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INFLUENCE OF SUNSPACE PARTITION WALL THERMAL MASS ON THE ENERGY EFFICIENCY OF INDIVIDUAL RESIDENTIAL BUILDINGS

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Abstract: In passive solar buildings, solar radiation is converted into thermal energy that is accumulated in the thermal mass of the building and used for heating. This research investigates thermal mass of a passive solar building with a sunspace by considering the vertical thermal mass within the wall that separates the sunspace and the adjacent room (thermos–accumulative partition wall). Twelve variants of the MODEL of a residential building with sunspace, with different types of thermo–accumulative partition walls (P1–P12) were considered. Model variants included partition walls with different thermal characteristics, different types of materials, and construction thicknesses. In this research, EnergyPlus software, based on the principles of heat balance, was used for dynamic simulation to determine the heat load of the building and the required energy for heating and cooling. Concerning the twelve considered variants of the thermal mass in the composition of the thermo–accumulative partition wall between the sunspace and the room, it was determined that the variants containing 0.4 m thick concrete or 0.38 m thick brick in the wall structure have better energy properties compared to structures with the same coefficient of heat transfer coefficient, but with a smaller thickness of concrete (d=0.20 m) or brick (d=0.25 m). Savings in the total annual required energy for heating and cooling were up to 7.20%.

Keywords: thermo–accumulative partition wall, sunspace, energy performance

1. INTRODUCTION

Compared to the period 40 years ago, world energy consumption in the building sector, increased by 1.8% on an annual basis. Past research shows that this trend of increasing energy consumption will continue. With the energy consumption of 2790 Mtoe (million tons of oil equivalent) in 2010, the consumption is expected to exceed 4400 Mtoe by 2050 [1] Three–quarters of the total energy consumption in buildings comes from the sector of residential buildings. Greater representation of passive solar buildings would contribute to the reduction of this percentage, while savings in energy used for heating, cooling, and air conditioning would be achieved at the same time.

In passive solar buildings, solar radiation is converted into thermal energy that is accumulated in the thermal mass of the building and used for heating of building interior space (living room, bedrooms and work rooms, etc.) [2] In areas with a warm climate, the use of thermal mass is recommended because thermal mass can prevent overheating of buildings and mitigate large day–night fluctuations of temperature. In areas with a moderate climate, the correct selection of materials depends on their mechanical, physical, and structural characteristics. Non–transparent elements of the envelope can represent the thermal mass of the object if the walls are composed of materials whose absorption capabilities are high in relation to the volume of the material (stone, concrete, brick).

The basic principle of passive solar sunspace is based on the "greenhouse effect". Solar radiation reaches the interior space through the glazed surfaces, where it is absorbed by the dark surfaces of the thermal mass. Between the sunspace and the room, a massive wall is most often formed, through which the heat is transferred to the interior of the building and the room adjacent to the sunspace. The thermal mass is usually the southern partition wall of the building (the wall between the sunspace and the interior rooms of the building) with a thickness of 20–40 cm made of concrete or brick [2]. The accumulated heat in the wall is further transferred by conduction into the building interior (living room, bedroom, study, etc.). The thermo–accumulative wall can be with or without an opening on it.

Suarez et al. investigated the thermal behavior of an experimental object with a sunspace using the ANSYS 12.1 software. The experimental building was located in the north of Spain. The thermal mass of the building consisted of the sunspace floor structure, with a 0.20 m thick sand filling. The obtained results showed that the heat energy transmitted from floor thermal mass to the environment was highest in spring and autumn [3] The effect of thermal mass on heat gains in a residential building with a sunspace, in cold climate conditions, was investigated by Rempel et al. [4]. The thermo–accumulative mass was the sunspace floor. Two types of thermal mass materials were considered, concrete and water (in tanks). In the considered variants of the thermal mass, a greater increase in air temperature (40–70%) was recorded in the morning hours and significantly less in the evening hours (20–40%). Remple et al. also investigated the influence of the thickness of concrete floor thermal mass and found that a thickness of 5.1 cm is the most suitable for interior space heating in the evening hours. If the interior room heating in the early morning hours is required, then the thickness of the concrete, within the thermal mass of the floor structure, is 15 cm [4].

Bastien and Athienitis investigated the influence of the position of the thermo–accumulative mass (floor, wall, or both) and the percentage of glazing of the sunspace on the air temperatures inside the room. They used numerical methods: finite difference thermal network – FD and frequency response – FR. The research included the analysis of the obtained internal temperatures depending on the thickness and position of the thermo–accumulative mass [5]

In Iran, research was conducted on a passive building with a sunspace and a thermo–accumulative partition wall with water. The sunspace of this building was positioned towards the south and had triple glazing on the front and single glazing on the roof surface sloped by a 35°. Two variants of the thermal mass were experimentally analyzed: with and without a water tank. For different climatic conditions of the location of the building, simulations were performed using the EnergyPlus software. The obtained results showed that the application of the sunspace has a positive effect on interior room heating. For the investigated variant of the building model with thermal mass consisting of water tanks, better thermal comfort conditions were achieved. It was found that the greatest increase in temperature is achieved in January, during the coldest days [6]

Sanchez–Ostiz et al. investigated the energy performance of a building with a sunspace, namely: a building with a sunspace and a horizontal thermal mass (P1), a building with a sunspace without a thermal mass (P2), a building without a sunspace (P3) and a building with a sunspace and a vertical thermal mass (P4), to determine the optimal model of a building with a sunspace for the climatic conditions of Spain [7]

This research investigates the influence of the thermal mass of the thermal storage wall in the building with a sunspace on the total required energy for heating and cooling during one year. A model of the building with a sunspace was created and model variants containing different types of materials in the structure of the partition wall. Different thermal mass and different layer thicknesses of the structure were also considered. The formed object model is located in Niš.

2. MATERIAL AND METHODS

— Building model

EnergyPlus software was used to determine the building's energy properties. The dynamic simulations in EnergyPlus software are based on the basic laws of physics and the principles of heat balance. Heat balancing is the basis of all calculations that determine the heat load of the building and the required energy for heating and cooling.

Research on the thermal mass of a passive solar building with a sunspace was conducted by considering the vertical thermal mass within the wall that separates the sunspace and the adjacent room (thermo–accumulative partition wall). A MODEL of the building with a sunspace was created, with G+1 floors with a floor aspect ratio of 2.25:1. Sunspace was placed on the entire length of the south–facing facade. The width of the sunspace in this model is 1.2 m. The length of the building is 14.4 m and the width is 6.4 m. The total area of the base of the building is Po=184.32 m^2 and the area of the sunspace is Ps= 34.56 m^2. The sunspace is fully glazed and the window–to–wall ratio of the building is WWR=20%. The model of a building is located in Niš.

Meteonorm software package was used to create a meteorological file for the city of Nis based on the measured meteorological parameters for the period from 1991 to 2010. The setpoint temperature for the heating system is 20°C, and for the cooling system is 25°C. The natural ventilation system is defined in such a way as to ensure a certain number of air exchanges per person during 24 hours. Table 1 shows the values of the heat transfer coefficient “U” for facade walls, floor and roof construction, and windows of the model of individual passive residential buildings with a sunspace.

Twelve sub–variants of the MODEL were considered with different types of heat–accumulating partition walls (P1 – P12) whose basic characteristics are shown in table 2. Formed variants of the model included walls with different thermal characteristics, different types of materials, and construction thicknesses. Within the formed variants different thermo–accumulative partition walls were considered: concrete constructions with a thickness of 0.2 m and 0.4 m, brick constructions with a thickness of 0.25 m and 0.38 m, and different thicknesses of thermal insulation material from 0.05 m to 0.15 m.

Table 1. Values of heat transfer coefficient for defined elements of the thermal envelope of the building

Type of structure	U [W/m^2K]
Facade wall	0.29
The floor on the ground	0.28
The flat roof	0.15
Windows, Sunspace glazing	1.50

Table 2. Considered partition wall types and their characteristics (structure, material composition, and thermal characteristics)

Marking of the partition wall	Name (thermo–accumulative partition wall)	Characteristics of the material in the composition of the wall						Wall heat transfer	Wall heat transfer
		Type of material in the composition of the partition wall	Material thickness [m]	Thermal conductivity [W/mK]	Specific heat capacity [J/kgK]	Density [kg/m^2]	Relative coefficient of diffusion of		
P1	Thermo–accumulative partition wall made of brick (0.25 m) and thermal insulation (0.15 m)	Exterior plaster	0.02	0.72	840	1860	20	5.02	0.199
		EPS (Expanded Polystyrene)	0.158	0.035	1400	25	150		
		Brick	0.25	0.85	840	1650	150		
		Internal plaster	0.01	0.72	840	1860	20		
P2	Thermo–accumulative partition wall made of concrete (0.2 m) and thermal insulation (0.15 m)	Exterior plaster	0.02	0.72	840	1860	20	5.021	0.199
		EPS (Expanded Polystyrene)	0.154	0.035	1400	25	150		
		Concrete	0.2	0.51	1000	1400	150		
		Internal plaster	0.01	0.72	840	1860	20		
P3	Thermo–accumulative partition wall made of brick (0.25 m) and thermal insulation (0.099 m)	Exterior plaster	0.02	0.72	840	1860	20	3.354	0.298
		EPS (Expanded Polystyrene)	0.099	0.035	1400	25	150		
		Brick	0.25	0.85	840	1650	150		
		Internal plaster	0.01	0.72	840	1860	20		
P4	Thermo–accumulative partition wall made of concrete (0.2 m) and thermal insulation (0.096 m)	Exterior plaster	0.02	0.72	840	1860	20	3.352	0.298
		EPS (Expanded Polystyrene)	0.0962	0.035	1400	25	150		
		Concrete	0.2	0.51	1000	1400	150		
		Internal plaster	0.01	0.72	840	1860	20		
P5	Thermo–accumulative partition wall made of brick (0.25 m) and thermal insulation (0.07 m)	Exterior plaster	0.02	0.72	840	1860	20	2.52	0.397
		EPS (Expanded Polystyrene)	0.07	0.035	1400	25	150		
		Brick	0.25	0.85	840	1650	150		
		Internal plaster	0.01	0.72	840	1860	20		
P6	Thermo–accumulative partition wall made of concrete (0.2 m) and thermal insulation (0.067 m)	Exterior plaster	0.02	0.72	840	1860	20	2.521	0.397
		EPS (Expanded Polystyrene)	0.0671	0.035	1400	25	150		
		Concrete	0.2	0.51	1000	1400	150		
		Internal plaster	0.01	0.72	840	1860	20		
P7	Thermo–accumulative partition wall made of brick (0.38 m) and thermal insulation (0.15 m)	Exterior plaster	0.02	0.72	840	1860	20	5.019	0.199
		EPS (Expanded Polystyrene)	0.153	0.035	1400	25	150		
		Brick	0.38	0.85	840	1650	150		
		Internal plaster	0.01	0.72	840	1860	20		
P8	Thermo–accumulative partition wall made of concrete (0.4 m) and thermal insulation (0.14 m)	Exterior plaster	0.02	0.72	840	1860	20	5.019	0.199
		EPS (Expanded Polystyrene)	0.14	0.035	1400	25	150		
		Concrete	0.4	0.51	1000	1400	150		
		Internal plaster	0.01	0.72	840	1860	20		
P9	Thermo–accumulative partition wall made of brick (0.38 m) and thermal insulation (0.094 m)	Exterior plaster	0.02	0.72	840	1860	20	3.353	0.298
		EPS (Expanded Polystyrene)	0.094	0.035	1400	25	150		
		Brick	0.38	0.85	840	1650	150		
		Internal plaster	0.01	0.72	840	1860	20		
P10	Thermo–accumulative partition wall made of concrete (0.4 m) and thermal insulation (0.0825 m)	Exterior plaster	0.02	0.72	840	1860	20	3.353	0.298
		EPS (Expanded Polystyrene)	0.0825	0.035	1400	25	150		
		Concrete	0.4	0.51	1000	1400	150		
		Internal plaster	0.01	0.72	840	1860	20		
P11	Thermo–accumulative partition wall made of brick (0.38 m) and thermal insulation (0.065 m)	Exterior plaster	0.02	0.72	840	1860	20	2.519	0.397
		EPS (Expanded Polystyrene)	0.0651	0.035	1400	25	150		
		Brick	0.38	0.85	840	1650	150		
		Internal plaster	0.01	0.72	840	1860	20		
P12	Thermo–accumulative partition wall made of concrete (0.4 m) and thermal insulation (0.053 m)	Exterior plaster	0.02	0.72	840	1860	20	2.519	0.397
		EPS (Expanded Polystyrene)	0.0533	0.035	1400	25	150		
		Concrete	0.4	0.51	1000	1400	150		
		Internal plaster	0.01	0.72	840	1860	20		

3. RESULTS AND DISCUSSION

Dynamic simulations were carried out in the EnergyPlus software package for the formed variants of the MODEL, and the dynamic behavior of the object throughout the year was determined and the required energy for heating required energy for cooling, and the total required energy for heating and cooling for the entire year was calculated.

The results of dynamic simulations for the considered variants of the partition wall MODEL P1 to P12 at the percentage of glazing WWR=20% are shown in table 2. Based on the results given in the table, the reference model, variant P8, was determined. The P8 variant requires the least energy for heating as well as the total annual required energy. Variant P8 includes a partition wall made of concrete 0.4 m thick with thermal insulation made of EPS (expanded polystyrene) 0.14 m thick. Table 3 shows the percentage increase, or decrease, of the total required energy for heating and cooling the building compared to the reference model P8.

Table 3. Results obtained by simulation for MODEL (variants P1 – P12), WWR=20%, for different types of the partition wall

Partition wall type designation	MODEL					
	Total required energy for heating [kWh]	Total required energy for cooling [kWh]	Total required energy for heating and cooling [kWh]	Percentage increase (+) or decrease (–) of the total required energy for heating	Percentage increase (+) or decrease (–) of the total required energy for cooling	Percentage increase (+) or decrease (–) of the total required energy for heating and cooling
P1	8878.34	5600.51	14478.85	+0.40	+0.10	+0.28
P2	8884.45	5604.68	14489.13	+0.47	+0.17	+0.36
P3	8905.98	6068.61	14974.59	+0.71	+8.46	+3.72
P4	8915.79	6074.31	14990.10	+0.83	+8.57	+3.83
P5	8927.08	6532.14	15459.22	+0.95	+16.75	+7.07
P6	8936.57	6540.97	15477.54	+1.06	+16.91	+7.20
P7	8843.63	5617.68	14461.31	+0.01	+0.41	+0.16
P8	8842.78	5595.01	14437.79	Ref.	Ref.	Ref.
P9	8878.58	6057.83	14936.41	+0.40	+8.27	+3.45
P10	8865.24	6053.39	14918.63	+0.25	+8.19	+3.33
P11	8901.01	6496.82	15397.83	+0.66	+16.12	+6.65
P12	8889.13	6490.22	15379.35	+0.52	+16.00	+6.52

Figure 1 shows the total annual required energy for heating, the total annual required energy for cooling and total annual required energy for heating and cooling, variants of the MODEL that include different types of the partition wall between the sunspace and the room (P1 – P12) at the percentage of glazing WWR=20%.

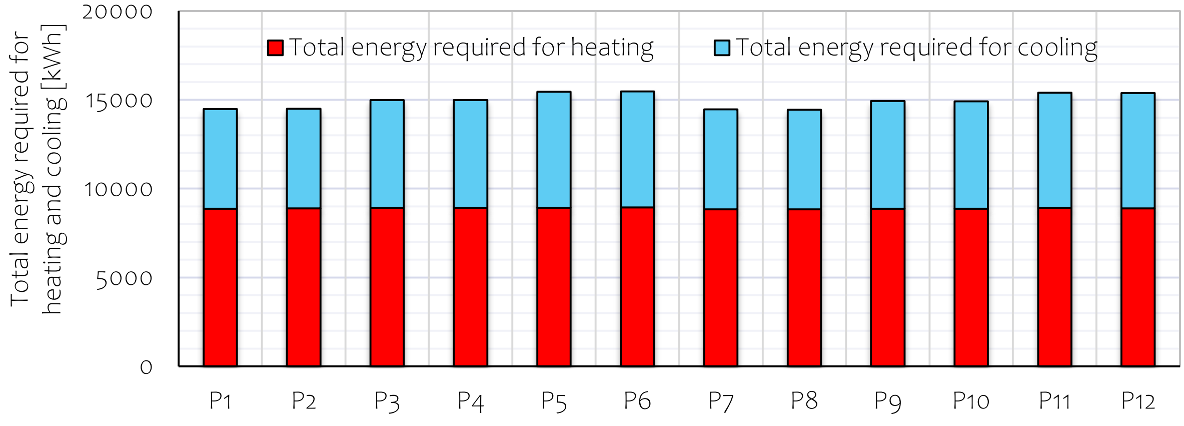

Figure 1. Total annual required energy for heating and cooling for MODEL of different types of the partition wall (subvariants P1–P12) with WWR=20%

The obtained results showed that the energy required for heating the building MODEL and all its variants (P1 – P12) is the lowest for variant P8 (MODEL variant P8), where the partition wall is made of concrete with a thickness of 0.40 m and thermal insulation made of EPS 0.14. That model was taken as a reference model.

The highest required energy for heating is for variant P6 (0.2 m thick concrete and 0.067 m thermal insulation) and amounts of 8936.57 kWh, i.e. 1.06% more compared to the reference model. In other considered subvariants of the model, the required energy for heating the building is slightly higher compared to the reference model (up to 1%), but the required energy for cooling of some models is significantly higher. In the case of variants P5, P6, P11, and P12, the required energy for cooling the building is higher by 16.75%, 16.91%, 16.12%, and 16.00% compared to the reference model, respectively. These subvariants have a heat transfer coefficient of U=0.397 W/m^{2}K.

The total annual required energy for heating and cooling is the highest in subvariant P6 (partition wall made of concrete 0.2 m and thermal insulation 0.067 m) and amounts to 15477.54 kWh, which is 7.20% more compared to the reference model.

4. CONCLUSIONS

Based on the analysis of the research subject, it can be concluded:

- When materials with a high thermal capacity are installed in certain parts of the building structure, such a building can store a larger amount of heat during the day, which will be released slowly into the interior space during the night.
- Concerning the twelve considered variants of the thermal mass in the composition of the thermo–accumulative partition wall between the sunspace and the room, it was determined that the variants that contained 0.4 m thick concrete or 0.38 m thick brick in the wall structure have better energy properties compared to constructions with the same heat transfer coefficient, but with a smaller thickness of the material of concrete (d=0.20 m) or brick (d=0.25 m). Savings in the total annual required energy for heating and cooling were up to 7.20%.

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