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Textile Subwaste as a Thermal Insulation Building Material

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Abstract. This research work is focused on analyzing the potential application of textile subwaste as an alternative building thermal insulation material for double external walls, and in a sustainable perspective. The studied textile subwaste results from the mattress industry and it was briefly characterized as a material. Taking into account that it is necessary to achieve the thermal insulation performance of the proposed technological building solution an alternative expedite experimental setup is also proposed here. It was concluded that using the textile subwaste, a double external wall's thermal insulation performance may be increased in 33%.

Keywords: textile waste, thermal insulation product, thermal transmission coefficient, sustainability

1. Introduction

The continuous search for better sustainable and economic processed solutions has been the centre of the attention of a broad research community worldwide. The resulting solutions can therefore be adapted by the industry thus leading to a more sustainable society. The building industry is not immune to this reality and huge efforts have been done in order to find alternative sustainable building materials and low technology methods which result in a more sustainable and affordable construction complemented with the comfort standards required nowadays. CO_2 emissions to the atmosphere, energy and water consumptions are some parameters that have significant impact in this equation. Reusing, opting for green building materials (which must be renewable, local, and abundant), retrofitting, choosing low technology methods and techniques are some practices that have given good results in this context. The main objective of this research work is to analyze the potential of using textile subwaste which is produced by the mattress industry in building applications and as a thermal insulation material. A substantial economic and sustainable benefit may be achieved through this proposed technological solution. This research was focused on studying this solution in external double walls which generally requires thermal insulation materials applications to meet the required thermal performance prescribed in the current applied codes. In the Portuguese context, the most current applied building thermal insulation materials for this purpose are extruded polystyrene (XPS) and expanded polystyrene (EPS). Expanded cork granulated panel, expanded clay, polyurethane foam and mineral wools are also commonly applied thermal insulation products in the building industry. Several authors [1-2] have already proposed using different agricultural product wastes such as bagasse, cereal, straw, corn stalk, corn cob, cotton stalks, kenaf, rice husks, rice, straw, sunflower hulls and stalks, banana stalks, coconut coir, bamboo, durian peel, oil palm leaves among others for product processing such as particleboard, hardboard and fiber board, and focusing on their thermal insulation ability. Other authors have been studying the

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technical potential of using other types of residue such as newspaper, honeycomb or polymeric wastes in the processing of different building components. There are already building thermal insulation products based on textile waste of wool thread [3]. This paper is structured as follows: firstly, the textile subwaste resulting from the mattress industry is briefly introduced; secondly, the proposed alternative expedite experimental setup is presented in which the inherent facility, the equipment and the sample preparation are described in detail; thirdly, the obtained experimental results are presented, analyzed and discussed, and the thermal transmission coefficient of the two studied technological solutions are quantified; finally, the main conclusions of this research work are drawn.

2. Textile Subwaste

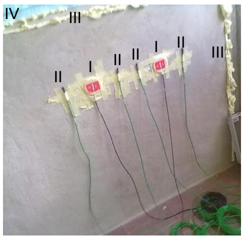
In the north of Portugal, in particular, in the Douro Litoral region, the textile industry is strongly implemented. The waste resulting from the textile industry (e.g. tissue or thread) may be used in other industries resulting in economic and sustainable benefits. For instance, in this region, this type of waste has been applied in the mattress and the car industries. Figure 1.a shows examples of a tissue textile waste. Meanwhile, Figure 1.b shows a textile subwaste which results from the mattress industry. As it was stated earlier, the main goal of this paper consists in studying the potential of the application of this subwaste in the building industry as a thermal insulation building material for double external walls. The composition of this subwaste depends on the composition of the thread which may be wool, cotton, acrylic among other types. In this case, the subwaste is mainly acrylic and the particles have a diameter between 8 and 15 μm (Figure 1.c).

a) Tissue waste b) Tissue subwaste c) Microstructure of the tissue subwaste

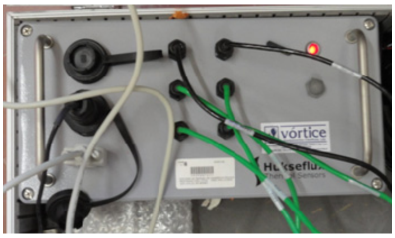
Fig. 1: Textile wastes and the microstructure of the textile subwaste

3. Experimental Setup

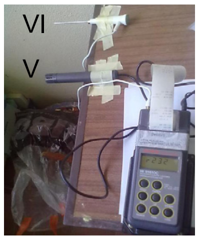
In order to evaluate the thermal properties (e.g. the thermal transmission coefficient, U, or the thermal conductivity, λ) of materials or building component systems, a thermal test cell which is a laboratory device is currently applied. In this research work, an alternative experimental procedure based in [2] was applied which may also be used in situ and may easily allow the evaluation of thermal properties of real scale building component systems such as a double external wall. The facilities, the equipment and the sample preparation are crucial for the success of this proposed experimental setup. A confined room sized 4.00 m × 3.00 m × 2.54 m (length × width × height) was used as and alternative expedite solution of a thermal test cell. An interior ceramic brick wall, sized 1.60 m × 1.20 m × 0.11 m (length × height × thickness), was built up 6 cm apart of an existing external cement based brick wall in the confined room. The existing external wall with the new added interior wall and with the air-box of 6 cm results in the double external wall sample model which is proposed in this research work. A heat transfer system was adopted, as well as two thermo hygrometric devices and a domestic heater device as the main equipments of the proposed experimental procedure in order to evaluate the thermal performance of the double external wall with and without the textile subwaste thermal insulation material. The heat transfer system is formed by two heat flux measurement sensors (I, Figure 2.a), four superficial temperature sensors (II, Figure 2.a), a datalogger (Figure 2.b) and a computer. The heat flux measurement sensors allow measuring the heat flow across a building component. A heat flow occurs when there is a significant thermal gradient between the two surfaces of a building component (i.e. indoor and outdoor surfaces). In this case, this gradient results from the existing thermal gradient between indoor and outdoor temperatures. The superficial temperature sensors were used as a complement and as reference of the heat flux measurement sensors and in order to evaluate the inner surface temperature of the double external wall sample model. Two superficial temperature sensors by heat flux measurement sensor were used and as Figure 2.a shows. Meanwhile, Figure 2.c shows the adopted thermo hygrometric device which includes a temperature (V, Figure 2.c) sensor and a relative humidity (VI, Figure 2.c) sensor. Two thermo hygrometric devices were used, one indoor and the other outdoor.



a) Heat flux measurement (I) and superficial temperature sensors (II). Polyurethane foam (III) and XPS (IV)



b) Datalogger



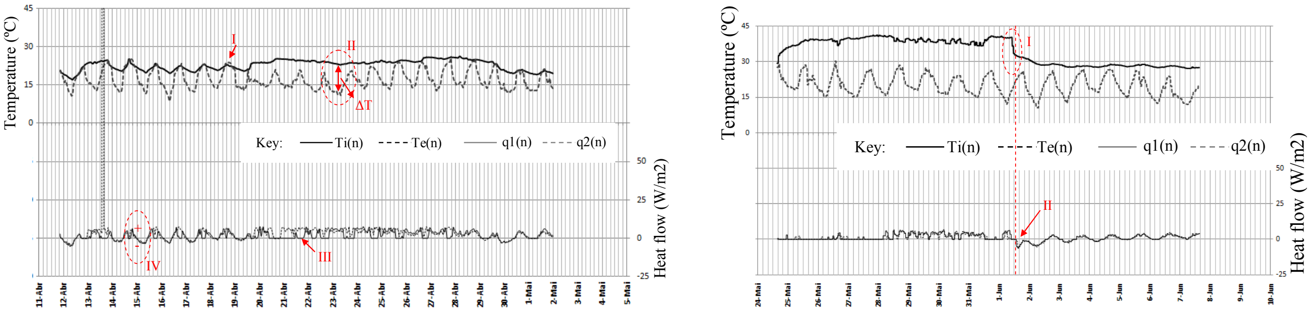
c) Thermo hygrometric device. Temperature (V) and relative humidity (VI) sensors

Fig. 2: Equipment and some materials

The left hand side limit of the sample was insulated by using layers of XPS panel. The connection between XPS and the wall was achieved by using polyurethane foam (e.g. detail III, Figure 2.a). The next experimental procedure consisted of filling completely the air-box of the wall with the textile subwaste followed by insulating the top of the wall sample with layers of XPS panel (e.g. IV, Figure 2.a). Polyurethane foam was also used to connect the layers of XPS with the top limit of the double external wall sample. All these experimental procedures have to be done carefully in order to avoid any possible insulation voids, thermal bridges, uninsulated headers and other faults which may compromise the feasibility of the final experimental results. According to [4], the test duration is related to the thermal inertia of the building component under study. For a high thermal inertia building component a minimum of fourteen days test duration is recommended. On the other hand, for a low thermal inertia building element a minimum of seventy two hours (i.e. 3 days) of test duration is recommended. In this case, the analyzed double external wall was considered as having a high thermal inertia and, therefore, a minimum of fourteen days test duration was necessary. In the Portuguese context and, in particular, in the north region of this country, it is convenient to perform this test during the winter or the summer because it is easy to ensure the desirable uniform high thermal gradient between indoors and outdoors. A uniform high thermal gradient between indoors and outdoors is desirable because it is the ideal condition to allow a significant heat flow across the material or the building component. During the winter, this condition can be achieved by using a simple domestic heating device placed indoors and able to keep the room constantly warm. In contrast, during the summer, an air conditioner can keep the room constantly cool. In this case, the tests were performed from April to June of 2011 and because of the logistics of this research work. Therefore, additional care concerning the guarantee of an existing uniform high thermal gradient between indoors and outdoors was done by placing a domestic heating device in the confined test room. The option of heating up the indoor space was based on the average value of the exterior temperature occurring during the week which preceded the date of the beginning of the tests (i.e. 12th May 2011).

4. Experimental Results and Discussion

Firstly, the double external wall was tested without any thermal insulation material application in the air-box (Case I). Secondly, the external wall with textile subwaste thermal insulation material (Case II) was tested. A continuous data acquisition was carried out during the tests in which the values of the heat flow across the wall measured by the two used heat flux measurement sensors ($q1(n)$ and $q2(n)$), the interior and the exterior temperatures ($Ti(n)$ and $Te(n)$), and the relative humidity were registered in each 10 minutes timing interval (n). Figures 3.a and 3.b represent graphically the above identified registered data for Cases I and II, respectively. In Case I, Figure 3.a, it is noticed that the interior temperature of the confined test room was kept approximately uniform (average value of 23ºC) during the test. On the other hand, the exterior temperature had shown its natural and expected swing in a day time, and in that period of the year, in the north region of Portugal. However, the exterior temperature had also shown unexpected high values for that time of the year. For instance, the maximum value registered of the exterior temperature was 27ºC. Furthermore, the exterior temperature, which is not possible to control, had shown similar values of the interior temperature in different occasions. Sometimes, its value even exceeded the value of the interior temperature. On the 18th of April of 2011 (I, Figure 3.a), the registered temperatures are one example of this fact. This condition was not the adequate one to guarantee a significant heat flow across the wall. This condition may also contribute for the inexistence of a heat flow or for the heat flow swapping across the wall. The condition occurred on the 22nd of April of 2011 (II, Figure 3.a) is an example of an adequate thermal condition in which a significant high thermal gradient between indoors and outdoors is achieved (ΔT, Figure 3.a). These aspects are consequently reflected in the measured heat flows (*q1(n)* and *q2(n)*), Figure 3.a, in which it is possible to verify that moments had occurred in which the heat flow was zero (III, Figure 3.a) or negative (i.e. inversion of the way of the heat flow across the wall, "+" corresponds to the heat flow from the indoor to the outdoor and "–" corresponds to the reverse way), detail IV in Figure 3.a.



a) Case I. April (Abr) and May (Mai) of 2011

b) Case II. May (Mai) and June (Jun) of 2011

Fig. 3: Temperatures and heat flow of the double external wall model

In order to mitigate the above described undesirable testing conditions, two heating domestic devices were placed in the confined room during the test of the double external wall with the textile subwaste, Case II. Therefore, it was possible to increase the gradient of interior and exterior temperatures (ΔT) and to reduce the risk of the occurrence of the above identified undesirable test conditions. Figure 3.b confirms this fact. The exterior temperature was lower than the interior temperature. The interior temperature was approximately 35ºC. One of the heating devices had failed on the 1st of June of 2011 and this is the reason that justifies the abrupt decrease of the interior temperature occurred in that date (I, Figure 3.b). The test had progressed with only one heating device which explains the fact that the interior temperature of the confined test room had kept lower from that date. It is noticed from Figure 3.b that thermal conditions occurred during the first half period of testing (i.e. from 25th of May to 1st of June) were more adequate than the others verified during the second part (i.e. from 1st of June to 7th of June). According to [4], the thermal transmission coefficient (U) 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: *U* is the thermal transmission coefficient; *q(n)* is the heat flow across the sample in the moment *n*; *Ti(n)* and *Te(n)* is the interior and the exterior temperature in the moment *n*, respectively; *ntotal* is the total number of moments is which the data was registered.

Taking into account that two heat flux measurement sensors are used corresponding to *q1(n)* and *q2(n)*, it is possible to estimate two thermal transmission coefficients, *U1(ntotal)* and *U2(ntotal)*, by applying Expression 1. Thus, the thermal transmission coefficient of each sample (*U`(ntotal)*) can be the average value of *U1(ntotal)* and *U2(ntotal)*. Based on the above presented experimental data (Figure 3) and applying the previous expressions it is possible to estimate the thermal transmission coefficient of the double external wall sample without any thermal insulation material application (Case I - *U`(ntotal)* = 0.42 W/m$^2$ºC) and the respective coefficient for the same wall with textile subwaste thermal insulation material application (Case II- *U`(ntotal)* = 0.14 W/m^{2}ºC). These results clearly give evidence for the positive benefit in terms of thermal insulation performance by applying the proposed textile subwaste as an alternative thermal insulation material solution in double external walls. The thermal transmission coefficient of this building component decreased 33%.

5. Conclusions

An alternative building thermal insulation material is proposed in this research work which has the particularity of being an industrial waste. The textile subwaste resulting from the mattress industry is the thermal insulation material suggested and analyzed. The analyzed textile subwaste samples are mainly acrylic and their particles have a diameter between 8 μm and 15 μm. A expedite experimental setup based in [4] is also proposed to evaluate the thermal insulation performance of a double external wall sample model whose air-box was totally filled with the textile subwaste. In brief, this expedite experimental setup consists in using a confined test room able to guarantee a constant interior temperature and as an alternative solution of a thermal test cell. A heat transfer system formed by two heat flux measurement sensors, four superficial temperature sensors, a datalogger and a computer are the used equipment to measure the heat flow across the wall sample and the superficial temperature of the inner surface of the sample. In parallel, thermo hygrometric sensors placed in the interior and the exterior allow measuring the respective interior and exterior temperatures and the relative humidity. Since the building component under study was considered as having a high thermal inertia, for the test duration a minimum of 14 days was adopted. The uncontrolled exterior temperature swing, the perfect contact between the surfaces of the heating transfer sensor and the inner surface of the wall sample, and the adequate equipment calibration are some technical aspects which may affect the accuracy of the proposed experimental setup. The tests were performed from April to June of 2011 and the registered interior and exterior temperatures shown to be quite similar. This thermal condition was not adequate to guarantee a significant uniform heat flow across the wall sample. Therefore, two domestic heating devices were placed in the confined test room (Case II) instead of one (Case I), and the thermal conditions were significantly improved. It was verified that there is a 33% thermal insulation performance gain by applying textile subwaste in the air-box of the analyzed double external wall sample model. This conclusion highlights the potential of using this industrial waste in different building applications and as a thermal insulation material. It also contributes for a more economic and sustainable building industry.

6. References

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