COMPARATIVE ANALYSIS OF RESIDENTIAL BUILDINGS HOIST-WAYS CONSTRUCTION SYSTEMS BASED ON LCA

Justo García Sanz-Calcedo - Doctor Ingeniero Industrial.

Sergio Pena Corpa - Máster Universitario en Arquitectura e Ingeniería

Universidad de Extremadura. Departamento de Ingeniería Mecánica, Energética y de los Materiales. Avda. Santa Teresa de Journet 38, (06800) Mérida (Badajoz). jgsanz@unex.es. Universidad de Extremadura.

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ABSTRACT:

This paper compares the environmental impact of the traditional construction systems of hoist-ways made for lifts in residential building, using techniques based on Life Cycle Analysis (LCA), carbon footprint calculation, quantifying total energy consumption and emissions in the material used, as well as building and recycling of all materials in use. Furthermore, other environmental variables directly related with environment sustainability will be studied. We have simulated the analysis with a 50 year time frame, 100 km average for the materials transport and 15 km average to dump residue.

Clay brick wall has proved to have the best behavior from building and maintenance cost, safety and intensive use health risks of workers point of view, variables all related with economical building aspects. On the other hand, from a sustainability point of view it is proven that the ½ foot clay brick wall with rock wool insulation and 4 cm clay brick sheeting had the best environmental sustainability behavior.

It's proven that from an environmental sustainability point of view, traditional materials and masonry construction systems are less polluting than concrete construction systems, showing advantages in building design when the sustainability concepts are applied at the stage of selecting materials and construction techniques.

Keywords: eco-design; sustainable building; LCA; elevator hoist-way; sustainability

1. INTRODUCTION

The energy consumed in the making and construction process is inherent to any type of activity. It implies changing and altering the environment and entails a serial of environmental impacts. The building sector delivers one of the greatest carbon dioxide emissions to our atmosphere, most of which is due to the high energy consumption derived from the making of building materials. Building and its maintenance consumes around a 40% of the materials used in the European Union [1]. The hoist sector has a considerable dimension in Europe given that there are 4 million installed up to date, with a growth rate of about 120.000 new lifts per year.

The hoist-way is a vertical structure closed by three sides, which fits one or more lifts and includes a pit and a room for the machinery. From the energetic demand limitation view, they are considered non inhabitable environments, needing to be isolated for two reasons: thermal and acoustic. Its structure must withstand the efforts produced by the machinery, the guide-ways (as a consequence of the emergency stopping system), the load in the cabin being out of centre, the stress caused by the shock absorbers in the case of impact and the tensions delivered by the anti-bounce system [3].

Although records which compare constructive systems in exterior and interior partitions do exist, there are no preceding studies related to the constructive techniques about residential building hoist-ways. Anyhow, there are previous studies

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about outer partition walls in which sustainability from several points of view such as consumed and saved energy and CO_2 [4] emissions are a matter of analysis.

Kyoung (2011) analyses the ones built with curtain wall and transparent elements [5] evaluating the overall energy consumed in its implementation and maintenance, as well as the CO_2 over a 40 year period and a building material transportation distance of 50 km.

Chia-Jen and Kang (2009) analyse the environmental impact of two material's acoustic characteristics (brick and stone) and five housing typologies with the use of ENVEST and CADNA software, obtaining different environmental impact values [6].

Cuéllar-Franca and Azapagic (2012) carry out a life cycle study of three housing typologies in the UK taking in to account their use and demolition over a period of 50 years [7].

Concerning the hoist-ways, Farh (2002) investigated the way of minimizing the pillars execution cost which define the hoistway structure, not considering the life cycle, the environmental impact or the sustainability of each structural system [8].

Brouna and Menziesa (2011) analysed UK's three most common partitions, the clay brick, the concrete block and the timber frame, using the ACV method [9]. Timber frame delivered less environmental impact and clay brick the most.

Chau et al (2012) analyse the emission of five types of material compositions along 60 years in an office building [10], coming to the conclusion that reusing the residue or remains from the same building can reduce the carbon foot-print in a 5,9% and that reusing resources and regional materials could diminish carbon foot-print in 3,2% and 3,1% respectively.

As far as applied sustainability refers in constructive elements [11], there are records [12-13] which compare the environmental impact of different constructive solutions, measuring their decomposing emissions from the basic materials they are made with.

The aim of this work is to compare from a sustainability perspective, the environmental impact of different construction systems in hoist-ways using life cycle analysis based techniques and the carbon foot-print estimation, quantifying consumed energy in the materials, the building process, the use of facilities and the partitions demolition, coming up with indicators related to the constructive process, grouped in to a socio-economic and environmental sustainability.

In order to create a sustainable construction model, it is important to carry out this type of researches due to the outcome of new tools which allow the differentiation between solution and alternative concepts or designs regarding their efficiency and environmental impact, which also have an added value as a contribution to the consciousness of the building sector.

2. HIPOTHETICAL STARTING POINT

To analyse how the partition has its influence in the environmental variables, a serial of constructive solutions have been studied which are common to residential building hoist-ways. The description of each one of these partitions figures in Table 1.

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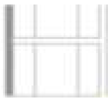
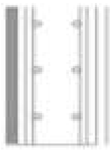
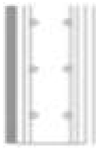
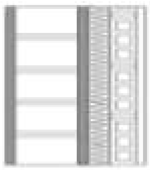
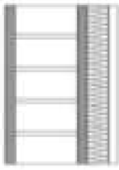
Type	Description	Constructive Section	Weight (kg)	Thickness (m)	Surface (m^2)
1	Perforated 1 foot thick 24x11x7 cm plain clay brick wall, laid with CEM II/B-P 32.5 N cement mortar and M-5 type river sand, all prepared at provider's site and delivered to building site. Inner claddings consist on a base coat and a setting of plaster 1.5 cm thick, and with a 1.5 cm cement mortar coat on the outer rendering.		360,72	0,27	1,83
2	Standard hollow concrete 40x20x20 cm bricks, laid with CEM II/B-M 32.5 N cement mortar and M-5 type river sand, filled with concrete of 330 kg/m^3 cement concentration, and B-500S reinforcing framework. Inner claddings consist on a base coat and a setting of plaster 1,5 cm thick, and with a 1,5 cm cement mortar coat on the outer rendering.		347,26	0,23	1,52
3	HA-25N/mm^2 reinforced concrete, plastic consistency, 20 mm Tmax for normal ambient, prepared at provider's site, with B-500S reinforcing framework casing and uncasing with two-sided fibreboard, poured manually and vibrated. Inner claddings consist on a base coat and a setting of plaster 1.5 cm thick, and with a 1.5 cm cement mortar coat on the outer rendering.		402,74	0,15	0,94
4	Prefabricated, 15 cm thick, reinforced concrete, made with HA-40 N/mm^2 concrete, 20 mm Tmax, plastic consistency, 20 mm aggregate, mobile crane assembly, and rubber-asphalt putty sealed joints. Inner claddings consist on a base coat and a setting of plaster 1.5 cm thick, and with a 1.5 cm cement mortar coat on the outer rendering.		443,41	0,18	1,15
5	Perforated 24x11x7 cm plain clay brick, ½ foot thick in the wall's inner side, laid with CEM II/B-P 32,5 N cement mortar and M-5 type river sand, all prepared at provider's site. Outer and inner rendering with cement mortar and river sand 1,5 cm thick each layer, 4 cm thick rock wool isolation with 40 kg/m^3 thickness and density with nylon attachments, coated with 4 cm single hole clay bricks laid with 1.5 cm thick M-5 cement mortar and a 15 mm plaster dressing.		299,86	0,195	1,26
6	Perforated 24x11x7 cm plain clay brick, ½ foot thick in the wall's inner side, laid with CEM II/B-P 32,5 N cement mortar and M-5 type river sand, all prepared at provider's site and delivered to building site. Coated with 3 cm thick rock wool panels. Lined with a panels structure made of galvanized stainless steel sheet on the outer side, with omega type profiles and 15 mm thick cardboard-plaster panel on the inner side.		229,68	0,141	0,88

Table 1: Constructive typology analysed

Once the efforts and requirements that each partition must withstand have been identified, we proceed to its measuring, to later make an inventory of materials, workforce and peripheral means used in the hoist-way's construction, checking the fulfilment of the established minimum legal regulations concerning thermal and acoustic isolation. Further on, an inventory of each one of those materials is done, using LCA techniques [14].

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Fig. 1: Architectonic solutions commonly used in hoist-ways

For the development of the research, a 450 kg load lift for handicapped people has been considered, with a capacity for 6 people and a speed of 1.6 m/s, with cabin dimensions of 1.00 x 1.25 m, automatic opening telescopic doors with 0.80 m shifting and 2.00 m high, installed in a residential three-storey building. The partition of the lift has been considered to be placed inside the building, as detailed in figure 2. The hoist-way is 1.55 x 1.70 m at the floor and is formed by 4 walls out of which one of them has the door spacing, considering a 3 m free height between floors.

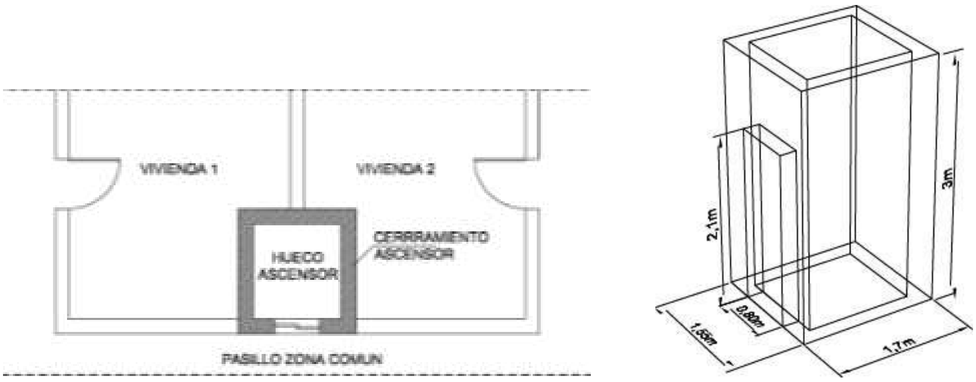

Fig. 2: Blueprint implementation and dimensions of the hoist-way

Geographically, the building has been placed in the town centre of Mérida (Spain), where a C-4 climate zone has been assigned in accordance with the Spanish TEC (Technical Edification Code) [15]. One of the main design conditionings is the thermal and acoustic isolation for energetic efficiency reasons and to avoid the noise and vibration transmission to the inhabitable spaces of the building.

We define enclosure system as to what serves to contain the buildings equipment, whether individual or collective [16]; therefore the lift shaft may be considered as such. When the lift's machinery is in an independent machine room, the lift shaft must have a weighted acoustic reduction index A (Ra) higher than 50 dB, which is calculated using the expression 1.

$$Ra = 36{,}5 \times \log(m_1 + m_2 + \cdots + m_n) - 41{,}5 \quad (1)$$

Where Ra is the weighted acoustic reduction index in A, expressed in decibels A and m_i the mass of each of the planes which form the partition, expressed in kg.

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The thermal isolation has been calculated in base of the Basic DB-HE [15] Document, considering an average energetic demand of 25 kWh/m^2 in the occupied facilities. To do this, the thermal resistance of each of the partitions is calculated, considering that R_t will be the overall thermal resistance of a component made of thermal homogeneous layers. It is calculated with expression 2.

$$R_t = R_{si} + R_1 + R_2 + ... + R_n + R_{se} \quad (2)$$

Where R_1,...R_n are the thermal resistances of each defined layer in accordance with expression (3) expressed in m^2 K/W, R_{si} and R_{se} are the superficial thermal resistances corresponding to the inner and exterior air expressed in m^2 K/W.

The thermal resistance of a thermal homogeneous layer is defined by expression 3:

$$R = \frac{e}{\lambda} \quad (3)$$

Where e is the thickness of the layer in meters and λ the designed thermal conductivity of the material that forms the layer's material, calculated from the UNE-EN-ISO 10456 in W/mK.

The consumption calculation has been done taking into account and average life span of 50 years for the building, value usually used in the calculation of structure life span and imposed in the CTE and in the Technical Datasheets of the ITEC [17].

In the process of calculation it was assumed that transport in the connection to the different life cycle stages is done by lorry which uses diesel fuel and has an energetic demand of 0.00073 kWh km^{-1} kg^{-1} [18]. Added to this an average run of 100 km was estimated for materials transportation to the building site and 15 km to the authorised dump site. For the emissions derived from energy sources, the ones corresponding to the Spanish electric mix [19] have been used.

As a functional unit of comparison the partitions surface was used, taking the m^2 as the measure unit. The emissions, energy and the materials refer to the following ones, respectively: MJ/m^2, kg CO_2/m^2, €/m^2.

In all cases it has been considered to have coat the inner surface with CEM II/B-P t 32.5-N type M-5 mortar, mixed on site with mortar with 300 kg/m³ of cement with a 1/5 volume proportion and no paint has been taken into account for the external surface.

3. METHODOLOGY

The life cycle analysis is a methodology which quantifies and characterizes the different potential environmental impacts which are associated to each of the stages of a products life span [20]. During the study, Life Cycle Analysis (LCA) techniques have been used applying UNE-EN-ISO 14040:2006 and 14044:2006 standards, dividing the life of each material which form part of the closure into 5 stages [21-22]: production, which includes the extraction of raw materials and their production process, the expedition of materials to consumption point, the work consumed by placing all resources used on the construction process, the life cycle of the used resources and demolition and recycling.

To determine the energy used in a construction and the environmental emissions, the BEDEC PR/PCT (2012), the bank of prices of the Catalan Institute of Building Technology has been used [23]. In the products which have been manufactured using recovered energy from either material or energy which may have been obtained from residue [24], the evaluation of the recovered energy has been calculated according to expression 4.

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$$Er = \frac{(R-E)}{(R-E)+P} \times 00 \quad (4)$$

Where *Er* the net recovered energy is expressed in %, *P is* the quantity of energy from primary sources used in the building process, *R* the energy resulting from the process of recovering energy and *E* the amount of energy used from primary sources in the recovering process, all expressed in MJ.

To determine the materials costs and performances and labour cost used in the execution process, the Base Prices CENTRO [25] have been used because they are the most commonly used in the analysed location. To calculate the economic cost of the closings, an average cost of 14.50 €/h per skilled worker and 13.50 €/h in the case of unskilled workers were estimated, meanwhile a cost of 13 €/h was estimated for the production process of materials. In the calculating process each construction unit has been decomposed in simple units in accordance to the professions which were involved in the constructive process.

On Table nº 2 the energy values are exposed, the CO_2, SO_2, NO_2 emissions and the specific weight used to quantify the environmental impact.

Material	MJ/kg	kgCO$_2$/kg	kgSO$_2$/kg	kgNO$_2$/kg	kN/m^3
Acrylic putty	20.00	2.95	0.0381	0.0020	17.00
Additive	93.00	13.73	0.1779	0.0096	10.40
Cement	3.78	0.83	0.0083	0.0004	14.00
Ceramic	2.76	0.21	0.0053	0.0003	13.50
Concrete block	2.35	0.22	0.0038	0.0002	16.00
Diesel	10.10	0.00	0.0034	0.0554	8.90
Gravel	0.15	0.01	0.0003	0.0000	20.00
Gypsum	1.80	0.16	0.0034	0.0002	9.70
Laminated gypsum	6.28	0.36	0.0120	0.0006	8.00
Lime	4.82	0.84	0.0092	0.0005	11.50
Mold-release compound	99.95	14.76	0.1913	0.0103	9.00
Nylon	100.00	14.79	0.0041	0.0002	11.40
PVC	70.00	10.33	0.1336	0.0072	13.60
Sand	0.15	0.01	0.0003	0.0000	18.60
Stainless steel	41.16	3.08	0.0794	0.0043	80.00
Steel	35.00	2.82	0.0670	0.0036	78.50
Stone wool	22.33	1.41	0.0322	0.0017	0.35
Tar putty	10.00	1.47	0.0191	0.0010	12.00
Water	0.20	0.00	0.0000	0.0000	10.00
Wood	14.00	0.83	0.0073	0.0004	5.00

Table 2: Energetic and emission values from basic materials

Preventive maintenance has been taken into account in each partition [26] estimating the costs over a period of 10 years, depending on the materials used on the construction. The CYPE [27] base has been used, for it is the one which best fits the proper specifications of the location of the modelled building.

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4. RESULTS

To facilitate the results interpretation, the following results have been grouped regarding their socio-economic or environmental sustainability.

4.1. Environmental indicators

4.1.1. Invested energy

The energy consumed in the constructive process is an indicator of the needed building energetic effort and makes a record of the energy used in the making process of each material used in the constructive process [28], as well as the needed energy for its arrangement in the construction. The needed energy of the analysed closures is exposed in the Figure 3.

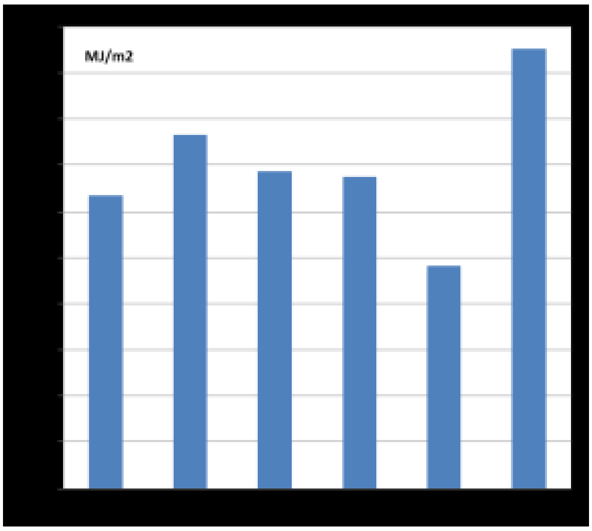

Fig. 3: Energy invested in the constructive process

We observe that from the perspective of invested energy in the process, the closure which less energy consumed was type 5, where type 6 needed the most due to the inclusion of wall sheeting of galvanized steel profiles which require a greater amount of energy for their production.

4.1.2. CO_2 emission

Carbon dioxide emission is a variable which shows the environmental impact of the building and is directly related to what we know as the Green House Effect which is related to the Global Warming [29]. Gas emission to the atmosphere is measured in equivalent kilograms of CO_2, points out the Global Warming Potential (GWP) due to the sorts of gases emitted during production and placed at building site of the construction materials which are Green House Effect Generators (GHEG) [30].

On Figure 4 there is a representation of carbon dioxide emission per surface unit during the making process, construction, use and demolition of each type of closing.

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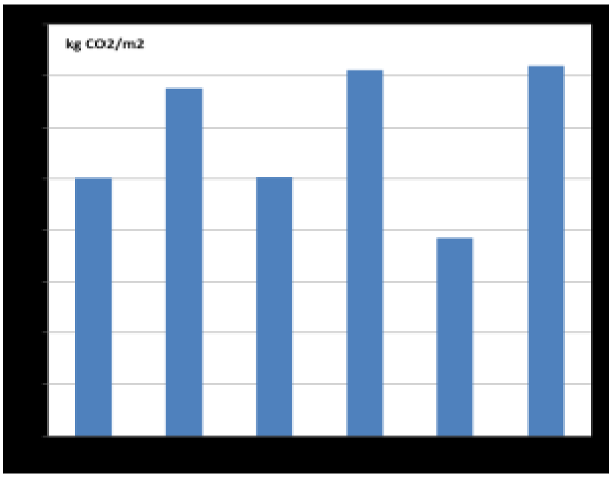

Fig. 4: CO_2 emissions in the process

We see type 5 closing emits the least CO_2 emissions, where type 6 delivers the most. This situation coincides with the one observed in point 3.1, although in this case we must point out that the closings with a greater amount of concrete in its composition have a more unfavourable behaviour.

Other gases derived from the making, transporting and building of the partitions process, such as carbon monoxide, or Fluor-Carbon compounds, which also cause the Green House Effect has been taken into account in the investigation.

4.1.3. Residue generation

The residue generated in the process, has been classified in four types: plastics (150102), cardboard paper (150101), wood (150103) and dangerous residue, for which a selective separation is used in accordance with the European Residue List (ERL) [31].

In Figure 5 the amount of residue generated per built surface unit for each constructive typology, is exposed.

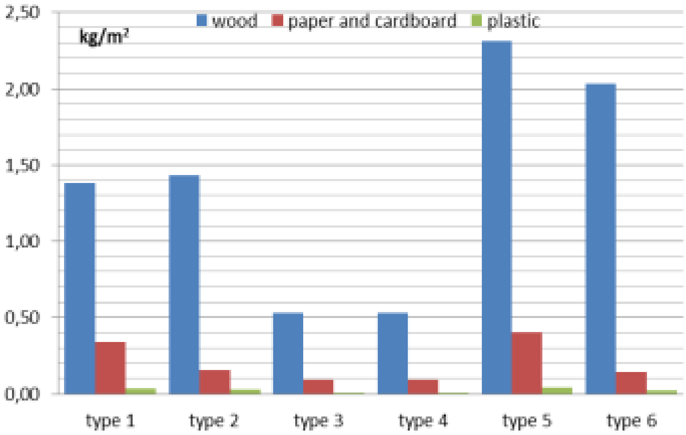

Fig. 5: Residue generated in the process

The greatest residue generated corresponds to the type 5 partition and the least we find on type 4 partition.

4.1.4. SO_2 and NO_2 emissions

Sulphur dioxide and nitrous oxide emissions, are the potential acidification and eutrophication indicators which these gasses generate during the making, transporting and installing of building materials on site. Figure 6 shows the sulphur and nitrous dioxide emission per surface unit.

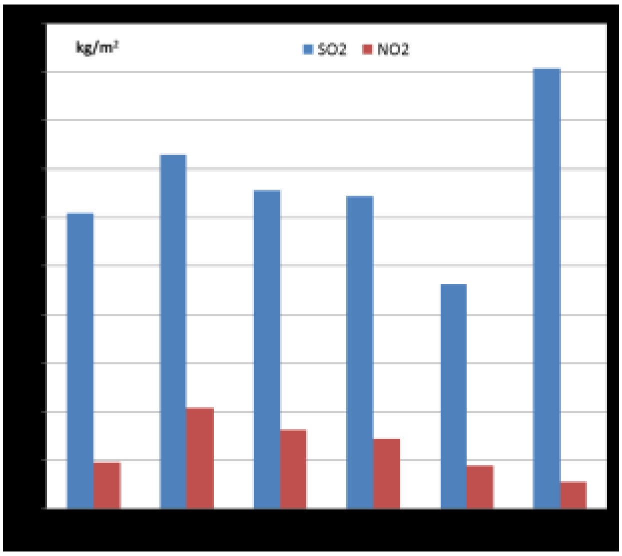

Fig. 6: SO_2 and NO_2 emissions

We see here that, from an emission perspective the partition type 5 has less emissions and type 6 has the most SO_2 and less NO_2.

4.2. Social-Economic indicators

4.2.1. Quantity and quality of workforce

On table nº3 we see the amount of workforce needed for the construction of hoist-ways depending on the constructive typology, expressed in labour hours per built surface unit (h/m^2).

type	Skilled worker (h/m^2)	Assistant (h/m^2)	total (h/m^2)
1	1.32	1.48	2.80
2	1.43	1.70	3.13
3	1.48	1.67	3.16
4	1.83	1.87	3.70
5	1.87	2.06	3.93
6	1.39	1.48	2.87

Table 3: Necessary workforce per built surface unit.

Partition type 5 requires more hours work per built surface unit compared with the rest of partitions. This circumstance which may be considered negative at first could turn out to be a decisive function in its influence with the final cost of the closure.

To compare the workforce proportion towards the materials which are used in the partition, a value called workforce intensity is defined as a relation between the labour costs used building the partition per surface unit and the total execution cost. The workforce intensity per constructive typology is exposed on table 7.

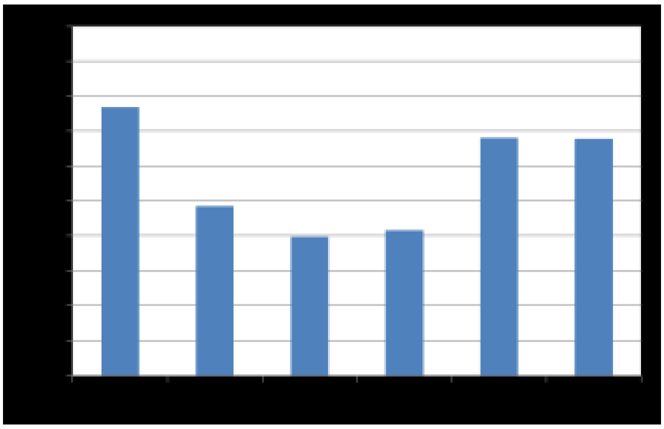

Fig. nº 7: Workforce intensity

We can observe that where ceramic building materials are used the amount of workforce intensity is greater and the opposite happens when concrete is used as the main construction material. This means that for each Euro of partition cost, in the first ones the greatest part is invested in workforce, especially in the mounting phase.

4.2.2. Execution cost

Execution cost is the indicator used to analyse the economic viability of each of the closings used [32]. The construction process cost per surface unit is shown on figure 8, workforce included, materials cost and the needed auxiliary means required for its construction, without taking indirect costs and general expenses, nor industrial benefits into account.

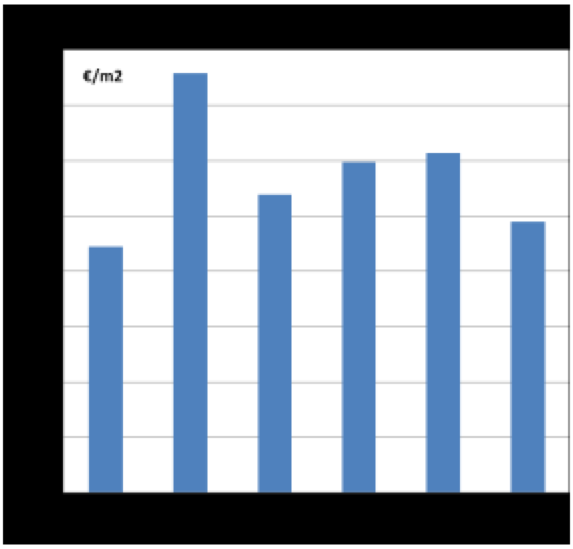

Fig. nº 8: Material execution cost per closure type.

It is shown that the lowest cost per surface unit corresponds to type 1 closure and type 2 has the highest cost.

4.2.3. Maintenance cost

The decennial maintenance cost is an economical evaluation sum which accounts for the closure maintenance for ten years after it was built, attending the operations expected in the calendar within the Buildings Maintenance Plan [27].

Figure 9 shows this indicator.

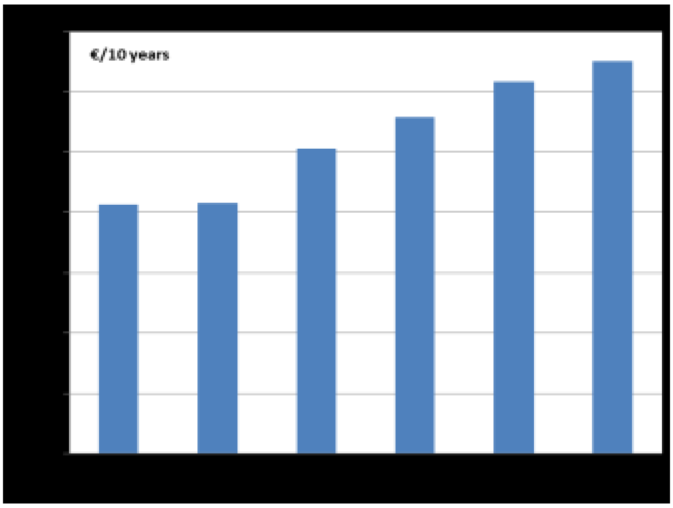

Fig. nº 9: Decennial maintenance cost

We see how the partitions built with the common perforated clay brick or with concrete reinforced hollow concrete block have the lowest maintenance cost and the highest cost is for type 6 partition.

4.2.4. Intrinsic execution risk

To analyse the intrinsic risk in the buildings execution, required safety and health measures have been taken into account in order to guarantee safety during the execution process, together with the auxiliary means. To do this, the materials gathering process is analysed at the building site, mounting, placing and the use of auxiliary means. In figure 10 it can see the execution intrinsic risk, classified from 0 to 5, from a smaller to a higher building labour incident risk.

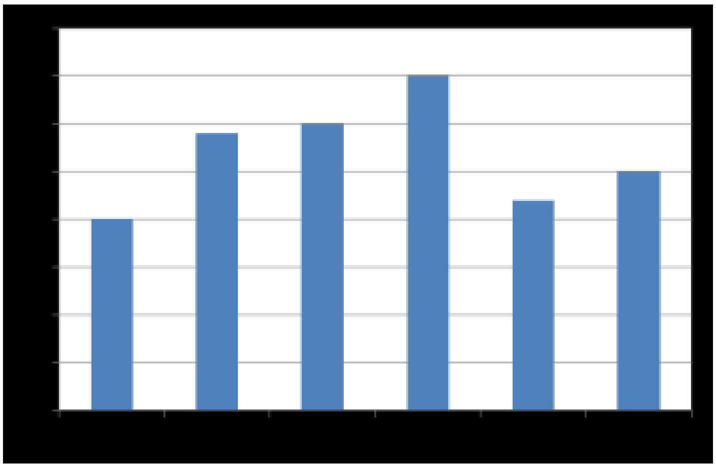

Fig. nº 10: Intrinsic execution risk

You can see that reinforced partitions (types 2, 3 y 4), have a higher risk at execution and therefore do require greater preventive measures.

5. CONCLUSIONS AND DISCUSIÓN

Although all the constructive solutions analysed are equivalent referring to their carrying capacity, in quantitative terms they aren't homogeneous in their environmental balance. To highlight the results of this research, all the analysed indicators have been grouped according to their characteristics in environmental and social-economic characteristics, referring in proportion to common clay perforated brick, this is, type 1 closure. This means that a 125 % value indicates that its absolute value surpasses by 25 % to what type 1 closing has.

Any praise has been avoided amongst the indicators to not include subjective parameters in the design process, handing this decision to the designer criteria.

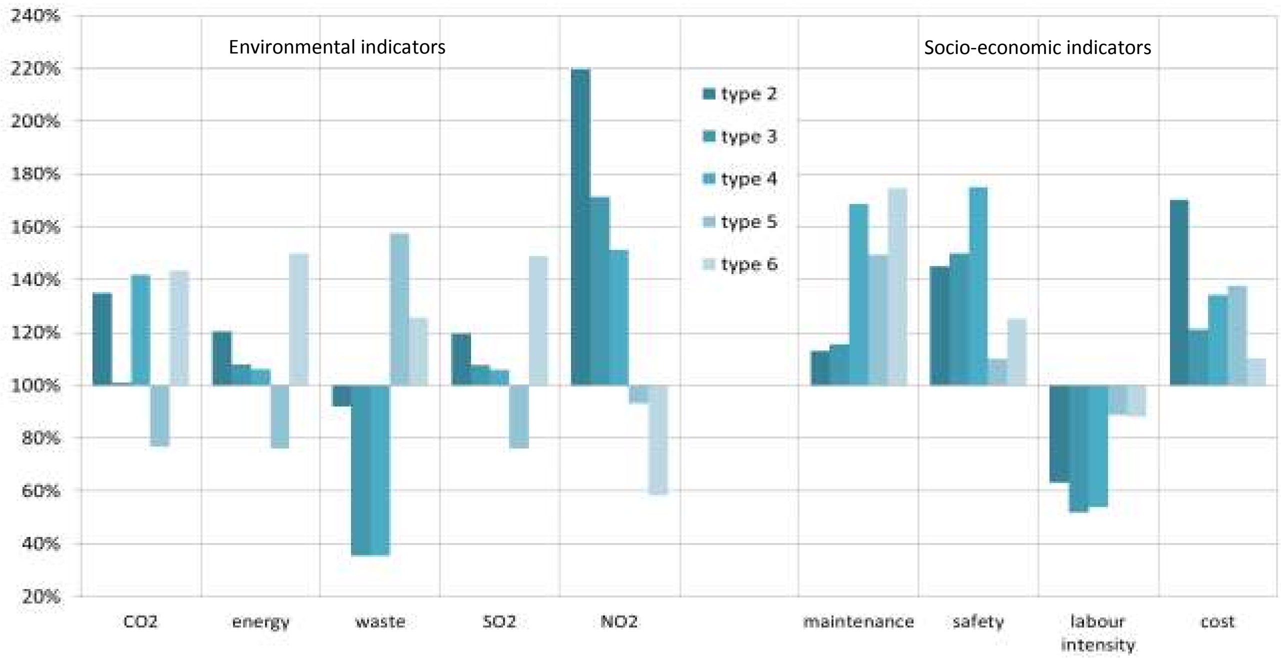

Fig. nº 11: Percentage ratio of environmental indicators

It shows up that closure type 1 offers the best behaviour from the execution cost point of view, maintenance cost, risk in security matters and health and intensity of workforce use, variables which are all related to socio-economic aspects.

Nevertheless, from a sustainability point of view, the closures which show the best behaviour regarding environmental impact, are the half foot thick, rock wool isolation and ceramic sheeting, which corresponds to type 5 which also has the lowest CO_2 emission and less energy needs with the materials production as well as in the building execution, allowing for a great reusing and recycling capacity.

It is proven that the use of constructive systems based on traditional techniques and conventional materials is less polluting than reinforced concrete and, although they need a greater workforce, this may be an advantage in scenarios where the unemployment rate is high and in periods of economy recession. It is also obvious that systems based on sheeting with plaster or cardboard panels are less efficient, from a sustainability view, than the ones that use ceramic materials.

The main improvement opportunities in the residential sector are found in the designing stage, for which the ACV method is used, because the decisions taken at this stage determine the impacts of a building during the rest of its life span. The research backs up the importance of taking into account the design phase, the environmental impact of each

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of the materials used in the building, including the efficient use of energy in order to achieve a more sustainable housing park.

The phase of building use hasn't been taken into account in the analysis, it has been left for future researches. The investigation has been focused on the constructive process impact only.

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