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Environmental footprint of external thermal insulation composite systems with different insulation types

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Abstract

In terms of upcoming energy directive for Nearly Zero Energy Houses (nZEB), we are very much focused on building skin and its properties. Not only thermal characteristics and design, but also durability and environmental aspects should play a role, when deciding on which system will be implemented. External Thermal Insulation Composite Systems or ETICS are generally made of adhesive, insulation, render with mesh reinforcement, primer and finish coat. In the following case study we have presented a life cycle assessment (LCA) study of three ETICS with different types of insulation: expanded polystyrene (EPS), mineral wool and wood fiber board insulation. The study complies to the standard EN 15804:2012. It was conducted in the program Gabi using the Gabi Professional 2012 Database. The scope of the study is covering the production phase (raw material supply, transport to the factory, manufacturing). We have compared the functional unit of 1 sqm of the ETICS system with U-value 0.27 W/m^2K taking into account different environmental impact categories. In the calculation the characterization factors proposed by Centre of Environmental Science (CML) at Leiden University were used. The comparison of ETICS shows the important impact of the insulation type used. Also there are some differences in the amount of other ETICS components applied, since changing the type of insulation affects the environmental footprint of the ETICS.

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Keywords: ETICS, life cycle assessment, nearly zero energy houses, insulation types.

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1. Introduction

The construction sector accounts for 40 % of the total energy consumption of Europe. In the recent years the focus of the building sector was how to reduce the energy consumption of the buildings. But by minimizing the operational energy, the energy embodied energy of the building became more important. Studies of low energy buildings have shown, that the embodied energy for production can account for 40-60 % of the total energy use in reference service life (RSL) of a building [1,2]. This increases the demand to perform analyses that do not deal just with the energy used in the operational phase of the building, but with the whole life cycle of the building, such as Life Cycle Assessment (LCA).

External Thermal Insulation Composite Systems or ETICS are widely used in buildings since 1990s [3]. The cladding system is made out of different layers: adhesive, insulation, render with mesh reinforcement, primer and finish coat. To ensure correct functioning of the system it is necessary to develop a working multi-layer system where the components are compatible with each other. Different insulation materials can be used in ETICS. This is important in terms of environmental footprint, for they have the biggest impact.

An additional advantage of ETICS beside energy savings is that it also prevents mechanical damage of the load bearing structure and its failure in tension because of temperature differences. Generally, the ETICS helps to protect climate and environment by reducing the CO2 emissions caused by the use of energy for heating and cooling. This system also increases the living comfort by reducing indoor temperature differences and reduces operational costs. Many different combinations of the ETICS components are possible. In the following study the insulation is the main difference between the different systems compared. There are also small differences in the quantity of other materials used in the system, since different insulations require different preparation or fixing. In the following study we will compare three ETICS with different insulation types in terms of environmental parameters.

The environmental impacts are different depended on the type of the façade system, the insulation materials used and the location of the building when analysing the whole life cycle of the building [4]. Researches comparing different insulation types most often show an advantage of the EPS or styrene based insulation upon other insulation types due to low material consumption and weight in most environmental impact categories [5–8]. Some also studied the environmental impact of innovative materials as cork, flax fibers or plant derived epoxy resin [9]. Most of the studies focus on the cradle-to-gate stage. Beside the environmental impact the economic indicators of the insulation materials are sometimes studied. Studies purpose additional indicators that evaluate the investment impact from the ecological point of view [10]. Insulation types used in ETICS influence the composition of the ETICS systems. For example, EPS insulation requires less render than soft insulations. This also affects the environmental footprint of the system. We have also performed a detailed analysis for three main components (render, primer, finish coat) to see how different components used in them influence their environmental footprint.

2. Methodology

The methodology used is based on the EN 15804 standard. This standard provides core product category rules for Type III environmental declarations for any construction product and construction service.Some results can be used in building assessment methods like LEED, BREAM, etc.

2.1. Functional unit and system boundaries

The defined functional unit is 1 m2 of a wall. The study focused on fixed thermal transmittance (U) parameter to the value 0.27 W/m^2K for all three cases. Thus, different thicknesses of insulation layer (EPS, mineral wool and wood fiber board insulation) were applied in the model. Other properties (for example sound performance, heat capacity) were not taken into account.

The included building life cycle stages based on standards EN 15804:2012 are covering stages A1 to A3. This is referred as the cradle to gate. The transport phase of raw materials is included in the used dataset or is modeled, but it does not significantly contribute to the result. The transport to the construction site is excluded from the scope of the study. Mass allocation is used in the study. Production waste and packing were excluded from the system boundaries.

- A1—production/extraction of raw materials,
- A2—transport and storage of raw materials;
- A3—manufacturing of thermal insulation material.

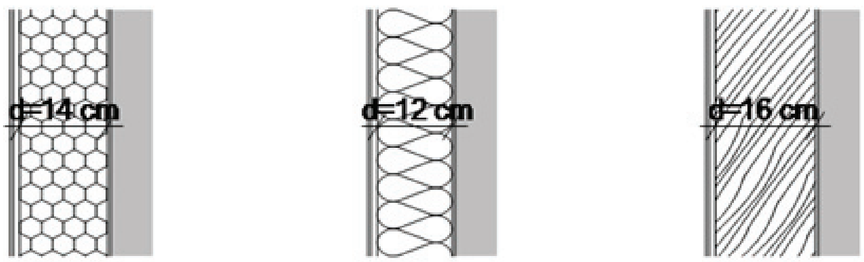
2.2. LCI and LCA

The modelling was done in GaBi 6.0 software. Additional Ecoinvent datasets were used to model ETICS components and access the Life Cycle Inventory (LCI). Some data have been gathered from a manufacturer of ETICS. Insulations and the mesh are generic datasets.

CML 2001 method has been applied to quantify the environmental impacts as proposed in the EN 15804:2012 standard. The environmental impact categories (Tab.1) we have focused on were: global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), ozone layer depletion potential (ODP), abiotic depletion potential (ADP), abiotic depletion fossil potential (ADFP), photochemical ozone creation potential (POCP). Other parameters such as those describing resource use and information describing waste categories and output flows were not analysed. The picture 1 is presenting the different ETICS that will be studied in our study.

Table 1. Environmental impact categories

Environmental impact categories	
Abiotic Depletion (ADP)	kg Sb-Eq.
Abiotic Depletion fossil (ADP fossil)	MJ
Acidification Potential (AP)	kg SO_2-Eq
Eutrophication Potential (EP)	kg Phosphate-Eq.
Global Warming Potential (GWP 100 years)	kg CO_2-Eq.
Ozone Layer Depletion Potential (ODP, steady state)	kg R11-Eq.
Photochemical ozone formation (POCP)	kg Ethene-Equiv



ETICS WITH EPS		ETICS WITH MINERAL WOOL		ETICS WITH WOOD FIBRE BOARD	
Adhesive	5,0 kg	Adhesive	5,0 kg	Adhesive	5,0 kg
Insulation	2,52 kg	Insulation	13,8 kg	Insulation	30,4 kg
M. fixing	0 pcs	M. fixing	6 pcs	M. fixing	6 pcs
Render	4,0 kg	Render	7,0 kg	Render	7,0 kg
Mesh	0,16 kg	Mesh	0,16 kg	Mesh	0,16 kg
Primer	0,25 kg	Primer	0,25 kg	Primer	0,25 kg
Finish coat	2,90 kg	Finish coat	2,90 kg	Finish coat	2,90 kg
U value	0.27 W/m^2K	U value	0.27 W/m^2K	U value	0.27 W/m^2K

Fig. 1: Composition of the analysed ETICS

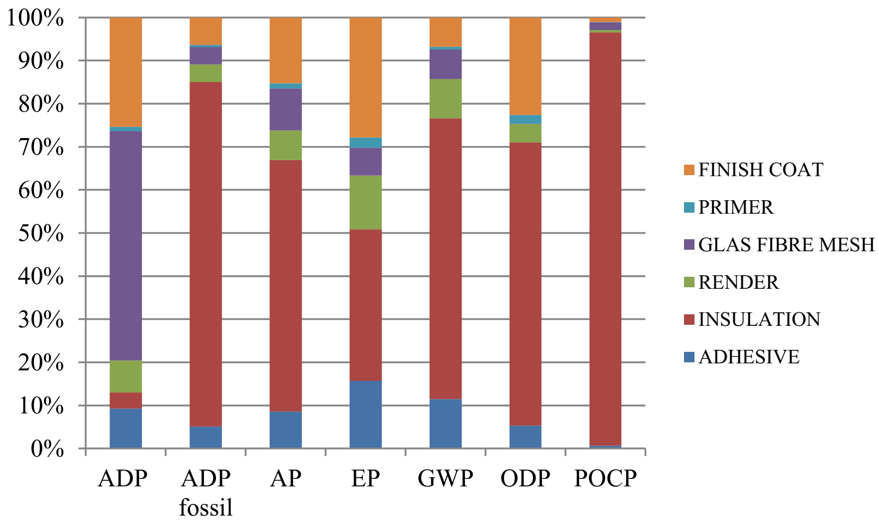
The adhesive is applied on the wall to provide fixing for the insulation. The insulation may be additionally fixed by other means for example with dowels or other mechanical fixing (rails). Adhesive consists of sand, cement and additives like dispersion powder, hydrophobiczers, fibers, etc.

Generic dataset obtained from Gabi 6.0 was used for the insulation. Mineral wool and wood fiber board are additionally fixed with mechanical fixing devices included in the model. The render is applied on the insulation layer. The adhesive and the render have a similar composition. Depended on the type of the insulation the amount of the render applied varies. This layer is used for the reinforcement and to provide a straight surface for the primer and the finish coat. Primer is a component that insures proper surface preparation and compatibility between the render and the finish coat. It enables an easier application for the plaster and improves plasters' adhesion to the substrate. The main components of the primer are filler, binder and water. Other components are added to improve its characteristic like biocides, defoamers, thickeners, dispersion agents, etc.

The function of the finish coat is to provide protection against environmental influences. It has low water absorbency, high mechanical resistance and good vapour permeability. At the same time it ensures an aesthetically pleasing appearance and stable colour coat. It consists of filler, dispersion binder, water and silicon binder with additives like fibers, biocides, defoamers, etc.

3. Results

3.1. ETICS with EPS insulation



	ADHESIVE	INSULATION	RENDER	MESH	PRIMER	FINISH COAT
ADP	9,2%	3,7%	7,4%	53,2%	1,0%	25,3%
ADP fosil	5,1%	79,9%	4,1%	4,0%	0,5%	6,4%
AP	8,5%	58,4%	6,8%	9,8%	1,2%	15,3%
EP	15,7%	35,2%	12,5%	6,4%	2,4%	27,8%
GWP	11,4%	65,1%	9,1%	6,9%	0,6%	6,8%
ODP	5,3%	65,7%	4,2%	0,0%	2,1%	22,6%
POCP	0,7%	95,8%	0,5%	1,8%	0,1%	1,1%

Fig. 2. Environmental impacts of ETICS with EPS insulation

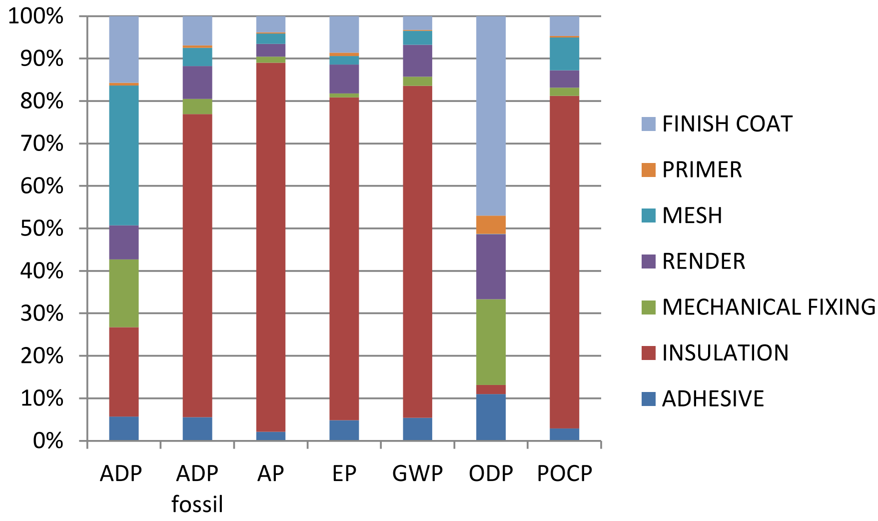
Fig. 2. is presenting the results of the LCA study of ETICS with EPS. In the environmental category abiotic depletion the glass fiber reinforcement mesh (53.2%) and the finish coat (25.3%) contribute the most, followed by adhesive (9.2%), render (7.4%), insulation (3.7%) and primer (1%). In the category abiotic depletion of fossil elements the EPS insulation (79.9%) has the biggest impact, followed by the finish coat (6.4%), adhesive (5.1%), render (4.1%), the glass fiber mesh (4.0%) and the primer (0.5%). EPS is produced out of polystyrene beads that are produced from fossil fuels and the depletion of fossil fuels causes a high impact in the abiotic depletion potential (ADP) fossil category. The EPS insulation (58.4%) causes the biggest footprint in the environmental impact category AP, followed by finish coat (15.3%), mesh (9.8%), adhesive (8.5%), render (6.8%) and primer (1.2%). In the category eutrophication potential (EP) the insulation (35.2%) and the finish coat (27.8%) have a big impact. Adhesive (15.7%), render (12.5%), mesh (6.4%) and primer (2.4%) have a smaller impact. The insulation (65.1%) footprint contributes the most to the global warming potential (GWP) impact, followed by adhesive 11.4%, render 9.1%, mesh 6.9%, finish coat (6.8%) and primer 0.6%. In the environmental category ozone depletion potential (ODP) the insulation (65.7%) and the finish coat (22.6%) contribute the most, followed by adhesive (5.3%), render (4.2%) and primer (2.1%). The photochemical ozone formation potential (POCP) is mostly caused by the insulation (95.8%), while the other components have only a small share.

The insulation is the part of ETICS that contributes the most to the environmental footprint of the system. Although EPS is considered as an environmental friendly insulation, it has the biggest impact in almost all evaluated categories except the category ADP, where the glass fiber mesh has the highest impact although it's low weight. However, compared to other insulation materials it is very light and hereby uses less resource providing high insulation capacity. The adhesive and render have the same composition. Their contribution is between 15.7% and 4.1%, in the category POCP under 1 %. The glass fiber mesh has a high impact in the ADP footprint, especially regarding its low mass share. The primer has a low mass share in ETICS and also its contribution to different environmental is low. The finish coat contributed more to the impact categories ADP, EP and ODP.

3.2. ETICS with mineral wool insulation

The ADP category is affected by the impact of insulation (21.0%), mesh (33.0%), finish coat (15.7%) and mechanical fixing (16.0%). The footprints of adhesive (5.7%) render (8.0%) and primer (0.6%) are smaller. In the environmental impact category ADP fossil the mineral wool insulation (71.4%) has the largest impact, followed by render (7.8%), finish coat (6.9%), adhesive (5.5%), mesh (4.3%), fixing (3.6%) and primer (0.6%). Insulation (86.8%) has the biggest impact to the AP footprint. Finish coat (3.8%), render (3.0%), mesh (2.4%), adhesive (2.1%), mechanical fixing (1.5%) and primer (0.3%) contribute less than 14 % to the AP footprint. In the environmental category EP the insulation (76.0%) contributes the most of the footprint, followed by finish coat (8.6%), render (6.8%), adhesive (4.9%), mesh (2.0%), fixing (1.0%) and primer (0.7%). The GWP footprint is mostly caused by insulation (78.2%). Render (7.6%), adhesive (5.4%), finish coat (3.2%), mesh (3.3%), mechanical fixing (2.1%) and primer (0.3%) contribute the rest. In the category ODP the finish coat (47.1%) has the highest impact, followed by fixing (20.2%). In the environmental category POCP the insulation has the highest contribution (78.3%), followed by mesh (7.7%), finish coat (4.7%), render (4.1%), adhesive (2.9%), fixing (1.9%) and primer (0.3%). The results are shown in fig. 3.

The mineral wool insulation has the highest impact in all environmental categories, except the category ADP and ODP. In the ETICS with mineral wool insulation more render is needed compared to the ETICS with EPS. In the ETICS we have 5 kg of adhesive and 7 kg of render. The impacts of adhesive and render are bigger in the category ODP, while they stay below 10% in other impact categories. The mechanical fixing devices affect the ADP and the ODP, other categories less. The glass fiber mesh has a relatively high share in the ADP category. The primer has a low mass and a low environmental footprint in all categories. The finish coat has a high environmental footprint in the category ODP.



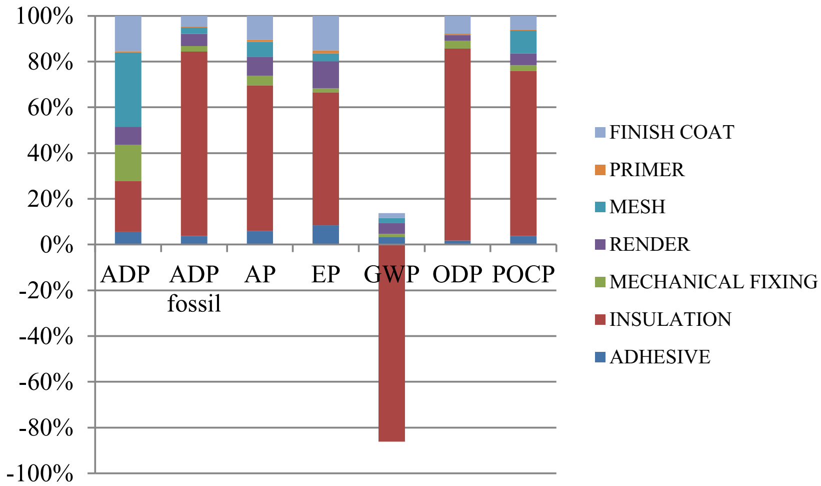
	ADHESIVE	INSULATION	FIXING	RENDER	MESH	PRIMER	FINISH COAT
ADP	5,7%	21,0%	16,0%	8,0%	33,0%	0,6%	15,7%
ADP fosil	5,5%	71,4%	3,6%	7,8%	4,3%	0,6%	6,9%
AP	2,1%	86,8%	1,5%	3,0%	2,4%	0,3%	3,8%
EP	4,9%	76,0%	1,0%	6,8%	2,0%	0,7%	8,6%
GWP	5,4%	78,2%	2,1%	7,6%	3,3%	0,3%	3,2%
ODP	11,0%	2,2%	20,2%	15,4%	0,1%	4,3%	47,1%
POCP	2,9%	78,3%	1,9%	4,1%	7,7%	0,3%	4,7%

Fig. 3. Environmental impact of ETICS with mineral wool insulation

3.3. ETICS with wood fiber board insulation

Fig. 4. is presenting the results of the LCA study of ETICS with wood fiber board insulation.In the environmental category ADP glass fiber reinforcement mesh (32.5%), wood fiber board(22.2%), finish coat (15.4%) and mechanical fixing (15.7%) contribute the most, followed by render (7.9 %), adhesive (5.6%) and primer (0.6%). The insulation (80.6%) causes the biggest footprint in the environmental impact category ADP fossil, while other components contribute less. The footprint AP is mostly caused by the insulation (63.8%), less by finish coat (10.5%), render (8.2%), mesh (6.7%), adhesive (5.9%), mechanical fixing (4.1%) and primer (0.8%). In the category EP the insulation (58.1%) has a big contribution to the footprint. The GWP of the insulation (-119.1%) is negative, thus it has a positive impact on the environment. Wood temporarily stores the CO_2 and therefor the CML method prescribes a negative impact factor for the insulation, since storing CO_2 is reducing the global warming. In the category ODP insulation (84.0%) has the highest impact, followed by finish coat (7.7%) while the other components have only a small contribution. The POCP is mostly influenced by insulation (72.1%) and the glass fiber mesh (9.9%).

The wood fiber board insulation has a high mass share in the ETICS but also a high footprint in all categories except ADP. Other components have a lower impact to different categories, with exception of the mesh in the category ADP.



	ADHESIVE	INSULATION	FIXING	RENDER	MESH	PRIMER	FINISH COAT
ADP	5,6%	22,2%	15,7%	7,9%	32,5%	0,6%	15,4%
ADP fosil	3,7%	80,6%	2,4%	5,2%	2,9%	0,4%	4,6%
AP	5,9%	63,8%	4,1%	8,2%	6,7%	0,8%	10,5%
EP	8,5%	58,1%	1,7%	11,9%	3,5%	1,3%	15,0%
GWP	4,7%	-119,1%	1,8%	6,6%	2,8%	0,2%	2,8%
ODP	1,8%	84,0%	3,3%	2,5%	0,0%	0,7%	7,7%
POCP	3,8%	72,1%	2,5%	5,3%	9,9%	0,4%	6,0%

Fig. 4. Environmental impact of ETICS with wood fiber board insulation

The comparison of the environmental impacts of ETICS is illustrated in Fig.5. The ADP environmental footprint is the highest using wood fiber board insulation, closely followed by the mineral wool. In the case of the ETICS with EPS, the insulation is a lot lighter and the depletion of abiotic resources in smaller. The mesh has the highest environmental footprint from all the components in this impact category. Also in the impact category ADP fossil the ETICS with wood fiber board insulation has the highest impact. The ETICS with the EPS has the second largest environmental footprint although the wood wool weights 30.4 kg and the EPS just 2.5 kg. EPS is produced out of product derived from oil. This is causing a high environmental footprint despite the relatively small weight. The ETICS with the mineral wool insulation has the highest impact on acidification compared with the WFB and EPS. The impact of the ETICS with EPS in this impact category is 75 % smaller and the impact of ETICS with wood fiber board insulation 65% smaller. Also the eutrophication potential is the highest with mineral wool insulation. The ETICS with wood fiber board has a 43 % smaller footprint; the ETICS with EPS has a 69% smaller impact. The CML method is applying a negative environmental coefficient on wood since it stores the CO_2. This means that the ETICS with wood fiber board insulation has a beneficial impact on the climate change. The mineral wool ETICS has a twice higher impact as the EPS ETICS. On the contrary, the use a wood has a high impact on the ozone depletion. Mineral wood insulation has almost no impact in this category. The EPS ETICS has a high impact on the category POCP, the mineral wool and the wood fiber board ETICS have a significantly smaller impact in this impact category. The ETICS with the EPS insulation need less render since EPS insulation is smooth. This means that the environmental impact of the render is smaller while the use of other component remains the same.

3.4. Comparison of environmental impacts of ETICS with different insulations

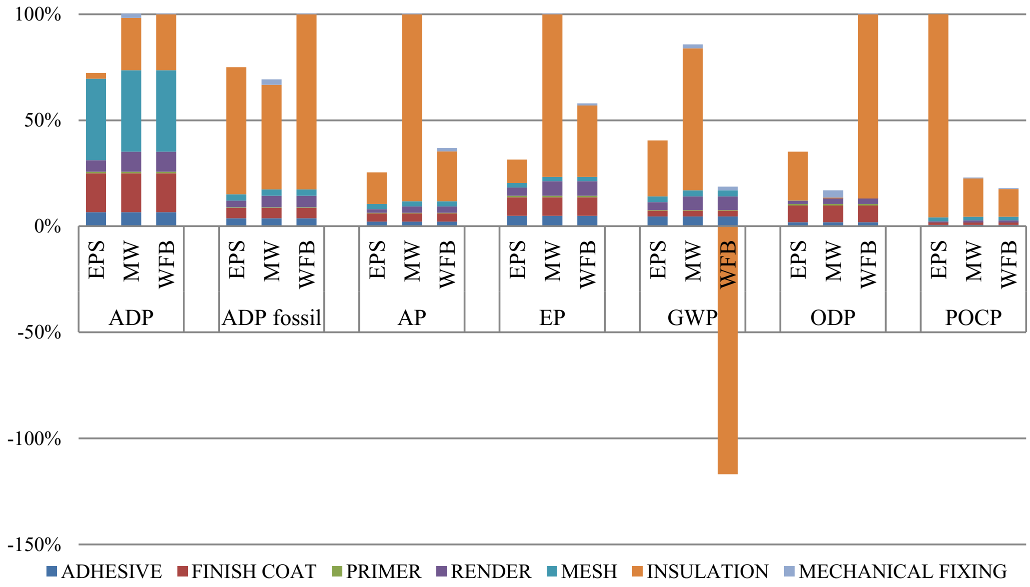


Fig. 5. Comparison of environmental impacts of different ETICS

3.5. Comparison of environmental impacts of ETICS with different insulations

In the following chapter we will study the environmental footprint of adhesive/render, primer and the finish coat.

3.5.1. Adhesive and render

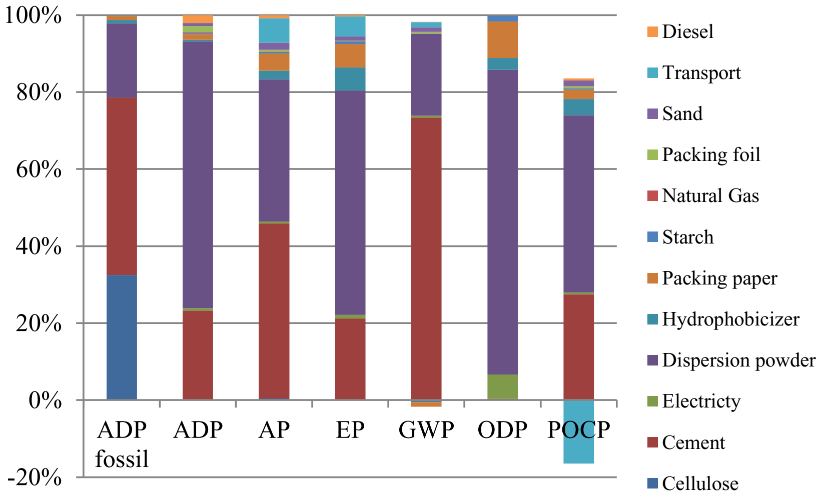


Fig. 6. Environmental impact of adhesive and render

In the chosen environmental impact categories cement has the highest environmental footprint (Fig.6). In the modeled case the dispersion powder was a mixture of vinyl acetate and ethylene. The dispersion powder also has a bigger impact on different environmental categories. The contribution of other components to the environmental footprint in the chosen categories has a smaller impact.

3.5.2. Primer

The acrylic binder has the greatest environmental impact in all impact categories examined in this study (Fig.7). Surprisingly, the second biggest contribution to the environmental footprint is the footprint of biocides. Although they form 0.45% of the entire mass of the primer, their contribution to the total footprint is not to neglect. This is important to know, especially because components with a low mass percentage are often neglected in the studies. However, datasets for biocides are generic in our study. To access more detailed and correct results, own datasets should be modelled with correct recapture for the biocide used in particular cases. Unfortunately we can not estime the uncertainty of the model because of this simplification.

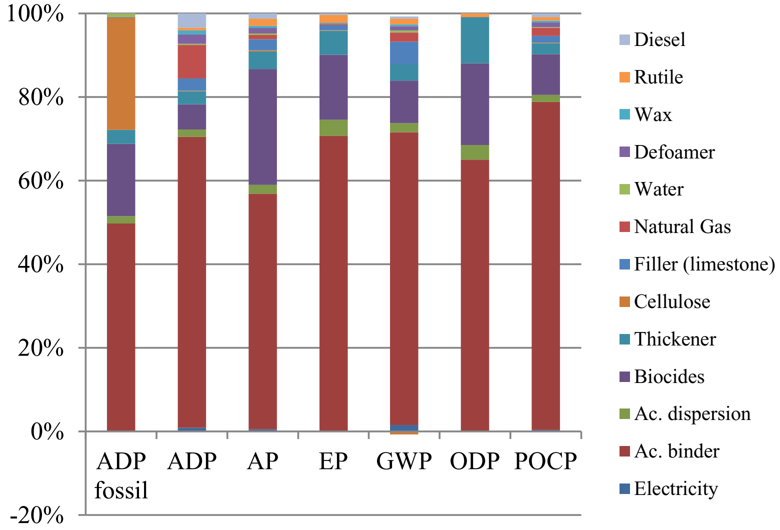


Fig. 7. Environmental impact of primer

3.5.3. *Finish coat*

The results are illustrated in Fig. 8.75 % of the finish coat is filler, in the studied case limestone flour. The highest environmental footprint is caused by the acrylic binder used in the finish coat. The acrylic binder is 11 % of the total mass. Biocides also have a great impact, although they have only 0.7% mass share. 5% of the finish coat consist out of water, the rest are additives like defoamer, dispersion agents, silicon binder, fibres, etc.

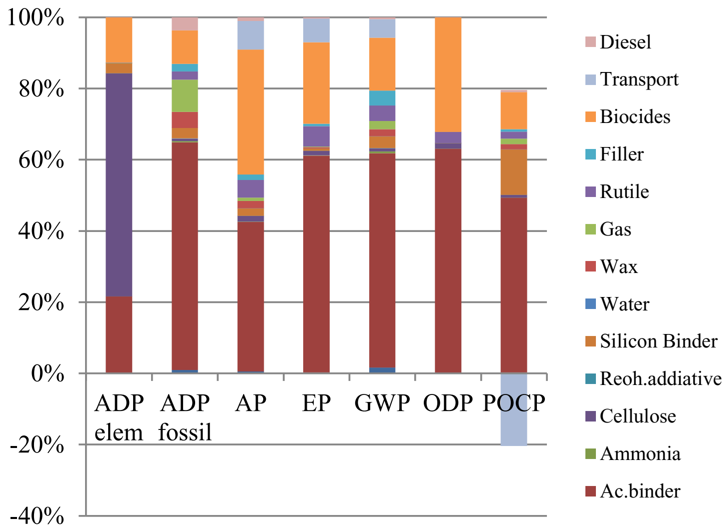


Fig. 8. Environmental impact of finish coat

4. Conclusion

The ETICS are used to reduce the environmental impact of the use stage of the building (lower the enery consumption) but are increasing the embodied energy and the environmental impacts since additional materials or larger quantities of it is used. We have compared the environmental impact of ETICS with EPS, mineral wool and wood fiber board insulation in the following categories ADP, ADP fossil, AP, EP, GWP, ODP, and POCP. The study revealed that the environmental impact is highly depended from the insulation used in the ETICS system, while other component like adhesive, render, mesh, primer and finish coat have a smaller environmental footprint. The different ETICS components have the same weight of all components with the exception of the render. The use of render is higher if soft insulations like mineral wool and wood fiber board are used in the system.

The comparison showed an advantage of the ETICS with the EPS insulation in most of the impact categories. EPS is considerably lighter compared to the other two ETICS systems. The wood fiber board has an advantage in the impact category global warming since wood stores the CO_2 and hereby contributes to the reduction of global warming. The mineral wool has a high environmental impact in the categories AP, EP and GWP compared with the other two systems.

Acknowledgments

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