m^2]	3.0	4.0	4.8	4.9	6.0	6.3	6.2	7.5	6.5	5.3	2.9	2.7
$Q_{C,gn}$ [kWh]	18926	20211	23449	23366	26230	26804	26781	30090	27259	24495	18323	18088
spec. $q_{C,gn}$ [kWh/m^2]	7.8	8.4	9.7	9.7	10.9	11.1	11.1	12.5	11.3	10.1	7.6	7.5
Q_{tr} [kWh]	55414	47663	43613	32235	22101	15541	12431	13906	22837	33779	41911	51153
spec. q_{tr} [kWh/m^2]	22.9	19.7	18.1	13.3	9.1	6.4	5.1	5.8	9.5	14.0	17.3	21.2
Q_{vr} [kWh]	37471	31004	27625	18131	9675	4202	1607	2838	10290	19419	26204	33915
spec. q_{ve} [kWh/m^2]	15.5	12.8	11.4	7.5	4.0	1.7	0.7	1.2	4.3	8.0	10.8	14.0
$Q_{C,ls}$ [kWh]	92885	78667	71238	50366	31776	19743	14037	16743	33127	53198	68115	85068
spec. $q_{C,ls}$ [kWh/m^2]	38.4	32.6	29.5	20.8	13.2	8.2	5.8	6.9	13.7	22.0	28.2	35.2

The loss utilization factor for cooling regime $\eta_{C,ls}$, is a function of the gain-loss ratio γ_C, and a numerical parameter, a_C that depends on the building thermal inertia. According to [21] the relations for $\eta_{C,ls}$ computation are (7-9).

$$\eta_{C,ls} = \frac{1 - \gamma_C^{-a_C}}{1 - \gamma_C^{-(a_C+1)}} \quad \text{if } \gamma_C > 0 \text{ and } \gamma_C \neq 1 \tag{7}$$

$$\eta_{C,ls} = \frac{a_C}{a_C + 1} \quad \text{if } \gamma_C = 1 \tag{8}$$

$$\eta_{C,ls} = 1 \quad \text{if } \gamma_C < 0 \tag{9}$$

where:

γ_C – dimensionless gain-to-loss ratio for the cooling mode, given by equation 10;

a_C - dimensionless numerical parameter depending on the time constant, τ_C and defined by equation 11.

$$\gamma_C = \frac{Q_{C,gn}}{Q_{C,ls}} \tag{10}$$

$$\boldsymbol{a_C = a_{C,0} + \frac{\tau_C}{\tau_{C,0}}} \tag{11}$$

where:

$a_{C,0}$ – dimensionless reference numerical parameter, depending on building type, and given in [21];

τ_C [h] - time constant of the building;

$\tau_{0,C}$ [h] - reference time constant, depending on building type, and given in [21].

The parameters values for the determination of a_C for studied building are given in Table 4. The computation of time constant of the building is not given here because it not represent the purpose of this paper. The building energy need for cooling is given in Table 5.

Table 4

Parameters used for the computation of a_C - dimensionless numerical parameter

$a_{C,0}$	$\tau_{C,0}$ [h]	τ [h]	a_C
1	15	27.40	2.83

Table 5

Parameters used for the computation of $Q_{C,n}$ - building energy need for cooling

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
γ_C	0.20	0.26	0.33	0.46	0.83	1.36	1.91	1.80	0.82	0.46	0.27	0.21
$\eta_{C,ls}$	0.20	0.25	0.32	0.43	0.66	0.84	0.92	0.91	0.66	0.43	0.26	0.21
$Q_{C,n}$ [kWh]	168	324	690	1508	5119	10239	13919	14931	5292	1556	329	179
spec. $q_{C,n}$ [kWh/m^2]	0.07	0.13	0.29	0.62	2.12	4.24	5.76	6.18	2.19	0.64	0.14	0.07

The building is cooled with intermittence with a regime of 5 days/week. In this case, according to [21], the building energy need for cooling is given by equation (12).

$$\boldsymbol{Q_{C,n\ interm} = a_{C,red} Q_{C,n\ cont}} \tag{12}$$

where:

$Q_{C,n\ interm}$ [kWh] - energy need for cooling, taking account intermittency;

$Q_{C,n\ cont}$ [kWh] - energy need for continuous cooling;

$a_{C,red}$ - dimensionless correction factor for intermittent cooling, expressed by equation (13).

$$\boldsymbol{a_{red,C} = 1 - b_{red,C}\left(\frac{\tau_{C,0}}{\tau}\right)\gamma_C(1 - f_{N,C})} \tag{13}$$

With maximum value $a_{red,C} = f_{N,C}$ and maximum value $a_{red,C} = 1$.

where:

$f_{N,C}$ - fraction of the number of days in the week, with normal cooling (at the cooling set temperature), equal with 5/7 for 5 days cooling per week;

$b_{red,C}$ - empirical correlation factor; value $b_{red,C} = 3$.

Table 6

Parameters used for the computation of $a_{red,C}$ - dimensionless correction factor for cooling taking account of intermittency

$f_{N,C}$ (5/7)	$\tau_{C,0}$ [h]	τ [h]	$b_{red,C}$
0.71	15	27.40	3

Table 7

Parameters used for the computation of the energy need for cooling, taking account of intermittency

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
γ_C	0.20	0.26	0.33	0.46	0.83	1.36	1.91	1.80	0.82	0.46	0.27	0.21
$a_{red,C}$	0.90	0.88	0.85	0.78	0.61	0.36	0.10	0.16	0.61	0.78	0.87	0.90
$a_{red,C}$ with max and min restrictions	0.90	0.88	0.85	0.78	0.71	0.71	0.71	0.71	0.71	0.78	0.87	0.90
$Q_{C,n\ interm}$ [kWh]	152	285	583	1180	3656	7313	9942	10665	3780	1219	288	162
annual total [kWh] 39226												
spec. $q_{C,n\ interm}$ [kWh/m²]	0.06	0.12	0.24	0.49	1.51	3.03	4.11	4.41	1.56	0.50	0.12	0.07
specific annual total [kWh/m²] 16.24												

Table 8

Monthly and total energy need for cooling for shadeless and shaded building

shadeless building												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
$Q_{C,n\ interm}$ [kWh]	152	285	583	1180	3656	7313	9942	10665	3780	1219	288	162
annual total [kWh] 39226												
spec. $q_{C,n\ interm}$ [kWh/m²]	0.06	0.12	0.24	0.49	1.51	3.03	4.11	4.41	1.56	0.50	0.12	0.07
specific annual total 16.24												
shaded building												
$Q_{C,n\ interm}$ [kWh]	67	111	285	746	2700	5773	8078	7088	1869	494	140	75
annual total [kWh] 27425												
spec. $q_{C,n\ interm}$ [kWh/m²]	0.03	0.05	0.12	0.31	1.12	2.39	3.34	2.93	0.77	0.20	0.06	0.03
specific annual total [kWh/m²] 11.35												

In order to take into account the effect of the shading louvers, on glazed south façade, instead of total radiation, was used only diffuse radiation value. Considering only the diffuse radiation represent a method of approximation of the total shading of a building component. Monthly and total energy need for cooling, taking account intermittency is presented in table 8, for shadeless and shaded building.

6. Conclusions

In this paper the influence of the shading devices on the building envelope was studied. A fixed metallic louvers system, located on south façade of an office and laboratory building was chosen. The vertical shaded distance on the wall for one louver was computed for each hour in three relevant days. All the time, the distance was found less than the possible distance to be shaded (distance between louvers extremities) of 88 mm. After that, the optimal distance between two louvers was determined; its value is 272 instead of current distance of 220 mm. This distance is specific to Bucharest climate for this type of louvers. A material economy could be thus realized.

After that, the shading device effect on the building need for cooling was computed. Reduction of annual total energy for cooling from 16.24 kWh/m^2, in the case of exposed building, to 11.35 kWh/m^2, in case of shaded building, was found. The energy need reduction is about 30.1%.

From table 8 results 18.8% reduction of energy needed for cooling in the case of shadeless building compared to shaded building for July and 33.6% for August. These values can be explained taking into account climatic parameters [22], for example total radiation for South orientation with value of 94.9 Wh/m^2 in July and 138.1 Wh/m^2 in August, compared with diffuse vertical radiation of 48.2 Wh/m^2 in July and 45 Wh/m^2 in August.

The obtained reductions are within the range previously reported by others in the field, although a very detailed comparison is not possible due to various climates and methodologies used. Thus, Hutchins [23], found by computation 33% (double clear glazing) or 37% (double clear low-e) mean cooling energy savings for Budapest (but his shading systems were not fixed). Hoffman and Lee [11] state simulated savings due to shading in a Chicago building, in the range from 24% to over 30% , in a recent study that used several types of exterior shadings. Dubois [24] in an older but much quoted review speaks about reductions in heating, cooling and lighting loads of 23%-89% also caused by building shading.

But we remember that the calculation method is a monthly one, only a dynamic simulation of the building behavior that takes into consideration all the hourly outdoor temperature variations can be the precise calculation method. When designing such a non-operable, fixed shading system, a special attention must be paid to the energy need in the cold season because solar gains are consequently lowered in this heating period, not very short in the Romanian climate.

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