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Optimisation of passive solar systems seasonal operation in conditions of central Europe

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Abstract. The paper deals with optimisation of passive solar systems installed on family and office buildings in central Europe locations. In these territories, in contrast to more southern countries, it is not typical to utilize passive solar systems on public or private buildings.

Although these systems can significantly influence thermal comfort inside the buildings, many controversions and myths reduce wider utilisation. It could be expected, that new European legislative tending to common energy savings will cause also wider usage of these systems.

In contrast of classic countries utilizing passive solar systems, the benefits can be expected either in hot season or in cold season. If we focus on systems that can supplement existing buildings – roller blinds and slats, significant energy and economy benefits can be easily reached. These systems can either decrease or avoid overheating during hot summer days or to limit thermal loses in cold winter days and nights.

This paper compares various roller blind and slat systems installed on office building and family house. Exact measurements explains the influence on thermal gains, thermal loses and thermal comfort in particular storeys during constituent seasons. The main results of these experiments and calculations are principles of operational charts for particular locations in the buildings leading to provable energy savings and economy profits. The measurements also serve as verification of computer simulations.

Key words. passive solar systems, solar thermal gains, thermal losses, energy savings.

1. Introduction and motivation

Although various passive solar systems are commonly used in many countries (in Europe e.g. Spain, Italy, southern France), they are not fully realized in central European territories, although also there can bring significant thermal comfort improvement and important energy savings leading to interesting economy benefits.[1]

While in traditional southern countries the passive solar systems are utilized only during warm season to prevent or decrease the interior overheating, in the conditions of central Europe can be used either during warm season with the same purpose and similar result, or in cold season to limit the thermal losses through cold nights and eventually also cloudy days. [2, 3]

New European technical legislative is focusing on common energy savings including energy consumption in residential and public buildings. Significant component of consumed energy originate traditionally from the heating. As consequence of global energy overconsumption and overproduction, the greenhouse effect leads to increasing average temperatures in particular regions. The result in central Europe is partially decreased energy consumption for heating in winter but at the same time increase energy consumption for air conditioning during summer. This effect is alongside supported with higher standards and requirements for interior conditions. [2, 4, 5]

New designed buildings should meet modern principles of energy savings and efficient energy usage. These structures profit from modern materials, efficient design and smart appliances. We talk about low energy, passive, zero and even energy plus buildings. Absolutely different situation is in existing buildings. These obsolete structures can be very hardly and with high investments converted to higher energy standards. In this case, very interesting way can be found in usage of particular passive solar system additionally mounted on the building. [6, 7, 8]

In principle, there are two technical solutions that can be adopted for these purposes – roller blinds and slats. Both systems have comparable purchasing and operating costs. Roller blinds have usually slightly higher installation requirements, but should have better results during cold periods. Side rails, casing and lower sealing guarantee lower air circulation and ventilation and thus better overall thermal insulation. [9, 10]

The aim of this research is to find optimal operational diagram for both systems leading to maximal energy savings. Usage of these systems affect not only thermal comfort but also lighting conditions. If we take into account standards valid for the working conditions in various types of rooms, maintaining the hygienic limits in the course of closed blinds can significantly decrease expected energy gains. This study evaluates the operation chart of passive solar system on the base of not just interior temperature and sensational temperature, but also of solar radiation, interior illumination intensity, ambient temperature, point in time and room utilisation chart [11].

2. Measurement and data acquisition

The measurement was performed repeatedly during particular periods. All windows were marked in 3 points on the glazing and in 1 point on frame with thin tape to correct the emissivity. Fig. 1 shows the scheme. These measuring points also allow to determine the thermal upward streams and their influence on the measurement. Main window frames were marked in the same sense and in similar diagram.

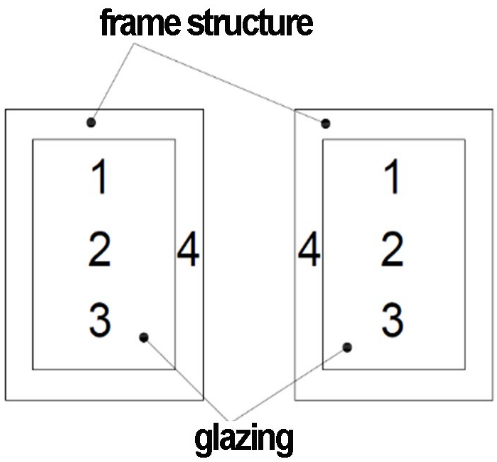

Fig. 1. Scheme of measuring points.

The measurements were repeatedly performed in 1 hr interval during various ambient conditions. Contactless thermometer Raytec ST-211 and infravision Flir 355 were used for measurements. Fig. 2 shows sample thermogram of a model window comparing partial sun protection during warm season (yellow-green areas).

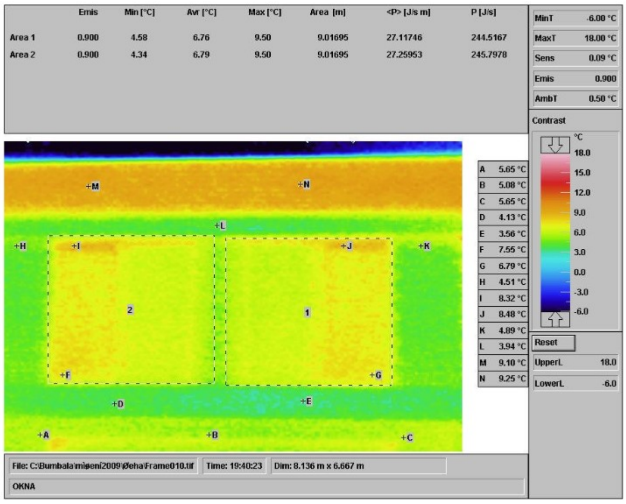
Fig. 2. Sample thermogram of partial sun protection.

The solar gains in warm season or thermal losses during cold period can be calculated from the equation 1 [11]:

$$VIE = \frac{U_0 - U_{x=d}}{U_0} \cdot 100 \qquad (1)$$

U_0 = 1,761 W/m^{2}K is the reference heat transfer while U_{xd} represents the coefficient of heat transfer through particular structure surface. This coefficient is equal to U_W for windows and can be expressed from particular window frame and glazing parameters in equation 2 [11]:

$$U_W = \frac{A_g \cdot U_g + A_f \cdot U_f + l_g \cdot \psi_g + l_{osazeni} \cdot \psi_{osazeni}}{A_g + A_f} \qquad (2)$$

Measured modifications of passive solar systems:

- closed window + closed roller blinds
- closed window + closed roller blinds with slots
- closed window + closed internal slats
- closed window + no passive system (reference)
- closed window + canvas curtain
- open window + no passive system
- closed window + closed external slats
- closed window + closed external slats with slots
- closed window + solar shelter

3. Passive solar systems during warm season

Fig. 3 demonstrates influence of particular passive systems in a model room. Temperatures measured in point 2 are presented. Significant temperature increase caused by additional hot air circulation in open window is evident between yellow and violet curve. This represents typical mistake of many residents opening windows during hot weather to achieve spurious feeling of fresher environment. Although actual chill factor can evoke lower temperatures, the exact opposite is true and the real interior temperature is higher for 3,2°C.

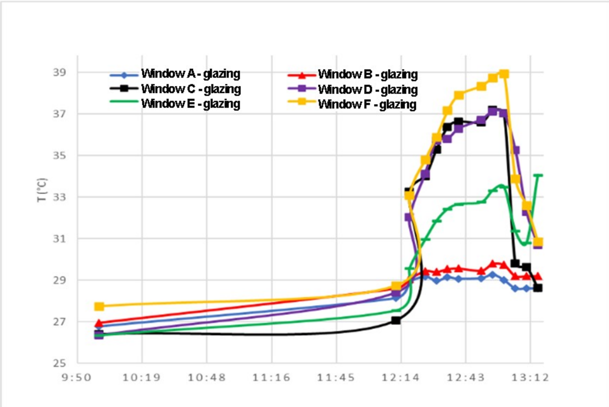

Fig. 3. Point 2 – measurements during warm season.

Fig. 4 shows distribution of average glazing temperature according to azimuthal orientation and storey position. The northern windows prove well known fact that during warm season the temperature raises for 2,4 °C with every storey. The average is calculated as weighted average of the temperatures in points 1-4. Points 1-3 have the same weight 1,00 while point 4 (frame) has the weight 0,83 representing relative surface and heat conductivity of the frame and glazing.

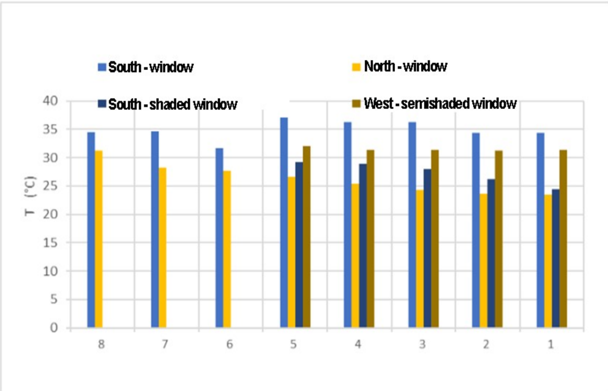

Fig. 4. Average temperature during warm season.

Fig. 5 represents the direct influence on internal environment conditions and also on conditions on working space (the surface temperature of working area). This chart also summarizes positive influence of simple solar shelters protecting sample windows in storey 1 – 5 (dark grey vs. light grey columns).

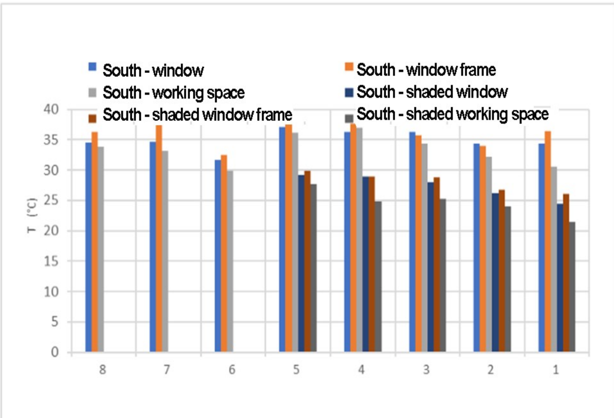

Fig. 5. Interior conditions during warm season.

4. Passive solar systems during cold season

Fig. 6 demonstrates influence of particular passive systems in a model room during the second part of the year. Temperatures measured in point 2 are presented. Significant temperature change caused by additional ambient air circulation in open window is evident between yellow and violet curve.

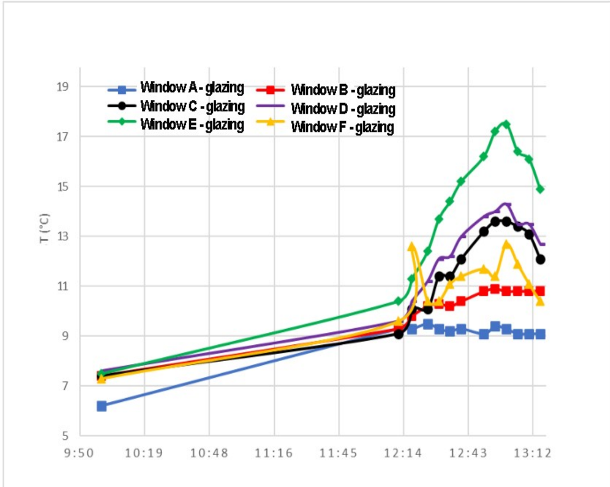

Fig. 6. Point 2 – measurements during cold season.

That represents another typical mistake of many residents opening windows during cold weather to achieve spurious feeling of fresher environment. Although actual chill factor can evoke lower temperatures, the exact opposite is true and the real interior temperature is different for 2,1°C.

Fig. 7 shows distribution of average glazing temperature according to azimuthal orientation and storey position. The northern windows prove well known fact that during warm season the temperature raises for 1,2 °C with every storey. The average is calculated as weighted average of the temperatures in points 1-4. Points 1-3 have the same weight 1,00 while point 4 (frame) has the weight 0,83 representing relative surface and heat conductivity of the frame and glazing.

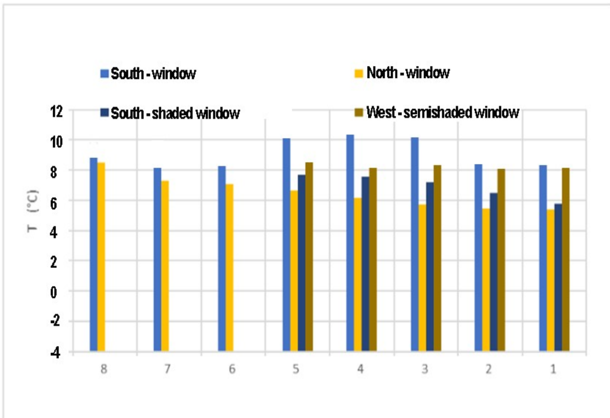

Fig. 7. Average temperature during cold season.

Fig. 8 represents the exact direct influence on internal environment conditions and also on conditions on working space (the surface temperature of working area). This chart also summarizes positive influence of simple solar shelters protecting sample windows in storey 1 – 5 (dark grey vs. light grey columns).

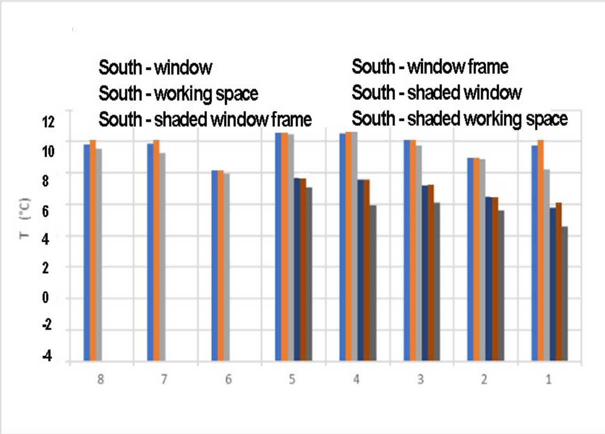

Fig. 8. Interior conditions during cold season.

If compared to warm season, it is evident that the temperature differences are not so significant between particular measuring points. It is the direct impact of solar gains in both seasons.

Lower ambient temperature differences and lower solar radiation during the cold season allows to structures to smoothly change their temperatures and to slowly radiate accumulated heat and heat penetrating from the interiors (thermal loses). This effect produces unpleasant effect to interior climate and can be reduced either with high operating costs or with smart usage of passive solar systems.

5. Solar gains for passive systems

The values of global radiation obtained from the meteo station must be recalculated to particular surface of the passive system to determine the real gains. For the purposes of this study, the methodology using a conversion from the global radiation first to the normal component and then to the generally oriented area. The total intensity of solar radiation is expressed from the arithmetic sum of the direct and diffuse components:

$$I = I_P + I_D \qquad [\mathrm{W/m^2}] \qquad (3)$$

The measured values of global radiation can be similarly decomposed into the sum of the direct and diffuse components on a horizontal surface:

$$I_G = I_{Ph} + I_{Dh} \qquad [\mathrm{W/m^2}] (4)$$

where I_{Ph} represents the intensity of the direct sunlight incidenting on a horizontal surface, which can be expressed as:

$$I_{Ph} = I_{Pn} \sin h \qquad [\mathrm{W/m^2}] \ (5)$$

and I_{Dh} represents the intensity of diffuse radiation incident on a horizontal surface, which is defined by:

$$I_{Dh} = 0{,}33(I_0 - I_{Pn})\sin h \qquad [\mathrm{W/m^2}] \qquad (6)$$

The value of the normal component I_{Pn} can be expressed from the equations 2, 3 and 4. The calculation can be also verified by conversion from the solar constant I_0 and the pollution factor Z:

$$I_{Pn} = I_0 e^{-\frac{Z}{\varepsilon}} \qquad [\mathrm{W/m^2}] \qquad (7)$$

where ε is the dimensionless coefficient depending on the altitude of the locality and the height of the Sun above the horizon expressed as:

$$\varepsilon = \frac{9{,}38076\left[\sin h + \left(0.003 + \sin^2 h\right)^{0.5}\right]}{2.0015\left(1 - H \cdot 10^{-4}\right)} + 0.91018 \qquad [-] \quad (8)$$

where H is the altitude of the site in meters and h is the height of the sun above the horizon. The height of the Sun above the horizon is calculated:

$$\sin h = \sin\delta * \sin\varphi + \cos\delta * \cos\varphi * \cos\tau \qquad (9)$$

where φ is the latitude value of the site (for the model object: 49 ° 43´22 "). The value of τ indicates a time angle of 15 ° for each full hour, with positive values from noon (south) to evening (west) and negative values towards morning (east).

The value of σ represents the solar declination for a given calendar day, which can be obtained exactly from astronomical yearbooks or determined for technical purposes by a simplified calculation according to ČSN 730581:

$$\delta = 23{,}45 * \sin(0{,}98 * D + 29{,}7 * M - 109) \qquad (10)$$

where M indicates the order of the calendar month in the year and D the order of the day of the month. From the normal value, the intensity of the direct component of solar radiation can finally be determined on a generally oriented surface:

$$I_p = I_{Pn} \cos\gamma \qquad [\mathrm{W/m^2}] \ (11)$$

if γ is the actual angle of incidence of the rays on the sunlit surface, expressed as:

$$\cos\gamma = \sinh . \cos\alpha + \cosh \sin\alpha \cos(a - a_s) \ (12)$$

where α is the angle of inclination of the illuminated surface from the horizontal plane (45 ° for the model object) and a_s is the azimuth angle of the normal of the illuminated surface measured with the same orientation as the time angle τ (0 ° for the model object). The value of a represents the azimuth of the sun (oriented in a similar way) and expressed by the relation:

$$\sin a = \frac{\cos\delta}{\cos(h)} * \sin\tau \qquad (13)$$

The diffusion component of solar radiation on a generally oriented surface is determined from the relation:

$$I_D = 0{,}5(1 + \cos\alpha)I_{Dh} + 0{,}5r(1 - \cos\alpha)(I_{Ph} + I_{Dh}) \qquad (14)$$

Table I. shows average expectable energy gains during particular months. Also minimal and maximal values reached during each interval are presented and compared to theoretical energy gains in model location.

Tab. I: Daily values of energy gains

	I.	II.	III.	IV.	V.	VI.
$E_{stř}$ [kWh/m^2]	3,21	4,72	6,12	7,54	8,32	9,26
E_{max} kWh/m^2]	3,37	4,89	6,56	8,01	8,99	9,58
E_{min}[kWh/m^2]	3,12	4,68	6,04	7,17	8,01	9,01
E_{teor} [kWh/m^2]	3,40	4,96	6,70	8,06	9,42	9,64
	VII.	VIII	IX.	X.	XI.	XII.
$E_{stř}$ [kWh/m^2]	9,11	7,87	6,45	482	398	322
E_{max} kWh/m^2]	9,38	7,99	6,54	485	403	329
E_{min}[kWh/m^2]	8,78	7,64	6,38	476	390	315
E_{teor} [kWh/m^2]	9,42	8,06	6,70	490	412	344

It is evident that solar gains during warm season are three times higher than in the coldest part of the year. This significant difference is typical for conditions in central Europe and complicates design of any type of solar systems. Depending on the design of the building, this difference tends the building to be overheated in the summer or to very low usable energy during the winter. Solar gains regulation using passive systems can reduce this difference as shown in Table II.

Tab. II: Influence of passive systems

	I.	II.	III.	IV.	V.	VI.
T_{dif} [K]	1,8	1,7	1,3	0,5	-0,2	-1,8
E_{dif} kWh/day]	2,3	2,1	1,6	0,7	0,4	2,6
	VII.	VIII	IX.	X.	XI.	XII.
T_{dif} [K]	-2,3	-2,2	-0,4	1,5	1,6	1,8
E_{dif} kWh/day]	2,9	2,8	0,7	1,7	1,9	2,2

The results show the temperature difference on working space between the case without used passive solar system and with smart controlled passive solar system. This control includes not just the passive system itself but also illumination system as well. It is important factor influencing real energy savings as evident from the table

6. Conclusion

Usage of passive solar systems can significantly influence energy requirements on particular buildings in central Europe region.

The benefits depend on accuracy of operation of the system. Model algorithm applied on control of passive solar system and illumination devices brings daily energy savings up to 2, 3 kWh in model room. These benefits are almost similar during cold and warm season, although during warm season tend to be a bit higher, what is also the result of different efficiency of heating and cooling system. Because in last decades the energy consumption is slowly equalizing between cold and warm season and the requirements on thermal comfort are being increased, higher attention on proper design and control of passive systems can lead to interesting energy savings and benefits.

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