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Full length article

Recycled versus non-recycled insulation alternatives: LCA analysis for different climatic conditions in Spain

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ABSTRACT

The construction sector represents more than 40% of energy consumption in the European Union, as well as one of the biggest causes of environmental impact. Therefore, this sector needs a great deal of intervention through policies that promote the energetic efficiency of the buildings. One of the most important structural components to reach this energetic efficiency is the facades. In this work, the facade ventilated is chosen due to its better thermal insulation behaviour. The environmental impact of the facade ventilated depends on the thermal insulation material. The goal of this paper is to evaluate the environmental impact of different ventilated facades according to their thermal insulation behavior. For this purpose, the life-cycle assessment is applied in ventilated facades with different materials in different locations. The materials studied are the rock wool, the natural cork and the recycled cork, and the locations considered are the different climatic areas of Spain. To reach a complete environmental assessment all the ventilated facades life-cycle is considered, from cradle to grave. To do this we use the Open LCA software with the Ecoinvent database with the ReCiPe method. The results show that the recycled cork is the thermal insulation with the lowest environmental impact regardless the location.

1. Introduction

The construction is one of the sectors with the greatest environmental impact in the European Union (EU), which presents more than 40% of energy consumption and more than 36% of CO_2 emissions (EC2 2012; UNEP, 2016). At present, approximately 35% of EU buildings are older than 50 years and about 75% of them are not energy efficient (UNEP, 2016). The renovation or refurbishments of these buildings will reduce a 5-6% of the total energy consumption and a 5% of CO_2 (UNEP, 2016). All these characteristics are considered by the Energy Performance Building Directive of 2010 (EPBD) (WCE 1987) and the Energy Efficiency Directive of 2012 (WCE 1987). The reducing of the energy consumption in the construction sector is one of the main European and Spanish objectives. For this reason, the goal of the nearly zero-energy buildings (NZEB) becomes increasingly important. (WeiÅenberger et al. 2014). For this reason, standards in Europe are implementing some strategies such as ESG in order to improve the investments in energy efficiency (Makijenko et al. 2016).

In order to assess and quantify the energy consumption and the environmental impact of the building or a part of it, a life cycle assessment (LCA) is used. The LCA is a very valuable tool that allows the environmental assessment of all products, processes and services. Furthermore, the LCA has become one of the most important and accepted tools to asses, reduce or improve the environmental impacts (Ren et al. 2021; VanderWilde and Newell 2021). Thus, the LCA is a useful method to achieve the goal of NZEB (Buyle et al. 2013; Cabeza et al. 2014; Zabalza Bribián et al. 2009). In this respect, the code ISO 14040 (ISO, 2006a) will be followed to define a methodology to carry out the LCA of ventilated facades. The LCA has been applied to different structures as bridges (Martínez-Muñoz et al., 2020; Penadés-Plà et al., 2020) , walls (Pons et al., 2018, and buildings Cabeza et al. 2014; Muãoz-Liesa et al. 2021; Sánchez-Garrido et al., 2021).

The facade of the buildings is one of the maximum responsible for both energy consummation and environmental impact. In recent years, the ventilated facade is more used due to its better thermal insulation behavior (Attia et al. 2018). This type of facade system, unlike traditional facade systems, allows the maintaining of the temperature in the interior of the building and the reducing of both the energy consumption and the environmental impact. The ventilated facade is a valid external envelope for any type of weather (Peci et al. 2015). In this facade the

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thermal insulation material is the most important (Barbosa and Ip 2014; Diarce et al. 2013; Ghaffarianhoseini et al. 2016). In the European Market, the thermal insulation materials are classified according to their origin: inorganic and organic. There are a lot of thermal insulation materials with different characteristics and properties. The thermal insulation materials most used in buildings are expanded polystyrene, extruded polystyrene, glass fibre, and rock wool (Marzban 2017; Sierra-Pérez et al. 2016; Stazi et al. 2011). The rock wool is one of the most used in ventilated facade because of its burning behaviour (Ingrao et al. 2016; Siligardi et al. 2017).

Over the last years, there is a trend towards the sustainability. It causes the investigation of new sustainable materials to minimize both energy consummation and environmental impact (Moussavi Nadoushani Zahra et al. 2017; Samani et al. 2015; Villoria Sáez et al. 2016; Zomorodian Zahra and Tahsildoost 2018). Some of these renewable materials that could be used as insulating material are cotton, linen, hemp and cork. In this group, the cork is the most widely used renewable material in northern Europe. However, there is a lack of studies that consider the analysis of its life cycle in order to compare it with other insulation materials. Therefore, in our study, we not only compare this material from a sustainable approach, but we also consider its recycling to make the comparison.

In this work, the environmental impact of three thermal insulation materials is compared along the ventilated facade life cycle. The thermal insulation materials compared are the rock wool, the natural cork and the recycled cork. The aim of this research is to demonstrate that recycled cork is a good alternative for hazardous rock wool from a Life Cycle Assessment (LCA) approach due to its insulation characteristics. In addition, twelve different climatic areas are considered according to the Spanish code DB-HE (Documento Básico Ahorro de Energía DB-HE 2017). These twelve areas are organized into three groups depending on its thermal resistance. For this purpose, the Ecoinvent database (Ecoinvent center, 2016) is considered, the OpenLCA software (Buyle et al. 2013; Zabalza Bribián et al. 2009) is used and the Recipe method (Goedkoop et al. 2009) is applied to obtain the environmental impact along the whole life cycle of the ventilated facade. The energy consumption and the CO_2 emission during the use stage are obtained by the CE3X software (CE3Xv2.3, 2015).

2. Materials and methods

The LCA is a process that carries out the evaluation and quantification of the environmental risks and impacts of a process, service or product. To obtain a complete environmental assessment, the process should involve from the cradle to the grave. In this work, the codes ISO 14040 (ISO 2006a) and ISO 14044 (ISO 2006b) are followed to perform the LCA. In the context of the building, LCA is defined in the norm EN 15978 (BSI 2011). This code exposes a guide that serves to quantify the environmental impacts that the buildings produce.

2.1. Goal and scope definition

In this point, the objectives of the LCA carried out in this work are detailed. The main goal of this work is to compare the environmental impact of different types of ventilated facade according to the thermal insulation used (De Gracia et al. 2013; Marique and Rossi 2018). The thermal insulations studied are the rock wool, the natural cork and the recycled cork (Barreca et al. 2019). These thermal insulations have similar thermal conductivity and thermal resistance. Therefore, these materials need the same thickness to accomplish the code (Documento Básico Ahorro de Energía DB-HE 2017). In addition, different climatic areas are considered. Fig. 1 shows the different climatic areas in which Spain is divided according to the Spanish code DB-HE (Documento Básico Ahorro de Energía DB-HE 2017). This study organizes these areas into three groups according to its thermal resistance. Depending on the thermal resistance of these groups the thickness of the thermal insulation required is different. The thickness of these materials is 0.04 meters for the group 1 (corresponding to areas A3, A4, B3, B4), 0.06 meters for the group 2 (corresponding to areas C1, C2, C3, C4), and 0.08 meters for the group 3 (corresponding to areas D1, D2, D3, E1) is 0.08 meters. In this way, the environmental impact of most used thermal insulations will be obtained in different climatic areas.

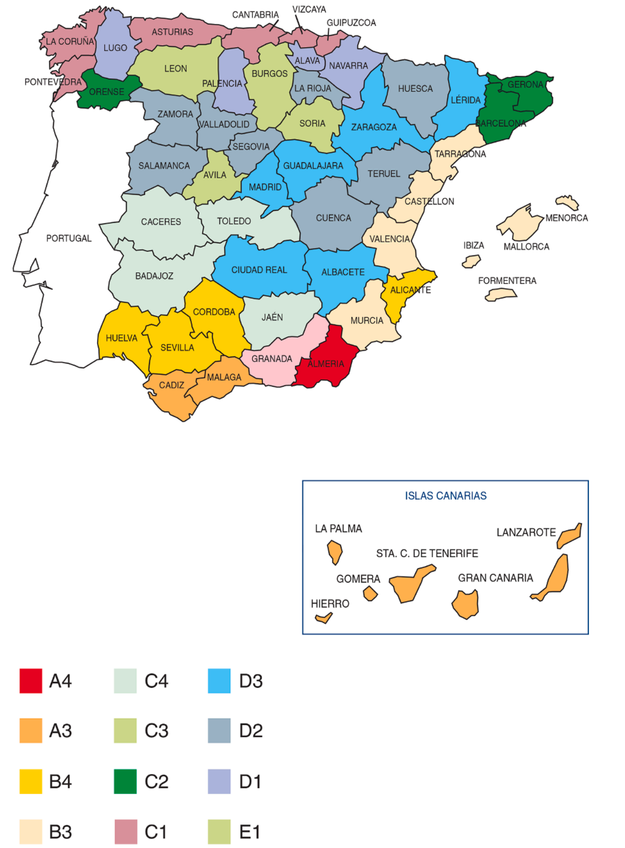

Fig. 1. Climatic areas of Spain (DB-HE) Documento Básico Ahorro de Energía DB-HE (2017)

2.1.1. Facade type selection

The ventilated facade is considered the best facade to minimize the energetic consumption and CO_2 emissions as state in some authors works (Barbosa and Ip 2014; Ibañez-Puy et al., 2017; Nizovtsev et al. 2014; Sierra-Pérez et al. 2016). For this reason, these researchers have made different studies about ventilated facades.

The constructive system of the ventilated facade is formed by multi layered and could be made with different materials. This facade is composed by two parts: (a) an interior layer that protects the interior area of the building, and (b) an exterior layer that supports the direct action of the weather. In the middle of these two parts there is an air chamber. This air chamber allows to maintain the internal temperature and removes internal humidity (López-Ochoa et al. 2018). Finally, both parts of the ventilated facade are joined by anchor or fixings. All of this cause that ventilated facade has a great energetic efficiency. For this reason, this facade is considered in this work (Ibañez-Puy et al., 2017; Ingrao et al. 2016; Madureira et al. 2017).

2.1.2. System boundaries

In this work, the whole life cycle of the ventilated facade is considered, from cradle to grave (Marique and Rossi 2018). The life cycle has been divided into four different phases according EN 15804 (BSI 2011) and ISO 14044 (ISO 2006b): (1) production of all the materials used, including all the processes associated, (2) construction of the ventilated facade, (3) use, including the energy efficient of the building, and (4) end of life, that take into account all the activities necessary for its demolition, and subsequent recycling in the plant (in the case of recycled cork).

2.1.3. Functional unit

The functional unit is the reference measurement used to compare different products. In this work, the functional unit considered to carry out the comparison of different ventilated facade is one square meter (1 m^2) (Zastrow et al., 2017). In this way, the environmental impact assessed for the different types of ventilated facades don't be affect by the total height or total width of the facade (EC 2015; Papadopoulos and Giama 2007; Pargana et al. 2014).

2.2. Life cycle inventory analysis

The analysis of inventory is carried out taking into account the corresponding inputs of energy and material used necessary to develop a process. In this case, three different thermal insulation materials are considered. For this purpose, the whole life cycle of three ventilated facade will be generated. After that, the results caused will be compared.

2.2.1. Software

The database selected to obtain the information necessary to carry out the LCA is Ecoinvent (Frischknecht et al. 2005; Pascual-González et al. 2016). Ecoinvent database is one of the most complete and used databases and scientific reliable database due to accurate information and its constant updates. The first version of this database was created in the year 2004 by the federal offices in Switzerland and the institutes of Investigation of the ETH (Eidgenossische Technische Hochschule Zürich) eco (accessed on January 2021). For this reason, most of the information provided in the first version of Ecoinvent database were obtained based on information of Switzerland (CH). In later versions, more information based on different geographical places were added, for example, Europe (RER), Canada (CA-QC), Germany (DE), the rest of the world (RoW) and Global (GLO).

However, this study is carried out in Spain, and Ecoinvent database has not too much information provided by this country. For this reason, the information considered in this work corresponds to RER in cases where data is available and RoW or GLO for the others. This causes the necessity to apply uncertainty in the products and processes considered.

2.2.2. Uncertainty

There are several uncertainties in the processes or products when the information used corresponds to an existent database. This is because the information used comes from a specific place, in a specific place, and in a specific technology. This uncertainty can be divided into two different stages. First stage is the basic uncertainty that depends on the intrinsic uncertainty of the products or processes considered. The second stage takes into account the differences between where the information comes from, and where the study is going to apply. For this purpose, the pedigree matrix is used (Ciroth et al. 2016; Frischknecht et al. 2005). The uncertainty obtained by the pedigree matrix depends on five indicators: integrity, reliability, temporal correlation, correlation geographical and technological correlation. (Hay and Ostertag 2018; Kovacic et al. 2016; Monteiro and Freire 2012; Motuziene et al. 2016). In this study both uncertainties are considered in order to reach more reliable information.

2.2.3. Ventilated facade design

The facade considered in this study is the ventilated facade (Fig. 2). This facade is formed by six layers where the outermost is a ceramic plate attached to the innermost layer of perforated brick, by means of aluminium fixations. In the middle part we find the air chamber and the thermal insulation. As described above, three types of thermal insulation are used: rock wool, natural cork and recycled cork. These materials have similar thermal conductivity (λ), for this reason, the thickness

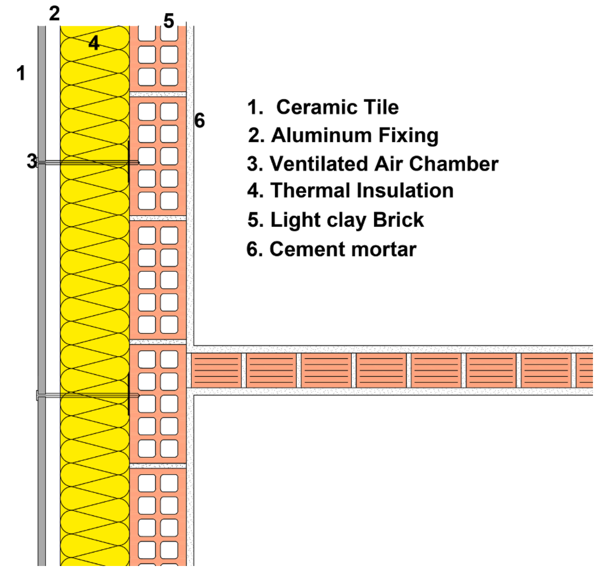

Fig. 2. Constructive section of ventilated facade

necessary to reach the same thermal resistance (R) is the sane. This thickness varies according to the group studied. However, the weight of these materials is different. Table 1 summarize the technical characteristics of each one of these materials for the functional unit (1 m^2) (Diarce et al. 2014; Ioannidou et al. 2014; Monteiro and Freire 2012; Nizovtsev et al. 2014). Note that the table shows three values for the thermal insulation. These values corresponds to the group 1 (corresponding to areas A3, A4, B3, B4), group 2 (corresponding to areas C1, C2, C3, C4), and group 3 (corresponding to areas D1, D2, D3, E1).

The materials and processes used to generate the constructive section of the facade ventilated are obtained from direct flows of Ecoinvent database, except the aluminium fixation, that have been created from other processes.

2.2.4. Life cycle model description

Fig. 3 shows the life cycle considered to carry out the environmental impact assessment of the facade ventilated. The facade ventilated life cycle is divided into four stages.

In the **production phase**, have included all the processes necessary for the manufacture the materials that required to build the facade. From the extraction of the raw material to their respective transportation to plant for processing. In the Ecoinvent database, exist different products that represent the main construction materials for the ventilated facade. Some these general products, not represent the characteristics that need to do the processes to produce the materials. For this, is separated the general processes or products in sub-processes that allow get the material that needed.

The **construction phase**, includes all the activities that need to build

Table 1
Material features of 1 square meter of ventilated facade

Material	R (m^2k/W)	Thickness (m)	λ (W/mk)	Weight (kg)
Ceramic Tile	0.03	0.03	1	10
Aluminium Fixation	-	0.02	230	8
Ventilated Air Chamber	0.09	-	-	-
Thermal Insulation: Rock Wool	0.8/ 1.2 /1.6	0.04/ 0.06 /0.08	0.05	6/ 9 /12
Thermal Insulation: Cork	0.82/ 1.22 /1.63	0.04/ 0.06 /0.08	0.049	4.8/ 7.2/ 9.6
Light Clay Brick	0.16	0.07	4.32	90
Cement Mortar	0.02	0.02	1.3	19.5

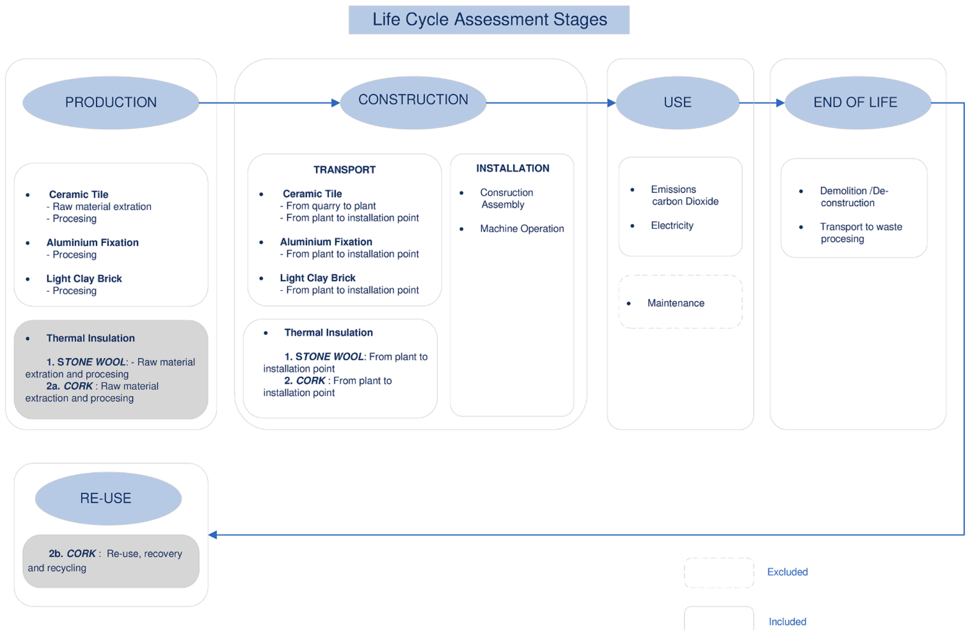

Fig. 3. Life Cycle General Scheme

the ventilated facade at every location that considered. As stated above, twelve cities have been considered in this work, therefore each one of them have different distances to the location of the facade. This phase includes the transport for each city and the precise machinery to carry out the assembly work of the materials.

The **phase of use** has been carried out calculating the CO_2 emissions and the electric consumption that would have inside the building. This calculation has been possible thanks to the use of the CE3x software (CE3Xv2.3, 2015).

This software allows introduce all the materials with his characteristics like thickness, thermal resistance and thermal conductance. Taking in account the Spanish code DB-HE (Documento Básico Ahorro de Energía DB-HE 2017), the results shown the CO_2 emission of the building and the electric consumption that suppose is generated inside the building during his use for the persons who living there. However, on the one hand, some authors do not take in account this phase (Monteiro and Freire 2012) because considered that these process have less importance than others. On the other hand, existing other authors than considered this phase (Ingrao et al. 2016; Sierra-Pérez et al. 2016; Soust-Verdaguer et al. 2016).

In the last phase, **end of life**, includes all the activities that have produce after the service life of the ventilated facade. In this phase, has taken into account the demolition and transport of each one of the materials to have converted in wastes. The different treatments that could be do of these wastes is recycling, recycled or disposal in landfill. In this case, the thermal insulation like natural cork is transported to a recycling plant for processing and recycled like thermal insulation again. Therefore, is defined in the planning and the design of the building, the destination of the materials after its useful life because the environmental impact differs depending of each one material and the treatment of the waste carrying out.

In Table 2 Ecoinvent flows from each LCA stage and its associated uncertainty have been summarized.

Table 2
Design variables and boundaries

Flows	Uncertainty value
Production	
cement mortar	2.240
ceramic tile	2.236
cork slab	1.515
aluminium alloy	1.098
metal working	1.225
light clay brick	2.236
rock wool	2.055
Construction	
machine operation, diesel, <18.64 kW	1.249
transport, freight, lorry 3.5-7.5 metric ton, EURO4	2.030
End of Life	
transport, freight, lorry 3.5-7.5 metric ton, EURO4	2.030
Use	
Carbon dioxide, in air	1.025
Electricity Mix Spain	1.025
Reuse	
diesel, burned in building machine	1.118
electricity, medium voltage, ES	1.153
heat, air-water heat pump 10kW	1.153
polyethylene, high density, granulate	1.153
polyurethane, flexible foam	1.153
transport, freight, light commercial vehicle	1.453

2.3. Impact assessment

The evaluation of the environmental impact assessment is carried out by the life cycle impact assessment (LCIA) methods. These methods convert the inputs considered in the LCA into more understanding outputs. Two different types of results can be obtained depending on the method used. For example, the CML (Goedkoop et al. 2009) method considers the midpoint approach and the Eco Indicador (Dong and Thomas Ng 2014) conider the endpoint approach. The midpoint approach provides a large number of indicators called impact categories, and the endpoint approach provides a small number of indicators called damage categories.

In this work, Recipe (Goedkoop et al. 2009) method is used. Recipe is a method that combines the midpoint approach and endpoint approach. For this reason, depending on the results needed, it is possible to use one of those approaches. In addition, the hierarchist (H) version was chosen to include the long-term perspective of impacts (Khatri et al. 2017), due to in this study the recycling of materials is considered. The impact categories are standardized by ReCiPe Europa H/H (person/year) to provide a complete vision of the results.

On the one hand, the midpoint approach presents more detail, reliability and precision in the results, although it implies a greater difficulty of understanding. The impacts are organized into 18 categories of impact: Terrestrial occupation (ALO), Climatic Change (GWP), (FD), freshwater ecotoxicity (FEPT), freshwater eutrophication (FEP), human toxicity (HTP), ionizing radiation (IRP), Marine ecotoxicity (MEPT), Marine eutrophication (MEP), metal (MD), Natural earth Transformation (NLT), ozone depletion (OD), particulate matter Formation (PMF), photochemical formation of oxidants (POFP), terrestrial acidification (TAP), Ecotoxicity (PTSD), occupation of Urban Land (ULO) and water depletion (WD). Some authors have used the midpoint approach to carry out the LCA (Soust-Verdaguer et al. 2016). On the other hand, the endpoint approach is capable of converting the indicators of the impact category into only three categories: resource availability (R), human health (HH) and ecosystems (E). Some authors have considered the endpoint approach to perform the LCA (Ingrao et al. 2016).

2.4. Interpretation

The interpretation of the results is the last phase of LCA. Depending on the objective of the study, these results can be used to compare the environmental impacts of different products or to obtain a single value that represent the environmental impact of the product (Guérin-Schneider et al. 2018; Ingrao et al. 2018; Lotteau et al. 2015; Petek Gursel et al. 2014; Taborianski and Prado Racine 2012). Therefore, for a better interpretation, the midpoint approach is used to compare the impact categories individually. The endpoint approach is used to study each of the three damage categories and/or combine them to achieve a single global impact score. The main goal of this study is to obtain the thermal insulation that generates the lowest environmental impact, according to the different climate areas in which the ventilated facade is located.

3. Results

As explained above, Recipe method allows to obtain both midpoint approach and endpoint approach. In addition, to consider the uncertainty 1000 simulations are generated according to Montecarlo method in other to study the uncertainty for midpoint impact categories.

3.1. Midpoint approach

The midpoint approach provides 18 impact categories. These 18 impact categories show results more reliable but more difficult to interpret due to the large amount of information. This approach is useful to know the environmental impact that the different processes studied causes. This analysis has been made to all the different cities considered. As an example, the Table 3 shows the information for the city of Valencia. In this table the mean and coefficient of variance for each thermal insulation material (rock wool, natural cork and recycled cork) is obtained for each impact category.

In this table, it is possible to see that the terrestrial occupation (ALO) has the highest coefficient of variance and the marine ecotoxicity (MEPT) has the lowest coefficient of variance, regardless the material studied. In addition, it can be observed that the value of different impact categories is similar for the three materials studied except the terrestrial occupation (ALO). The natural cork has the highest value for the ALO, followed by the recycled cork and the rock wool.

3.2. Endpoint approach

The endpoint approach provides three damage categories. These three damage categories provide information easier to compare. These damage categories have been standardized using the Europe Recipe (H) [person/year]. As noted in the point above, the results have been obtained for all the cities of the study. As an example, Table 4 have been represented the total environmental impact of different damage categories of all the materials for the city of Valencia. This table shows that in Valencia, the recycled cork is the thermal insulation material with the lowest environmental impact. The results in the resources and human health damage categories are similar for the three cases. However, the natural cork has a higher impact in the ecosystem damage category due to the strip the bark of the cork trees.

In addition, more specific information can be obtained. The Fig. 4 show the environmental impact for the different thermal insulation material in the three different groups explained in the point 2.1. The results clearly show that the recycled cork is the thermal insulation material that generates the lowest impact regardless of the city. The recycled cork is followed by the rock wool and the natural cork.

As explained above, the constructive section of the ventilated facade

Table 4
Damage categories contribution points in Valencia for each thermal insulation

	Damage Category		
Thermal insulation	Resources	Human Health	Ecosystems
Rock Wool	9.78877	6.17606	3.4559
Cork	9.98144	6.23764	5.06883
Cork Recycled	9.67358	6.03869	3.36921

Table 3
Midpoint impact categories

		Rock wool		Natural Cork		Recycled Cork	
Impact category	Reference unit	Mean	Cv (%)	Mean	Cv (%)	Mean	Cv (%)
ALO	m^2*a	15.05	132.40%	69.10	55.71%	34.62	110.60%
GWP	kg CO_2Eq	120.44	6.87%	120.29	6.81%	118.49	6.86%
FD	kg oil-Eq	30.21	7.38%	30.54	7.53%	30.06	7.56%
FEPT	kg 1,4-DCB-Eq	4.82	4.19%	4.84	4.28%	4.86	4.31%
FEP	kg P-Eq	0.05	5.56%	0.05	5.49%	0.05	5.57%
HTP	kg 1,4-DCB-Eq	69.74	5.03%	69.91	4.90%	69.50	5.08%
IRP	kg U235-Eq	7.18	7.13%	7.79	10.07%	8.29	9.82%
MEPT	kg 1,4-DCB-Eq	4.31	4.18%	4.33	4.26%	4.35	4.28%
MEP	kg N-Eq	0.06	20.58%	0.06	21.26%	0.06	20.41%
MD	kg Fe-Eq	22.21	5.21%	22.07	5.05%	22.12	5.39%
NLT	m^2	0.03	7.20%	0.03	6.77%	0.03	6.81%
ODP	kg CFC-11-Eq	0.00	7.09%	0.00	11.42%	0.00	11.29%
PMFP	kg PM10-Eq	0.40	13.45%	0.39	11.88%	0.39	13.32%
POFP	kg NMVOC	0.45	6.22%	0.45	6.23%	0.44	6.15%
TAP	kg SO2-Eq	0.63	6.64%	0.62	6.50%	0.61	6.48%
TETP	kg 1,4-DCB-Eq	0.19	40.27%	0.20	41.58%	0.19	39.92%
ULO	m^2*a	1.50	10.07%	1.47	9.33%	1.45	10.12%
WD	m^3	633.46	5.08%	644.25	5.10%	645.57	5.07%

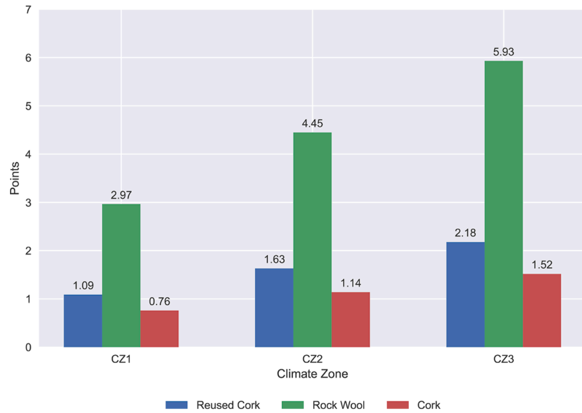

Fig. 4. Endpoint Total Impact Category of each thermal insulation in each climate zone

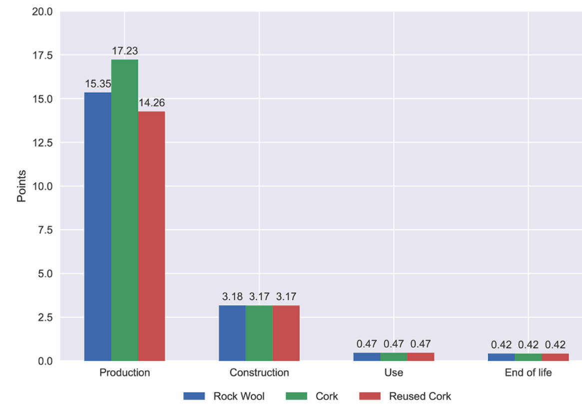

Fig. 5. Contribution of each phase in Valencia of each thermal insulation

studied is assessed according to the use of three different thermal insulation materials. This implies that the rest of the materials that make up the facade are the same. However, depending on the city considered the total environmental impact will be different according to the transport distance. Table 5 shows the total environmental impact as the sum of the three damage categories. On the one hand, the first part of the Table 5 shows the environmental impact assessment of the different thermal insulation materials according to the climate area of Spain. This impact is the same for all the cities of each one climate area. On the other hand, the second part of the Table 5 shows the rest of the environmental impact. Therefore, the differences of the environmental impact of the transport for the different cities can be observed. The sum of one thermal insulation material (first part of the table), and one city (second part of the table) represents the whole environmental impact.

Fig. 5 shows the total environmental impact for each thermal insulation material in each stage of the ventilated facade of the life cycle. The stages considered are production, construction, use and end of life. The production stage has the highest environmental impact regardless the thermal insulation considered, followed by construction stage. The other stages has a low impact. It can be observed that the differences among the different thermal insulation materials occur in the production stage. This figure is an example of the environmental impact in Valencia, therefore the environmental impact of the transport is the same for the different materials and the difference is due to the production of the material. As showed above, the cork recycled has the lowest environmental impact, followed by rock wool and natural cork.

Table 5
Endpoint Assessment

	Climate Zone		
Cities	1	2	3
A3: Málaga	16.58	-	-
A4: Almeria	18.52	-	-
B3: Valencia	18.32	-	-
B4: Córdoba	18.89	-	-
C1: Oviedo	-	19.92	-
C2: Barcelona	-	18.29	-
C3: Granada	-	18.10	-
C4: Badajoz	-	18.87	-
D1: Pamplona	-	-	19.31
D2: Teruel	-	-	19.28
D3: Madrid	-	-	18.84
E1: Avila	-	-	18.56
	+	Climate zone	
Thermal Insulation	1	2	3
Rock Wool	1.08865	1.63298	2.1773
Cork	2.96536	4.44804	5.9307
Cork Recycled	0.75898	1.13846	1.5180

4. Conclusions

The construction sector has one of the highest environmental impacts in the world. Therefore, conducting an analysis or evaluation of this sector could allow the reduction of their emissions and thus reduce the environmental impact. A complete LCA allows to study all the stages of the life cycle of any structure as well as to obtain a complete environmental profile. In this way, the products or processes with the highest environmental impact can be detected and try to replace for other materials or use recycled material. For this purpose the ecoinvent database is used and the ReCiPe method is considered. In this way it is possible to obtain results according to the midpoint and endpoint approach. Therefore, the uncertainty is considered.

This work focuses on the ventilated facades. The thermal insulation is the material with the highest environmental impact of all the materials of the ventilated facades. For this reason, three different thermal insulation materials are studies due to its similar thermal resistance. These materials are the rock wool, natural cork, and recycled cork. In addition, different climate areas are considered according to the Spanish code.

The results show that the natural cork has the highest environmental impact, followed by the rock wool. For this reason, the recycled cork has been included in this study. After include the recycled cork the results show that the environmental impact of the recycled cork is the lowest one. On the one hand, the midpoint approach shows more detailed information of the environmental impact and the uncertainty is considered. The ALO impact category has the highest coefficient of variance. On the other hand, the endpoint approach shows results easier to interpret. This results show that the production stage has the highest environmental impact regardless the city considered. In this stage is where the differences among the different thermal insulation materials are observed. Therefore, it shows that the recycled cork is the better thermal insulation material. In addition, the environmental impact due to the transport according to the different cities is obtained. Málaga is the city with the lowest environmental impact and Oviedo is the highest environmental impact. It should be noted that although in Spain the use of rock wool is widespread, in other countries it has been banned because it is considered dangerous to health. According to this study results, replacing rock wool with cork would not only have a lower impact, but would also eliminate the health risk. All these results can help the engineers and architects in order to select the best building materials and at the same time less damaging to the environment.

CRediT authorship contribution statement

N. Ata-Ali: Conceptualization, Methodology, Investigation, Writing – original draft, Formal analysis. **V. Penadés-Plà:** Validation, Visualization, Writing – review & editing. **D. Martínez-Muñoz:** Data curation, Validation, Visualization, Writing – review & editing. **V. Yepes:** Funding acquisition, Project administration, Resources, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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