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# Textile waste as an alternative thermal insulation building material solution

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## HIGHLIGHTS

- Study of a new sustainable building material.
- Textile wastes reuse.
- Innovative sustainable solutions for non-structural applications (thermal insulation).

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## ABSTRACT

The adoption of more sustainable behaviors, particularly in what concerns to the reduction of energy consumption and the emissions of greenhouse gases, is nowadays a priority. The construction sector is one of the key areas of intervention, which carries a high consumption of resources such as materials, energy, and water. Thus, it is essential to adopt more efficient actions during all stages of the construction process, including the use of more sustainable materials. The reuse of different types of waste in the construction or rehabilitation of buildings can contribute significantly to sustainability.

In this research work, the potential applicability of woven fabric waste (WFW) and a waste of this residue, named woven fabric subwaste (WFS), as thermal insulation building material was studied. Experimental work was conducted using an external double wall, with the air-box filled with these two types of waste, to determine their thermal characteristics. Two heat flowmeters and four surface temperatures sensors were placed on the wall surface to determine the thermal conductivity of the wastes.

The obtained results show that the application of the WFW and WFS in the external double wall increases its thermal behavior in 56% and 30%, respectively.

The thermal conductivity value of the WFW is similar to the values obtain for expanded polystyrene (EPS), extruded polystyrene (XPS) and mineral wool (MW). The value of this parameter for the WFS is approximately equal to the values for granules of clay, vermiculite or expanded perlite. Therefore, applying these wastes as a possible thermal insulation material seems to be an adequate solution. Environmental, sustainable and economical advantages may result from this practice.

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## 1. Introduction

The high energy consumption, the climate changes and the scarcity of natural resources require a human behavior more ruled by sustainable criteria to ensure the living of modern society and guarantee the future of the coming generations.

Taking into account that the construction sector carries out a high consumption of resources such as materials, energy, and water, it is imperative the use of more sustainable construction solutions.

The integration of ancient construction techniques and the reuse of materials and waste can contribute significantly to sustainability. The adaptation of construction techniques of the past to the current constructions has been made at various levels, particularly in what concerns to the use of earth and renewable energy sources such as solar energy. Work has been developed in order to recover the use of earth as a building material, namely as adobe, taipa and tabique [1–3]. The use of solar energy is also an important way to turn buildings more sustainable and more energy efficient. The use

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of passive solar systems was a technique commonly used in the past which has been lost a long time due to the emergence of new materials and technologies. However, recent studies show that their integration in the building envelope improves its thermal performance and increases its level of sustainability [4–7].

In addition to these techniques, the reuse of materials is also an area of great interest and with potential application due to the high amount of waste that is produced around the world in the most varied activities. So, it is important to analyze the reuse of materials and different types of waste in buildings construction [8–10]. Their integration can be carried out as thermal or acoustic insulation, structural reinforcement, or as coating and finishing material, among others. Different materials and waste with different origins have been studied. Research has been developed to study the potential application of natural material as thermal insulation [11–15] and of industrial and agricultural solid waste as a raw material to obtain lightweight bricks [16] or as concrete and soil reinforcement [17,18].

Textile waste integrates the group of reusable materials that can be included in the building construction and which have different possibilities of application. These textile wastes may have origin in the textile industry or may simply result from clothes that are no longer used. The study of the performance of these types of wastes in the construction should be partly based on the behavior of the tissues when they are used as clothing. The primary function of clothing is to protect the human body from cold and heat, in order to keep thermal comfort conditions. This can be acquired ensuring an appropriate heat transfer between the human body and the outside environment. In this regard, studies to analyze the phenomena of heat transfer through the textile fabrics have been developed. These studies show that their thermal insulation properties are highly related to the properties and configuration of their components, namely to the capillary structure, surface characteristics of yarns and air volume distribution in the fabrics [19–21].

Thus, the knowledge of thermal, mechanical and physical performance of various types of textile fabrics and their residues is essential to optimize its use as a raw material in the building construction.

Different textiles fibers are analyzed as a material to produce lightweight concrete, as reinforcement of cement mortars elements [17,22–24], or as fibrous insulation materials [25–27].

However, regarding the use of textile waste, further investigation is needed. The work developed so far is based essentially on the use of textile waste in the production of bricks and lightweight materials [28–31], more particularly using cotton combined with other materials, such as limestone powder, fly ash, barite, and paper. Sound insulation, thermal conductivity, bending strength and radioactivity are some of the properties studied.

In order to contribute to the scientific knowledge in this area, research work has been developed to study the use of woven fabric waste (WFW) and a waste of this residue, named woven fabric subwaste (WFS), as an alternative solution to commercial insulation materials, such as extruded polystyrene (XPS) or expanded polystyrene (EPS) products.

Experimental work was carried out to examine the influence of introducing each one of these textile wastes in the thermal performance of a external double wall. The heat transmission coefficient ($U$) of the double wall with the air box filled with these types of waste was determined. These results were used to calculate the value of thermal conductivity of WFW and WFS.

This paper is structured as follows: firstly, the textile waste is briefly put into context; secondly, the adopted methodology and the experimental setup are presented. Also, the equipment and the external double masonry wall model are described in detail; thirdly, the obtained experimental results are analyzed and discussed. The thermal transmission coefficient of the two studied technological solutions and the thermal conductivity of the two analyzed textile waste types are quantified and delivered; finally, the main conclusions of this research work are drawn.

## 2. Textile waste context

In the European Union (EU), around 5.8 million tonnes of textiles are discarded by the consumers per year. Only 1.5 million tonnes (25%) of these textiles are recycled by charities and industrial enterprises. The remaining 4.3 million tonnes goes to landfill or to municipal waste incinerators [32]. Adding to this type of waste, there is also the textile waste from the textile industry. This shows that there is a enormous source of secondary raw material that is not used, but can be re-injected into the market.

Thus, environmental concerns with the waste resulting from the textile industry have been increasing. This issue has been addressed by the European policies in order to define laws to regulate the management of waste.

In order to encourage recycling in the EU, the Directive 2008/98/EC [33] has been published on December 2008, as a recast of the Waste Framework Directive (WFD), Directive 2006/12/EC [34].

In Portugal, the main textile waste become from wool, cotton and synthetic and artificial fibers, according to the Technical Guide of the Textile Sector [35]. In 2009, 293,000 tonnes of textile waste were produced, according to National Plan for Waste Management [36].

After visiting several textile factories laboring in the north part of Portugal, it was found that there is a substantial amount of waste resulting from this industry.

Clothes, woven fabrics and threads are among the most common types of waste. Composition, texture and size are some material properties which may vary sharply as far as textile waste is concerned. Cotton, wool, linen, silk and acrylic are some possible composition of a textile product. On the other hand, the structure, the thickness and the arrangement of the threads are some parameters that contribute for the possible different textures that a textile fabric may have. For instance, taking into account that a textile waste results from the clothing process, in which there is an optimization of the fabric piece preparation, waste with different size and shape will result from this process. Therefore, the different properties of the materials may increase the difficulty of studying possible textile waste applications. Considering that a mixture of these materials is also very likely to occur then this complexity is even more evident.

The two types of textile waste studied in this research work, WFW and WFS, are presented in Fig. 1a and b, respectively.

Both materials are 100% acrylic. The density of the WFW and the WFS products was specifically quantified in this research work and the respective approximate values are 440 kg/m$^3$ and 122.5 kg/m$^3$, respectively.

In the building industry application context, the potential of using these two types of textile waste as an alternative thermal insulation solution for external double walls is emphasized in the following sections.

## 3. Methodological strategy and experimental setup

The methodology used to analyze the thermal insulation potential of the two textile waste types considered in this research was based on experimental work according to ISO 9869 entitled *Thermal Insulation: Building Elements – In Situ Measurement of Thermal Resistance and Thermal Transmittance* [37].

In order to apply this methodology to WFW and WFS to determine their thermal conductivity, an external double wall model was built. This wall was specifically built up in a test room, having as basis an existing simple external wall, composed by a cement based brick masonry wall with cement based coating mortar in both sides, southwest oriented. The chosen orientation was related to the existing



(a) WFW - Woven fabric waste (b) WFS - Woven fabric subwaste

**Fig. 1.** Textile waste types studied.

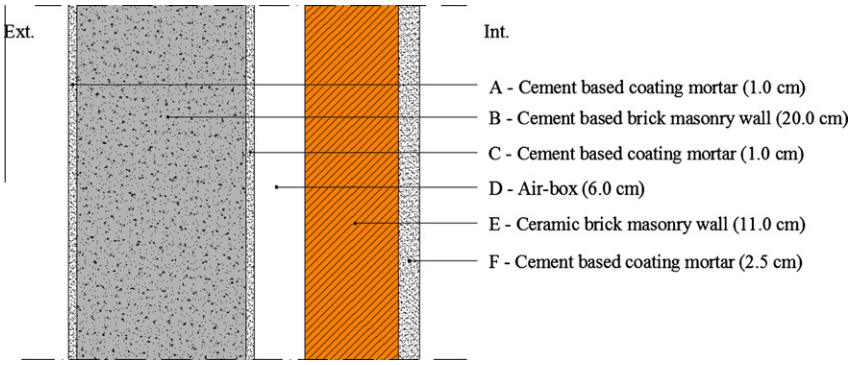



**Fig. 2.** External double masonry wall model.

facades on the test room. No particular orientation is necessary to apply the methodology referred above. The dimensions of the wall were constrained by the dimensions of the existing wall and by the need of filling the air box with the textile waste. The dimensions of the test wall are 1.60 m × 1.20 m × 0.42 m (width × height × thickness). This wall is composed by six layers, Fig. 2, which are, from the outside to the inside: 1.0 cm cement based coating mortar (*A*), 20.0 cm cement based brick masonry wall (*B*), 1.0 cm cement based coating mortar (*C*), 6.0 cm air box (*D*), 11.0 cm ceramic brick masonry wall (*E*) and 2.5 cm cement based coating mortar (*F*). The interior cement based coating mortar of the external masonry wall layer (*C*) is not a common building practice but it is justified by the fact that it already exists in the test room. In fact, only layers *D*, *E* and *F* were specifically created for this purpose.

The thermal characteristics of the materials of the different layers, according to Santos and Matias [38] are presented in Table 1.

Basically, the experimental analysis consisted on monitoring continuously the thermal performance of the wall model, reinforced with WFW and WFS, respectively. Thus, the air box was completely filled up with the two materials completely dried, separately, resulting in two building systems which are designated as external double wall model system types I and II.

**Table 1**
Thermal characteristics of the wall materials [38].

| Layers of the double wall | Thermal conductivity $\lambda$ (W/m °C) | Thermal resistance $R$ (m$^2$ °C/W) |
|---|---|---|
| Cement based coating mortar (*A*, *C*, *F*) | 1.3 | |
| Cement based brick (*B*) | | 0.30 |
| Air-box (*C*) | | 0.18 |
| Ceramic brick (*E*) | | 0.27 |
| Superficial exterior thermal resistance ($R_{se}$) | | 0.04 |
| Superficial interior thermal resistance ($R_{si}$) | | 0.13 |

The test room is a thermally controlled room which has been successfully used in previous work [9,12] as an expedite alternative of a thermal test cell. In Fig. 3a this room, and the wall model, which was placed in the southwest orientated façade, are shown schematically. An approximately constant interior temperature was guaranteed by using a domestic heater in the room which was continuously switched on during the test performance. The top and the left side of the wall model were carefully thermally insulated, applying several layers of XPS complemented by a polyurethane foam sealing.

According to ISO 9869 [37], the apparatus that should be used is composed by two heat flowmeters (1, Fig. 3b), four surface temperature sensors (2, Fig. 3b), two ambient temperature sensors, data logger and a computer. Both heat flowmeters and surface temperature sensors were fixed in the middle of the inner face of the wall. The interior and the exterior temperatures ($Ti(n)$ and $Te(n)$) were measured using thermo hygrometric equipments kept indoors and outdoors, respectively. The humidity sensor was not used because the humidity values do not interfere in the calculation.

According to the international standard, the thermal transmission coefficient ($U$) of a material or a building system can be quantified applying Expression (1).

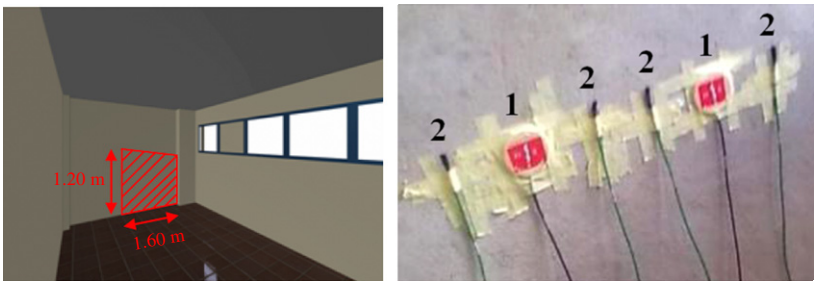
$$U(ntotal) = \frac{\sum_{n=1}^{ntotal} q(n)}{\sum_{n=1}^{ntotal} (Ti(n) - Te(n))} \quad (1)$$

in which $q(n)$ is the heat flow across the wall model in the moment $n$; $Ti(n)$ and $Te(n)$ are the interior and the exterior temperatures in the moment $n$, respectively; $ntotal$ is the total number of moments is which the data was collected.

Taking into account that two heat flowmeters were used corresponding to $q1(n)$ and $q2(n)$, it is possible to estimate two thermal transmission coefficients, $U1(ntotal)$ and $U2(ntotal)$, which are the thermal transmission coefficients related to the data registered by the heat flowmeters 1 and 2, respectively, by applying Expression (1). Thus, the thermal transmission coefficient of the wall model ($U'(ntotal)$) is the average value of $U1(ntotal)$ and $U2(ntotal)$ according to the following expression:

$$U'(ntotal) = \frac{U1(ntotal) + U2(ntotal)}{2} \quad (2)$$

Furthermore, the thermal transmission coefficient of a building system such as an external double masonry wall can also be quantified by applying the following expression:




(a) The room and the wall (b) Thermal test

**Fig. 3.** Thermally controlled room and thermal test under progress.

$$U = \frac{1}{R_{si} + \sum_{j=1}^{m} \frac{d_j}{\lambda_j} + R_{se}} \quad (3)$$

in which $U$ is the thermal transmission coefficient of a building system (e.g. wall model); $d$ is the thickness of the layer $j$; $\lambda$ is the thermal conductivity of the material of the layer $j$; $R_{si}$ and $R_{se}$ are the superficial interior and exterior thermal resistances, respectively; $m$ is the number of layers of the building system.

Therefore, knowing the thermal transmission coefficient of the external double wall model system types I and II, *UI* and *UII*, (by applying the achieved experimental data in Expressions (1) and (2)), $R_{si}$, $R_{se}$, $d_A$, $d_B$, $d_C$, $d_D$, $d_E$, $d_F$, $\lambda_A$, $\lambda_B$, $\lambda_C$, $\lambda_D$, $\lambda_E$ and $\lambda_F$, it is possible to estimate the thermal conductivity of the woven fabric waste ($\lambda_{WFW}$) and of the woven fabric subwaste ($\lambda_{WFS}$) by applying Expression (3).

According to the standard [37], a minimum of 3 days test is needed if the temperature is stable around the heat flowmeters. Otherwise this duration may be more than 7 days.

In this case, the temperatures ($Ti(n)$ and $Te(n)$) and the heat flow across the wall model ($q1(n)$ and $q2(n)$) were measured continuously (in-between 10 min intervals ($n$)) by the two heat flowmeters (1 and 2), during 10 and 12 consecutive days for the external double wall model system types I and II, respectively. These thermal tests were conducted in November 2011 and January 2012.

## 4. Experimental results and discussion

The obtained experimental data is presented graphically in Figs. 4 and 5 for the external double wall model system types I and II, respectively. In Table 2 the average (Av.), the maximum (Max.) and the minimum (Min.) values occurred for the thermal variables $Ti(n)$, $Te(n)$, $q1(n)$ and $q2(n)$ are identified for the wall model system types considered in this research work.

Through the analysis of the graphs in Figs. 4 and 5, and of Table 2, it is possible to verify that the values of the interior temperature in general are stable and higher than the exterior temperature. This was due to the use of a heater inside the test room. The thermal gradient between interior and exterior temperatures ($\Delta T$) achieved during the tests is adequate to apply the methodology already presented. These thermal conditions provided the occurrence of a desirable continuous heat flow across the wall model, always from the inside to the outside, which is necessary to evaluate the thermal

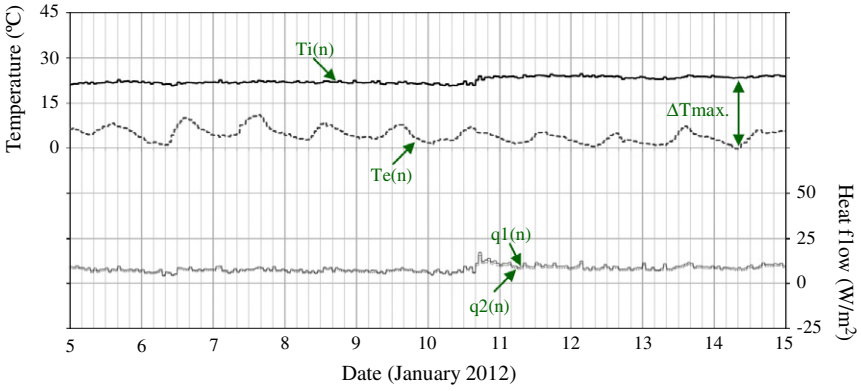



**Fig. 4.** Temperatures and heat flow of the external double wall model system type I.

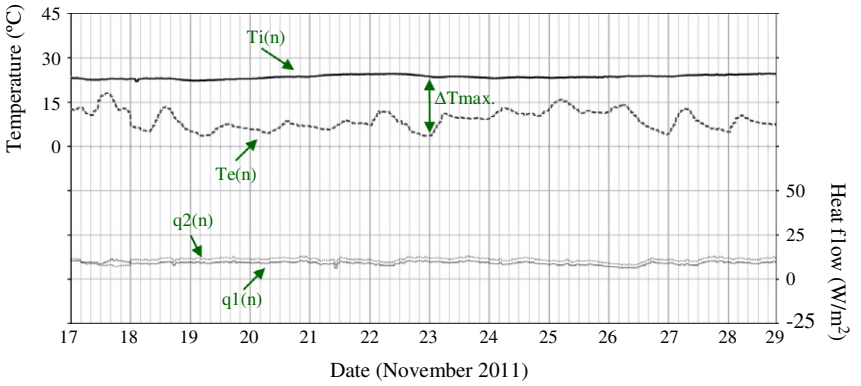



**Fig. 5.** Temperatures and heat flow of the external double wall model system type II.

**Table 2**
Summarized results of temperature and heat flow of both systems.

| Thermal variables | System type I | | | System type II | | |
|---|---|---|---|---|---|---|
| | Av. | Max. | Min. | Av. | Max. | Min. |
| $Ti(n)$ (°C) | 22.78 | 27.40 | 19.50 | 23.67 | 25.40 | 22.10 |
| $Te(n)$ (°C) | 4.50 | 11.20 | 0.70 | 9.07 | 18.30 | 3.20 |
| $q1(n)$ (W/m$^2$) | 8.64 | 23.38 | 3.04 | 9.15 | 14.33 | 1.62 |
| $q2(n)$ (W/m$^2$) | 7.77 | 21.63 | 2.52 | 11.00 | 16.50 | 3.66 |

**Table 3**
Quantified thermal transmission coefficients and thermal conductivities.

| $U_I'$ (W/m$^2$ °C) | $U_I'$ (W/m$^2$ °C) | $\lambda_{WFW}$ (W/m °C) | $\lambda_{WFS}$ (W/m °C) |
|---|---|---|---|
| 0.464 | 0.736 | 0.044 | 0.103 |

**Table 4**
Thermal conductivities of thermal insulation materials [38].

| Thermal insulation materials | Thermal conductivity, $\lambda$ (W/m °C) |
|---|---|
| Molded expanded polystyrene (EPS) | 0.037–0.055 |
| Extruded expanded polystyrene (XPS) | 0.037 |
| Mineral wool (MW) | 0.040–0.045 |
| Granules of clay, vermiculite or expanded perlite | 0.060–0.160 |

insulation performance of the analyzed building system. The values of the heat flow, $q1(n)$ and $q2(n)$, in both systems, are approximately the same, which allows to obtain values of the thermal transmission coefficient ($U$) more reliable.

The data obtain through the experimental test and registered by the heat flowmeters 1 and 2 were introduced in Expression (1) in order to obtain $U1(ntotal)$ and $U2(ntotal)$ for the walls systems type I and type II. Using Expression (2), the values of $U_I'$ and $U_{II}'$ were obtain and applying Expression (3) the values of the thermal conductivity ($\lambda$) for the WFW and for the WFS were determined, as shown in Table 3.

The Expression (3) was also applied to calculate de value of the thermal transmission coefficient of the external double wall with the air-box empty, $U_{empty\ air\text{-}box}$, which thermal parameters are indicated in Table 1. The $U_{empty\ air\text{-}box}$ value is equal to 1.048 W/m$^2$ °C.

Comparing the values of $U_I'$, $U_{II}'$ and $U_{empty\ air\text{-}box}$ it is possible to conclude that the application of the two types of waste improve the thermal behavior of the external double wall, in 56% and 30%, respectively.

These results show that WFW has a better thermal insulation capacity than the WFS (i.e. 0.044 W/m °C against 0.103 W/m °C). The thermal insulation capacity of the double external wall model system type I is 63% higher than system type II. Despite the fact that both analyzed textile wastes showed thermal insulation ability, it may be concluded that the WFW may be more interesting from a building thermal insulation perspective. The values of the thermal conductivities of different thermal insulation materials shown in Table 4 corroborate this conclusion. The value of $\lambda_{WFW}$ is similar to the $\lambda$ values of EPS, XPS and MW and the value of $\lambda_{WFS}$ is approximated to the $\lambda$ values of granules of clay, vermiculite or expanded perlite.

## 5. Conclusions

The research work presented in this paper was focused on the analysis of the thermal insulation benefit resulting from reinforcing thermally external double walls with woven fabric waste (WFW) and woven fabric subwaste (WFS) in the air-box. The experimental work showed that feeling the air-box with WFW and WFS increase the thermal resistance of the wall in 56% and 30%, respectively, when compared to the double wall with the air-box empty. This results leads to the conclusion that the WFW has better insulation characteristics than the WFS. The value of the thermal conductivity ($\lambda$) of the WFW is similar to the values of the well known thermal insulation materials XPS, EPS and MW. The value of $\lambda$ obtain for the WFS is a bit higher than the ones obtain for the other materials referred above. Even so, this can be considered as an insulation material with similar characteristics to the granules of clay, vermiculite or expanded perlite.

However, more research work is needed in order to define a commercial product that can be introduced in the air-box of double walls. This product should be similar to a quilt filled with these wastes in order to be fixed to the wall. Further research is required in this field in order to validate the obtain results.

In what concerns to the costs associated to the application of this materials in buildings, only after defining and studying a possible commercial product, this analysis can be done.

Other properties of these materials, such as compression resistance, water, water vapor, fire behavior, and sound insulation, should be studied.

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