APPROXIMATION TO THE CALCULATION OF THE ENERGY EFFICIENCY OF VENTILATED FAÇADES AND THEIR ENVIRONMENTAL IMPACT

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ABSTRACT

Today's architecture is increasingly interested in new solutions for building façades, such as the ventilated façade, mainly for aesthetic and energy efficiency reasons. The environmental advantage of the ventilated façade in comparison with the conventional ceramic double-leaf façade with inside insulation has not been sufficiently studied. In this study, we propose the method of carrying out this analysis through the use of the Lider 1.0 and Calener VYP 1.0 software for energy simulation in façades and the Life Cycle Analysis methodology for calculating the environmental impact. Since the algorithms for ventilated façades are not included in Lider 1.0 or Calener VYP 1.0, we use the method proposed in standard UNE-EN ISO 6946 to introduce the ventilated façade. For this, our proposal for calculating the energy efficiency and the environmental impact is an approximation, which can be improved when there are more precise calculation tools for the energy simulation of ventilated façades in Spain.

1. INTRODUCTION

Today's architecture is increasingly interested in new solutions for building façades, such as the ventilated façade, mainly for aesthetic and energy efficiency reasons. A ventilated façade in Spain usually consists of three main elements: leaf of perforated brick which is the base wall, insulation on the outside of this base wall and an external trans-ventilated cladding, which is often ceramic, anchored to the base wall by means of an aluminium sub-structure. Its energy performance is better than that of the ceramic double-leaf façades with internal insulation, which are widely used in southern Europe [1], for two main reasons:

- In the first place, because the outside insulation significantly reduces the problems of thermal bridges associated with the ceramic double leaf [1].
- Secondly, due to the effects of the ventilated chamber. The air current that circulates inside the façade insulates the building from the external thermal conditions and reduces the building energy demand [2].

The energy saving percentage ascribed to the energy façade in Spain is 25-40%. However, the literature does not specify in comparison with what this saving is obtained. It may be inferred that it is in relation to conventional façade solutions, but it is not specified when this tends towards one extreme (25%) or the other (40%). Also, these data on energy saving are prior to the Technical Building Code (TBC) coming into effect [3], which suggests that the range of values in which this energy saving moves may have varied, since construction practices in Spain are also changing in order to adapt to the new requirements. For these reasons, in our view, the energy saving due to the use of ventilated façades in comparison with ceramic double-leaf façades with internal insulation is not currently known.

In this study, our objective is not only to address the energy saving of ventilated façades in comparison with the ceramic double leaf, but also to analyse their life cycles, because the construction materials used in the construction systems also have associated impacts [4]. For example, in the case of the ventilated façade, the aluminium profiles have a high environmental impact which deserves to be compared with the impacts associated with energy consumption. The scientific community has accepted that the only method through which a fair environmental comparison can be made is Life Cycle Analysis (LCA), according to which all stages of a building's life must be considered. According to the Athena Institute, the stages to be taken into consideration are as follows [5]:

- Extraction of raw materials. This stage includes the collection, exploitation of mines or quarries, and activities like reforestation and raw materials transport.
- Manufacturing. This stage includes the energy and the emissions associated with the manufacturing of the construction products used, including their packaging, and possible associated transportation.

- Installation. This stage includes the transport of the construction products from the factory to the distributors and from these to the building site, as well as the energy and resources consumed while the façades are being built.
- Occupation/maintenance, also called "the use stage" or the "operational stage". This stage takes into consideration functions like heating, cooling, artificial lighting, the use of water, and the use of new maintenance products like paints, varnishes, floorings, and other types of finishes.
- Demolition. This stage marks the end of the building's life. It includes the energy and resources consumed during its demolition, and the transport involved.
- Recycling/reuse/withdrawal. This stage includes the treatment the building materials receive after demolition, such as recycling, reuse, withdrawal to the landfill or incineration, as well as the processing and transport involved.

In buildings, the stage with the highest environmental impact is the occupation/maintenance stage due to its long useful life [6]. This is why, when the environmental impact of solutions for building envelopes are assessed, as we do here, the use stage can be expected to tend to dominate the overall profile of the life cycle. However, in the literature, some studies on construction systems do not consider the use stage, for example [7]. In this study, we propose a method for analysing the life cycle, including the use stage. The method consists firstly of calculating energy consumption in thermal conditioning and then including these data in the comparative LCA.

2. RESEARCH METHODOLOGY

The research methodology consisted of:

1) Proposing a calculation method by using energy and environmental impact simulation software.
2) Applying it to a specific case (a detached single-family home).
3) Studying the contributions and limitations of the proposed method.

3. METHODOLOGICAL PROPOSAL FOR THE COMPARISON OF ENERGY SAVING AND THE ENVIRONMENTAL IMPACT OF A VENTILATED FAÇADE AND A CERAMIC DOUBLE-LEAF FAÇADE WITH INTERNAL INSULATION

The analysis methodology consists of carrying out a comparative LCA of the two types of façade taking the use stage into account.

The LCA methods follow the principles set out in the ISO 14040 standards. These describe four general steps that have to be taken in any LCA, which are detailed below:

a) Definition of **objectives and scope**. This step involves defining the reasons why the study is being carried out. An important part of it is also the definition of the functional unit, understood as the number of different solutions capable of providing the building with the same function. The definition of a functional unit allows us to compare solutions in a fair way.

The objective of the comparison between the ventilated façade and the ceramic double-leaf façade with internal insulation is to find out which of the two solutions is better from an environmental point of view, to what extent and in which cases. Therefore, the analysis must be done for different types of buildings, facing in different directions, in different climate zones, etc., as well as for ventilated façades with different characteristics (chamber thickness, type of anchorage, etc.) and ceramic double-leaf façades with different characteristics.

In this paper, we only define the methodology to be used and we apply it to only one case (only one type of building), facing in two different directions and in each one of the different Spanish climate zones.

Since the TBC sets different demands on the envelope in the different climate zones, the simulated façade solutions in each zone must be different. In this study, the façade solutions considered in each climate zone match the TBC requirements, without exceeding them, except to adapt the solution to products with a commercial format.

The functional unit to be considered is 210 m^2 of the above-mentioned façade solutions. The building useful life to be considered is 100 years for an average degree of preservation [8].

b) **Inventory analysis**. In this stage, the processes and activities involved in the manufacturing of a product or in achieving a result are compiled. In the case of construction systems, this involves all the previously mentioned stages of the building life. It is important to point out that when it is a case of an element of the envelope, such as the façade solutions, in the method we propose here, the use stage will include the energy consumption during the building's life, for which the construction element is responsible.

The thermal conditioning energy we save in a building does not only depend on its façade solutions, but also on other parameters like the other solutions used for the rest of the elements of the envelope, or the climate zone in which it is located, the degree to which the building is buried, the direction it faces, the amount of glazing surface, the renewals/time of its spaces, the possible thermal bridges present in the building, the thermal conditioning installations, etc. For this reason, it is difficult to ascribe absolute loads of operational environmental impact to one type of façade.

In order to solve this problem, it is better to establish a comparison in a way that, by analysing two identical buildings, except their type of façade, we can ascribe an amount of energy saving of one façade solution (in this case, the ventilated façade) as an environmental load to another solution (in this case, the ceramic double-leaf façade with internal insulation). In other words, the operational and environmental loads resulting from the thermal conditioning energy consumptions of buildings will always have to be relatively calculated.

For calculating the energy saving, the use of two tools is proposed:

- The free Lider v1.0 software [9], which helps to check if a building complies with the new energy demands in Spain [3, 9], in response to Directive 2002/91/CE which established the need to prepare methodologies for the energy assessment of buildings [10]. Some aspects with regards to its use should be mentioned:
  - It is worthwhile considering the thermal bridges in [11], which are more precise than those included by default in the Lider v1.0 software.
  - Since the algorithms for ventilated façades are not included in Lider v1.0, for the introduction of the ventilated façade, we use the method proposed in standard UNE-EN ISO 6946 [12]. In this standard, it is indicated that the total thermal resistance of a building element containing a highly ventilated air chamber is obtained by disregarding the thermal resistance of the air chamber and the other chambers between the layer of air and the external atmosphere, and including an external surface resistance corresponding to still air. In the case of the ventilated façade, we disregard the thermal resistance of the ceramic cladding and the chamber, and we include an external surface resistance of 0.13 $m^2 \cdot K/W$, instead of 0.04 $m^2 \cdot K/W$. To do this in the Lider v1.0 software, a fictitious material needs to be created with the thermal resistance 0.09 $m^2 \cdot K/W$, which is the difference between the previous surface resistance values.
- The free Calener VYP v1.0 software [13] is used for calculating the thermal conditioning energy consumption. This version of the software not only allows the energy efficiency of buildings to be assessed [10], but it also allows their energy consumptions to be established. To use it, data are imported from the Lider v1.0 software, and data are introduced of the thermal conditioning equipment.

Once the simulation has been carried out, the data on the final energy consumption of the heating and cooling of the building being studied are taken, because these are the data that refer to the use stage to be introduced into the environmental impact calculation software, SimaPro 7.0.

c) **Impact evaluation**. This stage follows several steps which, according to the international nomenclature, are: classification, characterisation, and normalisation. Classification means assigning the inventory data to impact categories, classified according to their potential impact on the environment, human health, and resources. In the characterisation, the potential contribution of each compound found in the inventory analysis is calculated for an environmental purpose. In the normalisation, the data described are normalised by dividing them by the actual or expected magnitude of each one of the impact categories for a certain geographic area and temporal moment. In order to be able to compare the environmental impacts of two different solutions, the LCA needs a final assessment step which allows the different impact categories to be weighted, but this step is not normalised. This has always been a debated subject, for it is difficult, for example, to decide whether acidification is more or less important than the use of the land.

On the other hand, without the assessment step, different environmental profiles cannot be compared. As discussed in [14], making a comparison based on the points obtained for each environmental effect is like applying a weighting factor of 1 to each one of them, which is less preferable than using carefully considered weighting factors. This is the reason why we suggest using the assessment step for the final comparison.

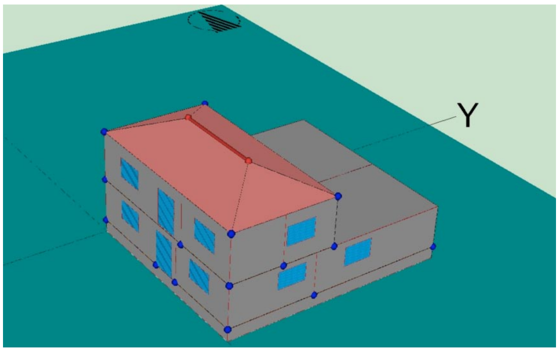
There are different methods for assessment, each one with its advantages and disadvantages [14]. However, the cost-based methods are the ones that are considered most reliable [14]. On the other hand, the ISO requires that important impact categories, like the use of the land, suspended particles and noise, should not be left out. As discussed in [15], the most complete method that includes these categories, and which is based on environmental costs, is the Swedish EPS 2000 method [16]. This is why we propose it for carrying out the assessment.

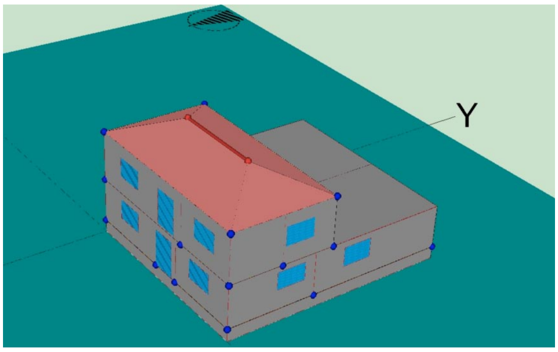
d) **Interpretation and conclusions**. This is the last stage and it combines the information obtained in the inventory stage with the evaluation of impacts to reach conclusions with respect to the study's objectives and scope.

4. CASE STUDY

4.1. Objective and scope.

The case study we present here is a comparison between the ventilated façade and the ceramic double-leaf façade with internal insulation used in a detached single-family home. We have carried it out for two cases facing in different directions in each one of the climate zones identified in the TBC, to find out if the ventilated façades are more beneficial as a function of the harshness of the climate or the orientation. Of the two orientations, from an energy point of view, the best is the one where the lounge and the kitchen face south, and only three windows – one in each bathroom and one in the garage – face north. The worst orientation is where the garage faces south (figure 1a) and six windows or glazed doors face north (figure 1b).





(a) (b)

Figure 1. Best (a) and worst (b) orientations considered in the study.

The characteristics of the studied building envelope are shown in table 1.

The following thermal conditioning installations have been taken into account for the case study:

- For cooling, multi-split inverter systems.
- For heating, radiators, with a mixed natural gas atmospheric boiler with a power of 28 kW.

4.2. Inventory analysis.

4.2.1. Materials stage.

This stage includes the environmental loads due to raw materials extraction, manufacturing, and the installation on the building site. Table 2 shows the data taken into account.

Climate zone	Characteristics of the building envelope		
Group 1: A3 Malaga A4 Almeria B3 Castellón B4 Seville	**Ceramic double leaf**: - 11.5 cm face brick - 1.5 cm mortar - 2 cm air chamber - 4 cm rock wool[1] - 7 cm ceramic HB - 1.5 cm plaster	**Ventilated façade**: - Ceramic cladding. - 2 cm vent. chamber. - 4 cm rock wool - 11.5 cm PB - 1.5 cm plaster	**Windows**: - Metal profile with no thermal bridge rupture for A3 and A4 and with thermal bridge rupture of 4 to 12 mm for B3 and B4 - 4-6-4 glazing
	Sloping roof: - 10 cm tiles - 3 mm waterproofing - 3 cm mortar - Ventilated chamber - 4 cm rock wool[1] - Beam and pot reinforced concrete 25+5 deck - 1.5 cm plaster	**Flat roof**: - 7 mm ceramic tiles. - 3 cm mortar - 4 cm rock wool[1] - 3 mm waterproofing - 10 cm slope form. - Beam and pot reinforced concrete 25+5 deck - 1.5 cm plaster	**Sanitation deck**: - 7 mm ceramic tiles - 5 cm self-lev. mortar - 4 cm rock wool[1] - Beam and pot reinforced concrete 25+5 deck - Ventilated chamber
	Inside partition: - 1.5 cm plaster - 7 cm ceramic HB	- 4 cm rock wool[1] - 7 cm ceramic HB - 1.5 cm plaster	
Group 2: C1 Santander C2 Barcelona C3 Granada C4 Badajoz	**Ceramic double leaf**: Same as group 1, but: - with vapour barrier[2] - 5 cm rock wool[1]	**Ventilated façade**: Same as group 1, but: - 5 cm rock wool[1]	**Windows**: - Metal profile with thermal bridge rupture over 12 mm - 4-6-4 glazing
	Sloping roof: Same as group 1, but: - 5 cm rock wool[1]	**Flat roof**: Same as group 1, but: - 5 cm rock wool[1]	**Sanitation deck**: Same as group 1, but: - 5 cm rock wool[1]
	Inside partition: Same as group 1		
Group 3: D1 Pamplona D2 Logroño D3 Madrid	**Ceramic double leaf**: Same as group 2, but: - 6 cm rock wool[1]	**Ventilated façade**: Same as group 2, but: - 6 cm rock wool[1]	**Windows**: - Metal profile the thermal bridge rupture over 12 mm - 4-12-4 glazing
	Sloping roof: Same as group 2, but: - 6 cm rock wool[1] - slightly ventilated air chamber	**Flat roof**: Same as group 2, but: - 6 cm rock wool[1]	**Sanitation deck**: Same as group 2
	Inside partition: Same as group 1		
Group 4: E1 Burgos	**Ceramic double leaf**: Same as group 2, but: - 8 cm rock wool[1]	**Ventilated façade**: Same as group 2, but: - 8 cm rock wool[1]	**Windows**: Same as group 3
	Sloping roof: Same as group 2, but: - 8 cm rock wool[1]	**Flat roof**: Same as group 2, but: - 8 cm rock wool[1]	**Sanitation deck**: Same as group 1, but: - 6 cm rock wool[1]
	Inside partition: Same as group 1		

Table 1. Characteristics of the building envelope.

1. $\lambda = 0{,}04 W/m \cdot K$
2. $\rho = 1100\ kg/m^3$, thickness =0,005 m

4.2.2. Use stage.

For the operational stage, the difference in energy consumption between the ceramic double-leaf façade with internal insulation and the ventilated façade was included in the inventory of the ceramic double-leaf façade, because the ventilated façade always entailed lower energy consumption. The energy saving values after 100 years of useful life of the building can be seen in table 3. We have not considered the demolition and withdrawal stages since we do not know the methods that will exist in 100 years. We thus avoid making additional assumptions.

Ventilated façade			Ceramic double leaf		
Products	**Materials and processes in SimaPro 7.0**	**Amounts**	**Products**	**Materials and processes in SimaPro 7.0**	**Amounts**
External ceramic cladding	Keramics I	46 kg/m²	Face brick	Solid facing brick	228 kg/m²
	Transp. distrib.	300 km		Transp. distrib.	150 km
	Transp. to site	10 km		Transp. to site	10 km
Aluminium	Alum. 25% rec.	4,2 kg/m²	Cement mortar	Cement	78,5 kg/m²
	Section bar extr.	4,2 kg/m²		Sand	570 kg/m²
	Transp. distrib.	0 km		Water	80 l/m²
	Transp. to site	100 km		Transp. to site	10 km
Cement mortar	Cement	31 kg/m²	Insulation	Rock W., pack.	4 cm:1,6 kg/m² 5 cm:2,0 kg/ m² 6 cm: 2,4 kg/m² 8 cm: 3,2 kg/m²
	Sand	225 kg/m²		Transp. distrib.	300 Km
	Water	32 l/m²		Transp. to site	10 Km
	Transp. to site	10 km	Vapour barrier	Bit. refin. Eur.	5,5 kg/m²
Insulation	Rock Wool, packed	4 cm:1,6 kg/m² 5 cm:2,0 kg/ m² 6 cm: 2,4 kg/m² 8 cm: 3,2 kg/m²		Transp. distrib.	300 km
	Transp. distrib.	300 Km		Transp. to site	10 km
	Transp. to site	10 Km	LH	Brick at plant	47 kg/ m²
Perforated brick	Brick at plant	78 kg/m²		Transp. distrib.	150 km
	Transp. distrib.	150 Km.		Transp. to site	10 km
	Transp. to site	10 km.	Plaster	Base plaster, pl.	22 kg/ m²
Plaster	Base plaster,pl.	22 kg/m²		Water	11 kg/ m²
	Water	11 kg/m²		Transp. to site	10 km
	Transp. to site	10 km	Concrete mixter	Electr. LV Sp.	0.004 Kw/ m²
Concrete mixer	Electr. LV Sp.	0.004 Kw/m²	Elev. platform	Electr. LV Sp.	0.015 Kw/ m²
Drill	Electr. LV Sp.	0.0025 Kw/m²	Added heating energy consumption	Gas natural for heat boiler atmospheric burner <100 kW	B1 Column in table 3
Elevating platform	Electr. LV Sp.	0.015 Kw/m²	Added cooling energy consumption	Electricity LV use in Spain	B2 Column in table 3

Table 2. Inventory data of the studied façade solutions.

4.3. Results.

4.3.1. Energy consumption.

Table 3 shows the annual energy consumption per m^2 housing for the 48 cases studied. The following conclusions can be drawn from the table:

- Heating produces higher energy consumption than cooling, even in the climate zones with severe summers and mild winters (A4).
- The orientation initially considered best is, in fact, better than the one considered the worst from a heating viewpoint. However, from a cooling point of view, it is the opposite. Considering the heating and cooling consumptions jointly, the orientation considered best is, in fact, the best because heating always produces higher energy consumption than cooling. This is how it is for the simulated building, which had no summer passive strategies.

4.3.2. Energy saving.

From table 3, it may also be inferred that:

- The use of a ventilated façade in comparison with the ceramic double-leaf façade with internal insulation produces a thermal conditioning energy saving that ranges from 13.8% to 17.6%. This range is lower than the 25-40% previously reported in the literature, as could be expected because, after the TBC came into effect, the ceramic double-leaf solutions that match this have a better thermal performance than those before the TBC, with which the ventilated façade was compared.
- The severer the climate, the more energy is saved (both for heating and cooling) with the use of a ventilated façade.

Zones	City	Orientation	A. Annual energy consumption				B. Energy consumption saving with the use of a ventilated façade after 100 years	
			A1. Double-leaf brick wall		A2. Ventilated façade			
			A11 kw·h/m² Heating	A12 kw·h/m² Cooling	A21 kw·h/m² Heating	A22 kw·h/m² Cooling	B1 kw·h Heating	B2 kw·h Cooling
A3	Malaga	Better	28.4	7.9	22.8	7.6	109.262	5.853
		Worse	30.5	7.1	25.4	7.0	99.506	1.951
A4	Almeria	Better	22.2	8.9	18.0	8.7	81.946	3.902
		Worse	24.6	8.2	20.3	8.0	83.897	3.902
B3	Castellón	Better	42.3	6.3	35.5	6.2	132.675	1.951
		Worse	44.1	5.7	37.0	5.4	138.528	5.853
B4	Sevilla	Better	32.2	9.7	26.4	9.3	113.164	7.804
		Worse	34.3	10.3	27.9	9.8	124.870	9.756
C1	Santander	Better	62.2	0.0	51.6	0.0	206.817	0
		Worse	63.8	0.0	53.4	0.0	202.914	0
C2	Barcelona	Better	54.2	4.1	44.1	4.0	197.061	1.951
		Worse	57.1	3.2	46.6	3.1	204.866	1.951
C3	Granada	Better	66.4	6.8	54.8	6.5	226.328	5.853
		Worse	69.0	5.9	57.2	5.4	230.230	9.756
C4	Badajoz	Better	45.4	8.4	38.4	8.0	136.577	7.804
		Worse	46.5	7.6	39.5	7.2	136.577	7.804
D1	Pamplona	Better	98.8	0.9	82.9	0.9	310.225	0
		Worse	100.7	0.2	84.6	0.0	314.127	3.902
D2	Logroño	Better	83.1	2.8	69.4	2.7	267.301	1.951
		Worse	85.4	2.4	71.5	2.3	271.203	1.951
D3	Madrid	Better	75.3	5.5	61.8	5.3	263.399	3.902
		Worse	77.4	4.4	63.7	4.0	267.301	7.804
E1	Burgos	Better	118.6	0.0	99.0	0.0	382.416	0
		Worse	121.1	0.0	101.4	0.0	384.367	0

Table 3. Annual energy consumptions and saving in consumption with a ventilated façade.

4.3.3. Environmental impact.

Figure 2 shows the environmental impact of the studied façade solutions, only taking into account the environmental loads resulting from raw materials extraction, manufacturing, and the installation on the building site of the façade materials. As may be observed, the materials that make up the ventilated façade (the two columns on the right) have a higher environment impact than those that make up the ceramic double-leaf façade, due to the high impact of the aluminium profiles.

However, when the operational stage is considered, the significant environmental improvement caused by the ventilated façade is observed. Figure 3 shows the environmental impact, including the use stage, of the ceramic double-leaf façade, according to the climate zone and the good or bad orientation. As can be seen, the environmental impact of the ceramic double leaf is approximately between 1.5 and 5 times higher than that of the ventilated façade, mainly depending on the climate zone.

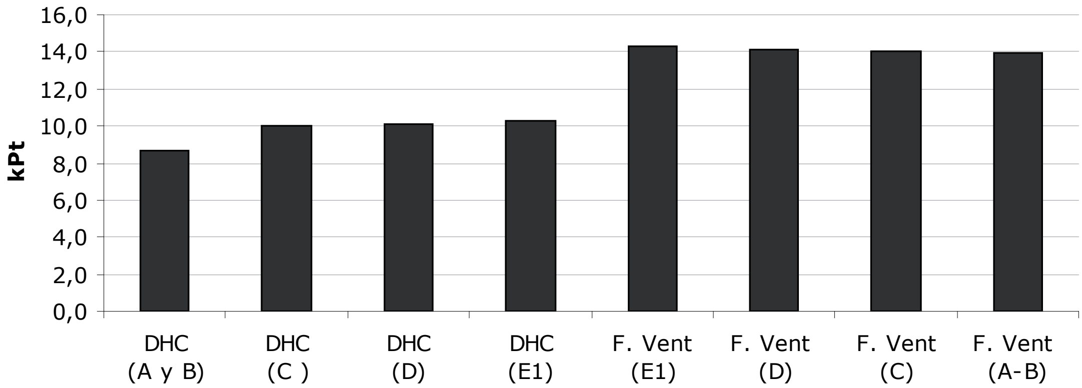


Figure 2. Environmental impact of the materials for 210 m² of façade in kilo points (DHC: ceramic double leaf; climate zone in brackets).

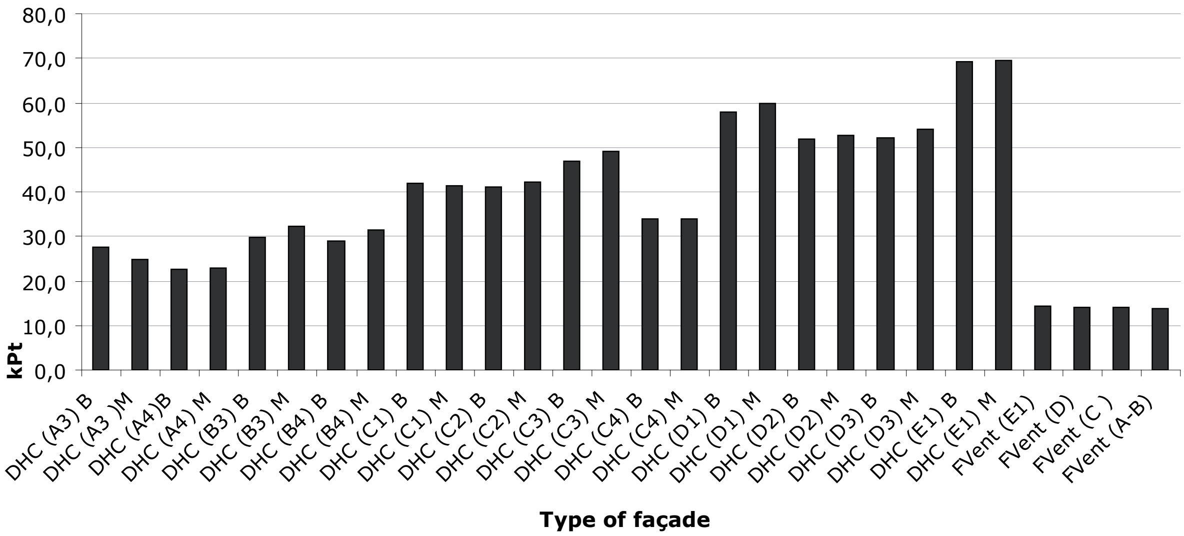


Figure 3. Environmental impact of 210 m² of each type of façade in kilo points, including the use stage (DHC: ceramic double leaf; FVent: Ventilated façade; Climate zone in brackets; B: good orientation; M: orientation considered bad).

5. CONCLUSIONS

In this paper, a method of comparative analysis of the environmental impact of two façade solutions, the ventilated façade and the ceramic double-leaf façade with internal insulation, has been presented. The method has been applied to the case of a detached single-family home. The greatest innovation of the proposed method is the incorporation of the use stage into the inventory of the façade solutions. The use stage means considering the thermal conditioning energy saving resulting from the use of the ventilated façade in comparison with the ceramic double leaf.

This method has allowed us to assess the two types of façade from an environmental point of view. The results show that, although the materials of the ventilated façade have a higher environmental impact than those of the ceramic double-leaf façade owing to the high impact of the aluminium profiles, the energy saving obtained throughout the useful life of the building more than compensates this difference, making the ventilated façade a much more advantageous solution from an environmental point of view.

It would be interesting to extend this study to other cases like the multi-family home between party walls and the detached one, as well as to singular buildings such as museums, school buildings, etc.

However, we also have to comment on some limitations of the proposed method, which should be the object of future research. The first limitation is the fact that the algorithms of the ventilated façade are not included in the Lider v1.0 energy simulation software. This has led us to use the approximation proposed in standard UNE-EN ISO 6946 for introducing the ventilated façade into the software. However, this approximation does not consider the effects of the air chamber according to the climate zone, the orientation of the façade or the characteristics of the chamber and the ceramic cladding. We consider that these effects could be subject to study for a higher precision in the results obtained. Another limitation is the fact that the energy simulation software used take into account that the home is being used 100% of the time, which is not real and which favours the environmental results of the ventilated façade in comparison with those of the ceramic double-leaf façade. We understand that, if patterns of use of the home that are closer to reality are considered, the ventilated façade would continue to result more advantageous from the point of view of its environmental impact, but the difference would be smaller than that found in this study. The matter of the patterns of use should also be investigated in the future.

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