FACTA UNIVERSITATIS
Series: **Working and Living Environmental Protection** Vol. 10, N° 2, 2013, pp. 111 - 117

THE THERMAL MASS OF PASSIVE BUILDINGS WITH DIRECT GAIN OF SOLAR RADIATION *

UDC 536.2:620.9

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Abstract. *This paper presents a method for determining the position and thickness of the thermal mass on the premises with solar windows depending on their location and size, as well as the climate of the place where the object with the passive system is placed.*

Key words: *solar windows, thermal mass*

1. INTRODUCTION

In passive solar systems, the elements of the building for the collection, storage and distribution of solar energy are used. The goal of passive systems is to deliver the energy that the system receives to tenant of the building at the time when it is needed. The system for direct abstraction of the sun's energy requires a window whose slope and orientation should be selected to so they can provide maximum heat gain in the winter and a minimum of overheating in the summer and in the transitional period. In solar architecture, windows occupy 60-90% of the south façade of residential buildings. Beside the vertical façade, the windows there are also roof windows of different shapes, sizes and positions. The window size depends on the purpose, mass of thermal accumulation walls, rooms in which they are located, and so on.

Solar radiation through the southern window falls directly on the thermal mass i.e. storage of heat, the elements that constitute the building with a large heat capacity. Solar energy, which is due to heat storage during the day is absorbed and stored in the elements and during the night is emitted into the object space [1, 4].

Received November 10, 2013
* **Acknowledgement**. This research is part of the project Development, realization, optimization and monitoring of a 5kWp grid-connected modular sun-tracking photovoltaic system (No. TR-33035) and project Improvement of the monitoring system and the assessment of a long-term population exposure to pollutant substances in the environment using neural networks (No. III-43014). The authors gratefully acknowledge the financial support of the Serbian Ministry for Science for this work

2. THE THERMAL MASS OF THE CEILING AND THE FLOOR

Solar radiation reaches the room through solar windows and it can be accumulated in the floor, walls and ceiling of the room. The floor of the room accumulates solar radiation which is coming into the room through vertical solar windows. To make sure that the thermal mass of the room is getting direct solar radiation, the width of the thermal mass (b) must be correctly determined (Fig.1).

Coefficient N is the ratio of the total area of solar windows and the total floor areas of a residential building, and it is shown in Table 1. Along with coefficient N, the required area of a solar window is calculated, if it is a known floor area of living place. The value of the coefficient N is given, depending on the average ambient temperature on the location where the object is placed in winter [6].

Table 1 The value of coefficient *N*

Average ambient temperature of air in the winter [°C]	Coefficient *N* [solar window area/room floor area]
Cold climate	
- 9.4	0.27 – 0.42 (with night insulation)
- 6.7	0.24 – 0.38 (with night insulation)
- 3.9	0.21 – 0.33
- 1.1	0.19 – 0.29
Moderate climate	
+ 1.7	0.16 -0.25
+ 4.4	0.13 – 0.21
+ 7.2	0.11 – 0.17

In table 1 average winter ambient temperatures are shown for the coldest months of the year (January and December).

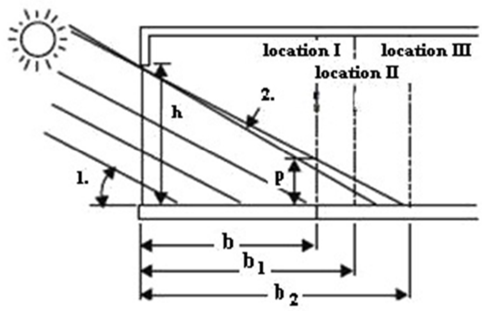


Fig. 1 A vertical solar window with an ideal thermal mass floor with a width b. 1. Solar altitude angle on December 21 at 12^{00}, 2. Solar altitude angle on. January 21 at 12^{00}

The width of the thermal mass b is determined by the equation:

$$b = \frac{h_{window}}{tg\,\alpha} \tag{1}$$

where: h_{window} – is the height of the solar window, α – the angle of elevation of the Sun, b – the width of the thermal mass of the floor [m].

The angle of elevation of the Sun is determined using the following equation:

$$\alpha = \arcsin(\cos L \cdot \cos\delta \cdot \cos h + \sin L \cdot \sin\delta) \quad (2)$$

where: L – is the local latitude, δ – the declination of the Sun [°], h – the hour angle [°]

The hour angle varies with the change of the observation point and the apparent daily movement of the sun on circles parallel to the equator. The size of the hour angle h is calculated using the formula:

$$h = \pm\frac{1}{4} \text{ (the number of minutes by local sun time)} \quad (3)$$

$$\delta = 23{,}45 \sin\left[\frac{360}{365}(284+n)\right] \quad (4)$$

Where 'n' – is the day of the year ($1 \leq n \leq 365$)

If the floor area is known for the building with a solar window, the solar window size is determined by the equation:

$$A_{SW} = N \cdot A_2$$

where: A_{SW} – is the solar window area [m^2], A_2 – the floor area in the room where there is a solar window [m^2].

Figure 2 shows the location of a ceiling-mounted thermal mass in the room with rooftop solar windows. The position of the ceiling-mounted thermal mass depends on the height of the solar windows. It can be calculated by the equation:

$$l_1 = H_{P2} \quad (5)$$

$$l_{21} = 1{,}5 \cdot H_{P2} \quad (6)$$

where: H_{P2} – is the installation altitude of the sunroof (from the floor level to the bottom edge of the solar window), H_{P1} – the height of the roof window.

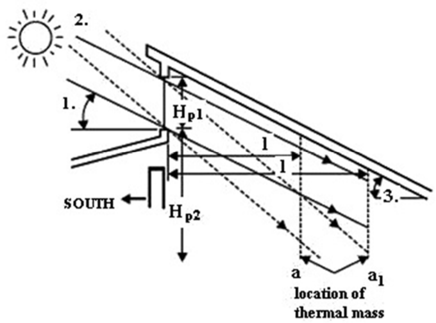


Fig. 2 Roof solar window: 1. Solar altitude angle on December 21, 2. Solar altitude angle on February 21 and October 21 at 12^{00}, 3. Solar altitude angle on December 21 at 12^{00}

Figure 3, shows how the solar radiation enters the room through roof solar window and accumulates in the upper part of the thermal wall. By placing reflective panels on the solar roof windows, solar radiation is reflected from them and via solar roof windows enters the room, reflects off the ceiling into the room and then reaches the lower thermal wall (Fig. 3). Using reflective panels enabled the accumulation of heat in the thermal wall across its surface [7].

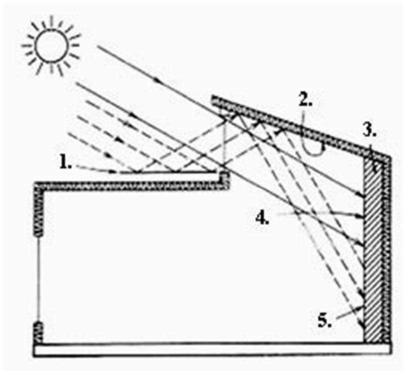


Fig. 3 Solar skylight with reflective panels: 1. Reflection surface, 2. Internal reflection of solar radiation from the room ceiling, 3. Massive thermal wall, 4. Places of absorbing of reflected solar radiation, 5. Direct solar radiation which is absorbed in the upper part of the thermal wall

3. THE HEAT CAPACITY OF THE THERMAL MASS IN ROOMS WITH THE DIRECT INTERVENTION OF SOLAR RADIATION

Absorbed solar radiation that reaches the thermo accumulative wall (thermal mass) is calculated by the following equation:

$$I_{absorbed} = \beta \cdot I_u \cdot \tau \tag{7}$$

where: β – is the coefficient of absorption of the sun radiation with the material of the thermo accumulative wall, τ – is the coefficient of transmission trough glass windows, I_u – is the total solar radiation reaching the surface of the thermo accumulative wall [W/m^2].

Solar radiation, which has entered the room through the windows and reach its walls, floor and ceiling, is partially absorbed and partially reflected. The absorbed part of the energy heats the surface layers of the thermo accumulative structure (wall, floor and ceiling) above the temperature in the inner layers of the frame, above the temperature of the room air. The established temperature difference between the surface of the wall (Tz) and its deeper layers leads to heat conduction in the wall mass and it accumulates there. The heat absorbed in the material of the massive wall per unit time and per unit surface of the absorbing wall is calculated by the following equations:

$$Q_a = q_a A \ \tau = mc\ (T_{Z\tau} - T_z) \tag{8}$$

$$m = \rho\ d\ A = \rho\ V \tag{9}$$

$$Q_a = \rho V c\ (T_{Z\tau} - T_z) \tag{10}$$

$$Q_a = C_v V\ (T_{Z\tau} - T_z) \tag{11}$$

where: m – is the mass of the wall, which accumulates solar radiation [kg], ρ – the density of the massive wall material [kg/m^3], c – the specific heat of the massive wall [J/kg K], A – the absorption area of the massive wall [m^2], $T_{Z\tau}$ – is the average temperature of the wall after τ period of heat transfer [K], T_Z – is the temperature of the wall at the beginning of the insulation of the wall [K], τ_I – the time of insulation of the wall [s].

The total heat capacity of the thermal mass in the room with direct catching of the solar radiation is calculated by the following equation:

$$S_{TM} = A_{SW} \cdot C_A \tag{12}$$

where: A_{SW} – is the solar window area [m^2], C_A – the heat capacity of the heat storage material per m^2 of the receiving surface of the solar window [J/m^{2}K].

The heat storage volume is calculated according to the equation:

$$V_{TM} = \frac{S_{TM}}{C_V} \tag{13}$$

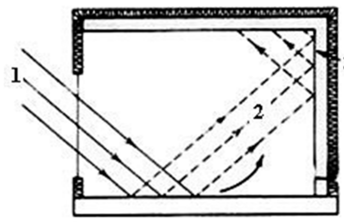
$$C_V = c \cdot \rho \tag{14}$$

where: C_V – is the volumetric heat capacity of material storage [J/m^{3}K], c – the specific heat capacity of the heat storage material [J / kg K], ρ – the specific density of the heat storage material [kg/m^3].

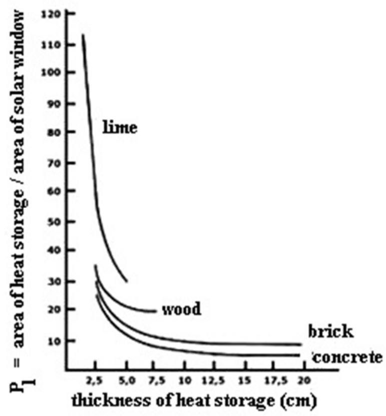
The thickness of thermal storage, where reflected sunlight enters, in the case of passive objects with direct catching of solar radiation can be determined by knowing the size of p1, which is the ratio between the surface area of heat storage and the solar window. Figure 4.b. shows a diagram with which one can determine the thickness of the thermal storage, depending on the size of p_1.

$$p_1 = \frac{A_{TM_1}}{A_{SP}} \tag{15}$$

where: A_{SW} – is the area of the solar window [m^2], A_{TM_1} – is the area of the structural thermal storage [m^2].



a.



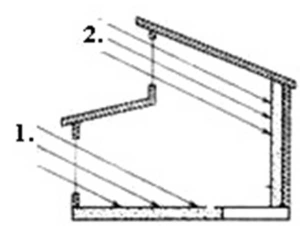
b.

Fig. 4 a) A cross-section of the room with reflected sunlight radiation, b) The diagram which determined the thickness of heat storage that absorbs the reflected solar radiation: 1. Solar radiation, 2. Reflected solar radiation, 3. Solar radiation reflected by the thermal wall

The thickness of thermal storage, where direct sunlight enters, in case of passive objects with the direct entry of solar radiation, can be determined by knowing the size of p2 which is the ratio between the surface area of heat storage and solar window. Figure 5.b. shows a diagram with which one can determine the thickness of the thermal storage, depending on the size of p_2.

$$p_2 = \frac{A_{TM_2}}{A_{SP}} \tag{16}$$

where: A_{SW} – is the area of the solar window [m^2], A_{TM_2} – the surface of the structure that accumulates direct sunlight [m^2].



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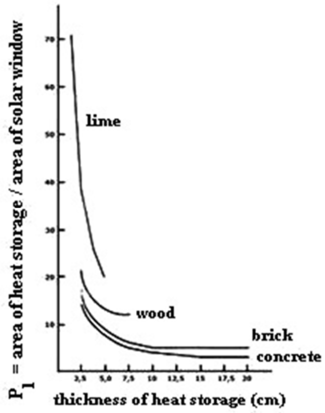

b.

Fig. 5 a) A cross-section of the room with direct sunlight, b) The diagram with which the thickness of the thermal storage that absorbs direct sunlight can be determined: 1. Direct solar radiation, 2. Direct solar radiation

4. Conclusion

In places where the thickness of thermal storage has been applied, the direct catching of solar radiation depends on the type of material storage, the storage surface, the surface of the solar window through which sunlight flows directly. Direct sunlight in a room, which flows through south-oriented windows, is absorbed in the thermal mass in the floor but it is also reflected. The sun's radiation witch is reflected is absorbing in the thermal mass of the wall.

Solar radiation that through solar skylights enters the room is stored in the upper part of the thermal wall. By placing reflective panels on solar skylights, the solar radiation reflected from them via solar skylights enters the room, reflecting off the ceiling in the room and then reaching the lower thermal wall. Using reflective panels enabled the accumulation of heat in the thermal wall across its entire surface.

The proper sizing and installation of solar windows ensures the entrance of solar radiation into the thermal mass and its accumulation in it.

References

1. J. Radosavljević, T. Pavlović, D. Petković: The Influence of Direct Capture of Solar Radiation on the Heat Gain in Rooms, *Facta Universitatis*, Series: Physics, Chemistry and Technology, 2, (3), 131-139, 2001.
2. J. Radosavljević, Lj. Živković, N. Živković, A. Đorđević: Određivanje energetski efikasnih dimenzija pasivnih solarnih objekata kvadratne i pravougaone osnove, Tehnika, 64, (6), 17-20, 2010.
3. M. Đurđanović, J. Radosavljević, T. Pavlović: Uticaj prozora kod zgrada koje se pasivno hlade. Tehnika - Naše građevinarstvo, 59, (1), 13-16, 2005.
4. J. Radosavljević: Urbana ekologija i prostorno planiranje, Fakultet zaštite na radu u Nišu, Niš, 2006.
5. J. Radosavljević: Urbana ekologija, Fakultet zaštite na radu u Nišu, Niš, 2009.
6. J. Radosavljević, T. Pavlović: Urbanistički parametri potrebni za projektovanje solarnih pasivnih sistema, Renewable Energy and Future of its Applications in Yugoslavia, The Section of Natural Sciences, The Montenegrin Academy of Sciences and Arts, Podgorica, 2004.
7. Jasmina M. Radosavljevic, Miroslav R. Lambic, Emina R. Mihajlovic, Amelija V. Djordjevic: Estimation Of Indoor Temperature For A Direct Gain Passive Solar Building, Journal of Energy Engineering, DOI: 10.1061/(ASCE)EY.1943- 897.0000104 (in press, online).

TERMALNA MASA PASIVNIH OBJEKATA SA DIREKTNIM ZAHVATOM SUNČEVOG ZRAČENJA

U radu je prikazan način određivanja položaja i debljine termalne mase u prostorijama sa solarnim prozorima u zavisnosti od njihovog položaja i veličine kao i od klimata lokaliteta objekta sa ovim pasivnim sistemom.

Ključne reči: *solarni prozori, termalna masa*