Re-use waste for building thermal insulation : case study of loose-fill plastic waste in cold and humid climate

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Abstract

Plastic waste is a major environmental and scientific challenge of our century. The current paradigm of "waste management" must evolve towards "resource management" by identifying a highly sustainable material consuming sector. The general objective of this paper is to propose a simple, economical and efficient solution for the recovery of plastic waste for the building sector. We have experimentally evaluated the performance of a Loose-Fill Plastic Waste (LFPW) as a thermal insulation solution. For this purpose, a literature review was conducted to guide the design and conduct of an experimental study on test cells in the cold and humid climate of Reunion Island (France). Our literature review shows that this form of plastic waste recovery is a world first. The LFPW reduces surface temperatures by nearly 5.4 °C, with a maximum difference of nearly 16.5 °C. The thermal phase shift is also remarkable (between 70 and 150 minutes). This technical solution makes it possible to achieve performances comparable to conventional thermal insulation solutions while combining circularity and technological development. It is a realistic opportunity for emerging countries.

Keywords: *recycling | plastic waste | construction | thermal insulation | loose-fill*

1. Introduction

Waste management seems to be a never-ending challenge as its quantity is steadily increasing. In 2010, the United Nations Program (UN-Habitat) considered waste as one of the biggest challenges of the 21st century. By 2050, its global production is expected to increase by almost 70%. The most alarming situation is observed with plastic waste. The situation is even quite critical in emerging countries. Indeed, plastics' durability does not facilitate their degradation after use, which turns them into a real source of contamination. Global agreements have established the Sustainable Development Goals (SDGs) to overcome this problem. They were supported by the mandatory reduction of inequalities between states facing global challenges such as poverty, climate, or environmental degradation. The 12th SDG, "Responsible Consumption and Production," describes solid waste recycling, especially plastics, as the first key environmental challenge. Today, plastic is present in many applications and often, in large quantities. Indeed, it has remarkable properties that make it a versatile material used throughout the world. However, this intensive use has led to a significant accumulation of plastic waste in the environment, impacting animal and human health because of their limited degradation [1]. While developed countries are already working to meet this challenge, emerging countries that are mainly affected by the energy and climate crises, need to make much greater efforts. In addition to the reduction of plastic use, one possible solution is to shift the current paradigm from "waste management" to "resource management."

Waste management is a current environmental issue with great potential. Building construction is a sector that produces a very large amount of plastic waste. Thus, replacing part of the conventional materials with new materials made from recycled waste from buildings (or household origin…) seems to be an excellent compromise to reduce the environmental impact of this sector of activity.

As La Reunion is an island, waste management is a significant issue because space is necessarily more limited than on a continent. The burial of waste is therefore not a realistic and acceptable solution indefinitely. We are therefore interested in this local problem to develop a solution for recovering plastic waste at a reduced cost. Also, the island is subject to a humid tropical climate, which, in the heights, can combine problems of cold and very high relative humidity. The variation of temperature and humidity can cause the condensation of water contained in the air which impacts the efficiency of traditional insulators (glass wool, rock wool, cellulose) while generating fungal developments. However, due to the saturated coastal zone, the demographic evolution of the island shows that the high zone (altitude above 600 m) will be largely densified. New forms of insulating materials must be developed

This article aims to propose a solution for the reuse of plastic waste without preliminary sorting and with limited technicality. The purpose of these different elements is to offer a high-performance technical solution at a lower cost. It consists in valuing this waste as thermal insulation in bulk. The only constraint would be to crush the waste to a size that guarantees a low density and thus a high thermal resistance. This method, associated with plastic parameters (durability, hydrophobicity, low thermal conductivity), is likely to offer an economical, thermo-hydric, and sanitary efficient answer.

In the first part, a brief review of state of the art is proposed to identify the modes of recovery of plastic waste, highlighting the originality and simplicity of our technical solution. In a second step, we study the thermal performances of the LFPW experimentally in a cold and humid tropical climate, representative of the high altitude area (1560 m). The analysis allows us to conclude about the interest of the technology in a cold and humid climate.

2. Plastic Waste for building construction

Several authors have addressed the issue of the environmental impact of incorporating recycled plastic into building materials. In 2011, a study compared the life cycle assessment of an insulation board made from recycled PET with one made from virgin PET [2]. It concluded that using recycled PET reduced the product's carbon footprint by 50%. Another 2014 study showed that recycling PET means no more PET is produced, thus decreasing health, ecosystems, global warming, and resource impacts. The impact of using recycled PET has a negative score for all environmental criteria studied by [3]. Literature shows us that plastic waste has real potential as material and that we should ignore where it comes from (waste).

A bibliographical analysis was carried out to identify the modes of treatment of plastic waste for the construction sector. It allowed us to demonstrate that the solutions for recovery of these wastes in the building sector are essentially based on the solutions presented hereafter.

2.1 Integration in a cementing matrix in the form of an aggregate

Plastic waste in the form of aggregates is the most used in composite concrete and mortar because it is a simple technique [4–10]. It requires crushing or shredding of the waste material. They are then incorporated in the same way as the natural aggregates already used in the preparation. The problem with this recovery is the deconstruction of the concrete-polymer element because the separation of the two materials is a consequent technical lock. Plastic waste is generally integrated into two sizes: coarse aggregate (CA) or fine aggregate (FA).

Since the density of plastic materials is lower than natural aggregates, composite concretes are considerably lighter [11,12]. The composite material's density decreases as the proportion of plastic used increases. This results in a reduction in the slump of the concrete [11]. The interactions between the plastic aggregates and the cementing matrix are weak, so few bonds allow the different elements to combine well. The interfacial transition zone [11] between the plastic aggregates and the cementing matrix is weaker than in the case of natural aggregates. The morphology and the smooth, hydrophobic surface of plastic aggregates do not help for good cohesion. The addition of a superplasticizer improves these interactions [13]. The results of the literature differ regarding the tensile and flexural strength. However, the tendency is towards reducing strength in proportion to adding plastic aggregates [11,14,15]. Plastic is a material with suitable elastic properties, it is resistant to cracking, and its flexibility gives composite concrete better ductility than conventional concrete [16]. Another study by [15] showed that the addition of CA in composite concrete has a beneficial effect on abrasion resistance. Most studies show that fine aggregates achieve better mechanical properties than coarse aggregates. Logically, the latter are the most common aggregates used in composite concrete.

2.2 Integration in a cement matrix in the form of fibers

The scientific papers related to this topic are showing satisfactory results. The addition of plastic fibers in cemented composite materials generally improves the mechanical properties in contrast to aggregates [4,9,17–21]. The reduced quantities of fibers that are necessary for the formulation make it a low-waste plastic solution. Indeed, the optimal rate is around 1%. Beyond that, the properties are weakened.

2.3 Integration as a binder

Another method of incorporating plastic waste into concrete is used to create a composite material, referred to in the literature as "polymer concrete" [3,14,22–24]. The plastic waste is converted into a polymer resin. This resin is mixed with aggregates (gravel, sand, ash) and sometimes additives (such as initiator or catalyst). The process is then similar to conventional concrete (methods of vibration, hardening, and molding). The technique of manufacturing resin from plastic waste is described in the work of some authors [8,9,25].

2.4 Plastic brick or block with or without other materials

Some studies are interested in developing bricks or pavers using all or part of the plastic waste. In some cases, a mineral, vegetable, or polymeric filler is used for modifying the final product's properties. Note that waste is generally transformed (grinding, extrusion, 3D printing). In some cases, plastics, such as PET, can be directly reused from their initial form. This is a low-cost approach. Extrusion plays a significant role in recycling plastic waste into valuable products. The created paste can be combined with various plastics or even with different fillers. For example, the paper [26] describes the use of waste rubber powder as a filler. The developed composite brick shows mechanical results that are higher than those characteristics of usual clay bricks. The interest of this method also lies in the notable consumption of plastic waste (60-80% by weight) or in the good level of finishing or again reduced water absorption [27]. The use of plastic waste in bituminous mixtures improves its properties and also its resistance [28]. The most used waste plastics used are polyethylene, polystyrene, and polypropylene. The waste plastics are shredded, covered with aggregates, and mixed with hot bitumen.

2.5 Insulating panel

There is another form of recovery of plastic waste. The process consists in developing a rigid or semi-rigid insulating panel. In 2011, a study by [2] compared the insulating panel made from recycled PET with other insulating materials commonly used in the building sector. From an environmental point of view, the PET board is equivalent to a rock wool board, which has a much lower impact than expanded PS or PU foam boards. The insulating performance of this plastic board made from waste is dependent on the final density of the material.

3. Loose-fill material for thermal insulation

Insulation materials can be manufactured in different forms: loose fill, roll, rigid or padded board, or again foam. The choice of the appropriate form and, at the same time, of the type of insulation material mainly depends on the type of application as well as the wished physical properties [29]. Loose-fill insulation achieves a higher thermal resistance due to its low density with entrapped air resulting in a low thermal conductivity [30]. This technical solution has the advantage of being simple to implement practically since it is generally done by blowing/insufflation in vertical and horizontal walls.

Most of the related studies concern cellulose [31–35], wood chips [36], glass fiber [37], raw hemp fiber [38], perlite [39] or hemp shives [40]. For example, for cellulose fiber, the thermal conductivity can be around 0.04 W/(m.K) with a consistency similar to that of absorbent cotton [33]. This value is close to that of hemp fibers in bulk, for which a study has shown a variation of 0.040 to 0.049 W/(m-K) for a density of about 85 kg/m^3 [38]. Perlite, a mineral filler, achieves a thermal conductivity close to 0.054 W/(m.K) for a density of 94 kg/m^3 [2]. Studies indicate that in environments where the relative humidity exceeds 90%, fungi growth is potentially favored [33]. This is likely to have significant consequences on the durability and thermal properties of the insulation [41], not to mention the health risks. Moreover, it is widely recognized that wet lignocellulosic materials can allow fungi growth, but this unwished phenomenon can be corrected by adding additives [33]. The choice of the material to be disposed of in bulk must therefore be made according to the environmental conditions and the risks of fungal developments.

As we have seen, most studies devoted to the possible use of plastic waste in building investigated the development of composite concrete and rigid or flexible thermal insulation panel. These recovery routes require processing steps with possible additional environmental impacts or energy consumption. However, all these works agree that the addition of plastic in any form improves the thermal performance of the final product. This improvement of thermal properties in cemented composite materials is mainly because plastic has a lower conductivity than the components usually found in conventional concrete and mortar [23]. This advantage is observed with the "loose-fill" technique but has the additional advantage to require a reduced processing cost. Mixing different plastics is also not prohibited, which facilitates its reuse since it does not require any form of sorting. Also, the limits of use and constraints of the plastic waste are an added value here: great durability; low interaction with other materials (low surface energy); hydrophobicity limiting the fungi development.

Therefore, we looked to identify studies that have paid particular attention to the use of loose-fill plastic waste and its characterization as a thermal insulator. The keywords used in this bibliographic section were: waste; plastic; flakes; thermal insulation; bulk; loose fill; insulation material. But, as a result, no studies could be found on the use of loose-fill plastic aggregates. Our paper can be considered as a pioneer in studying shredded and loose plastic waste for thermal insulation.

3. Materials and methods

The performance of this type of insulation were evaluated in a tropical context, in the winter, and at high altitudes (cold and humid climates). This climate allows us to demonstrate this technology's interest in limiting heat transfers or thermal losses from the roof.

3.1. Description of the test cells

The experimentation was carried out on small-scale measurement cells, named "ISOTEST", whose dimensions are shown in Figure 1.

To investigate the interest of the technical solution, two cells were studied: one reference cell (without LFPW) and the other one equipped with a horizontal wall-type false ceiling containing the loose-fill plastic waste (LFPW).

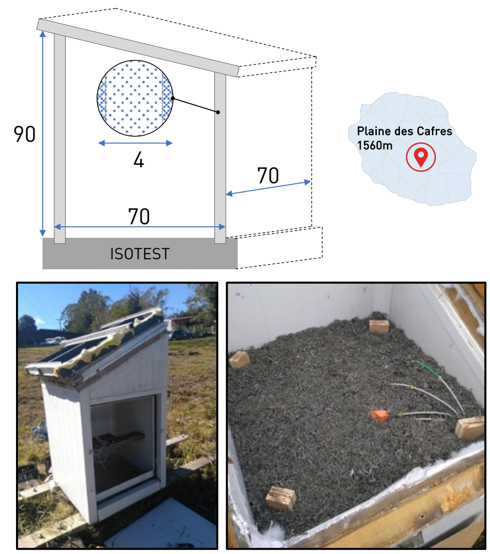

Figure 1: Schematic representation of the ISOTEST, location of the experiment and view of the LFPW wall

The vertical walls were composed of expanded polyurethane encapsulated in two steel plates for an overall thickness of 4 cm. The roof was made of dark blue corrugated sheet. A horizontal wall acted as a false ceiling. In the case of the cell equipped with the insulation to be tested, the loose-fill plastic was placed on this ceiling. In other words, this configuration was similar to a sandwich panel composed of plasterboard in the lower part (1.3 cm), 8 cm of loose-fill plastic wastes (LFPW) and topped by a plywood panel in the upper part (4 mm), allowing guaranteeing the thickness homogeneity of the plastic layer (Figure 2). The contribution of this last plate to the global thermal behavior of this wall was neglected in our study.

Different sensors have been installed in an identical way on both cells. K-type thermocouples were manufactured and calibrated following a rigorous experimental protocol.

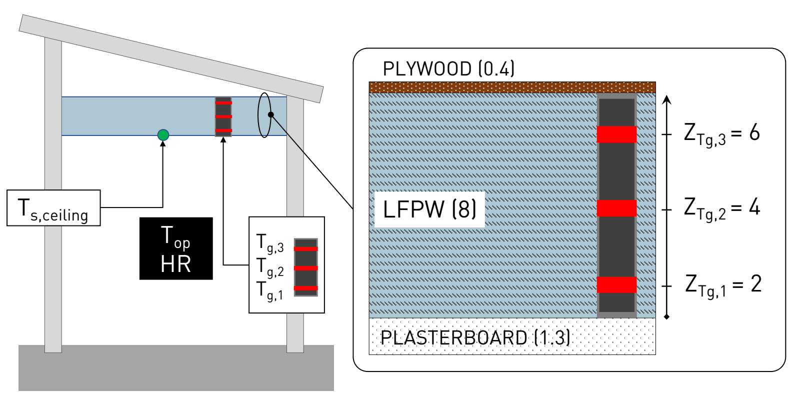

Figure 2: Detail of the LFPW wall and sensor placement

The different sensors were positioned as shown in Figure 2. A thermocouple was positioned at the surface of the plasterboard ceiling ($T_{s,ceiling,REF}$ for the reference cell and $T_{s,ceiling,LFPW}$ for the tested wall). Three thermocouples were placed at various thicknesses to measure the thermal gradient $T_{g,1}$, $T_{g,2}$ and $T_{g,3}$ within the loose-fill plastic layer. All these thermocouples were connected to a multiplexer (AM25T from Campbell Scientific®), which allowed for deporting an acquisition unit's channels (CR3000). We also placed Testo® brand stand-alone thermohygrometers in each of the ISOTESTs, to measure the operative temperatures ($T_{op,REF}$ and $T_{op,LFPW}$) as well as the relative moisture (HR_{REF} and HR_{LFPW}) throughout the experiment. In parallel, weather conditions were measured from Meteo France stations. Thus, the air temperature $T_{a,out}$, relative humidity HR_{out}, and global solar radiation GLO_{out} were regularly measured along the experiment phase. All data were collected at a time step of one minute for ISOTEST cells, and hourly for meteorological data.

3.2. Plastic wastes used

The plastic waste used was made of a mixture of polypropylene (PP) and polyethylene (PE), two thermoplastics from the retail sector and the industrial sector (packaging, household appliances, etc). These plastics were ground and then analyzed using a sieve column to determine their particule size distribution. Indeed, this parameter is likely to influence the apparent density of the resulting insulating layer and its thermal performance.

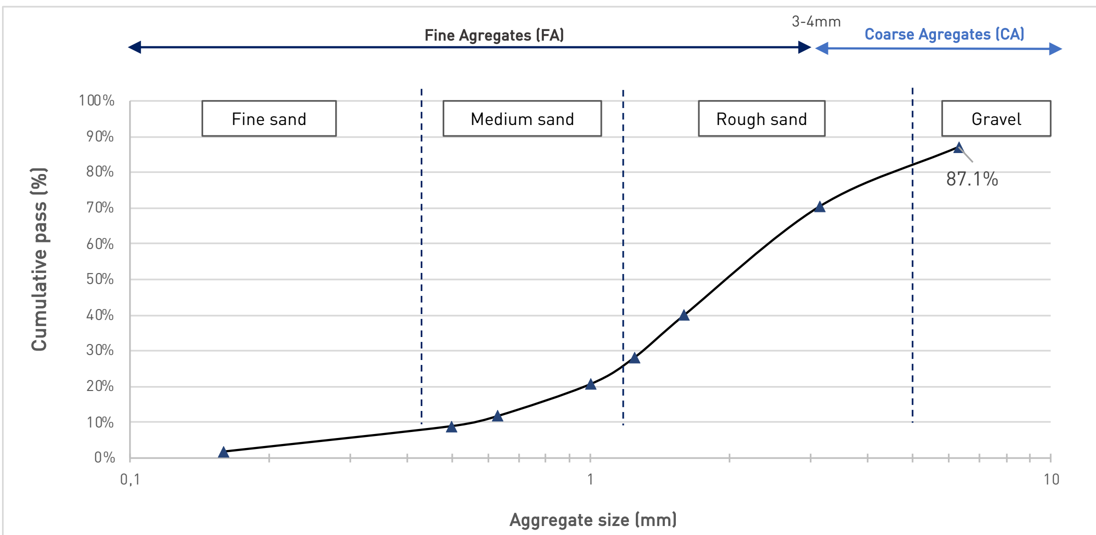

Figure 3 : Size analysis of loose-fill plastic waste with aggregate size equivalence

The results of the granulometry analysis can be seen in Figure 3, which shows the weight percentage of aggregates that passed through each of the sieves. According to the ranking used in literature, 70% of the waste analyzed can be considered as Fine Aggregate (FA), and the remaining 30% as Coarse Aggregate (CA). If we compare with the aggregates usually used for concrete, such granulometry would be represented by coarse sand and normal sand. The LFPW wall was made using only plastic particles larger than 3-4 mm.

3.3. Study climate and analysis period

La Reunion Island is subject to a humid tropical climate, divided into about forty microclimates related to its very uneven relief resulting from its volcanic geology. The standardization of these climates made it possible to orient the climatic classification described in the thermal regulation available on the island. The latter divides the territory into three climatic zones: the low zone (altitude < 400 m), the mid-height zone (400 m < altitude < 600 m), and the high zone (altitude > 600 m).

In our case, we were interested in the high-altitude zone represented in particular by the city of La Plaine des Cafres (altitude 1560 m) located in the commune of Le Tampon (France). We conducted a brief climatic study of where the cells are positioned representative of the zone of high altitude, a cold and wet climate.

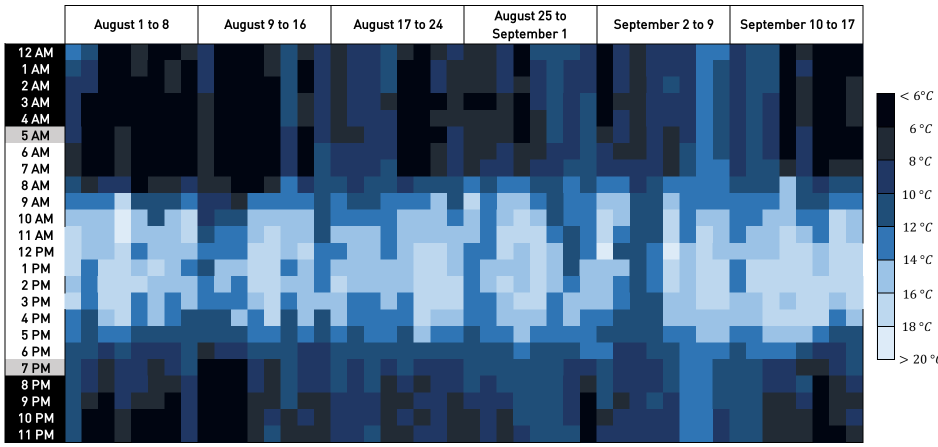

Figure 4: Temporal evolution of air temperature from August 1 to September 17, 2020

This analysis consisted in measuring the outdoor air temperature with a thermometer under shelter and registering its evolution during a period long enough to be representative of the winter season. The corresponding data, presented in Figure 4, group the meteorological data from August 1 to September 17, 2020, divided into 6 periods.

The column on the left shows the magnitude of daylight duration while the different colors illustrate the range of registered outdoor air temperatures. These values clearly show that the site is in the winter period. Indeed, the days are short (less than 10 hours) and temperatures do not exceed 16 °C until midday to finally drop as early as 4:00 p.m. At the beginning and end of the day, average temperatures are below 6 °C.

The period of experimental data acquisition with the cells extended from August 18 to September 11, 2020.

4. Results and discussion

4.1 Impact of LFPW on surface temperatures

We analyzed the surface temperature $T_{s,ceiling}$ at the bottom of the plasterboard and compare the cell equipped with LFPW with the reference cell. This measurement allowed us to evaluate the attenuation power of the LFPW on the conductive exchanges between the roof and the cell enclosure.

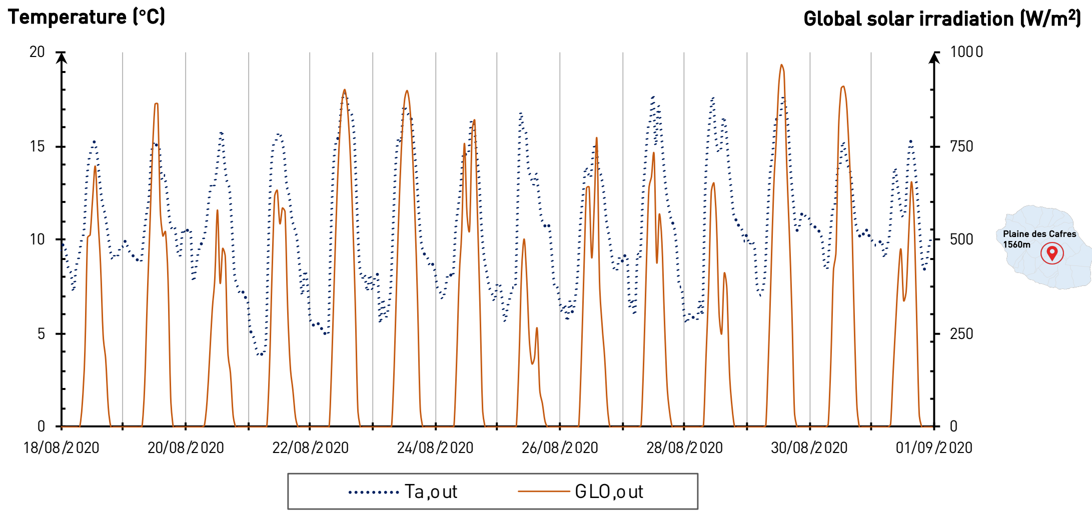

Figure 5: Evolution of outdoor meteorological parameters ($T_{a,out}$ and GLO_{out}) during period 1 (winter season)

To get an overview of the weather conditions, we plotted the evolution of the outdoor air temperature $T_{a,out}$ as well as the global solar radiation GLO_{out} (Figures 5 and 7). The latter parameter was representative of the energy transmitted by the sun and could be correlated to the cloud density. For instance, a clear sky is characterized by the daily profile of its radiation similar to a Gaussian. Such situation was observed on August 22, 23, and 29. In this case, the global solar radiation was close to the direct solar radiation, with nominal values close to 1050 W/m^2 (September 6). In contrast, the overall solar radiation profile on overcast (cloudy) days is up and down, as was the case on August 25 or September 4, when the nominal values were around 500 W/m^2. The outdoor air temperatures were only slightly affected, given the density of the surrounding vegetation and the seasonal temperatures at this altitude. Indeed, they ranged from 4 to 17 °C.

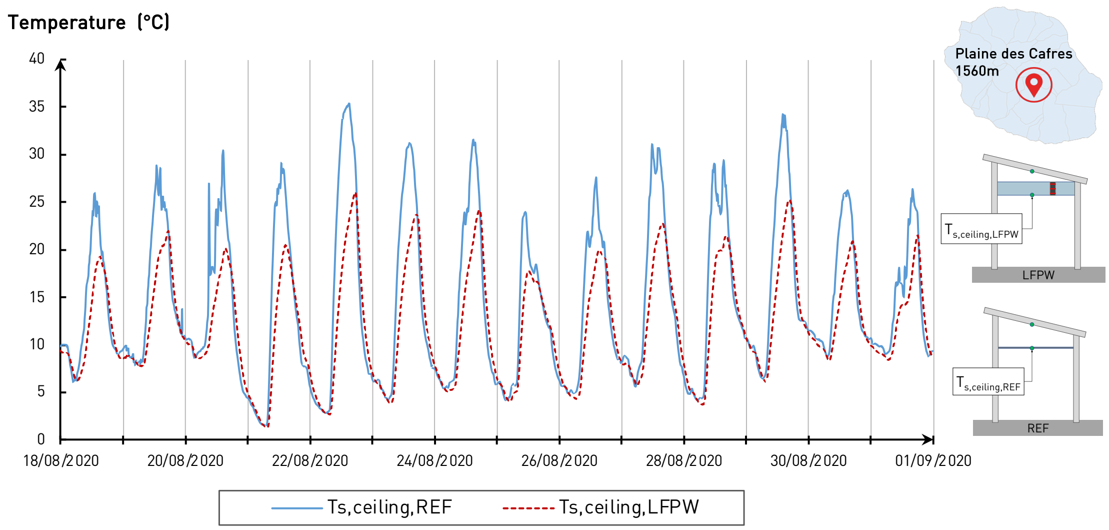

Figure 6: Evolution of the surface temperature of the ceiling during period 1 (winter season)

The examination of the surface temperatures of the ceiling (Figures 6 and 8) shows that the presence of the loose-fill insulation reduced the value of maximum temperature during the day. Overnight, the temperatures of the two cells were similar. The influence of solar irradiation is probably the reason for this equality. During the day, the sun irradiated the dark roof that raised the temperature of this metallic panel. Then, the temperature of the air gap increased faster than that of the outside environment. However, the LFPW, whose thermal conductivity results from the combination of the plastic's insulating power and the air trapped between the chips, attenuated the conductive and radiative effects of the air/sheet complex.

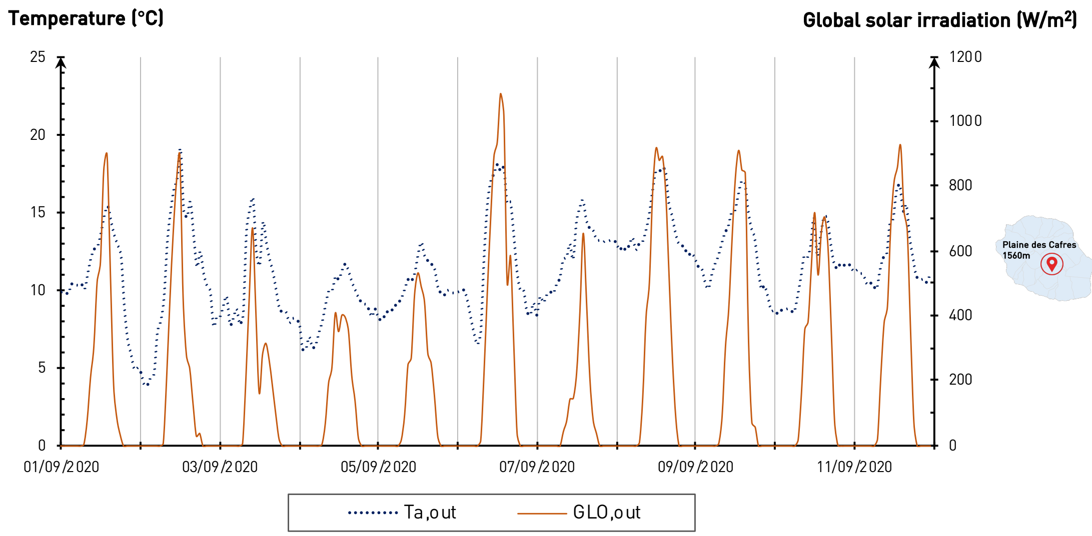

Figure 7: Evolution of outdoor weather parameters (Ta and GLO) during period 2 (winter season)

On August 22nd, under clear sky, the maximum global solar irradiance reached nearly 850 W/m^2 at 1:00 p.m (Figure 5). The maximum surface temperature in the reference cell reached 35.3 °C almost two hours later (3:10 p.m.) against 23.2 °C simultaneously in the cell equipped with the LFPW (Figure 6). The maximum surface temperature in the test cell was reached was attained 140 minutes later with a nominal value of about 26°C. Thus, from the peak of maximum solar irradiation, the cell equipped with the LFPW reached its maximum surface temperature not less than 270 minutes later with an attenuation factor of the order of 0.73 compared to the reference cell. The thermal inertia of the LFPW wall is also visible in the rate of the variability of the surface temperatures. On a cloudy day, when the global irradiation has evolved in a sawtooth pattern, the surface temperature of the ceiling of the reference cell undergoes a multitude of temperature amplitudes. On the opposite, the LFPW wall reduced the variations of the surface temperature. This observation highlights the increase of thermal inertia by simply adding the LFPW.

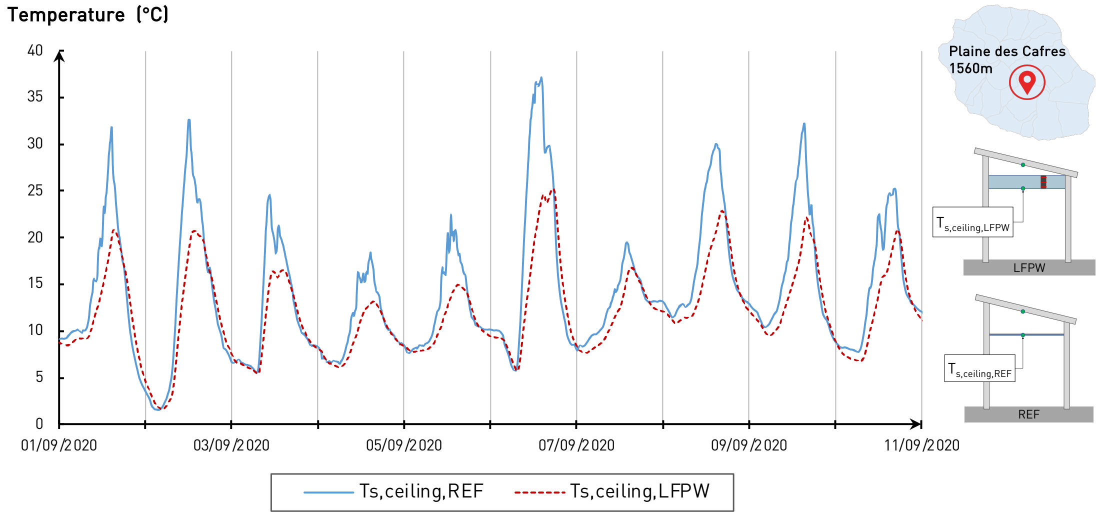

Figure 8: Evolution of the surface temperature of the ceiling during period 2 (winter season)

4.2 LFPW performance on 2 typical days

Let's focus now our attention on other typical days.

The day of August 22nd, for example, was the day with the most important difference in the surface temperature of the reference and test cells, respectively. As shown in Figure 5, the weather conditions were typical of a clear sky day with a nominal irradiance of nearly 873 W/m^2 and a temperature of 17.7 °C.

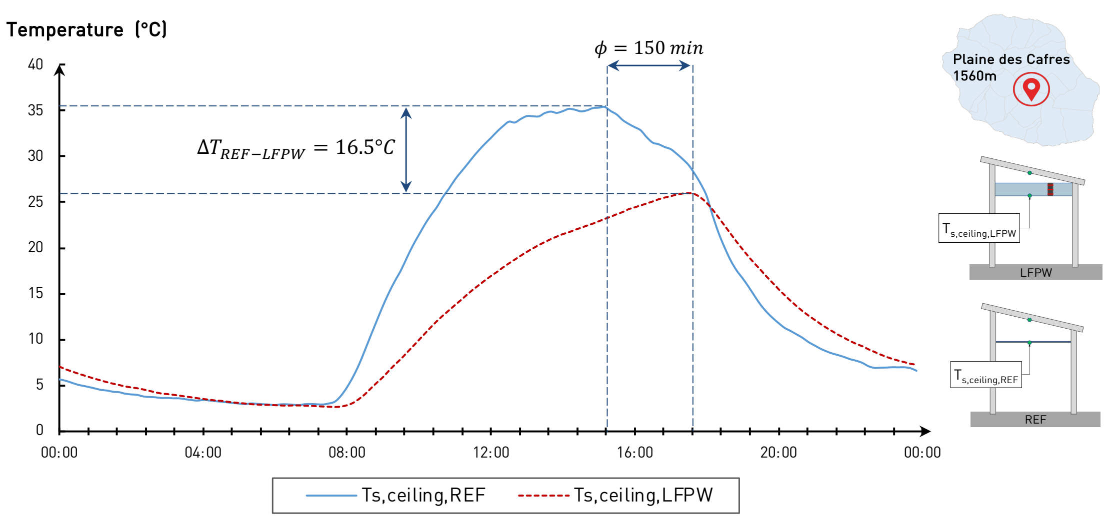

Figure 9: Evolution of the surface temperature of the ceiling for the day with the highest deviation (22/08) (winter season)

Figure 9 shows the evolution of both surface temperatures throughout the day. At night, the values registered with both ceilings were quite similar. As soon as the sun rose, the roof of the cells absorbed the solar irradiation. Then, in the reference cell, the surface temperature increased rapidly and stabilized at 12:50 p.m., reaching a maximum value of 35.4 °C at 3:10 p.m. With the days being short at this time of year, the surface temperature decreased in two phases: a gentle slope until 5:00 p.m., then a rapid drop to 7 °C by nightfall. The cell equipped with the LFPW showed different behavior. The surface temperature increased slowly from 8:00 a.m. (i.e., 30 minutes later than in the reference cell) to reach a maximum temperature of 26 °C at 5:40 p.m. The difference in maximum temperatures reached 16.5 °C. The peak temperature of the cell with LFPW was reached 150 minutes after that of the reference cell. As with conventional insulation, the air trapped between plastic chips reduces the thermal conductivity of the material. In other words, the presence of LFPW significantly increased the thermal inertia of the horizontal wall.

However, nighttime data show that the vertical walls and floor of the cells exchanged with their surroundings, and the solar energy stored by the thermal mass is quickly lost.

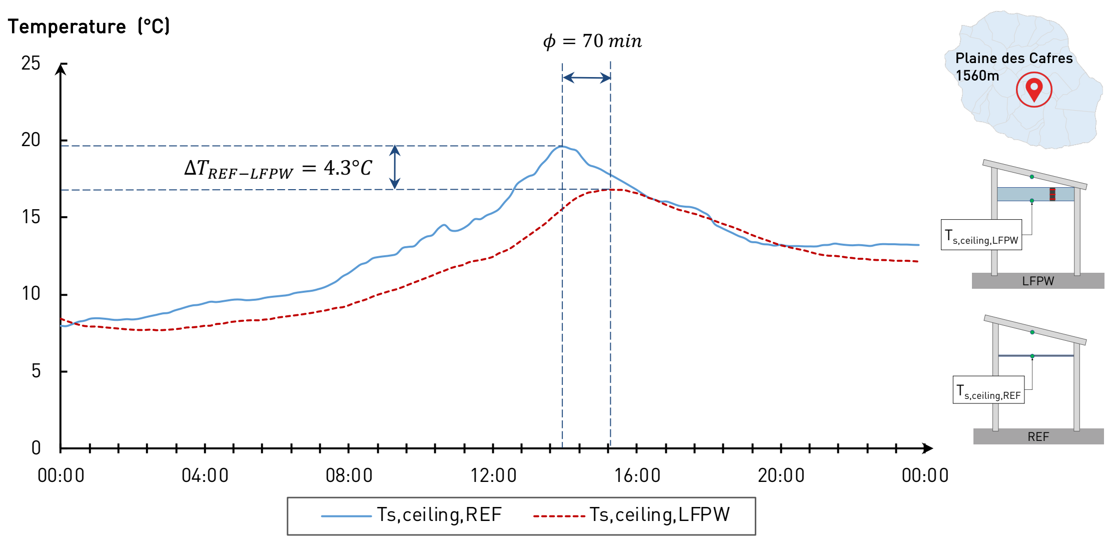

Figure 10: Evolution of the surface temperature of the ceiling on the day with the lowest deviation (07/09) (winter season)

The evolution of solar irradiance for September 7 presented in Figure 7 is characteristic of a cloudy day, with a maximum value of 654 W/m^2 for a maximum temperature at the same time of 14.5 °C. For the day with the smallest surface temperature difference between the two cells, a significant phase shift was observed with the use of LFPW (70 minutes). Inside the cells, the peak temperature was reduced by 4.3 °C between the reference and test cell, as shown in Figure 10. The added value of LFPW on the thermal inertia of the ceiling could also be observed by comparing the slopes of surface temperature evolution of each cell.

4.3 LFPW performance on the whole periods

Table 1 summarizes the data over the entire measurement period (from August 18 to September 11), including those from the thermohygrometric sensors. The average difference in air temperature between the two cells was about 4.9°C with the advantage for the LFPW cell. The temperatures were more stable there, even if the deployment of the LFPW on all the walls, (i.e., horizontal and vertical), would make it possible to increase the benefits due to its use. The air temperatures reached in the test cell are largely within the comfort range defined by ASHRAE. The maximum temperature did not exceed 26.6°C, while the reference cell reached 30.7°C. The observation is the same for the surface temperatures, where the average difference was about 5.4°C. The presence of the LFPW also reduced the amplitude of variation of the relative humidity due to a higher value of the minimum measured. Indeed, in the test cell, the relative humidity remained above 57.6%, while without insulation, it could decrease down to 44.8%. A similar hierarchy was observed as concerns the average RH value but both values (test and reference) remained below that registered outdoor. The LFPW seems able to regulate the hygrometric exchanges between the ceiling and the airspace. This insulating complex containing air will tend to "trap" water in the bulk of plastic chips.

Table 1: Summary of measurements in La Plaine des Cafres

Plaine des Cafres		*Average*	*Minimum*	*Maximum*
Air temperature (°C)	$T_{A,OUT}$	**11,1**	3,8	19,1
	$T_{op,REF}$	**13,7**	1,9	30,7
	$T_{op,LFPW}$	**12,9**	1,7	26,6
	$\Delta\, T_{op\,(REF-LFPW)}$	**0,8**	0,2	4,1
	Average deviation $T_{op\,(REF-LFPW)}$		4,9	
Surface temperature (°C)	$T_{s,ceiling,REF}$	**14,2**	1,5	37,2
	$T_{s,ceiling,LFPW}$	**12,0**	1,3	26,0
	$\Delta\, T_{s\,(REF-LFPW)}$	**2,2**	0,2	11,2
	Average deviation $T_{s\,(REF-LFPW)}$		5,4	
Relative humidity (%)	HR_{OUT}	**88,4**	43,0	100,0
	HR_{REF}	**77,4**	44,8	99,9
	HR_{LFPW}	**79,9**	57,6	98,3
	$\Delta\, HR_{\%\,(REF-LFPW)}$	**-2,5**	-12,8	1,6
	Average deviation $HR_{\%\,(REF-LFPW)}$		6,8	

4.4 Study of the thermal gradient within the LFPW

The time has come to look at the evolution of the thermal gradient within the loose-fill plastic. Indeed, it is important to know if the thermal behavior of the bulk can be considered proportional to its thickness. To this end, two types of days were studied.

The first one, September 4th, was the coldest day of our measurement period, i.e., when the maximum temperature presented the lowest value registered as shown in Figure 7. Figure 11 represents the evolution of the thermal gradient for this day at different times. A first examination of these data indicated that the temperature profile could vary depending on the time of day due to the variations of sunshine. Then, different characteristic hours were examined with much attention.

At 6:00 a.m., at the beginning of the day, the cell has not yet received any heat, which justifies that the temperatures within the material, the air gap, and the sheet remained stable at

6.5 °C. At 9:00 a.m., the temperature $T_{g,1}$ was 6.4 °C higher than the temperature $T_{g,3}$ close to the plywood. However, the temperature of the sheet metal reached 18 °C. This is because the outside air temperature remained low, but the cell received the first irradiation from the sun. The vertical walls and the sheet metal heated up, while the bulk plastic and the air gap maintained their temperatures. This demonstrates the low thermal conductivity of the wall, in contrast to the steel roof. At noon, temperatures continued to rise with the maintenance of a thermal phase shift within the LFPW. At 6:00 p.m., the trend was reversed. When the solar radiation became zero, the temperature near the plasterboard and the temperature of the metallic sheet stabilized at 11 °C, while the temperature within the LFPW was 3.3 °C higher. At 11:00 p.m. and midnight, the temperature difference outside the LFPW was reduced but remained positive: the thermal inertia of the LFPW was deemed sufficient to induce a remarkable thermal phase shift.

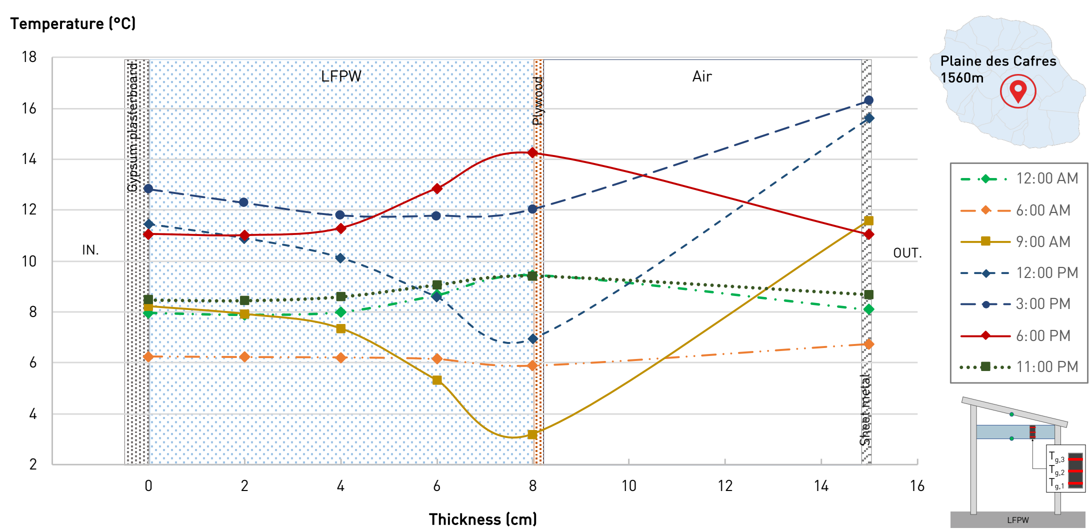

Figure 11: Evolution of the thermal gradient of the roof for the coldest day (with the lowest $T_{A,OUT,MAX}$) (September 4)

The maximum amplitude of the thermal gradient was notable. Indeed, the temperature difference between the upper and lower nodes could reach more than 5 °C over 8 cm. Also, in the middle of the day, the closer you get to the interior (i.e. towards the ceiling), the more the temperature increases which proves the insulating ability of this loose-fill plastic waste.

5. Conclusion and perspectives

The literature revealed that plastic waste as loose insulation has not yet been studied. Most of the articles refer to valorization as aggregate for concrete or mortar or as raw material for the realization of insulating or massive building materials (brick, paving stone). As for loose insulation, it is generally of vegetable or mineral origin, but no study mentions polymeric materials and even less waste. Our study is, therefore, the first on the potential of LFPW.

To demonstrate the potential of this technology, we conducted an experimental study on small-scale cells over 24 days during the winter season on Reunion Island. The testing platform was located in the town of La Plaine des Cafres in the island's heights, at an altitude of 1560 m. A cold and humid tropical climate marks this place.

Our data showed that the loose-fill insulation increased the thermal mass of the cell and largely limited the conductive exchanges between the roof and the air zone. The use of a thickness of 8 cm of loose-fill plastic wastes reduced the ceiling temperature by nearly 5.4 °C on average, with a maximum difference of nearly 16.5 °C. The time lag on the ceiling surface temperatures was also found worth of interest with a value comprised between 70 and 150 minutes.

The use of LFPW also impacted the relative humidity inside the cell. The insulation acted as a water barrier and did not allow moisture to escape. This explains why the reference cell showed better results. In a real situation, the use of minimum air exchange rates is likely to prevent this problem.

We also studied the thermal behavior within the material by measuring the thermal gradient. The maximum amplitude was notable since the temperature difference between the upper and lower nodes could reach more than 5°C over 8 cm during the day. The related profile was found to be no linear and probably depended on the chips' relative moisture and the bulk density variability.

The attenuation of temperatures by the insulation was minimized when the outside temperatures were low (for a low stress, there is a low impact).

These findings supported a follow-up to this first study. Measurements are still in progress to evaluate the behavior of the LFPW in summer in a hot and humid climate.

The impact of chip settling on the global conductivity of LFPW will also be investigated. Indeed, when used as insulation in attics, an additional quantity of loose-fill insulation is usually added beyond the level required for insulation to solve the problem of settlement associated with material creep. Since this creep is generally related to changes in relative humidity, the use of plastic material could be an asset since it is hydrophobic.

The optimal chip size also deserves to be studied with further attention to get the best performance of this class of insulating substrate. The improvement of the wall efficiency could also be achieved by the coupled use of PCM microcapsules, as described in a previous study combining loose-fill cellulose fibers [42].

All these leads that the deployment of LFPW walls considering is a technical solution that is interesting considering the thermal efficiency for energy management and building efficiency improvement. At the same time, both simplicity of implementation and nature of raw material lead to a cost-effective technical solution that is accessible to all.

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11. References

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