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Composite utilizing residues of marble and granite for building popular homes

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ABSTRACT

The use of composite materials for the construction industry has been the subject of numerous scientific studies in Brazil and worldwide. This paper presents a composite that was obtained from waste generated in the process of obtaining plates of granite and marble, cement, gypsum, sand, crushed EPS and water. These wastes cause great damage to the environment and are thrown in landfills in large quantities. Several blocks from varied compositions were manufactured and preliminary tests of mechanical and thermal resistance were performed, allowing the selection of the most appropriate proportion. Manufacturing processes and assembly of the blocks to build an experimental residence were discussed. The blocks were obtained in two configurations: with voids and with PET bottles filling. It was studied which type of block and residue was more viable for the proposed order. The formulation that was more efficient in terms of mechanical and thermal resistances was: 1.0 Cement +2.0 Sand +1.0 Styrofoam +1.0 Marble and Granite Powder+Water. The mechanical strength of the blocks was above 3.0 MPa. The thermal resistance of the blocks was confirmed by the maximum difference between the inner and outer walls of 8.0 °C. The acoustic absorption levels were higher than the levels provided by the conventional bricks, but lower than the minimum level of a material that has acoustic insulation capacity around 45%.

1. Introduction

The interest for the use of residues like cement parts for the manufacturing of blocks is linked to its low cost of acquisition, high availability, and the preservation of the environment [1–9].

The amount of residues that the ornamental rocks industry produces in Brazil range around 1,610,000 t per year. The use of this residue for the production of blocks destined for construction work is a way to reduce the negative impacts on the environment caused by the improper disposal, and also to reduce the consumption of natural resources [10–18].

Most of these tailings are discarded in decantation ponds and landfills, which are formed by materials of high fineness generated by processes such as cutting, polishing, and glossing of marble and granite plates [10–21].

According to a publication of the ministry of cities, the housing deficit in Brazil is about 6.490 million units that correspond to 12.1% of homes in the country. Although there was a significant drop of the number of Brazilian housing deficit in comparison to 2007, which was around 10%, the Brazilian population rose from 184 million to 194 million, which represents an increase of 5.5%, lowering the reach of the increase of housing units [22]. Globally the problem of the housing deficit would be lessened if the rhythm of housing construction doubled in the next 15 years [23].

Seeking to reduce the edification cost of a residence and to contribute to the reduction of the housing deficit, it was obtained a composite material composed of cement, marble and/or granite residue, gypsum, EPS (Expanded Polystyrene), sand and water, with inferior cost in relation to the conventionally used building materials. The obtaining and use of such composite had also as objective a contribution to withdraw harmful residues (marble/granite, EPS and PET) from the environment.

Cement, gypsum and sand are the conventionally used materials for the residential construction. The cement has plastic and reinforcement functions; the sand can present a fillment or a reinforcement function, depending on its relation with the cement; the gypsum has plastic and curing accelerator function. The EPS is also widely used in construction with plastic, thermal and fillment functions. The marble and granite had fillment function, reducing the amount of inputs in the concrete obtaining and increasing its resistance to compression.

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There were built blocks with full and/or empty 500 ml PET bottles. Such bottles had thermal and fillment functions, providing the block a mass reduction and increase in its thermal resistance.

The blocks had an area of around 0.2 m^2 with which were built four rooms, that would compose a house, with an area of 8.1 m^2 each. The research determined which type of block is more viable in relation to a combination of mechanical, thermal and acoustic resistances. Preliminary tests were concluded to determine the formula of the most adequate composite.

The referred block has as main characteristics its low-cost, good compressive strength, low thermal conductivity, good aesthetics, versatility and easy processes of manufacturing and assembly.

Another advantage of the produced composite is its fast curing process, allowing a considerable agility to its constructive process. It shall be noted that the good surface finishing of the produced block consequently results in a reduction of the labor costs, since the finishing work would be no longer needed.

It is also important to highlight the uniqueness of this research. It brings a combined research of the mechanical, thermal and acoustic resistance of the proposed composite. It is also important to emphasize that, in addition to the characterization of the designed and produced composite, rooms were built, which demonstrated a mechanical viability of the proposed material, being the thermal and acoustic resistance tests realized in prototypes instead of restricted studies to models richly presented in the relevant literature [22–25].

2. Materials and methods

In this section are detailed the materials and processes that were utilized in the manufacturing of the proposed composite blocks and the methods for the characterization of the composite. The property that was focused in the research was the compressive strength. Subsequently, it was prioritized the thermal resistance and, as a third parameter, the acoustic resistance.

Each analyzed parameter followed relevant standards of ABNT and ASTM (ABNT – 15220-1, 15220-2, 15270-1, 15575, 10151, 13818, 6502; ASTM Standard D3878-01, ASTM Standard D638-99) [26].

For the manufacturing phase of the blocks the following steps were followed: (1) collect the residues, (2) transport the residue to a manufacturing block site, (3) prepare the molds, (4) clean the parts that form the mold, (5) apply the coating agent [22].

Subsequently, each constituent material was separated, and afterwards each element was mixed for the preparation of the composite, which was poured in the mold. After manufacturing 500 blocks, the rooms were constructed.

The proposed composite was obtained by using varied proportions of cement, marble and granite powder, gypsum, EPS, and sand. Water was added in the proportion of approximately 50% of the dry volume to enable the mixture and the homogenization of the composite. An amount of each mixed constituent was measured by volume to facilitate the operation, which was carried out in a container with known volume. Table 1 shows the constituent elements of the proposed composite. The manufacturing process of the blocks in two configurations, with empty and full PET bottles, are shown in Fig. 1.

Table 1
Constituent elements of the proposed composite.

Nomenclature	Material
MP	Marble powder waste
M/GP	Marble/granite powder waste
C	Cement
S	Sand
G	Gypsum
STY	Styrofoam
W	Water

Initially the compressive tests were realized with diverse mixing proportions, varying the proportions of cement, marble and granite powder, gypsum, EPS, sand, and water. Through the analysis of three samples of each formulation, manufacturing cost, mechanical resistance and thermal resistance were evaluated. The formulation that was more efficient for mechanical and thermal resistances was chosen as: 1.0C+2.0S+1.0STY+1.0PM/G+WATER.

This formulation was selected for the composite blocks that were used for the construction of three rooms, that are shown in Fig. 2. Room 1 (R1) was built with marble powder residue composite blocks with voids, Room 2 (R2) was built with conventional eight holes bricks, Room 3 (R3) was built with marble/granite powder residue composite blocks with PET bottle fillment and Room 4 (R4) was built with marble/granite powder residue composite blocks with voids.

The tests that were performed for the characterization of the composite were: DRX, FRX, size analysis, apparent density, SEM, compressive strength; thermal resistance, water absorption, thermal comfort and acoustic resistance [22–39].

2.1. Thermal conductivity and thermal diffusivity test procedure

Conductivity and thermal diffusivity were measured using Quickline 30 equipment (Anter Thermal Properties Corp.). The equipment made the measurements of thermal properties based on the analysis of the thermal response of the material with respect to the excitation through a thermal flow.

This heat flux is produced by electric heating of a resistor inserted in the sensor which comes into direct contact with the material under analysis. Measurements of thermal conductivity and thermal diffusivity were based on periodic sampling of temperature as a function of time.

The sensor was fixed on top of the sample, heating the specimen to a temperature of 50 °C. The data was sent and recorded on a computer. The tests were performed in three samples for each marble/granite residue. For each sample the thermal properties were determined in five points.

2.2. Thermal comfort test procedure

Measurements were made with open and closed doors and windows. Data collection was performed on days with good solarimetric conditions. K type thermocouples were fixed in the central region of the housing unit at a height of 1.5 m in relation to the floor. The chromel-alumel type thermocouples were connected to a digital thermometer to measure the internal ambient temperature.

The data acquisition on the walls was done manually by means of an infrared thermometer, model HIGHMED HM-88C, positioned on the wall at a distance of 0.1 m. Temperatures were measured from 8:00 a.m. to 2:00 p.m.

The temperatures of the internal and external surfaces of the tile were measured with an infrared thermometer also every thirty minutes. They were measured at three points on both surfaces.

An Instrutherm thermal stress meter, recorded the following meteorological parameters: internal air temperature, wind speed, wet and dry bulb temperatures, obtaining with these last two parameters the relative humidity of the air. The parameters were measured every half an hour.

Global solar radiation was measured with an Instrutherm radiometer. Instantaneous global solar radiation was measured every thirty minutes.

2.3. Acoustic test procedure

A function generator was used to obtain the acoustic signal for the acoustic test of the proposed composite. For the transmission of the sound were coupled to the equipment four Leadership speakers and a subwoofer, which was in charge of directing the sound to the wall.

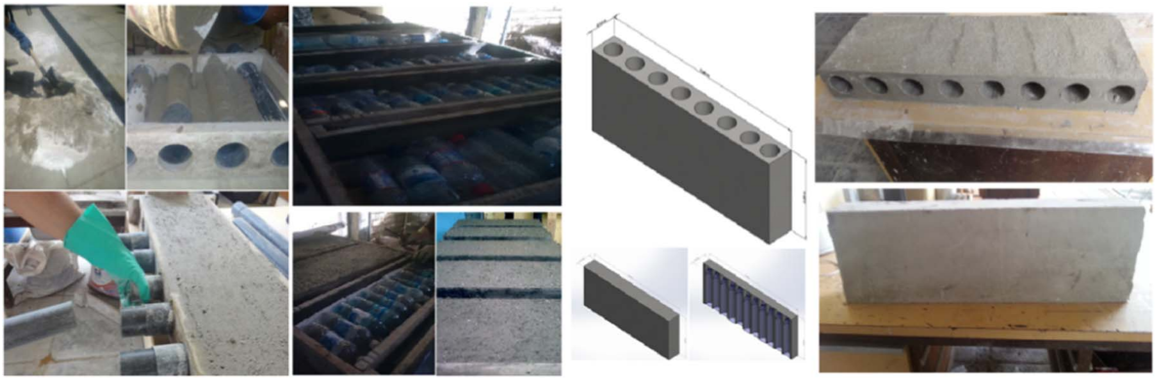

Fig. 1. Steps of the manufacturing process of the blocks.

Fig. 2. View of the four built rooms.

The instrument used to measure the sound pressure was a LT Lutron SL-4012 dB meter. The sound pressure levels of the measurement points were determined according to the C scale weighting, expressed in dB, according to the adopted technical standard. The slow meter response was used.

The sound was emitted on the inner wall, and the attenuation or magnification on the outer wall was measured. Measurements to evaluate acoustic performance occurred in the period from 8:00 a.m. to 04:00 p.m. The decibel meter was located at 0.50 m from the floor, leaning against the wall, in all rooms.

3. Results and discussion

3.1. X-ray fluorescence (FRX) and X-ray diffraction (DRX)

The results of the FRX analysis from samples of marble powder and marble/granite powder were collected after the sieving process, which showed the main chemical elements that compose the samples. The DRX identified the structure of the composite. The test results are shown in Fig. 3.

It was observed that X-rays from the diffractometer spectrum, shown in Fig. 3, presented well-defined peaks of minerals, such as Mica, Quartz, Gehlenita, and others. These peaks indicated the presence of crystalline phases, which was shown in the samples; therefore, it is possible to say that the material that generates the residue was constituted of well-defined crystals, bearing in mind that the granite came from crystalline magmatic rocks.

The X-rays from the diffractometer spectrum, showed peaks of characteristic diffractions of the crystalline phases related to calcite ($CaCO_3$), which is the largest observed peak, demonstrating the presence of marble. It was determined a predominance of quartz (SiO_2) and fayalite (Fe_2SiO_4) in the residue. By using X-ray fluorescence analysis, it was confirmed the residue was in fact marble [28,31,34,35].

3.2. Particle size analysis

For the use of residues it is necessary a compatibility between the particles, and all of the constituted elements, so that there is a better performance of the newly formed material. Table 2 introduces the results of the particle size analysis of the marble and marble/granite powder and the composite.

It was verified that the granite had a smaller size in its average diameter, which suggests a larger interaction in the formation of the composite. With basis on the granule size, it could be said that the used materials, marble and marble/granite powder, were appropriate for the formulation of the chosen composite, since 80% of the particles have an average diameter between 13 and 29 µm. The range that defines a material as powder is between 1 and 44 µm [27–29].

3.3. Scanning electron microscope (SEM)

The SEM micrographs showed the microstructure images of the

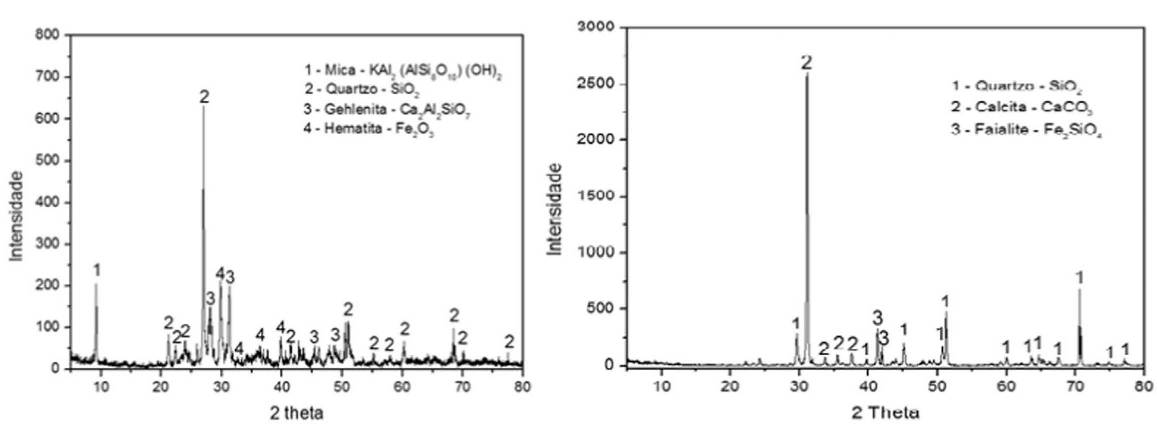

Fig. 3. X-ray diffraction of pure marble and marble/granite powder.

Table 2
Granule size of the marble powder, marble/granite powder and composite.

Samples	Average diameter (μm)	Diameter (μm)		
		10%	50%	90%
MP	27.32	2.04	20.91	69.19
M/GP	13.64	1.48	9.78	31.64
Composite	15.67	1.72	13.26	32.68

obtained composite materials. Several clusters were verified in the cement/aggregate-residue interfaces. Fig. 4 shows the micrographs for the composite formulations with marble/granite and marble residues, increased 500 times.

In relation to the formulation with marble/granite powder it was possible to realize that the material had a very varied granulometry, which contributed to a better packaging of the composite, with an increase in mechanical strength. It was possible to observe a variety of grains of dimensions above 100 μm and with dimensions close to 1.0 μm. The variation in grain size was quite visible in the image, being expected due to the variety of residues applied.

The micrograph of the formulation with pure marble confirmed the differences of the transition zones between the matrix and the aggregate residues and the presence of larger voids. It was observed that the sample with marble/granite addition was more compact than the one with only marble residues, which was the most agglomerated.

In the micrographs the presence of the EPS grains mixed with the other constituent elements of the composite and the marble and sand grains aggregated to the cement matrix, as shown in the micrographs of Fig. 5, was clear.

3.4. Bulk density

Table 3 shows the results of the bulk density tests of the composite. The bulk density of the composite, for the two used residues, is slightly higher when compared to clay bricks (1.80 g/cm^3) and lower when compared to concrete (2.20 g/cm^3) [12]. The reason for the low bulk density of the composite is the shredded EPS in its composition. The reduction of around 15% in the mass of the composite makes it easier to transport and also for the laying of the produced blocks that use this type of material.

3.5. Compressive strength

Table 4 shows the compressive strength test results for the composite formulations and for the standard formulation used for the construction of houses.

The compressive strength for the formulation that used residues of marble powder and crushed EPS is about 3.7 MPa, a value that was slightly higher than the established by the standard of structural masonry, which is around 3.5 MPa (NBR 6136). Therefore, this formulation can be used for the two masonry types (sealing and structural). In addition, it creates a higher thermal resistance because of the presence of EPS.

The compressive strength for the formulation that used residues of marble/granite powder and crushed EPS was in a lower limit than the established by the standard of structural masonry (around 3.5 MPa).

3.6. Thermal conductivity

Table 5 shows the results of the average thermal conductivity of the composite. The measurements were performed in five different points from a sample of the composite.

The average thermal conductivity of the formulation that used residues of marble powder was 32.3% higher than the value for the formulation that used residues of marble/granite powder. The thermal conductivity of pure marble powder and of marble/granite powder were also measured, corresponding to 0.180 W/m K and 0.307 W/m K.

The thermal conductivity of the other elements that compose the composite were also measured and their values were 0.30 W/m. K (cement), 0.40 W/m. K (gypsum), 0.33 W/m. K (sand) and 0.025 W/m. K (crushed EPS).

Comparing such results with the values for the construction materials typically used, such as bricks and concrete blocks, the thermal conductivity of the composite in the selected formulation was very low. The thermal comfort provided by the composite blocks is other result that favors its use for the proposed end [22,28,36–39].

3.7. Water absorption

Table 6 shows the test results for of the water absorption percentage of the composite.

The formulation that used residues of marble powder showed a lesser percentage of water absorption. The NBR 7171 standard determines that the water absorption for seal blocks in structural tests of ceramic concrete shall be lower than 22%.

The results obtained from the tested formulations were slightly higher, but this does not make it impossible the use of the manufactured blocks for its designed purpose. The built rooms are almost two years old and there are no signs of visible water absorption degradations in the walls.

3.8. Thermal resistance

Table 7 shows the thermal resistance test results performed on the walls of the built rooms with open doors and windows.

Taking an average of the internal and external temperatures of both walls of the rooms that were exposed to radiation, it was noticed that the room with PET bottles had the most thermal resistance, which supposedly should provide a larger thermal comfort.

No significant variations were detected in relation to the ambient temperature of the interior of each room. The room that was constructed with the traditional eight holes bricks showed a 2.5% higher internal temperature, corresponding to 0.8 °C.

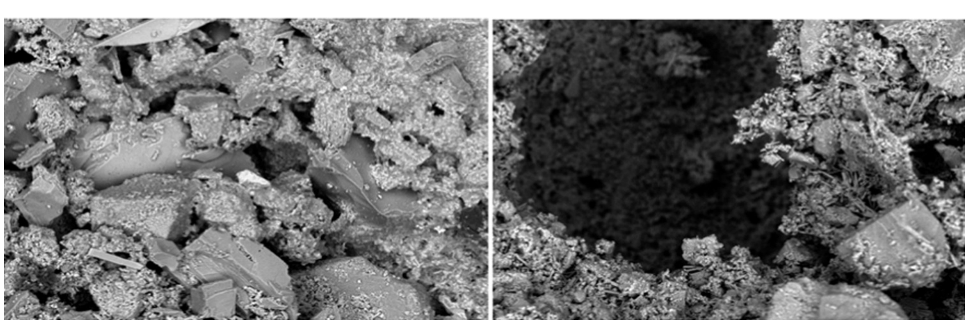

Fig. 4. SEM micrographs of the formulations with pure marble and marble/granite powder.

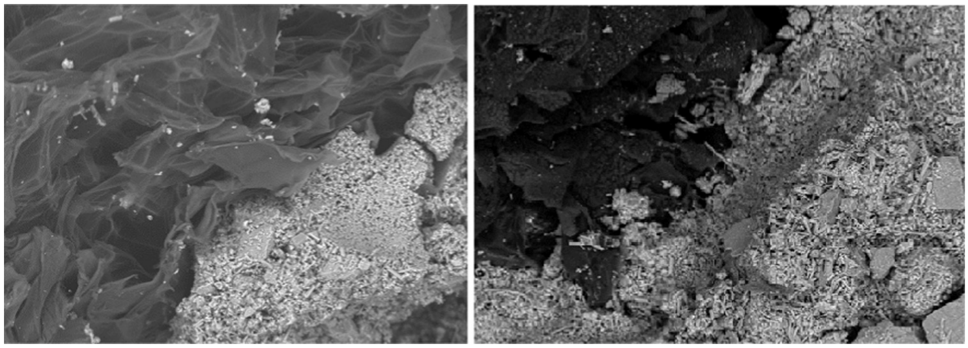

Fig. 5. Micrographs of the formulation with marble/granite powder.

Table 3
Bulk density of the two composite formulations.

Temperature (°C)	MP (g/cm^3)	M/GP (g/cm^3)
25.5	1.748	1.842
25.5	1.940	1.962
25.5	1.967	1.953
25.5	1.894	1.906
25.5	1.872	1.880
Average	**1.880**	**1.900**

Table 4
Results of the compressive strength test.

Formulation	RC (MPa) 7 Days	RC (MPa) 14 Days	RC (MPa) 28 Days
1C+1G + 3S	4.93	6.09	7.71
1C+1G+1S+1MP+2S	1.61	2.20	3.70
1C+1GYP+1STY+1M/GP+2S	1.77	2.34	3.52

Table 5
Thermal conductivity test results for the composite formulations.

Sample	Point 1	Point 2	Point 3	Point 4	PTO 5	K_A (W/m K)
M/GP1	0.339	0.330	0.346	0.325	0.326	0.333
M/GP2	0.347	0.334	0.352	0.351	0.357	0.348
M/GP3	0.352	0.341	0.361	0.355	0.364	0.355
$\mathbf{K_{Average}}$						**0.344**
RMP 1	0.455	0.468	0.491	0.413	0.425	0.450
RMP2	0.493	0.438	0.469	0.480	0.469	0.470
RMP3	0.444	0.458	0.442	0.435	0.457	0.447
$\mathbf{K_{Average}}$						**0.455**

Table 6
Water absorption test results of the composite formulations.

Sample	Dry mass (g)	Wet mass (g)	Water absorption (%)
MP	280.05	345.05	**25.03**
	261.91	329.64	
	257.16	324.47	
Average	**266.37**	**333.05**	
MGP	276.01	350.71	**28.24**
	264.49	339.90	
	256.23	331.17	
Average	**265.57**	**340.59**	

All of the rooms presented a similar behavior and it is not affirmed that the rooms built with the blocks could have had offered a higher thermal resistance than the conventional built rooms [38,39].

Despite of the similar behavior it was noticed that the better thermal sensation was provided by the blocks with PET bottles fillment. This fact represents a positive ecological factor, because of the use of numerous PET bottles. Thus, this system would result in finding use for PET waste that would otherwise become burden to the environment.

It should be emphasized that the produced blocks has an advantage of not needing plaster, which lowers the cost of construction labor. Furthermore, the construction time is smaller, in accordance to the block area. It shall also be emphasized that, for a new construction, the length of the blocks shall be reduced to allow more agility in the constructive process.

Table 7
Thermal resistance test results of the room walls.

Room	$T_{internal\ wall}$ (°C)	$T_{external\ wall}$ (°C)	ΔT (°C)	$T_{internal\ room}$ (°C)
1	34.3	40.2	6.9	30.5
2	34.7	42.4	7.7	30.8
3	35.0	41.6	6.6	30.5
4	33.5	40.6	7.1	30.6

3.9. Acoustic resistance

Table 8 shows the results of the amount of decibels and the sound fraction that is absorbed in the acoustic tests on the walls of the built rooms.

With regard to the acoustic tests, the walls with higher capacity of absorption were from room 1, with a value of 30.7%. Rooms 2 and 4 had a decrease of acoustic absorption capacity of 22.5% and room 3 a value of 19%.

In relation to the frequency level, there was similar behavior for all rooms with higher absorption to the high frequencies, which is more than 1000 Hz. Room 1 exhibited an average absorption of 31.2% in the low and medium frequency ranges and 30.2% in the high frequency, being more efficient in terms of acoustic absorption. The highest acoustic absorption capacity was registered in the walls of room 1 for the frequency of 100 Hz.

Despite the fact that the levels of absorption were higher than the ones for the conventional bricks, they were below the minimum level relative to a material with an acoustic isolated capacity, around 45% [22,24,25].

Table 8
Acoustic resistance tests on the room walls.

Rooms	$\mathbf{DB_{absorbed}}$	$\mathbf{F_{sound\ absorbed}}$ **(%)**
1	21.33	30.67
2	16.24	23.78
3	18.07	24.89
4	16.89	23.78

Table 9
Summary of the studied composite material properties.

Property	MP composite	MGP composite
Mechanical resistance (MPA)	3.70	3.52
Thermal conductivity (W/m K)	0.455	0.344
Thermal capacity (MJ/m^3 K)	1.53	1.37
Bulk density (g/cm^3)	1.88	1.90
Water absorption (%)	25.03	28.24
Thermal transmittance (W/m^2 K)	2.169	2.564
Thermal delay (h)	9.00	8.52
Solar factor (%)	1.73	2.05
Acoustic absorption (%)	30.7	24.9
ΔTmax (°C)	10.0	10.9
Diffusivity (mm^2/s)	0.29	0.25

Table 9 shows a summary of the studied composite material properties.

4. Conclusions and suggestions

- The proposed composite block was viable for use in residential construction.
- All the tested formulations showed a lower mechanical resistance compared with traditional formulations used for the construction of blocks for structures.
- The formulation for the best combination among mechanical and thermal resistance was 1C+1G+2S+1STY+1M/GP, which was chosen for the manufacturing of the blocks.
- The rooms that were built with composite blocks had an identical behavior in relation to the thermal resistance and an equivalent thermal comfort.
- Room 3, built with blocks containing PET bottles, presented a better thermal sensation, which allows to assume that it would provide more thermal comfort.
- The walls with highest capacity of acoustic absorption were from room 1, which has the blocks built with the pure marble powder composite.
- Reduce the length of the block by half to ensure a greater stability in the settlement process and also to make the transportation easier.

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