Life-cycle assessment of lightweight textile membrane partition walls

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Abstract

This paper analyze the environmental, functional and economical performances of some conceptu al lightweights textiles membranes partitions walls and to compare one of them with two technologies present in Portuguese market: i) the heavyweight conventional hollow brick partition wall; and ii) the lightweight reference plasterboard partition wall. Advantages of use textile/ fibrous/ membrane based materials in partition walls are focused and they may contribute for the development of new partition wall technologies. The comparative evaluation of these solutions is based on a standard Life-cycle Ass essment method.

Keywords: Life-cycle assessment; textiles; membranes; interior partition walls.

1. Introduction

The growing necessity to save material and energy resources, together with a growing concern over the environmental issues, are impelling the development of new building technologies with lower embodied material quantity [1]. In most cases, a partition wall is a non load bearing and thin element, used to divide the indoor space into rooms or other compartments. Lightweight interior partitions technologies require less material, save fuel on transport to the building site, and can be designed with smaller assembly fittings. The environmental life-cycle impact of an internal partition wall technology result directly from the attributes of the used materials, such as the embodied energy, thermal properties, and from the way the solution is built and maintained. When compared to other non-load bearing construction elements, interior partition walls have higher contribution to the material input of a building. And in previous studies [2] was concluded that lightweight framed partitions perform better than heavyweight masonry walls in terms of environmental performance.

1. Textile membrane partition walls

Textile membrane partitions have several advantages as an alternative solution to conventional rigid partition walls made by plasterboard or hollow brick, in terms of flexibility and economy.

A lightweight interior partition walls is certainly a wiser option in many situations as it can be more flexible and even portable having as well, in some cases, a lower environmental LCA impacts.

The developed interior partition wall is composed by a textile or a fibrous core, a plastic grid, and a structure.

This study compares ten possible lightweight sandwich membrane partition walls (LSM) and then compares the best solutions The selected core materials are: polyester fibers (POLIES), recycled fibers (RF), polyurethane foam (PU), agglomerated recycled foam (ARfoam), agglomerated cork (ACK) and wood wool (WW). The alternative materials for the grid are: rigid polyvinyl chloride (rPVC), rigid polyurethane (rPU), rigid polystyrene (rPS), or cardboard (CB). The study considers the following alternatives for the coating layer: expanded PVC (ePVC), cork (CK), pressed POLIES (p POLIES), rPU, cardboard (CB) and medium density fiber board (MDF). The selected finishing materials (over coating) are: PVC or PU coated woven polyester membrane, acoustic perforated membranes, polyurea or cork. The lightweight wall's structure is composed by polyester straps (PS straps), tensors, and galvanized steel profile (GS profile) to fix the structure to the floor and ceiling. Table 1 resumes the analyzed technologies.

2.1. Analysed partition walls technologies

Conventional solutions analysed were: i) the heavyweight conventional masonry partition wall (HCM) - Fig. 2a); and ii) lightweight reference plasterboard partition wall (LRP) - Fig.2b). These solutions have two considerable differences: the weight and the type of building technology. The heavyweight conventional

masonry partition wall (HCM) is a single wall made of hollow brick units (0.30x0.20x0.11m), coated with a 0.02m thick cement plaster layer on both sides, which results in a total wall thickness of 0.15m and in a total specific weight of about 150kg/m2 (Fig. 2a). This is the most common system for partition walls in Portugal

a) HRP (heavyweight reference partition)

b) LRP (lightweight reference partition)
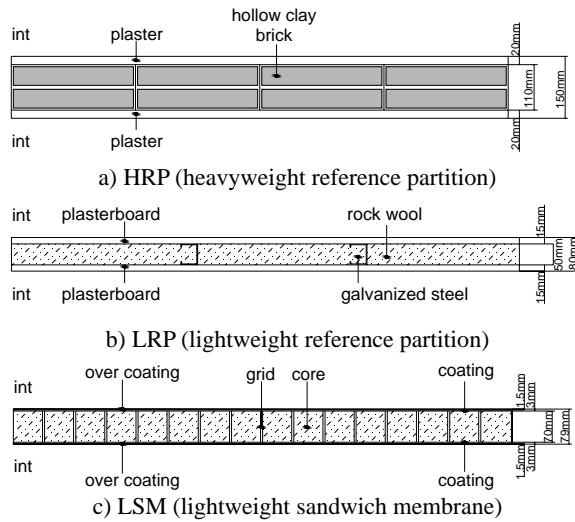

c) LSM (lightweight sandwich membrane)

Fig. 2 Horizontal section of interior dividing wall technologies.

The LRP is the most used lightweight solution in Portugal (Fig.2b). It is a technology based on plasterboards fixed on both sides of a structure made by cold formed galvanized steel profiles. Between the plasterboards there is rock wool, used as an acoustic insulation material.

Table 1 Description of analyzed solutions.

Solution	Gird	Core	Coating	Over Coating	Structure
LSM1	rPVC	PU	ePVC	Membrane	Lashing straps, metallic trough, moorings and angles
LSM2	rPVC	ACK	CK	Membrane	Lashing straps, metallic trough, moorings and angles
LSM3	rPVC	RF	Pressed POLIES	Membrane	Lashing straps, metallic trough, moorings and angles
LSM4	rPVC	POLIES	Pressed POLIES	Membrane	Lashing straps, metallic trough, moorings and angles
LSM5	rPU	PU	rPU	Acoustic membrane	Lashing straps, metallic trough, moorings and angles
LSM6	rPU	ACK	rPU	Polyurea	Lashing straps, metallic trough, moorings and angles
LSM7	rPS	POLIES	Pressed POLIES	Membrane	Lashing straps, metallic trough, moorings and angles
LSM8	CB	PU	CB	Membrane	Lashing straps, metallic trough, moorings and angles
LSM9	-	WW	MDF	Membrane	Lashing straps, metallic trough, moorings and angles
LSM10	CB	ACK	CB	CK	Lashing straps, metallic trough, moorings and angles

The LSM is the technology under development within a project of R&D at the University of Minho. This solution is made of a core with a grid, a coating and over coating membrane layer, fixed between ceiling and pavement slabs. This study analyzes ten alternatives for the LSM partition solutions (Fig. 2c), based in the use of alternative materials as presented in Table 1.

2. Life-Cycle Assessment (LCA) methodology

The life-cycle assessment is based in the Methodology for the Relative Sustainability Assessment of Building Solutions S (MARS-SC) [4]. This methodology is based in three groups of indicators: environmental, functional and economy.

2.1. Boundaries and Functional Unit

At this stage, the results will include the embodied environmental impacts (cradle-to-grave) of the compared partition wall solutions, plus the environmental impacts resulting from the transportation of the materials to the building site and, in the end-of-life, to the waste management centre. In this study, the functional equivalent is 1 m^2 of wall that fulfils the minimum functional requirements for a partition wall. This study is divided in two parts. In the first part it were analyzed ten lightweight membrane partition walls. In the second part it were compared the best LSM with the two reference walls above mentioned.

2.2. Indicators

The considered environmental impact indicators are based in the Life-Cycle Assessment (LCA) method. In this study three functional indicators were considered: air born sound insulation (Dn,w); thermal insulation (U); and flexibility in use (F). At this stage, this study considers just one economy indicator: construction cost (CC).

2.3. Quantification of Indicators

Once the indicators were selected, they need to be quantified or qualified.

The first step for the quantification of the environmental impacts is the inventory analysis [4]. For the materials transport it is considered the distance from the nearest manufacturer of each material to the building site (Guimarães, Portugal). Impacts on construction sites are based in Portuguese average data [2].

At this phase, generic LCI European average data, mainly the the LCI database Ecoinvent

v2.0, was used to compare the alternative solution. The environmental impact categories were quantified using two LCA methods: CML 2 baseline 2000 (for the impact categories of the LCA) and Cumulative Energy Demand (for the embodied energy). The SimaPro software was used to modulate the life-cycle of each analyzed technology. For the functional performance there are two quantitative indicators (air born sound insulation -Dn,w and thermal insulation – U) and one qualitative indicator (flexibility in use -F). Dn,w was evaluated using the analytical methodology proposed by Meisser [3] and the thermal insulation was quantified according to the Portuguese thermal regulation. For the flexibility in use, the study considers three qualitative levels of performance. The qualitative performance is converted in a quantitative scale using the following key: low flexibility = 0.0; medium flexibility = 0.5; and high flexibility = 1.0. The economy performance assessment is based in the construction cost (CC). This cost is based on the up-to-date unitary values of the Portuguese construction market.

2.4. Normalization

The objective of the normalization of indicators is to avoid the scale effects in the aggregation of indicators and to solve the problem that some indicators are of the type "higher is better" and others "lower is better". Normalization is done using the Diaz-Balteiro *et al.* [4] Equation 1.

$$\overline{P}_i = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall_i \tag{1}$$

In this equation, P_i is the value of ith parameter. P_i^* and P_{*i} are the best and worst value of the ith sustainable parameter. The best value of an indicator represents the value of the partition wall with the highest performance and worst value represents the solution with lower performance. With this method the normalized valued are bounded between 0 (worst performance) and 1 (best performance).

2.5. Graphical representation

The graphical representation (Sustainable Profile) is global, involving all evaluated indicators. To fulfill this objective, the Amoeba or "radar" diagram is used.

2.6. Aggregation of indicators

A long list of indicators and their respective

performance will only be useful in order to compare the solution at the level of each indicator and is useless to compare the performance of the solutions at the level of each requirement (environmental performance, functional performance and economy performance). As an example, for the environmental performance this process uses Equation 2.

$$ND_A = \sum_{i=1}^{m} WA_i \, xNIA_i \tag{2}$$

Where ND_A represents the aggregation of the environmental indicators, m is the number of considered environmental parameters, WA_i is the weight of the ith environmental indicator and NIA_i is the normalized value of the ith environmental indicator. For this study the weights were distribute equally (33% for each indicator).

2.7. Global performance

The last step is the quantification of the Sustainable Score (SS). SS is a single index that resumes the global performance of a solution. A sustainable score closer to 1 represents a more sustainable solution. The aggregation method used to calculate the SS is presented in Equation 3.

$$SS = ND_A.w_A + ND_F.w_F + ND_E.w_E \tag{3}$$

Where W_A, W_F and W_E are respectively the weight of the environmental, functional and economic performances. MARS-SC uses the following system of weights: $W_A = 0.30$; $W_F = 0.50$; $W_E = 0.20$.

3. Results and discussion

Table 2 presents the results from the quantification of the environmental indicators of the ten analyzed LSM solutions and the two conventional solutions. Table 3 summarizes the quantification of the functional and economy indicators between the two reference solutions and lightweight membrane partition wall with the best environmental, acoustic and thermal performance.

Table 2 Results from the quantification of the environmental indicators.

Solution	Environmental impact categories					
	GWP	ODP	AP	POCP	EP	ENR
	[KgCO₂eq]	[KgCFC-11eq]	[KgSO2eq]	[KgC2H4eq]	[KgPO4eq]	[MJ equiv.]
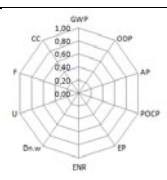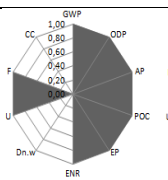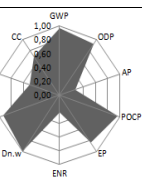
HCM	1.5E03	2.9E-06	1.1E-01	2.9E-02	4.7E-01	4.4E03
LRP	3.8E02	1.9E-06	8.6E-02	9.4E-03	8.9E-02	3.4E03
LSM1	5.8E01	3.6E-06	3.9E-01	1.9E-02	5.2E-02	1.2E03
LSM2	3.7E01	2.6E-06	1.9E-02	1.2E-02	2.7E-02	6.6E02
LSM3	1.2E02	4.5E-06	9.3E-01	4.0E-02	2.8E-01	1.7E03
LSM4	1.4E02	4.5E-06	1.1E00	4.7E-02	1.1E-01	1.9E03
LSM5	7.7E01	3.4E-06	4.9E-01	3.1E-02	6.9E-02	1.5E03
LSM6	8.9E01	5.5E-06	4.9E-01	3.4E-02	7.8E-02	1.8E03
LSM7	1.4E02	7.1E-06	1.1E00	4.8E-02	1.2E-01	2.2E03
LSM8	4.9E01	5. 6E-06	3.2E-02	1.7E-02	4.8E-02	8.5E02
LSM9	-3.5E00	1.8E-06	1.1E-01	8.8E-03	1.7E-02	3.6E02
LSM10	3.3E01	5.3E-06	1.8E-01	9.6E-03	3.1E-02	5.7E02

Table 3 Results from the quantification of the functional and economy indicators.

Partition technology	Functional indicators			Economy indicator
	$D_{n,w}$ [dB]	U [W/m^2.°C]	F	CC [€/m^2]
HCM	41.0	1.80	0.0	26.56
LSM9	40.0	0.59	1.0	37.81
LRP	41.5	0.80	0.5	30.00

The results from the application of the MARS-SC to the quantified values of the environmental, functional and economy performances are presented in Table 4. The worst solution is the one that is represented nearest to the centre of the sustainable profile.

Table 4 Results from the application of the MARS-SC to the quantified values of the environmental, functional and economy performances.

Sustainable profile			
Partition system	HCM	LSM	LRP
Global indicators			
ND$_A$	0.00	0.31	0.13
ND$_F$	0,00	0,40	0,34
ND$_E$	0.20	0.00	0.13
Sustainable score (SS)	0,20	0.71	0.60

Analysing the results it is possible to realize that in accordance with the considered indicators and their respective weight the partition wall technology with the best life-cycle performance is the conceptual lightweight sandwich membrane partition technology (LSM). This solution is better than the conventional solution (HCM) at the environmental and economy levels. Nevertheless, it has a higher construction cost. Most of the higher construction cost is justified by the cost of the material used in its structure:

cold formed galvanized steel, such as in the LRP solution. Comparing the three solutions at the environmental level it is possible to notice that LSM is the best one.

4. Conclusions

In order to reduce the whole building environmental impacts, project teams should select technologies with high environmental performance, but that fulfil at the same time the necessary functional and economy requirements.

This paper is focused in a project which aims to develop an optimized construction technology for partition walls. At this stage it is possible to realize that the solution under development is better from the environmental performance point of view, than the two reference solutions used in the Portuguese building market: the conventional heavyweight masonry hollow brick wall and the alternative lightweight partition solution made of plasterboard panels and a cold formed galvanized steel structure. Nevertheless it is necessary to highlight that at this stage the study only includes the embodied environmental impacts, until the end of the construction phase.

5. Acknowledgements

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