Energy and greenhouse gas assessment of Thermal Insulating Inorganic Composites with Different Binders

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to år	
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ABSTRACT

In this thesis, it has been done further research of the new building composite materials with low thermal conductivity developed in NTNU & Sintef. The production of some new insulation composite materials has been studied to conduct the environmental impact of the production of these materials. The main aim was to conduct an LCA of these new composites compared to traditional insulation materials. Because of the lack of data from several components of these composites such as Aerogel and calcined clay, it wasn't possible to do an LCA consist of LCA standards. Therefore, the aim is changed to do an energy and greenhouse climate analysis based on the available data in EPDs and Simapro. While for the components where there is no available LCA data, the claimed energy and CO_2 equivalent from the producers were used. The thesis presents the energy consumption and CO_2 equivalent of production of these composites. Then compare them with the energy consumption and CO_2 equivalent of production of the traditional insulation materials. By this comparing, it was possible to get a partial knowledge if these new composites are more environment - friendly solution to use the thermal insulation in the walls than the traditional insulation panels. These materials have high energy consumption and CO_2 equivalent than the traditional insulation materials. The research considered the composites from AIC and AIM with 60 % aerogel content as multifunctional building materials which combine the low thermal conductivity and applicable strength to walls.

This thesis has also made some conclusions which can be generalized to other composites. First, the aerogel reduces the energy consumption and CO_2 of the production of Aerogel concrete aggregates because it reduces the density of the aggregate which reduces the amount of cement in the aggregate. Second, the replacement of cement by calcined clay will reduce the CO_2 equivalent since the calcined clay low CO_2 equivalent compared with cement. Then, the Silica fume has no environmental impact as co-product to the ferrosilicon. Therefore, the Silica fume reduces the environmental impact of concrete aggregates. The production of MKP has a higher environmental impact than the production of Portland cement. Therefore, the use of MKP as cement mass in the aggregates will increase the environmental impact of the aggregates. But it can reduce the environmental impact of the aggregate in the use phase by as energy saving based on their improved properties as strength and thermal conductivity. Finally, the fly ash will reduce the environmental impact of the aggregates since it defines as waste with no environmental impact.

PREFACE

This report is the final report for the master thesis " *Energy and greenhouse gas assessment of Thermal Insulating Inorganic Composites with Different Binders*" this master thesis is submitted in partial fulfillment of the requirement for the degree of Master of Sustainable manufacturing at Norwegian University of Science and Technology (NTNU). The thesis has been performed at the Department of Manufacturing and civil engineering in the faculty of Engineering with Associate professor Mohammad Hajmohammadian Baghban as a supervisor. The thesis work has been carried out between 09 - January 2015 and 08 - June 2018.

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Amjed Naji

Gjøvik, Norway

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List of abbreviations

Composites

AIM - Aerogel incorporated mortars

AIC – Aerogel incorporated concrete

MKP – Magnesium potassium phosphate ceramic

FA – Fly ash

LCA

GHG - Greenhouse gas

LCA - Life cycle analysis

CED - Cumulative energy demand

EPD - Environmental product decleration

CO2 - Carbon dioxide

CO2-eq - Carbon dioxide equivalent

EPD Environmental Product Declaration

EU European Union

FU Functional unit

MJ Megajoule

LCI - Life Cycle Inventory

LCIA - Life Cycle Impact Assessment

Insulating materials

EPS – Expanded polystyrene

XPS – Extruded polystyrene

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1 Introduction

The thermal insulation is a very important concept for the building industry. The buildings consume a lot of energy to regulate the inside climate of the building. The thermal insulation will hinder the thermal transfer between the inside and outside climate (Bjørn Petter et al., 2010, Sintef, 2006). Consequently, the thermal insulation reduces the energy consumption of the buildings (Ozel, 2012). The reduction of energy consumption will reduce the resources consumption and emissions from power generation. Based on that the thermal insulation supports the sustainable development approach in building industry. The sustainable development is defined in (our common future report) as a *development which meets the needs of the current generation without compromising the need for the next generations* (Brundtland, 1987). The Sustainable development concept has got more attention today, because of the increasing of risks on the future of this world (Brundtland, 1987). The building industry is one of the important sectors which consider the sustainable development of their business. The building industry has made huge progress forward to achieve the sustainable development. It has been developed some approaches to make the buildings more sustainable like smart grid (Healy and MacGill, 2012, Bayindir et al., 2016, Sioshansi, 2011), low- emissions house (Ismailos and Touchie, 2017, Knudstrup et al., 2009, Romanach et al., 2017) and zero emissions house (Houlihan Wiberg et al., 2014, Kwan and Guan, 2015, Pauli, 1997, Nsaliwa et al., 2015). The aim is to reduce the energy consumption and emissions of the buildings.

Thermal insulation is the protection of buildings from thermal loss outwardly. It can be used to hold the temperature inside the building (either cold or hot). It can be used in many countries with different weather. The thermal loss causes when it happens a temperature difference over material or construction; then it becomes a heat transfer between the hot side to the cold side. That main way to the insulation of building is to set a suitably thick layer of material which has low thermal conductivity (Ozel, 2012). That will reduce thermal transfer outward or inward. The building materials were mainly focused in this field because the properties and the specifications of these materials (Bjørn Petter et al., 2010) have a high influence on the sustainability performance of buildings. Materials which have low thermal conductivity are more sustainable than materials with high thermal conductivity. The low thermal conductivity will reduce the need for the inside climate regulation (heating or cooling). The energy consumption of inside climate regulation will be reduced.

The thermal insulation can be defined as sustainable technology because of this reducing of energy consumption. Although, it is possible to improve the sustainable performance of choosing an Eco or recycle material, an environment-friendly productions method and secure social workers.

1.1 Problem statement

There were previous attempts to develop composite building materials with low thermal conductivity to reduce the negative environmental impact of the buildings (Widodo et al., 2017). NTNU & Sintef have corporate research to develop new construction composite materials with low thermal conductivity by incorporating inorganic materials and other additives to the traditional concrete. The main focus was to develop materials which have low thermal conductivity and meet the mechanical strength requirements of concrete as well (Gao et al., 2014). On the other hand, there were no attempts to study the environmental impact of these new composites in the existing literature.

Further, the research in this paper focuses on using these composite materials as more sustainable alternatives to the traditional insulation materials. The main idea of this research project is to compare the environmental impact between the insulation composite material which is studied in NTNU and Sintef with traditional insulation materials as organic like Polyurethane (EPS) or polystyrene (XPS) or inorganic like mineral wool. The main aim is to find if this new insulation composite has a less environmental impact than the traditional insulation materials which achieve the same thermal insulation. The traditional thermal insulation materials like cellulose, EXPs, polystyrene foam, urethane foam are organic materials which have a negative environmental impact during their production phase. In this paper, it will be a comparison of the environmental impact during their production phase of these traditional materials with the new composite materials. The analysis will consider only energy and CO_2 equivalent because of lack of data.

1.2 Objectives

1. Perform energy and greenhouse analysis of the new composites: AIC, Calcined clay – AIM, MKP – FA – Aerogel
2. Compare the energy consumption and CO_2 of the equivalent of these new composites with the conventional insulation materials.

1.3 Scope

The research will focus on comparing the environmental impact of the new insulation composites and the traditional materials to define if these new composites are more sustainable than traditional materials. The environmental dimension of the sustainability will limit the research. The research will result in LCA of these new composites. The analysis will consider only energy and CO_2 equivalent in the comparison because of the limited available data of the compared materials. The project will include the environmental impact of the materials from the production phase. The LCA doesn't need to include the use phase since the used amount of material in the research will ensure the same desired the same R-value.

1.4 Research Questions

The main research question of this project is: *Do the new insulation composites have a lower energy and CO_2 equivalent than the traditional insulation materials?*

The main research question is divided into several research questions:

RQ1 - What is the thermal insulation and how it affects the environment?

RQ2 - Describe the traditional insulation material?

RQ3 - What are the inorganic materials: aerogel, fly ash?

RQ4 - What is aerogel – concrete composites?

RQ5 - What is MKP – FA -Aerogel?

RQ6 - What is life cycle assessment (LCA)? How can the LCA be done?

RQ7 – Do the AIC have lower energy and CO_2 equivalent than the conventional insulation materials?

RQ8 - Do the Calcined clay – Aerogel incorporated mortars (AIM have lower energy and CO_2 equivalent than the conventional insulation materials?

RQ9 - Do the MKP – FA - Aerogel have lower energy and CO_2 equivalent than the conventional insulation materials?

RQ10 – Discuss the environmental issues of these composites?

RQ11 - Discuss if the new composites with inorganic materials are environmental-friendly alternatives to the conventional insulation materials?

1.5 Organizing of the report

Chapter 1 ***introduction*** of the master thesis

Chapter 2 ***literature review*** of the thermal, thermal insulation, conventional insulation materials, study of inorganic materials, the new composites, previous research about LCA of insulation materials and aerogel - concrete

Chapter 3 ***Materials*** presents the studied composite materials AIC, Calcined clay – AIM, and MKP – FA- aerogel. Although, it will be presented a comparison of this composites.

Chapter 4 LCA description presents the LCA method

Chapter 5 ***methodology*** presents the undertaken methodology in this research. It includes data collection, LCA Simapro, the comparison between the materials and research approach.

Chapter 6 Goal & scope present goal and scope,

Chapter 7 LCI presents the Life cycle inventory (LCI)

Chapter 8 LCIA presents Life cycle impact assessment (LCIA)

Chapter 9 Results presents the results from LCIA

Chapter 10 ***Discussion*** the results are drawn from the LCA and discussed.

Chapter 11 ***Conclusion*** concludes the thesis report, states the limitations of work and possible further research.

Chapter 12 future research present the future research in this field

Chapter 13 Bibliography present the reference list

Appendix A Drafts of scientific papers retrieved from this research

Appendix B Emails from producers

Appendix C Excel calculations

Appendix D presents the Epds, reports, and data from the producers

2 Literature review

In this chapter, it will be presented some theoretical topics related to the research problem. First, it will be a review of thermal insulation and conventional insulation materials. Second, it will be presented studies of inorganic materials. Third, it will be presented some composite materials with low thermal conductivity. Then, it will be presented previous research on the environmental impact of insulation materials and Aerogel concrete.

2.1 Thermal insulation

2.1.1 What is thermal insulation?

Thermal insulation is the protection of buildings from thermal loss outwardly. It can be used to hold the temperature inside the building (either cold or hot). It can be used in many countries with different weather.

The thermal loss causes when it happens a temperature difference over material or construction; then it becomes a heat transfer between the hot side to the cold side. That main way to the insulation of building is to set a suitably thick layer of material which has low thermal conductivity. That will reduce thermal transfer outward or inward.

The efficiency of thermal insulation material depends on how much low thermal conductivity is. Examples of materials that used to thermal insulation of buildings are cellulose, rock wool, polystyrene foam, urethane foam, vermiculite, perlite, cork, etc. The thermal conductivity of a material depends on the material structure, density, temperature and moisture content.

2.1.2 What are the environmental benefits of thermal insulation?

The main goal of using the thermal insulation is to reduce the high energy consumption that used to maintain an acceptable temperature in the buildings either by cooling or heating. That because the thermal insulation prevents loss of thermal energy outward the buildings (Prestrud, 1949). Both heating or cooling the buildings has a high energy consumption will result in high gas emissions and pollution. The thermal insulation reduces this energy consumption that is why it is used as a green technology (Al-Homoud, 2005, Gellert, 2010). The thermal insulation is very important in the buildings to reduce the energy consumption for inside climate regulation in the building. The inside climate regulation in the buildings consumes a big part of the total energy consumption (Sintef, 2006).

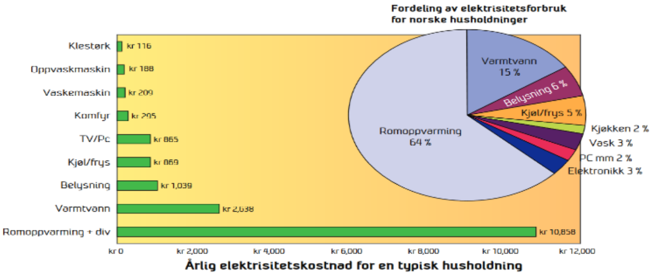


Figure 1 Electricity demand for Norwegian house

The low energy consumption will reduce the emissions, waste and other negative environmental hazards (Ng et al., 2016). Consequently, the insulation reduces the environmental impact of the buildings. The reducing of energy consumption in the buildings will improve their sustainable performance. The thermal insulation can be assessed from sustainable view based on this reducing of energy consumption, choose an Eco or recycle material, an environment-friendly productions method and secure social workers (Benkreira et al., 2011, Adamczyk and Dylewski, 2017).

2.1.3 Thermal characterization of materials

The thermal characterization of material can be measured by some values like thermal conductivity, thermal resistance, and heat flow.

- Thermal conductivity is the heat flow that passes through a unit area of a 1 m thick homogeneous material due to a temperature gradient equal to 1 K; it is expressed in W/m K.
- U-value is the heat flow that passes through a unit area of a complex component or inhomogeneous material due to a temperature gradient equal to 1 K; it is expressed in W/m^2 K.
- Thermal resistance or R-value is a measure of how well an object, per unit of its exposed area, resists the conductive flow of heat.
- Thermal transmittance also considers the thickness of an insulator and the heat transfer due to convection and radiation. (Standardization, 2007).

2.2 Conventional insulation materials

In this section, it will be presented some traditional insulation materials used in Norway.

2.2.1.1 Expanded Polyurethane (EPS)

EPS is organic insulation material produced by evaporating the pentane added to polystyrene grains. The thermal conductivity of EPS is ranging from 0.031 to 0.037 W/mK, while the density of EPS from 15 to 75 kg/m^3. EPS isn't a good acoustic insulator, because of the closed porosity and low density. The recycling and combustion are environmental problems for EPS (Schiavoni et al., 2016).

2.2.1.2 Extruded polystyrene (XPS)

XPS has similar insulation properties to EPS. XPS is produced by melting the polyester grains into an extruder with the addition of a blowing agent. XPS usually costs 10–30% more than EPS. Concerning recycling and combustion issues, there are the same problems reported for EPS (Schiavoni et al., 2016).

2.2.1.3 Stone wool

Stone wool is a cheap and good thermal and acoustic insulator. The thermal conductivity of stone wool is ranging from 0.033 to 0.040 W/m K, while the density of stone wool is ranging from 40 to 200 kg/m^3. Stone wool is manufactured by melting rocks at 1600 °C to obtain them in fibers form. Then bound the fibers together using binders, usually resins, food-grade starches and oils (Schiavoni et al., 2016).

2.2.1.4 Glass wool

Glass wool is also a cheap and good thermal and acoustic insulator. The thermal properties of glass wool are similar to those of stone wool. The glass wool is manufactured by mixing natural sand and glass (usually recycled) at 1300–1450 °C. The glass wool has some environmental advantages: first, the used glass in the manufacturing is usually recycled. Second, the used glass wool can be recycled by the producing manufacturers *(Schiavoni et al., 2016).*

2.3 Study of incorporated materials

In this section, it will be presented studies of some incorporated materials: Aerogel, Calcined clay, and Fly ash which can be added to concrete.

2.3.1 Study of Aerogel

Aerogel is a synthetic porous ultralight material. Aerogels are formed by removing the liquid from a gel under special drying conditions, bypassing the shrinkage and cracking experienced during ambient evaporation. Aerogel was invented as quite revolutionary solid-state materials contents 90 % air. The aerogel has extremely low density and better physical properties (Rumble, 2017, Baetens et al., 2010), especially for many applications of aerogel-like thermal insulation, acoustical insulation (Prassas, 2011), or transparent to light or solar radiation (Platzer, 1987, Schwertfeger et al., 1998). The material can be produced in monolithic or granular form (Prassas, 2011, Mark DOWSON, 2011). There are different types of aerogel: silica aerogel, carbon aerogel, and metal oxide aerogel. The aerogel is the most used type of insulation composite materials (Prassas, 2011).

Silica aerogels are lightweight and highly porous materials, with a three-dimensional network of silica particles. The silica aerogel produces by extracting the liquid phase of silica gels under supercritical conditions (Maleki et al., 2014, Prassas, 2011, Baetens et al., 2010). Silica has promising characteristics, such as extremely low thermal conductivity, low density, high porosity and high specific surface area (Prassas, 2011, Yokogawa and Yokoyama, 1995, Maleki et al., 2014, Pierre and Rigacci, 2011). Based on these characteristics, the aerogel has excellent potential application for thermal insulation (Gao et al., 2014, Hanif et al., 2016, Ng et al., 2016, Júlio et al., 2016). Silica aerogels are known as the best known thermal insulating materials with thermal conductivity around 0.015 $W.m^{-1}.K^{-1}$ at ambient temperature and pressure (Pierre and Rigacci, 2011). Additionally, Silica aerogels present further advantages such as good fire, acoustic resistance (Prassas, 2011), resistance to moisture, waterproofing and self-cleaning properties, corrosion protection, UV reflection, durability (Pierre and Pajonk, 2002, Prassas, 2011, Júlio et al., 2016).

2.3.2 Study of calcined clay

Clay is a “ naturally occurring material composed primarily of fine-grained minerals, which is plastic at appropriate water contents and will harden with dried or fired”(STEPHEN GUGGENHEIM, 1995). Clay can be found in great abundance all around the world, and it has been found that (Ng et al., 2016). The clay minerals can be divided into three main classes:

Kaolin Group (e.g., Kaolinite, Dickite, Nacrite), Smectite Group (e.g., Montmorillonite, Nontronite, Beidellite) and Illite Group (e.g., Illite, Glauconite)

The calcined clay is clay which has been treated with calcination process. The clay heats to drive out volatile materials: a natural abrasive. Calcined clay can be used as a replacement of the cement (Ng et al., 2016).

2.3.3 Study of Fla Ash

Fly Ash is the finely divided residue from the combustion of pulverized coal in the power generation or factories. The most amounts of Fly ash in the world today is a waste from a coal-fired electric and steam generating plants (Fauzi et al., 2016). The huge consumption of coal in the power generation release million tons of Fly ash. Because of that, The fly ash is the world's fifth largest raw material resource (Mukherjee et al., 2008). Fly ash consists primarily of oxides of silicon, aluminum iron, and calcium. Magnesium, potassium, sodium, titanium, and sulfur (Ahmaruzzaman, 2010). Fly Ash has significant environmental benefits when its incorporates to concrete as: Increasing the life of concrete by improving concrete durability, reduction in energy use and greenhouse gas when fly ash is used to replace or displace manufactured cement, reduction in amount of coal combustion products that must be disposed in landfills, and conservation of natural resources and materials (Yao et al., 2015), (Association, 06-13-2003).

2.4 A literature review of new composite materials with low thermal conductivity

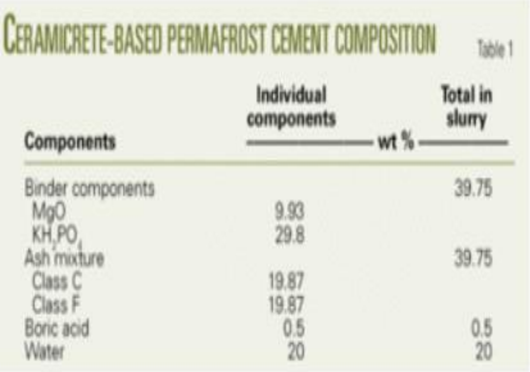
In this section, it will be presented some new alternative composites with low thermal conductivity advantage.

2.4.1 Chemically bonded phosphate ceramic

The chemically bonded phosphate ceramics (CBPCs) combine some advantages from both types of cement and conventional ceramics. CBPCs are synthesized by chemical reactions, most of them at ambient conditions. The main types are magnesium phosphate, aluminum phosphate, and iron phosphate ceramics. The CBPCs is developed as materials which have middle properties between the sintered ceramics and the cement. The sintered ceramics have superior mechanical properties and ceramics are far more stable in acidic and high-temperature environments. While the traditional cement like Portland cement is an inexpensive product and can be used in high volumes. However, The CBPCs can fulfill this need. The CBPC is produced by controlling the solubility of the oxide in the acid-phosphate solution. Oxides or oxide minerals of low solubility are the best candidates to form CBPCs because their solubility can be controlled easily (8).

2.4.2 Permafrost cement

According to Aruns, the permafrost cement is a new cement with very low permeability, very low thermal conductivity, and superior strength has been developed for use in cold regions. The permafrost cement is a composition of magnesium oxide (MgO) and monopotassium phosphate (KH_2 PO_4) mixed with some additives. The additives include the ash which does a better strength and integrity. Another additive can be insulating material Styrofoam, sawdust, hollow silica spheres (cenospheres or extend spheres) and other inorganic fillers. The monopotassium phosphate lowers the freezing point of the slurry and prevents it from freezing during mixing, pumping, and setting. Aruns has tested the composition with ash and acid boring as a figure. The fly ash has low thermal conductivity and will reduce the thermal conductivity of the composition (Arun S. Wagh, 2005).



CERAMICRETE-BASED PERMAFROST CEMENT COMPOSITION

Table 1

Components	Individual components	Total in slurry
	wt %	
Binder components		39.75
MgO	9.93	
KH_2PO_4	29.8	
Ash mixture		39.75
Class C	19.87	
Class F	19.87	
Boric acid	0.5	0.5
Water	20	20

Figure 2 Permafrost composition

2.5 Literature focusing on research of Aerogel – concrete

In this section, it will be presented the literature focusing on incorporating Aerogel into concrete. It will be presented three research papers: High-performance aerogel concrete (Fickler et al., 2015), Calcined clay with aerogel incorporated concrete (Ng et al., 2016), Silica-based aerogels as aggregates for cement-based thermal renders (Júlio et al., 2016).

2.5.1 High-performance aerogel concrete

Fickler and his research group have researched in development of high-performance aerogel concrete. The high-performance aerogel concrete is developed by embedding silica aerogel granules in a high strength cement matrix. The research aims to develop a building material which combines both low thermal conductivity and good mechanical strength. This building material will be suitable for the construction of single-leaf exterior walls of multi-story buildings without any further thermal insulation. Fickler has used a concrete mixture of High-Performance Concrete (HPC), Ultra-High-Performance Concrete (UHPC) and Lightweight Concrete (LC) mixtures. Fickler find that by embedding 60 % aerogel to the concrete mixture, it is possible to get good compressive strength and comparable thermal conductivity. The found thermal conductivities in the research are in the range $0.16 \leq \lambda \leq 0.37$ W/(mK). While the highest compressive strength is 23,6 MPa. The heat treatment or dry period does not influence the compressive strength or thermal conductivity. Fickler found that the most suitable mixture achieved compressive strength of 10 MPa, a density of 860 kg/m³ and a thermal conductivity of 0.17 W/(mK) (Fickler et al., 2015). Figure 3 shows the difference between the measured values of the Fickler research and the studied composite (AIC) in this paper.

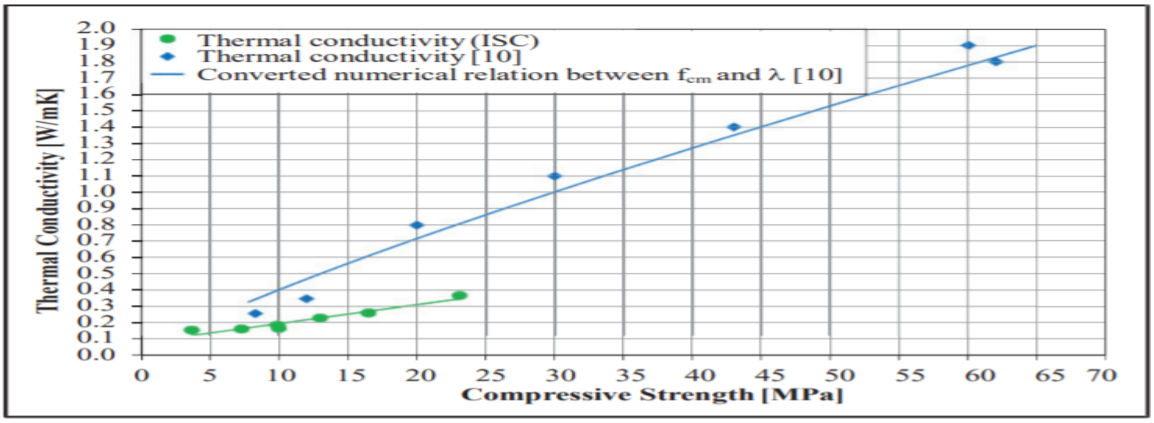


Figure 3 the correlation between the compressive strength and thermal conductivity

2.5.2 Calcined clay with aerogel incorporated concrete

Serine, her research group, have researched the replacement of cement with calcined clay in aerogel incorporated mortars (AIM) to decrease the thermal conductivity. Serine has tested samples of aerogel incorporated concrete with cement as a binder. These samples contents aerogel from 20 % to 80 %. Then tested samples aerogel incorporated concrete with calcined clays as a binder (replacement of cement). The replaced calcined clay has two types of CS (mainly contain smectite) and CK (mainly contain kaolinite). The replacement of ordinary Portland cement with calcined clay as a binder was in two contents 65% and 35%. The samples with calcined clay were tested and the result compared with the first samples. Serina found that at an aerogel loading of between 40 vol% and 80 vol%, replacement of cement with calcined clay lowered the thermal conductivity by up to 20% when <70 vol% aerogel was present (0.410 W/(mK) to 0.370 W/(mK)), and by up to 40% with >70 vol% aerogel (0.164 W/(mK) to 0.145 W/(mK)), driven mainly by the innate thermal conductivity of the binders. At replacement level of up to ~30% by weight of binder (%bwob), the properties of the mortar were independent of clay types. When the replacement increased to above 40%bwob, calcined smectite enriched clays were favored for lowering the thermal conductivities of the mortars as compared to those containing kaolinite. The figure show conducted measured the thermal conductivity of the different samples based on the increasing of aerogel contents (Ng et al., 2016).

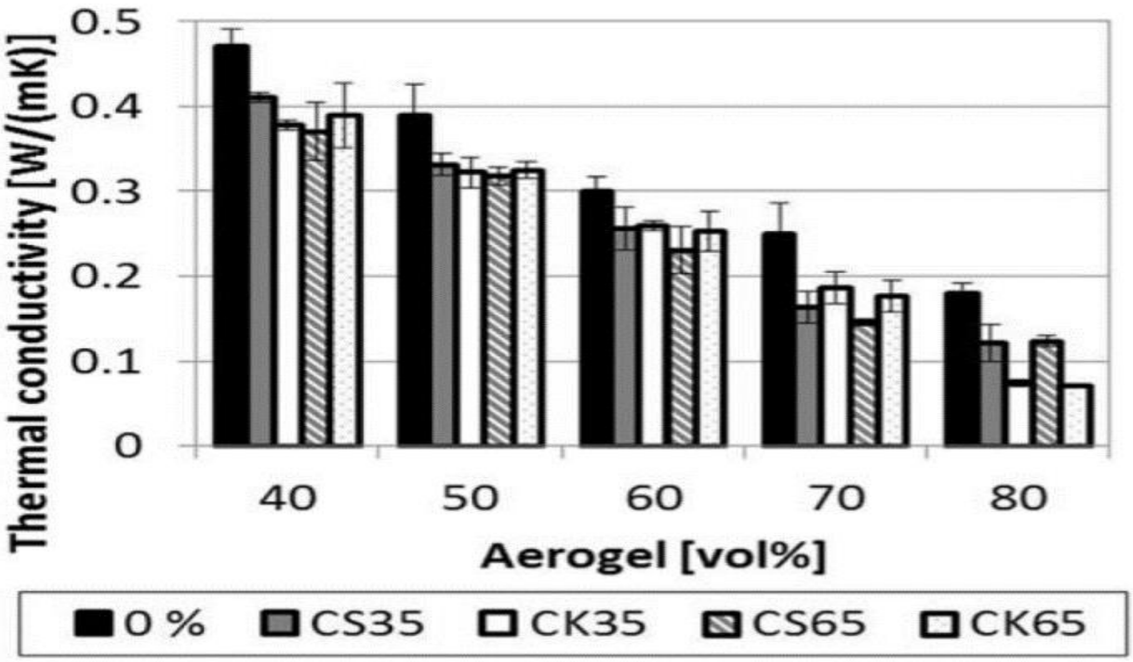
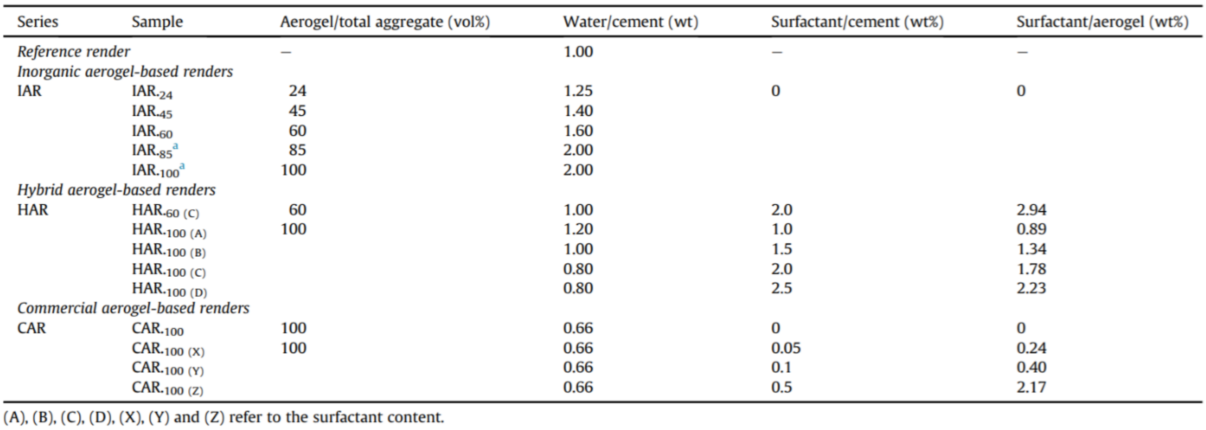


Figure 4 Thermal conductivity. Retrieved from (Ng et al., 2016)

2.5.3 Silica-based aerogels as aggregates for cement-based thermal renders

Julio at the University of Lisboa presented the Silica-based aerogels as aggregates for cement-based thermal renders. The results of the study are that the replacement of silica sand by a subcritical hybrid aerogel synthesized by design lead to successfully produced lightweight and low thermal conductivity cement based renders. Julio has studied several samples of Cement-based mortars incorporated aerogel. Julio studied mortars incorporated inorganic aerogel (IA), mortars incorporated hybrid aerogel (HA), mortars incorporated the commercial aerogel (CA). Julio finds that using a subcritical sol-gel process for the hybrid aerogel results in the formulation of more sustainable renders. The advantages of incorporating hybrid aerogel are: the particle size distribution may be controlled by grinding and sieving, total pore volumes to the renders, high aerogel contents that yield the lowest thermal conductivities. On the other hand, high aerogel contents are responsible for very low mechanical strength (Júlio et al., 2016).

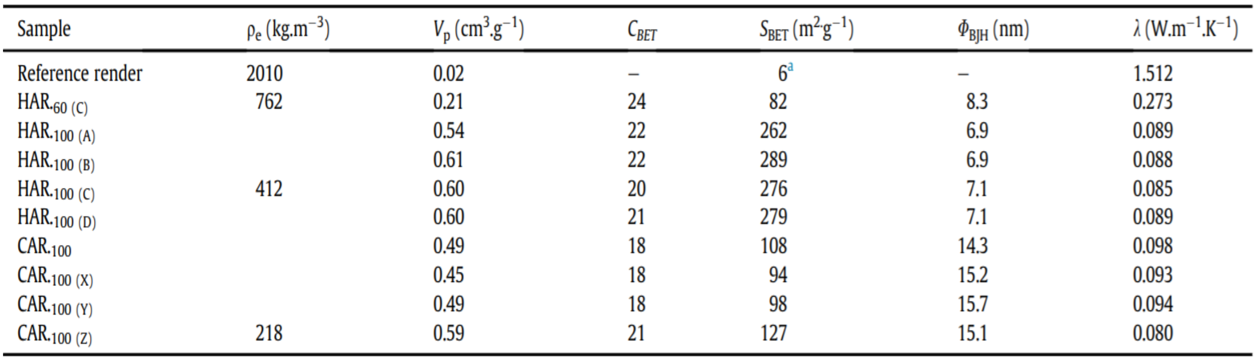
Tabell 1 Samples with aerogel contents



Series	Sample	Aerogel/total aggregate (vol%)	Water/cement (wt)	Surfactant/cement (wt%)	Surfactant/aerogel (wt%)
Reference render		–	1.00	–	–
Inorganic aerogel-based renders					
IAR	IAR$_{24}$	24	1.25	0	0
	IAR$_{45}$	45	1.40		
	IAR$_{60}$	60	1.60		
	IAR$_{85}$[a]	85	2.00		
	IAR$_{100}$[a]	100	2.00		
Hybrid aerogel-based renders					
HAR	HAR$_{60}$ (C)	60	1.00	2.0	2.94
	HAR$_{100}$ (A)	100	1.20	1.0	0.89
	HAR$_{100}$ (B)		1.00	1.5	1.34
	HAR$_{100}$ (C)		0.80	2.0	1.78
	HAR$_{100}$ (D)		0.80	2.5	2.23
Commercial aerogel-based renders					
CAR	CAR$_{100}$	100	0.66	0	0
	CAR$_{100}$ (X)	100	0.66	0.05	0.24
	CAR$_{100}$ (Y)		0.66	0.1	0.40
	CAR$_{100}$ (Z)		0.66	0.5	2.17

(A), (B), (C), (D), (X), (Y) and (Z) refer to the surfactant content.

Tabell 2 measured values of the samples. thermal conductivity & density



Sample	ρ_e (kg.m^{-3})	V_p (cm^3.g^{-1})	C_{BET}	S_{BET} (m^{2}g^{-1})	Φ_{BJH} (nm)	λ (W.m^{-1}.K^{-1})
Reference render	2010	0.02	–	6[a]	–	1.512
HAR$_{60}$ (C)	762	0.21	24	82	8.3	0.273
HAR$_{100}$ (A)		0.54	22	262	6.9	0.089
HAR$_{100}$ (B)		0.61	22	289	6.9	0.088
HAR$_{100}$ (C)	412	0.60	20	276	7.1	0.085
HAR$_{100}$ (D)		0.60	21	279	7.1	0.089
CAR$_{100}$		0.49	18	108	14.3	0.098
CAR$_{100}$ (X)		0.45	18	94	15.2	0.093
CAR$_{100}$ (Y)		0.49	18	98	15.7	0.094
CAR$_{100}$ (Z)	218	0.59	21	127	15.1	0.080

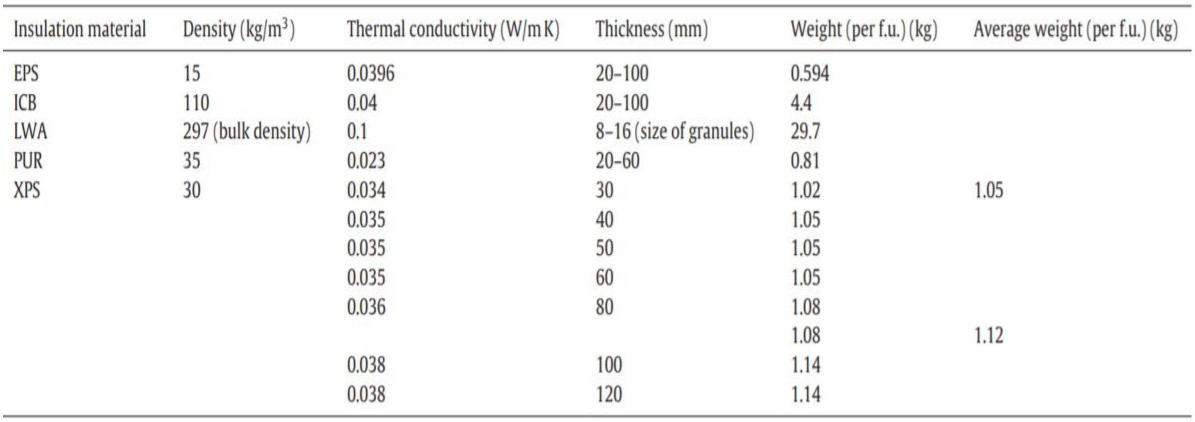
2.6 Literature review focusing LCA of thermal insulation materials

In this section, it will be presented the literature focusing on incorporating Aerogel into concrete. It will be presented three research papers: Comparative environmental life cycle assessment of thermal insulation materials of buildings (Pargana et al., 2014) & LCA study of transparent aerogel analyze the environmental impact of aerogel (Mark DOWSON, 2011).

2.6.1 Comparative environmental life cycle assessment of thermal insulation materials of buildings

Pargana at the University of Lisboa presented a comparative environmental life cycle assessment of thermal insulation materials of buildings. The study is based on the LCA ISO standards (Standardization, 2006a) and compare many types of insulation materials like extruded and expanded polystyrene, polyurethane, expanded cork agglomerate and expanded lightweight clay aggregates. The Pargana paper aims to evaluate the environmental impacts and the consumption of renewable and non-renewable primary energy on the production of conventional thermal insulation materials. The study results are performed in "cradle to gate" (Pargana et al., 2014). Table 4 presents values of the thermal conductivity & density of the insulation materials and the functional unit for the analysis.

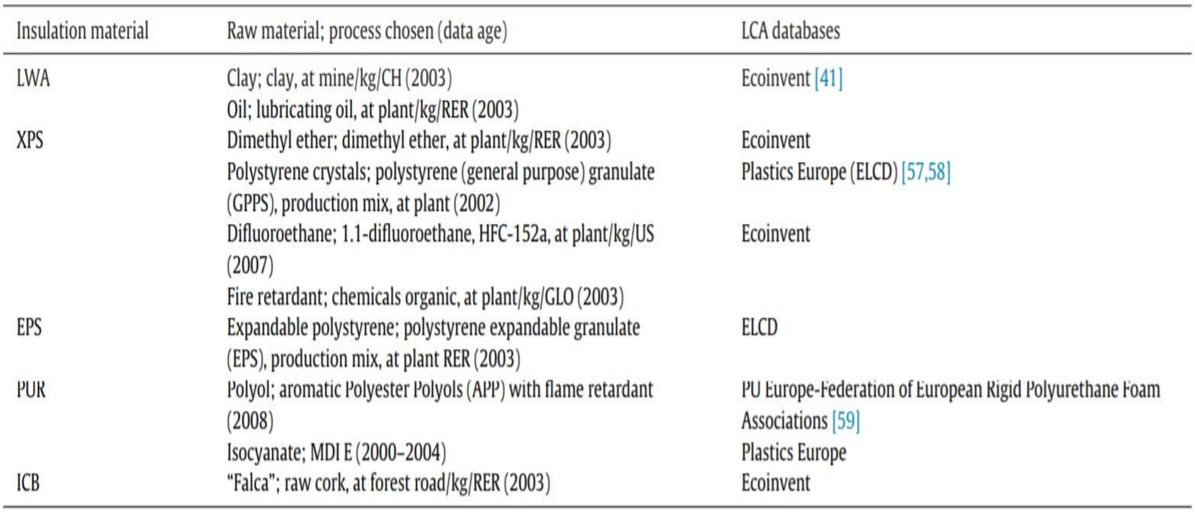
Tabell 3 properties of the insulation materials. Retrieved from(Pargana et al., 2014)



Insulation material	Density (kg/m³)	Thermal conductivity (W/m K)	Thickness (mm)	Weight (per f.u.) (kg)	Average weight (per f.u.) (kg)
EPS	15	0.0396	20–100	0.594	
ICB	110	0.04	20–100	4.4	
LWA	297 (bulk density)	0.1	8–16 (size of granules)	29.7	
PUR	35	0.023	20–60	0.81	
XPS	30	0.034	30	1.02	1.05
		0.035	40	1.05	
		0.035	50	1.05	
		0.035	60	1.05	
		0.036	80	1.08	
				1.08	1.12
		0.038	100	1.14	
		0.038	120	1.14	

Table 3 present the LCI data of the compared insulation materials:

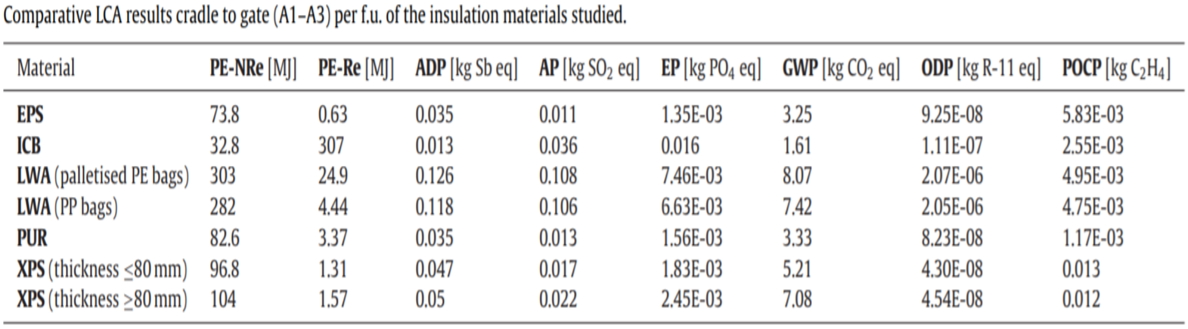
Tabell 4 LCI data. Retrieved from (Pargana et al., 2014)



Insulation material	Raw material; process chosen (data age)	LCA databases
LWA	Clay; clay, at mine/kg/CH (2003)	Ecoinvent [41]
	Oil; lubricating oil, at plant/kg/RER (2003)	
XPS	Dimethyl ether; dimethyl ether, at plant/kg/RER (2003)	Ecoinvent
	Polystyrene crystals; polystyrene (general purpose) granulate (GPPS), production mix, at plant (2002)	Plastics Europe (ELCD) [57,58]
	Difluoroethane; 1.1-difluoroethane, HFC-152a, at plant/kg/US (2007)	Ecoinvent
	Fire retardant; chemicals organic, at plant/kg/GLO (2003)	
EPS	Expandable polystyrene; polystyrene expandable granulate (EPS), production mix, at plant RER (2003)	ELCD
PUR	Polyol; aromatic Polyester Polyols (APP) with flame retardant (2008)	PU Europe-Federation of European Rigid Polyurethane Foam Associations [59]
	Isocyanate; MDI E (2000–2004)	Plastics Europe
ICB	"Falca"; raw cork, at forest road/kg/RER (2003)	Ecoinvent

Table 5 shows the environmental impacts per f.U. of the insulation materials studied for two of the categories related to the harmful effects of air emissions (AP and POCP).

Tabell 5 comparative insulation materials



Comparative LCA results cradle to gate (A1–A3) per f.u. of the insulation materials studied.

Material	**PE-NRe** [MJ]	**PE-Re** [MJ]	**ADP** [kg Sb eq]	**AP** [kg SO_2 eq]	**EP** [kg PO_4 eq]	**GWP** [kg CO_2 eq]	**ODP** [kg R-11 eq]	**POCP** [kg C_2H_4]
EPS	73.8	0.63	0.035	0.011	1.35E-03	3.25	9.25E-08	5.83E-03
ICB	32.8	307	0.013	0.036	0.016	1.61	1.11E-07	2.55E-03
LWA (palletised PE bags)	303	24.9	0.126	0.108	7.46E-03	8.07	2.07E-06	4.95E-03
LWA (PP bags)	282	4.44	0.118	0.106	6.63E-03	7.42	2.05E-06	4.75E-03
PUR	82.6	3.37	0.035	0.013	1.56E-03	3.33	8.23E-08	1.17E-03
XPS (thickness ≤80 mm)	96.8	1.31	0.047	0.017	1.83E-03	5.21	4.30E-08	0.013
XPS (thickness ≥80 mm)	104	1.57	0.05	0.022	2.45E-03	7.08	4.54E-08	0.012

Pargana find that Expanded clay lightweight aggregates LWA makes the biggest contribution to the environmental impact, due to the large consumption of fossil fuels in the production stage.

2.6.2 Insulation materials for the building sector: A review and comparative analysis

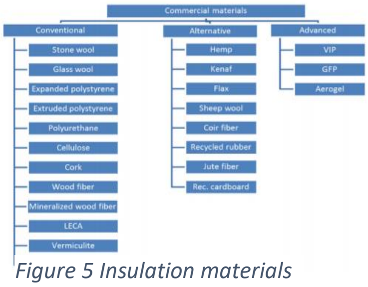
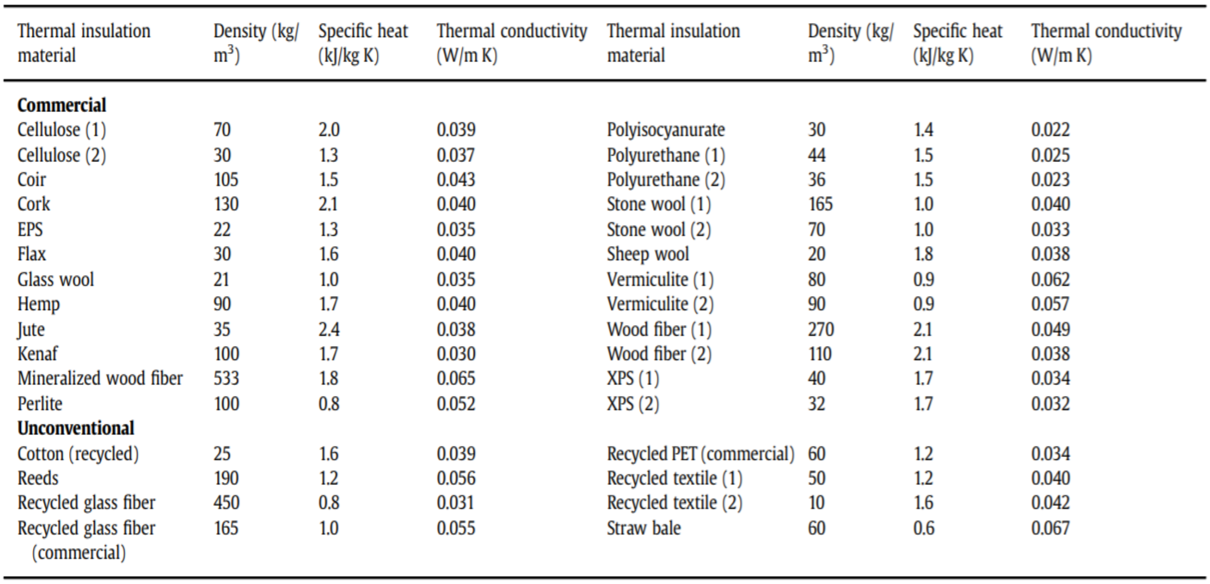


Figure 5 Insulation materials

Schiavoni at the University of Perugia includes the aerogel and stone wool as a good insulation material in their LCA study (Schiavoni et al., 2016). Schiavoni provides a review of the main commercialized insulation materials (conventional, alternative and advanced) for the building sector. Schiavoni considers several properties of the compared materials such as thermal properties, acoustic properties, reaction to fire and water vapor resistance. Although, the environmental impact is taken into the research by considering the life cycle assessment approach. Then conduct a case study by evaluating both thermal transmittance and dynamic thermal properties of one lightweight and three heavyweight walls, with different types of insulating materials and ways of installation.

Tabell 5 Thermal insulation performance, reaction to fire classification and m-value of commercial and unconventional products



Thermal insulation material	Density (kg/m^3)	Specific heat (kJ/kg K)	Thermal conductivity (W/m K)	Thermal insulation material	Density (kg/m^3)	Specific heat (kJ/kg K)	Thermal conductivity (W/m K)
Commercial							
Cellulose (1)	70	2.0	0.039	Polyisocyanurate	30	1.4	0.022
Cellulose (2)	30	1.3	0.037	Polyurethane (1)	44	1.5	0.025
Coir	105	1.5	0.043	Polyurethane (2)	36	1.5	0.023
Cork	130	2.1	0.040	Stone wool (1)	165	1.0	0.040
EPS	22	1.3	0.035	Stone wool (2)	70	1.0	0.033
Flax	30	1.6	0.040	Sheep wool	20	1.8	0.038
Glass wool	21	1.0	0.035	Vermiculite (1)	80	0.9	0.062
Hemp	90	1.7	0.040	Vermiculite (2)	90	0.9	0.057
Jute	35	2.4	0.038	Wood fiber (1)	270	2.1	0.049
Kenaf	100	1.7	0.030	Wood fiber (2)	110	2.1	0.038
Mineralized wood fiber	533	1.8	0.065	XPS (1)	40	1.7	0.034
Perlite	100	0.8	0.052	XPS (2)	32	1.7	0.032
Unconventional							
Cotton (recycled)	25	1.6	0.039	Recycled PET (commercial)	60	1.2	0.034
Reeds	190	1.2	0.056	Recycled textile (1)	50	1.2	0.040
Recycled glass fiber	450	0.8	0.031	Recycled textile (2)	10	1.6	0.042
Recycled glass fiber (commercial)	165	1.0	0.055	Straw bale	60	0.6	0.067

The results of LCA is presented as energy consumption and impact on global warming potential and drawn based on two views: CTGR for cradle to grave, CTGA from cradle to gate. The figures down present that.

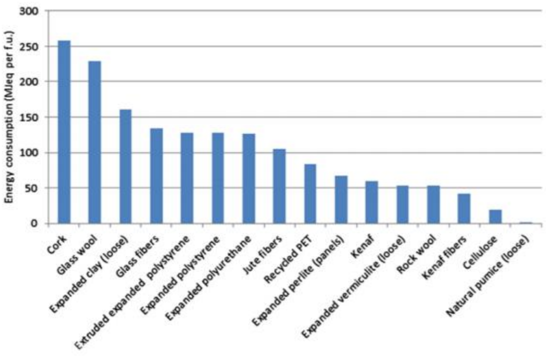


Figure 6 Energy consumption CTGR

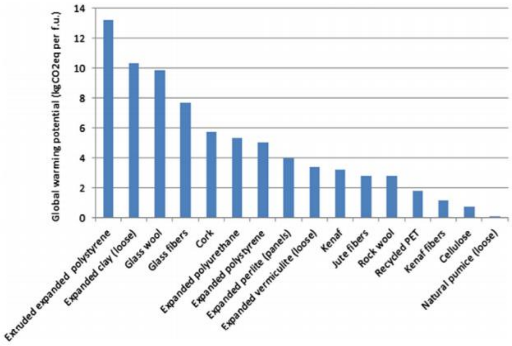


Figure 7 global warming potential CTGR

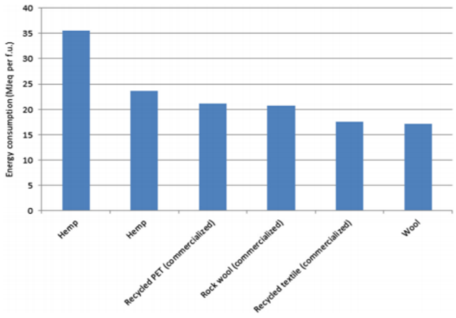


Figure 8 Energy consumption CTGA

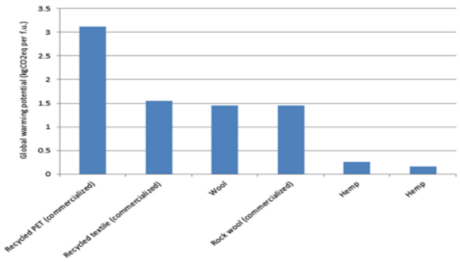


Figure 9 Global warming potential CTGR

Figure 8 presents the thermal transmittance properties of the case study. The case includes timber wall and Masonry wall.

Figure 10 The thermal transmittance of the case study.

2.6.3 LCA study of transparent aerogel analyze the environmental impact of aerogel

Another research is an LCA study of transparent aerogel analyze the environmental impact of aerogel done by Mark DOWSON at the University of Bath. Mark presented the aerogel as a good insulation material and has responsibly high emissions and energy consumption of their production compared with traditional insulation materials. Mark investigated the environmental impact of two production methods of the silica – aerogel compared them with the industrial production. The investigated production methods in the laboratory are Low-Temperature Supercritical Drying (LTCD) and High-Temperature Supercritical Drying (HTCD) (Mark DOWSON, 2011).

Figure 11 presents the CO_2 emissions and production energy of two production methods and the commercial, industrial production.

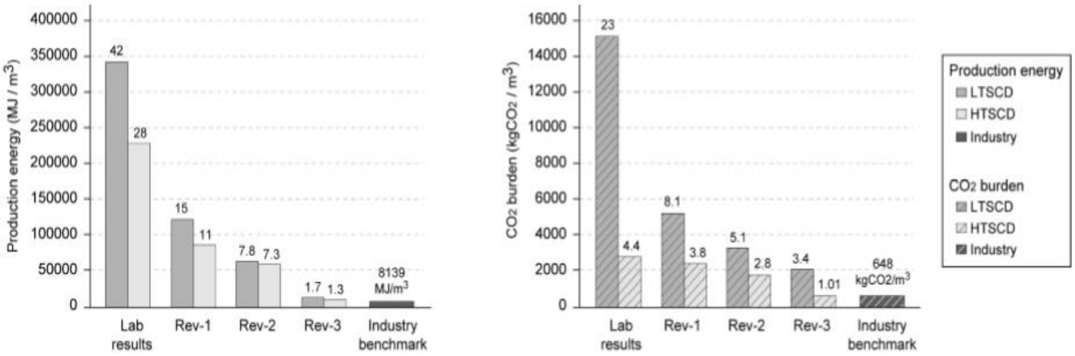


Figure 6 *The CO_2 emissions and production energy of Aerogel*

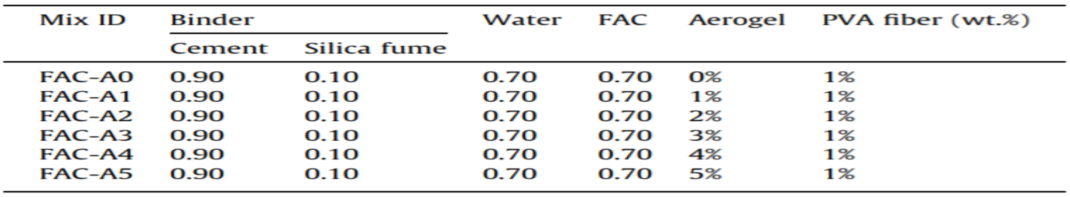
2.7 Literature focusing on research of incorporating Fly Ash into concrete

In this section, it is going to be presented previous research incorporating Fly Ash into concrete. The first paper is “Green lightweight cementitious composite incorporating aerogels and fly ash cenospheres – Mechanical and thermal insulating properties” (Hanif et al., 2016). The second paper is “Development of ultra-lightweight cement composites with low thermal conductivity and high specific strength for energy efficient buildings” (Wu et al., 2015).

2.7.1 Green lightweight cementitious composite incorporating aerogels and fly ash cenospheres – Mechanical and thermal insulating properties

Hanif and his group in The Hong Kong University of Science and Technology developed ultra-lightweight cementitious composite with both excellent mechanical and thermal insulating properties. Hanif has used Fly ash cenosphere (FAC), and aerogel as lightweight aggregates. Although, Hanif have used Polyvinyl alcohol fibers to improve the mechanical behavior of the cementitious composite. Hanif tested five samples based on aerogel contents as shown in Table 7.

Tabell 6 Mix proportions



Mix ID	Binder		Water	FAC	Aerogel	PVA fiber (wt.%)
	Cement	Silica fume				
FAC-A0	0.90	0.10	0.70	0.70	0%	1%
FAC-A1	0.90	0.10	0.70	0.70	1%	1%
FAC-A2	0.90	0.10	0.70	0.70	2%	1%
FAC-A3	0.90	0.10	0.70	0.70	3%	1%
FAC-A4	0.90	0.10	0.70	0.70	4%	1%
FAC-A5	0.90	0.10	0.70	0.70	5%	1%

Hanif concluded that the utilization of aerogel in the composites reduce the permeability of these composites. The reduced permeability shows better durability-related properties of these composites. Beside the incorporating of aerogel into the composites make these composites desirable for use in buildings and construction for energy conservation while the adequate mechanical strength. Figure 7 shows the decreasing in thermal conductivity coefficient & density by increasing the aerogel content in the composite (Hanif et al., 2016).

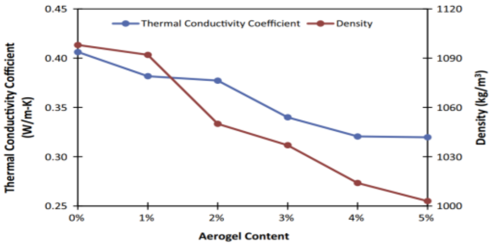
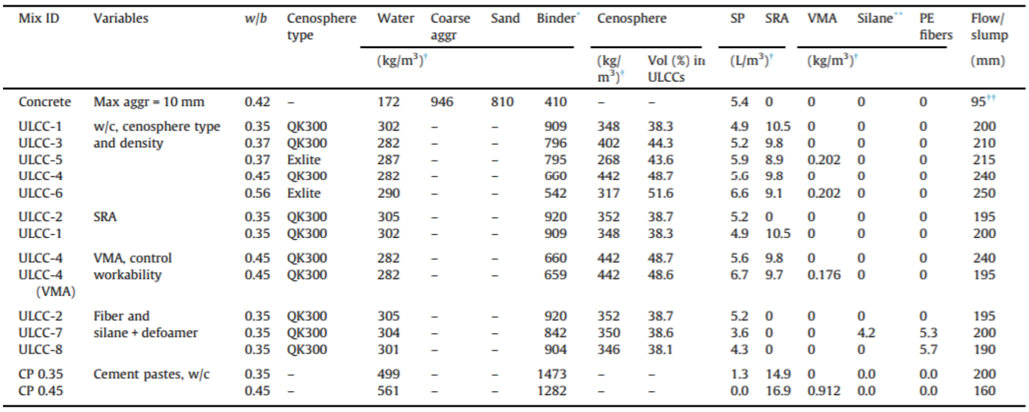


Figure 7 The change in thermal conductivity coefficient & density by incorporating aerogel

2.7.2 Development of ultra-lightweight cement composites with low thermal conductivity and high specific strength for energy efficient buildings

This study focuses on the development of ultra-lightweight cement composites (ULCCs) with low thermal conductivity but high specific strength so that they can be used for structural applications. The lightweight is achieved by incorporating hollow cenospheres from fly ash generated in thermal power plants (Wu et al., 2015).

Tabell 7 Mix proportion of samples



Mix ID	Variables	*w/b*	Cenosphere type	Water	Coarse aggr	Sand	Binder*	Cenosphere		SP	SRA	VMA	Silane**	PE fibers	Flow/ slump
				(kg/m^3)†				(kg/ m^3)†	Vol (%) in ULCCs	(L/m^3)†		(kg/m^3)†			(mm)
Concrete	Max aggr = 10 mm	0.42	–	172	946	810	410	–	–	5.4	0	0	0	0	95††
ULCC-1	w/c, cenosphere type and density	0.35	QK300	302	–	–	909	348	38.3	4.9	10.5	0	0	0	200
ULCC-3		0.37	QK300	282	–	–	796	402	44.3	5.2	9.8	0	0	0	210
ULCC-5		0.37	Exlite	287	–	–	795	268	43.6	5.9	8.9	0.202	0	0	215
ULCC-4		0.45	QK300	282	–	–	660	442	48.7	5.6	9.8	0	0	0	240
ULCC-6		0.56	Exlite	290	–	–	542	317	51.6	6.6	9.1	0.202	0	0	250
ULCC-2	SRA	0.35	QK300	305	–	–	920	352	38.7	5.2	0	0	0	0	195
ULCC-1		0.35	QK300	302	–	–	909	348	38.3	4.9	10.5	0	0	0	200
ULCC-4	VMA, control workability	0.45	QK300	282	–	–	660	442	48.7	5.6	9.8	0	0	0	240
ULCC-4 (VMA)		0.45	QK300	282	–	–	659	442	48.6	6.7	9.7	0.176	0	0	195
ULCC-2	Fiber and silane + defoamer	0.35	QK300	305	–	–	920	352	38.7	5.2	0	0	0	0	195
ULCC-7		0.35	QK300	304	–	–	842	350	38.6	3.6	0	0	4.2	5.3	200
ULCC-8		0.35	QK300	301	–	–	904	346	38.1	4.3	0	0	0	5.7	190
CP 0.35	Cement pastes, w/c	0.35	–	499	–	–	1473	–	–	1.3	14.9	0	0.0	0.0	200
CP 0.45		0.45	–	561	–	–	1282	–	–	0.0	16.9	0.912	0.0	0.0	160

Figure 8 presents the comparison between ultra-lightweight cement composites (ULCCs) with various lightweight aggregates reported in the literature. The presented values are density, compressive strength, and thermal conductivity of the Compared Materials.

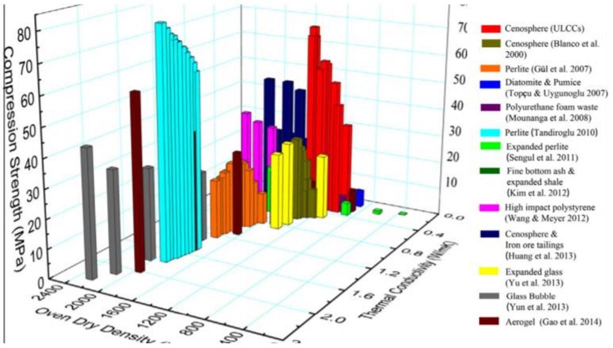


Figure 8 the comparison between ultra-lightweight cement composites (ULCCs) with various lightweight aggregates reported in the literature

3 Materials

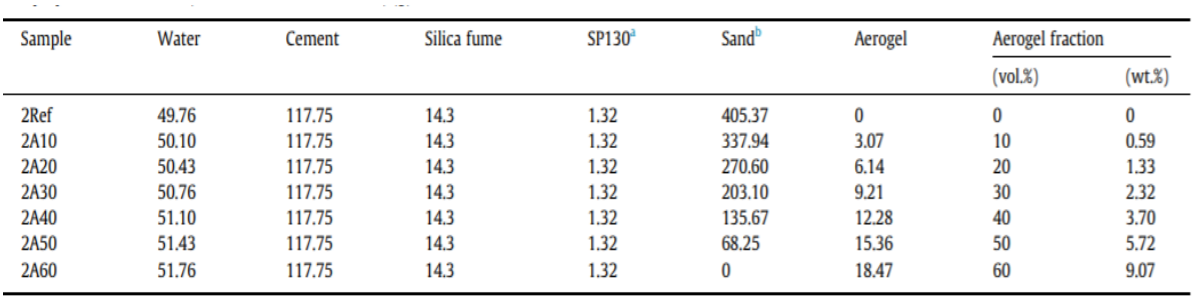
In this chapter, it will be presented the new composite materials studied in this paper. Then it will be done a comparison between them. The included composites in this research are AIC, AIM, and MKP – FA. Then it will be presented chosen composite to be compared with other composites and conventional insulation materials

3.1 AIC

The AIC composite in the NTNU research consists of traditional components of concrete such as water, cement, and sand. Then incorporate the Aerogel in the concrete samples. The contents of aerogel in samples will be increased gradually from 10 % to 60%. After preparing the samples in a standard Hobart 2-litre mixer. The samples will be scanned the structure of particles. Then some tests will be done to measure the density, thermal conductivity, compressive strength and flexural strength of the samples. Finally, draw graphs which show the change in the characterization based on the increasing of aerogel content of the sample.

According to the paper: The AIC consist of traditional concrete components, Aerogel hydrophobic granules. Then a Superplasticizer (Dynamon SP130) which is modified acrylic polymer solution for precast concrete was added during the stirring stage to increase cohesion and homogeneity of the concrete mixture. The mixture is formed in samples (40 mm - 40 mm - 160 mm). The table shows the mix proportion of the AIC samples.

Tabell 8 AIC composition



Sample	Water	Cement	Silica fume	SP130[a]	Sand[b]	Aerogel	Aerogel fraction	
							(vol.%)	(wt.%)
2Ref	49.76	117.75	14.3	1.32	405.37	0	0	0
2A10	50.10	117.75	14.3	1.32	337.94	3.07	10	0.59
2A20	50.43	117.75	14.3	1.32	270.60	6.14	20	1.33
2A30	50.76	117.75	14.3	1.32	203.10	9.21	30	2.32
2A40	51.10	117.75	14.3	1.32	135.67	12.28	40	3.70
2A50	51.43	117.75	14.3	1.32	68.25	15.36	50	5.72
2A60	51.76	117.75	14.3	1.32	0	18.47	60	9.07

The graphs show the change in the thermal conductivity and density of AIC samples based on increasing of aerogel content in the composite. The graph 1 shows the decreasing of density with increasing of aerogel content. The measured density of 60 % aerogel incorporated aerogel is about 100 kg/m^3 compared to the density sample 1980 kg/m^3 of reference plain concrete. The aerogel is porous ultralight material and has an extremely low density (density: 100 kg/m3), therefore replacing normal aggregates (i.e., sand with a density of 2600 kg/ m3) in the plain concrete by aerogel particles results in lightweight concrete.

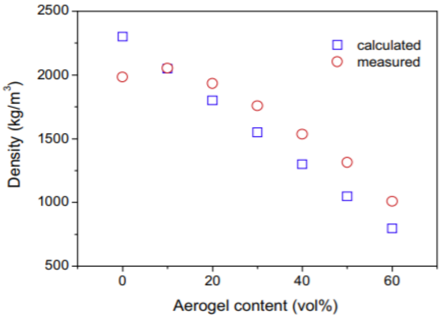


Figure 9 AIC density

The graphs show the change in the thermal conductivity and density of AIC samples based on increasing of aerogel content in the composite. The graph 1 shows the decreasing of thermal conductivity with increasing of aerogel content. The measured thermal conductivity of 60 % aerogel incorporated aerogel is about 0.26 W/mK compared to the density sample 1.86 W/mK of reference plain concrete. The aerogel is had a low thermal conductivity of about 0.01–0.02 W/mK. Therefore incorporation of aerogel particles to concrete will result in a thermal insulating composite.

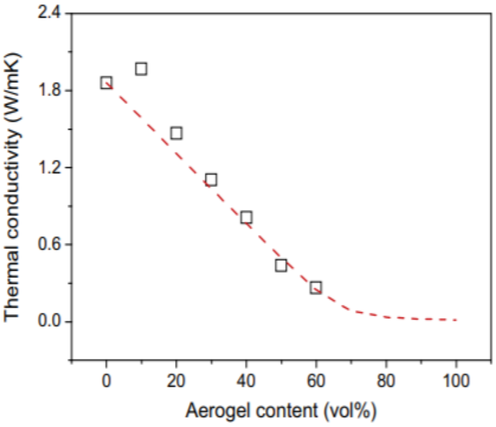


Figure 10 AIC thermal conductivity

The graphs show the change in the compressive strength of AIC samples based on increasing of aerogel content in the composite. The graph shows the decreasing of compressive strength with increasing aerogel content. The measured compressive strength of 60 % aerogel incorporated concrete is about 8.3 MPa compared to 63 MPa as compressive strength of reference plain sample. The aerogel has no compressive strength, the AIC with high aerogel contents doesn’t meet the concrete requirements. Therefore, the composite material cannot be used in the buildings soyles or grounds, but the research in this paper focuses on using it in walls.

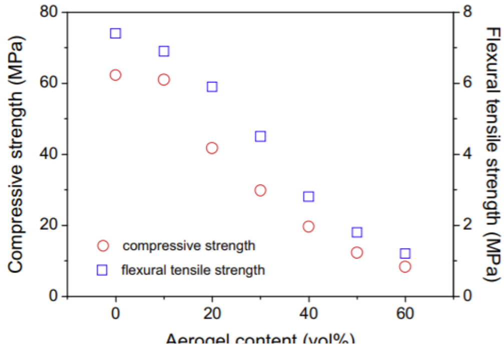
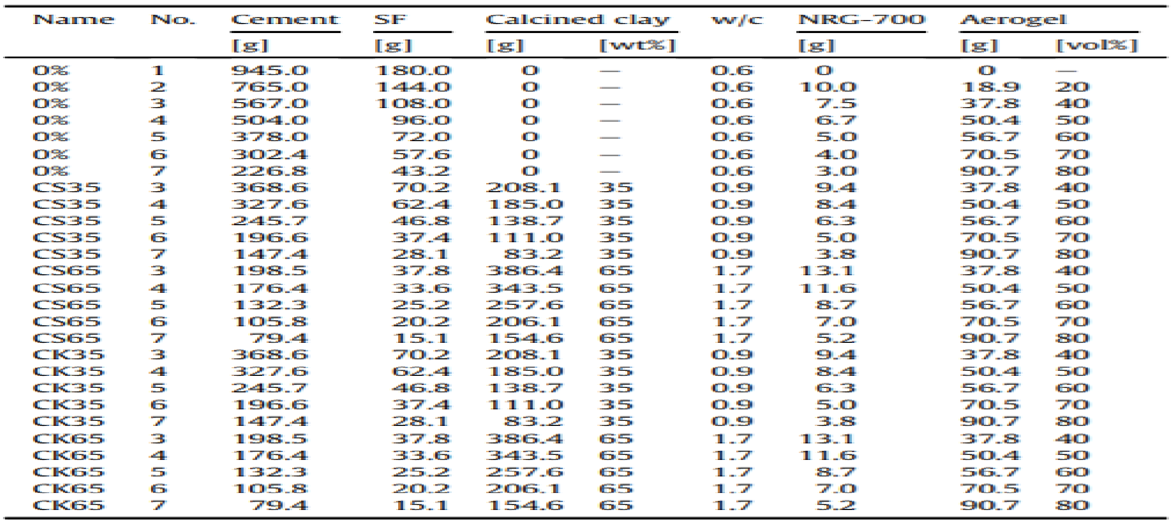


Figure 11 AIC compressive strength

3.2 Calcined clay – aerogel - concrete

Serine has researched the replacement of cement with calcined clay in aerogel incorporated mortars (AIM) to decrease the thermal conductivity. Serine has tested samples of aerogel incorporated concrete with cement as a binder. These samples contents aerogel from 20 % to 80 %. Then tested samples aerogel incorporated concrete with calcined clays as a binder (replacement of cement). The replaced calcined clay has two types of CS (mainly contain smectite) and CK (mainly contain kaolinite). The replacement of ordinary Portland cement with calcined clay as a binder was in two contents 65% and 35%.

Tabell 9 AIM composition



Name	No.	Cement	SF	Calcined clay		w/c	NRG-700	Aerogel	
		[g]	[g]	[g]	[wt%]		[g]	[g]	[vol%]
0%	1	945.0	180.0	0	—	0.6	0	0	—
0%	2	765.0	144.0	0	—	0.6	10.0	18.9	20
0%	3	567.0	108.0	0	—	0.6	7.5	37.8	40
0%	4	504.0	96.0	0	—	0.6	6.7	50.4	50
0%	5	378.0	72.0	0	—	0.6	5.0	56.7	60
0%	6	302.4	57.6	0	—	0.6	4.0	70.5	70
0%	7	226.8	43.2	0	—	0.6	3.0	90.7	80
CS35	3	368.6	70.2	208.1	35	0.9	9.4	37.8	40
CS35	4	327.6	62.4	185.0	35	0.9	8.4	50.4	50
CS35	5	245.7	46.8	138.7	35	0.9	6.3	56.7	60
CS35	6	196.6	37.4	111.0	35	0.9	5.0	70.5	70
CS35	7	147.4	28.1	83.2	35	0.9	3.8	90.7	80
CS65	3	198.5	37.8	386.4	65	1.7	13.1	37.8	40
CS65	4	176.4	33.6	343.5	65	1.7	11.6	50.4	50
CS65	5	132.3	25.2	257.6	65	1.7	8.7	56.7	60
CS65	6	105.8	20.2	206.1	65	1.7	7.0	70.5	70
CS65	7	79.4	15.1	154.6	65	1.7	5.2	90.7	80
CK35	3	368.6	70.2	208.1	35	0.9	9.4	37.8	40
CK35	4	327.6	62.4	185.0	35	0.9	8.4	50.4	50
CK35	5	245.7	46.8	138.7	35	0.9	6.3	56.7	60
CK35	6	196.6	37.4	111.0	35	0.9	5.0	70.5	70
CK35	7	147.4	28.1	83.2	35	0.9	3.8	90.7	80
CK65	3	198.5	37.8	386.4	65	1.7	13.1	37.8	40
CK65	4	176.4	33.6	343.5	65	1.7	11.6	50.4	50
CK65	5	132.3	25.2	257.6	65	1.7	8.7	56.7	60
CK65	6	105.8	20.2	206.1	65	1.7	7.0	70.5	70
CK65	7	79.4	15.1	154.6	65	1.7	5.2	90.7	80

The samples with calcined clay were tested and the result compared with the first samples. Serina found that at an aerogel loading of between 40 vol% and 80 vol%, replacement of cement with calcined clay lowered the thermal conductivity by up to 20% when <70 vol% aerogel was present (0.410 W/(mK) to 0.370 W/(mK)), and by up to 40% with >70 vol% aerogel (0.164 W/(mK) to 0.145 W/(mK)), driven mainly by the innate thermal conductivity of the binders. At replacement level of up to ~30% by weight of binder (%bwob), the properties of the mortar were independent of clay types. When the replacement increased to above 40%bwob, calcined smectite enriched clays were favored for lowering the thermal conductivities of the mortars as compared to those containing kaolinite. The figure show

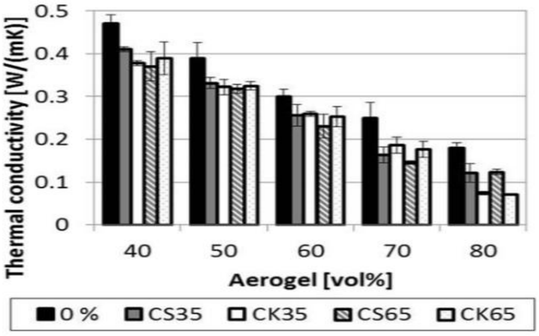


Figure 12 AIM thermal conductivity

conducted measured the thermal conductivity of the different samples based on the increasing of aerogel contents.

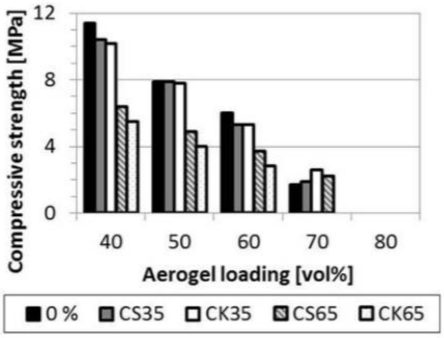


Figure 13 AIM compressive strength

The samples with calcined clay were tested and the result compared with the first samples. Serina found that at an aerogel loading of between 40 vol% and 70 vol%, replacement of cement with calcined clay lowered the compressive strength. The replacement of cement by calcined clay type CK in 35% and 65% lower the compressive strength down to 50% as shown in the figure. The AIM composite with aerogel content 80% has very low compressive strength. Therefore it is n't measured. Therefore At replacement level of up to ~30% by weight of binder (%bwob), the properties of the mortar were independent of clay types. When the replacement increased to above 40%bwob, calcined Kaolinite enriched clays were favored for lowering the thermal conductivities of the mortars as compared to those smectite enriched clays. The figure show conducted measured compressive strength of the different samples based.

3.3 MKP-FA -Aerogel

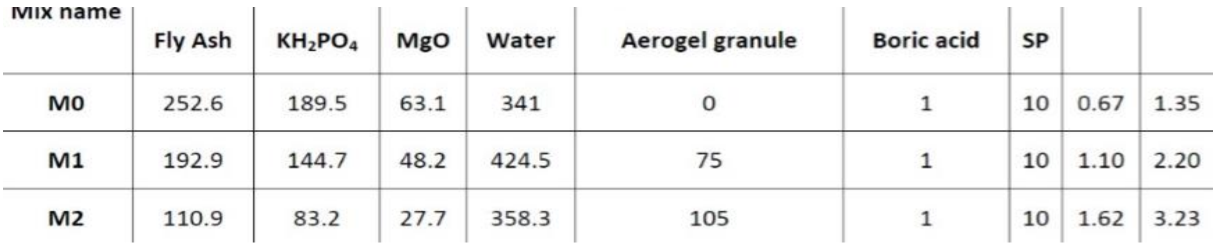
The Magnesium potassium phosphate ceramic incorporated with Fly Ash and Aerogel (MKP – FA - Aerogel) is the third type of composites in this research. These composites are retrieved from the doctor study of the supervisor of the master thesis. Mohammad presented in the doctor thesis paper " Cementitious Nanocomposites with low thermal conductivity" MKP composites and incorporation of aerogel into MKP composites. The physical properties of MKP such as density, thermal conductivity, and compressive strength are measured in that research and presented in the tables down. That study aims to find a multifunctional building material which combines good properties compared with concrete. The multifunctional material will be used as an alternative to the concrete aggregates by incorporating additives to the composites such as fly ash, MKP, and aerogel.

Wagh and his research group developed the new composite Magnesium potassium phosphate ceramic by reacting the oxide with monopotassium phosphate in an aqueous solution. Then the composite can have better mechanical strength by mixing the fly ash within the mixture. The compressive strength of this new composite is in the range from 55 to 83 MP. While the new composite has low thermal conductivity. Furthermore, to get a composite with lower thermal conductivity, the Aerogel was incorporated into the new composite. Research as shown in the table. In the table, it is presented apart from previous research of incorporating aerogel to MKP – FA composite.

the MKP is from the group of chemically bonded phosphate ceramics. These composites can be used as alternatives to the Portland cement based on their properties. These composites are more environment-friendly to produce because they can be made without firing. Therefore the production of these composite consumes less energy than Portland cement.

The table presents the mix composition of samples of MKP. The samples incorporate fly ash as waste material. Although, two of samples incorporate aerogel to improve the properties of the samples.

Tabell 10 MKP composition



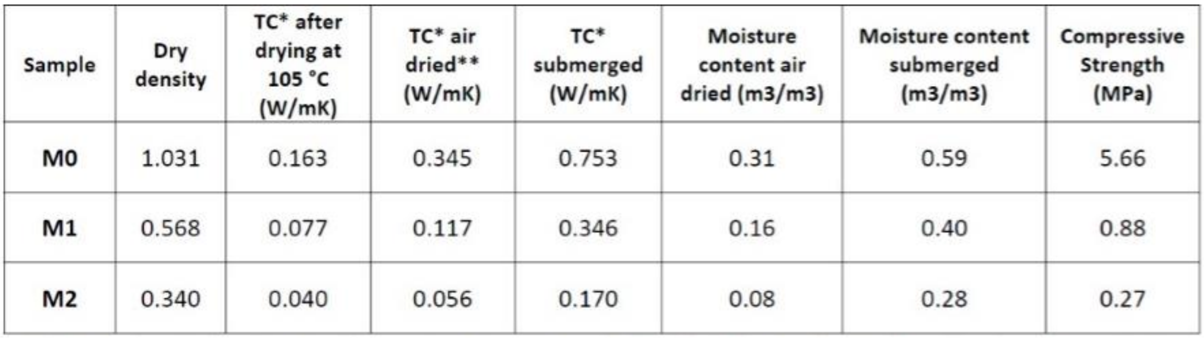
Mix name	Fly Ash	KH_2PO_4	MgO	Water	Aerogel granule	Boric acid	SP		
M0	252.6	189.5	63.1	341	0	1	10	0.67	1.35
M1	192.9	144.7	48.2	424.5	75	1	10	1.10	2.20
M2	110.9	83.2	27.7	358.3	105	1	10	1.62	3.23

Table 11 presents the measured thermal conductivity and compressive strength of samples of MKP. M0 had no aerogel content and considered as reference plain MKP – FA. M1 & M2 samples are incorporated with aerogel in a different amount.

Figure 14 casted Block

Then the samples then are cast in cubic molds. Then the samples are air dried for four months to measure the thermal conductivity in air-dry condition, then dried at 105 C for seven days to measure the dry thermal conductivity. Finally, the samples are submerged in the water for three days to measure the thermal conductivity after the submersion of water.

Tabell 11 MKP Thermal conductivity and density



Sample	Dry density	TC* after drying at 105 °C (W/mK)	TC* air dried** (W/mK)	TC* submerged (W/mK)	Moisture content air dried (m3/m3)	Moisture content submerged (m3/m3)	Compressive Strength (MPa)
M0	1.031	0.163	0.345	0.753	0.31	0.59	5.66
M1	0.568	0.077	0.117	0.346	0.16	0.40	0.88
M2	0.340	0.040	0.056	0.170	0.08	0.28	0.27

3.4 Conventional insulation materials

The table shows the conventional insulation materials which will be compared with the composites.

Tabell 12 conventional insulation materials

Conventional insulation material	Producer	Product	Country	Thermal conductivity W/(m)K	Density (kg/m^3)	Thickness with R = 1 (mm)	Chemical
Glass wool	Glava	Glassull 16,5 kg/m^3 , λD = 0,035 W/(m)K	Norway	0,035	16,5	35	Inorganic
	Saint-Gobain Isover	Glassull Isover UNI skiva 35	Sweden	0,035	17	35	
Rockwool	Rockwool	Rockwool 29 kg/m^3 , λD = 0,037 W/(m)K	Denmark / Norway	0,037	29	35	
XPS	Exiba	Exiba XPS snitt	Europa	0,0355	34,5	35,5	Organic
	Dow Deutschland	Dow XENERGY XPS foam insulation snitt	Europa	0,031	35	31	
EPS	EUMEPS	EUMEPS EPS u/ flammehemmer snitt	Scandinavian	0,034	25	34	

3.5 Thermal conductivity Aerogel – concrete

The thermal conductivity of the compared composites and conventional insulation materials.

AIC

The figure 15 and table 13 present the thermal conductivity of the compared AIC composites with conventional insulation materials.

Tabell 13 thermal conductivity of AIC & conventional insulation materials

Aerogel wt%	AIC	Glass wool Glava	Glass wool Saint-Gobain	Rockwool	XPS ExiBa	XPS Dow	EPS
0 %	1,9	0,035	0,035	0,037	0,0355	0,031	0,034
10 %	2						
20 %	1,5						
30 %	1,1						
40 %	0,8						
50 %	0,4						
60 %	0,3						

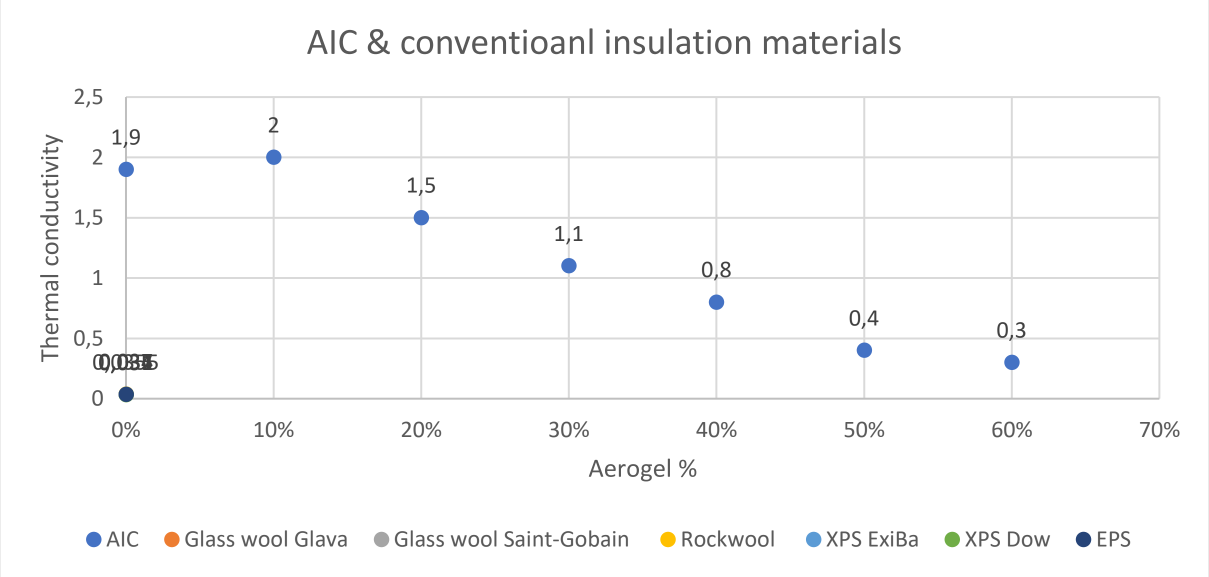


Figure 15 thermal conductivity of AIC & conventional insulation materials

AIM

The figure 1 and table 14 present the thermal conductivity of the compared AIM composites with conventional insulation materials.

Tabell 14 Thermal conductivity of AIM and conventional insulation materials

Aerogel wt%	Anlegg cement	CS 35 %	CS 65 %	CK 35 %	CK 65 %	AIC	Glass wool Glava	Glass wool Saint-Goba	Rockwool	XPS ExiBa	XPS Dow	EPS
0 %	1					1,9	0,035	0,035	0,037	0,0355	0,031	0,034
20 %	0,9					1,5						
40 %	0,47	0,41	0,36	0,38	0,39	0,8						
50 %	0,4	0,32	0,31	0,32	0,33	0,4						
60 %	0,3	0,26	0,23	0,26	0,25	0,3						
70 %	0,25	0,15	0,15	0,19	0,19							
80 %	0,18	0,12	0,12	0,07	0,07							

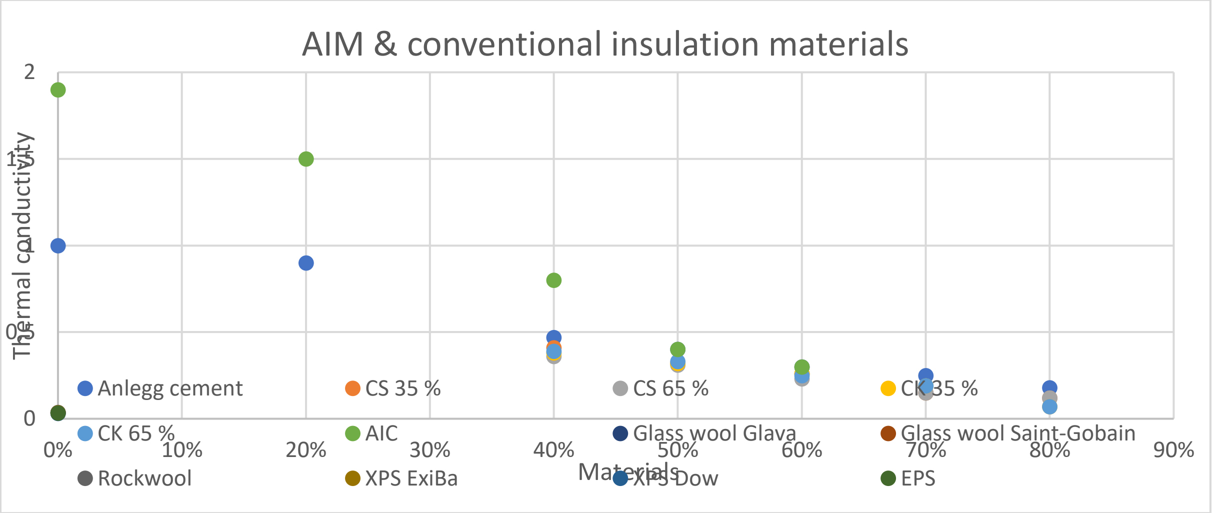


Figure 16 Thermal conductivity of AIM & conventional insulation materials

MKP

The figure 17 and table 15 present the thermal conductivity of the compared MKP composites with conventional insulation materials.

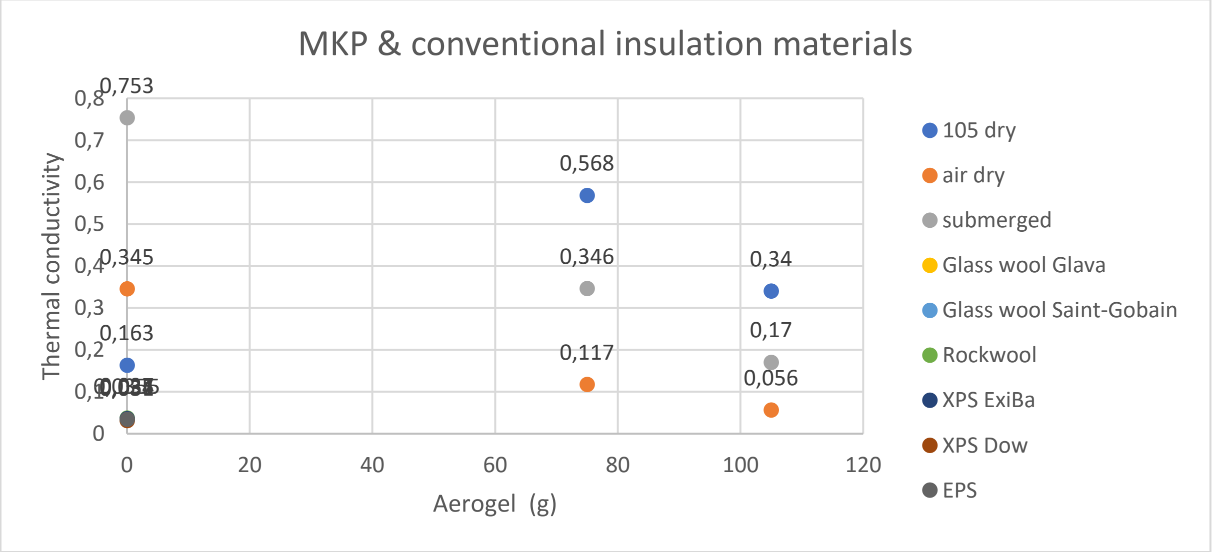


Figure 17 Thermal conductivity of MKP & conventional insulation materials

Tabell 15 Thermal conductivity of MKP & conventional insulation materials

Aerogel (g)	105 dry	air dry	submerged	Glass wool Glava	Glass wool Saint-G	Rockwool	XPS ExiBa	XPS Dow	EPS
0	0,163	0,345	0,753	0,035	0,035	0,037	0,0355	0,031	0,034
75	0,568	0,117	0,346						
105	0,34	0,056	0,17						

3.6 Density

The tables down present the density of the new composites compared with conventional insulation materials.

AIC

The figure 18 and table 16 present the density of the compared AIC composites with conventional insulation materials.

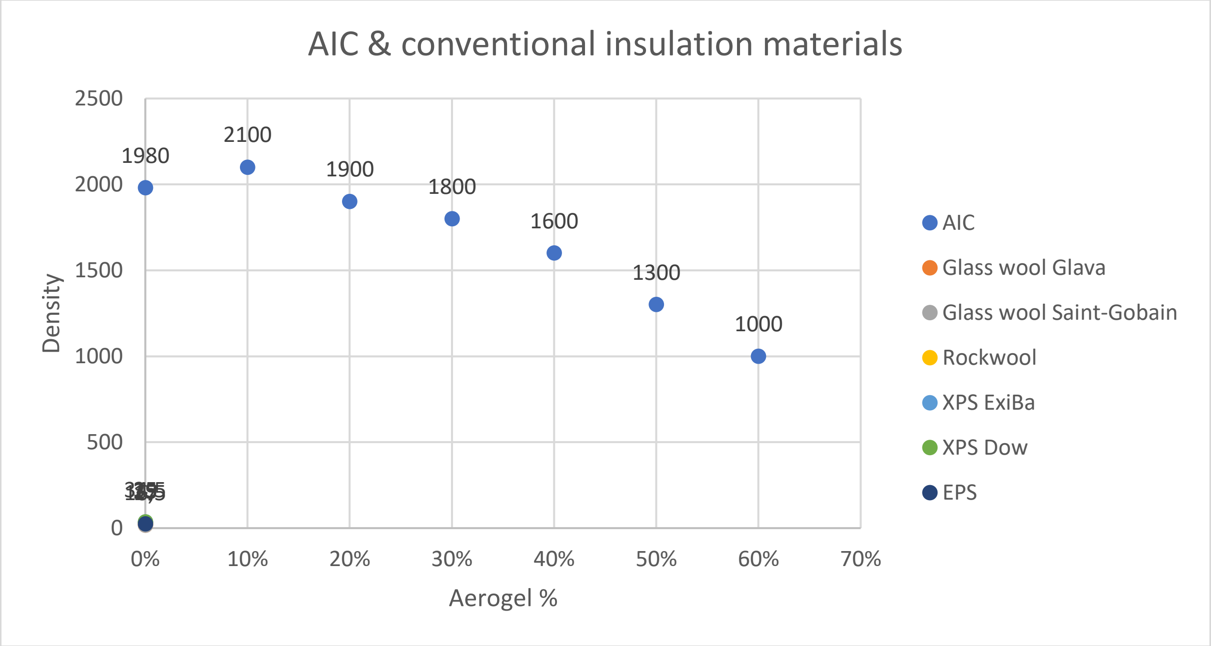


Figure 18 Density of AIC and conventional insulation materials

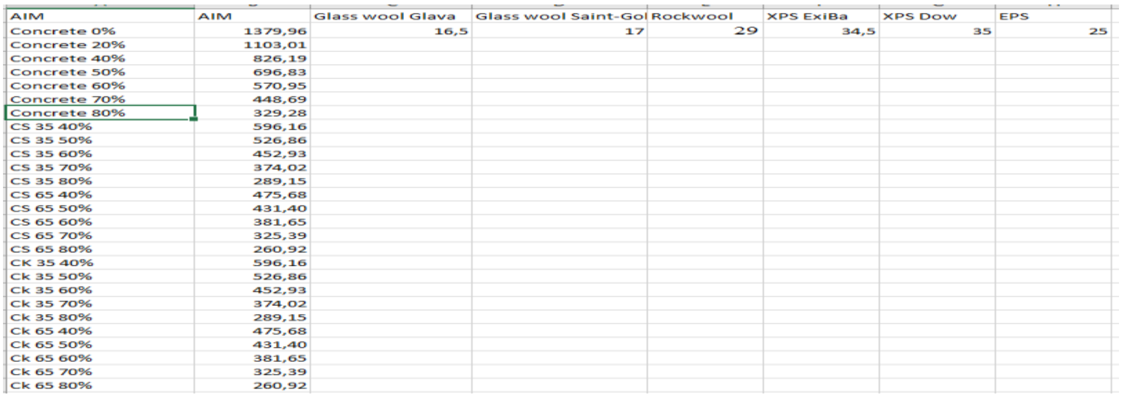
Tabell 16 Density of AIC and conventional insulation materials

Aerogel	AIC	Glass wool Glava	Glass wool Saint-Gobain	Rockwool	XPS ExiBa	XPS Dow	EPS
0 %	1980	16,5	17	29	34,5	35	25
10 %	2100						
20 %	1900						
30 %	1800						
40 %	1600						
50 %	1300						
60 %	1000						

AIM

The table down present the density of AIM composites. The density of the AIM composites is calculated by excel (see the appendix C). The figure 18 and table 18 present the density of the compared AIM composites with conventional insulation materials.

Tabell 17 Density of AIM and conventional insulation materials



AIM	AIM	Glass wool Glava	Glass wool Saint-Gol	Rockwool	XPS ExiBa	XPS Dow	EPS
Concrete 0%	1379,96	16,5	17	29	34,5	35	25
Concrete 20%	1103,01						
Concrete 40%	826,19						
Concrete 50%	696,83						
Concrete 60%	570,95						
Concrete 70%	448,69						
Concrete 80%	329,28						
CS 35 40%	596,16						
CS 35 50%	526,86						
CS 35 60%	452,93						
CS 35 70%	374,02						
CS 35 80%	289,15						
CS 65 40%	475,68						
CS 65 50%	431,40						
CS 65 60%	381,65						
CS 65 70%	325,39						
CS 65 80%	260,92						
CK 35 40%	596,16						
Ck 35 50%	526,86						
Ck 35 60%	452,93						
Ck 35 70%	374,02						
Ck 35 80%	289,15						
Ck 65 40%	475,68						
Ck 65 50%	431,40						
Ck 65 60%	381,65						
Ck 65 70%	325,39						
Ck 65 80%	260,92						

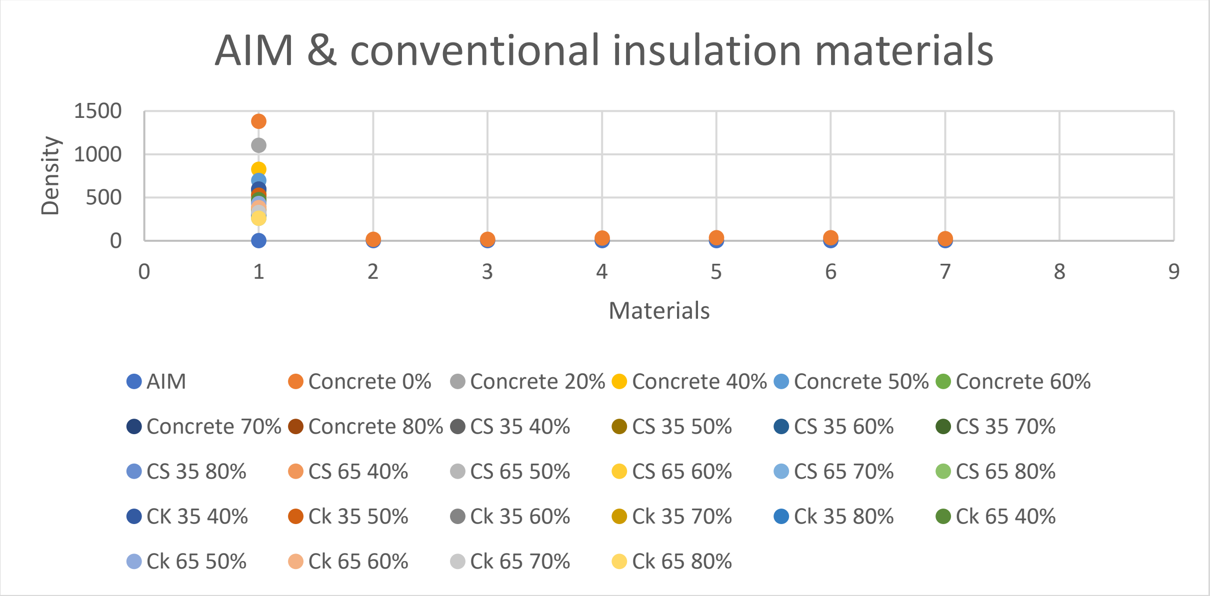
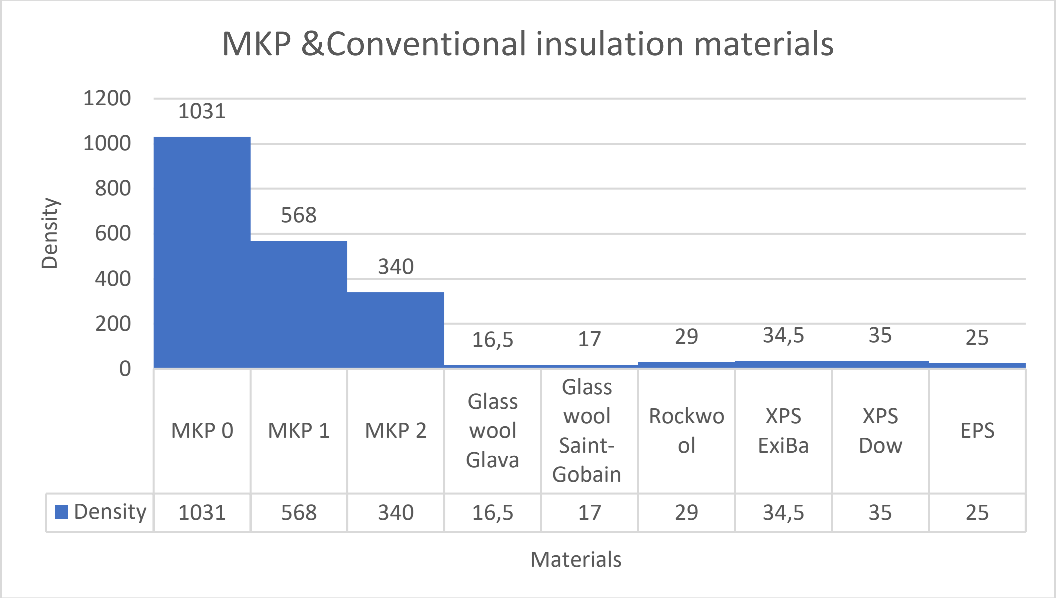


Figure 19 Density of AIC and conventional insulation materials

MKP

Figure 20 present the density of the compared MKP composites with conventional insulation materials.



	MKP 0	MKP 1	MKP 2	Glass wool Glava	Glass wool Saint-Gobain	Rockwo ol	XPS ExiBa	XPS Dow	EPS
■ Density	1031	568	340	16,5	17	29	34,5	35	25

Figure 20 thermal conductivity of MKP and conventional insulation materials

3.7 Multifunctional materials

The new composites which achieve the good mechanical strength and low thermal conductivity can be used as multifunctional materials which are used for both walls buildings and insulation of buildings. Figure 21 presents the density of the new composites with 60 % aerogel and MKP 2

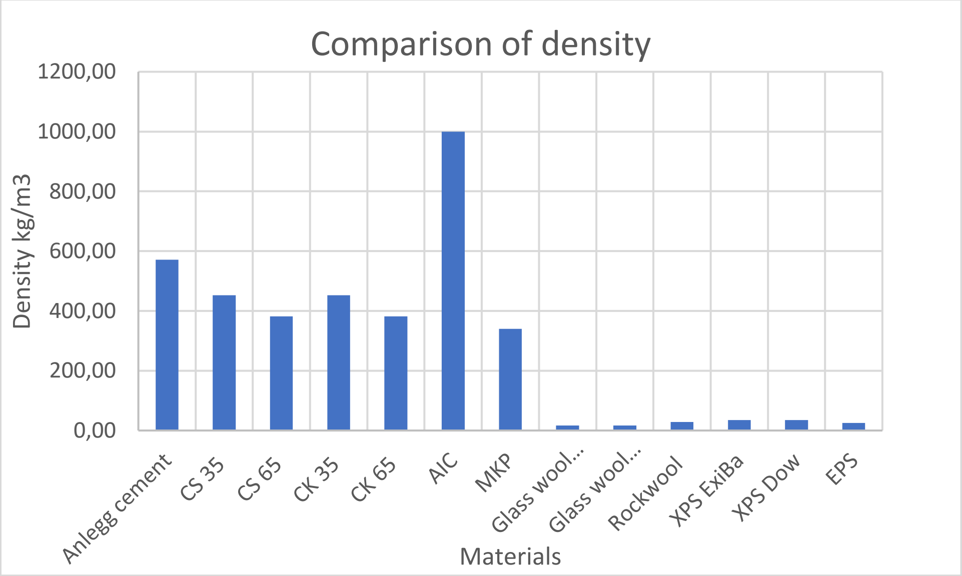


Figure 21 Density of the new composites and conventional insulation materials

Figure 21 presents the density of the new composites with 60 % aerogel and MKP 2

Figure 22 present the thermal conductivity of the new composites with 60 % aerogel and MKP 2.

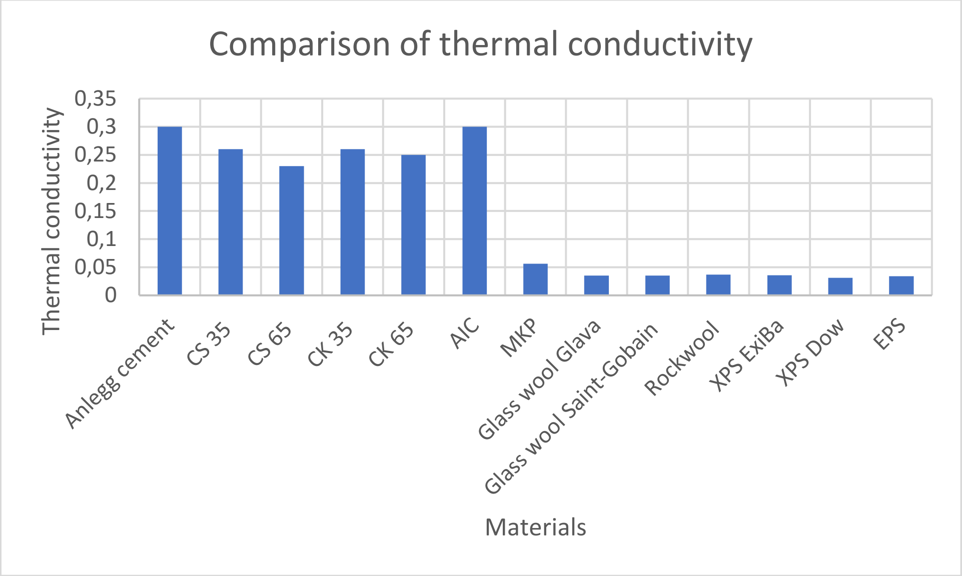


Figure 22 thermal conductivity of the new composites and conventional insulation materials

The new composites which achieve the good mechanical strength and low thermal conductivity can be used as multifunctional materials which are used for both walls buildings and insulation of buildings. The new composites which combine both insulation and mechanical strength are composites with aerogel content 60%. These new composites can be used as multifunctional materials. The figures show the decreasing of compressive strength by increasing of aerogel content in the composites.

Figure 23 shows the change of compressive strength of AIC with concerning aerogel content.

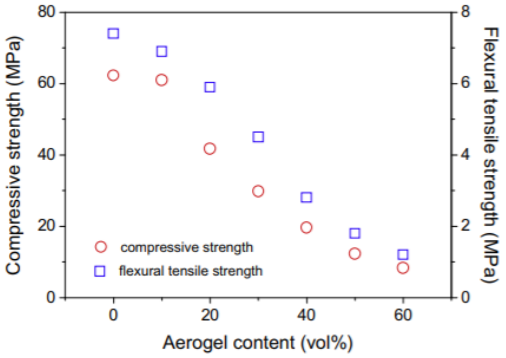


Figure 23 the compressive strength of AIC with concerning aerogel content. retrieved from (Gao et al., 2014)

Figure 24 shows the change of compressive strength of calcined clay - AIM with concerning aerogel content.

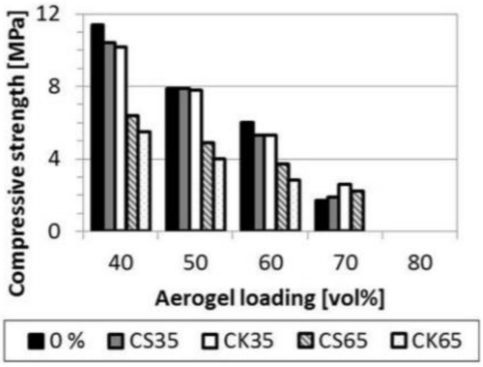


Figure 24 the compressive strength of AIC with concerning aerogel content. retrieved from (Ng et al., 2016)

Figure 25 shows the compressive strength of MKP - FA with concerning aerogel content.

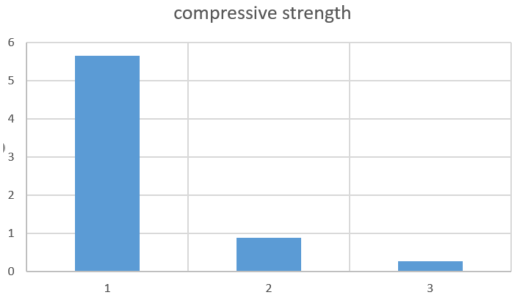


Figure 25 the compressive strength of MKP - FA with concerning aerogel content. retrieved from

4 Description of LCA

Life cycle assessment (LCA) is a method to analyze environmental aspects and impacts of product systems. LCA aims at comparing and analyzing the potential environmental impacts of given products and services at every stage of their life. The ISO 14040 (Standardization, 2006a) and 14044 (Standardization, 2006b) are related standards to perform LCA. The methodology in this part is based on these standards.

LCA consist of four stages.

- Goal and Scope Definition
- Life Cycle Inventory Analysis
- Life Cycle Impact Assessment
- Interpretation

Figure 26 presents the framework included the stages of LCA and their application.

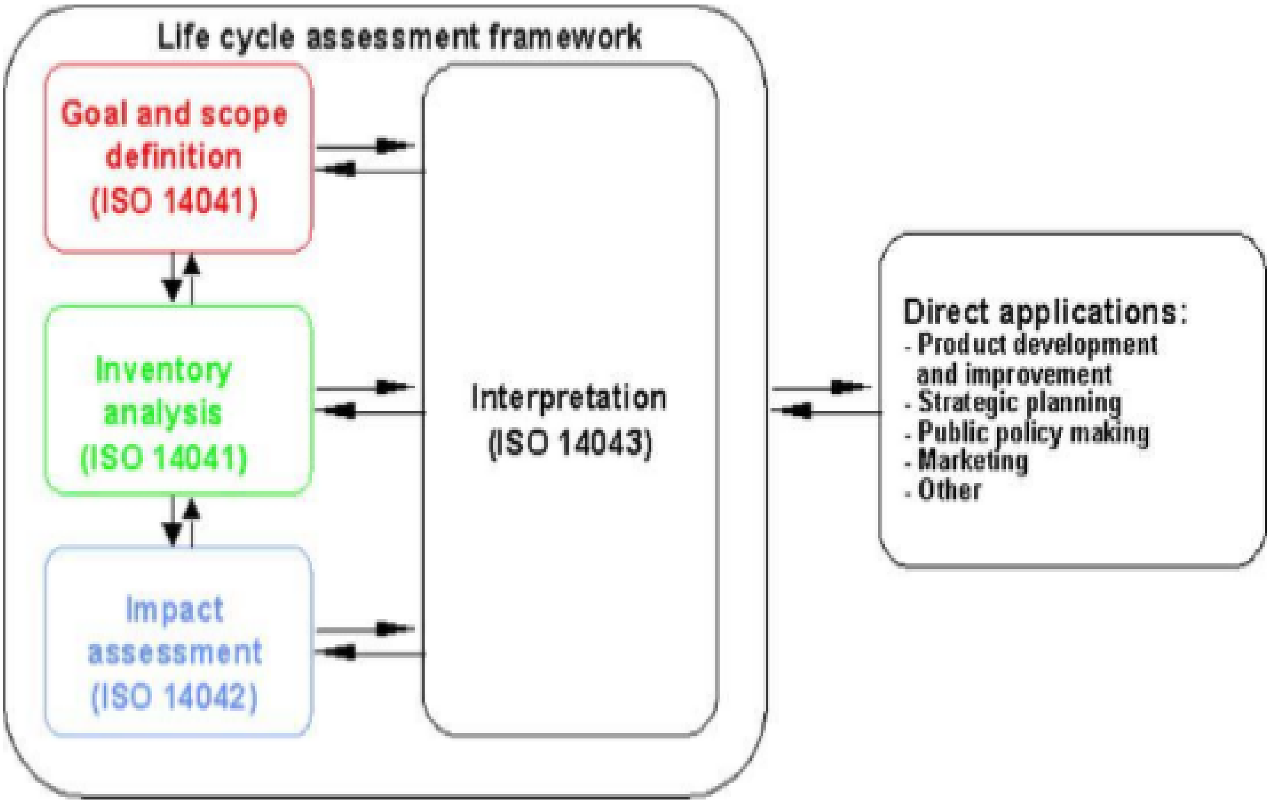


Figure 26 Lifecycle assessment framework

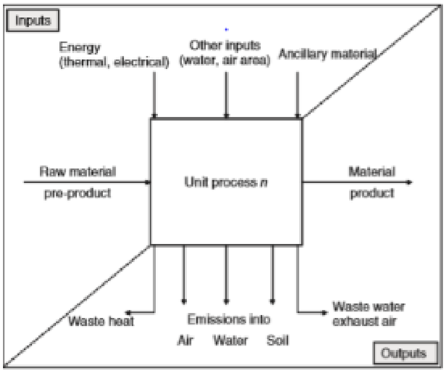
4.1 Goal and scope

The first stage of LCA is goal and scope definition. The goal of an LCA includes the intended application, reasons for conducting the study and the target group. The goal could be identifying the main environmental problems of the system, comparing the systems and their potential impacts, and identifying opportunities for improving the existing system.

The scope of LCA identifies the product system or process to be studied. This include all functions of the system functions of the system as: the functional unit, the product system studied, the system boundary, allocation procedures, cut of rules, assumptions, limitations, data requirements, methods selection, type of critical review, if any, type and format of the report required for the study.

Product system

First, the should be identified as a system regarding its function. The product system will be divided into a set of unit processes that are linked to one another by flows of intermediate products or waste. The dividing of the system will help to identify the input and output of the system.



Functional unit

The functional unit is (as defined in ISO 14044: 2006E) Quantified performance of a product system for use as a reference unit.

Reference flow

It is a measure of the outputs from processes in a given product system required to fulfill the function expressed by the functional unit.

System boundaries

The system boundaries are formulated based on the scope and consistent with the goal of LCA. The system boundaries. The system boundaries are boundaries between the system and its environment. The system boundaries describe which unit process are included in LCA and which are excluded. The processes can be removed from LCA (cut off) if it does not significantly affect the overall conclusions.

Allocation

It describes co-products, by-products, and raw materials.

Cut off criteria

Specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be excluded from the study. If these processes can be neglected because they haven't significantly effected the conclusions. In ISO 14044, it states three cut off criteria: 1) mass, all the inputs that contribute less than 1-5% to the total mass input of the product system. 2) Energy, all the inputs that contribute less than 1-5% to the total energy input of the product system. 3) Environmental significance, any input that contributes less than 1- 5% of the environmental significance of a specially selected environmentally relevant individual data.

Impact categories

Impact categories refer to the types of environmental impacts to be considered in LCA. The selection of impact categories will determine the types of data that will be needed.

Data requirements

It depends on the level of detail of the study and the need for site-specific or generic data.

There are also other types of scope like temporal, technological, geographical, but they are irrelevant for this LCA study.

4.2 Life inventory analysis (LCI)

LCI (as defined in ISO standard 14040:2006) is a "phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its entire lifecycle" (Standardization, 2006a). In this phase, the data of all included unit processes in LCA will be collected to quantify the inputs and outputs of the system. LCI includes several steps: first, collect all data which are relevant to the functional unit. The types of data include the energy, raw materials, products, co-products, and wastes; releases to air, water, and soil; and other environmental aspects. Second, create a flow model (or flowchart) which include all unit processes in the system. The flow model should be consistent with the system boundaries defined in the goal and scope phase. Third, perform the calculations to estimate the total amounts of resources used and pollution emissions about the functional unit. Finally, present the results as an inventory of the environmental input and output data of the system being studied. LCI include all inventory results but will focus on the related data to the goal and scope.

Databases

Databases include documented data of environmental impact of materials or processes provided from institutions with third-party certification based on ISO standards for life cycle assessment.

Data from the producers

The most used data from producers are based on environmental product declaration (EPD) which has been required in many countries. Other data are technician data from producers or sustainability reports for the producer.

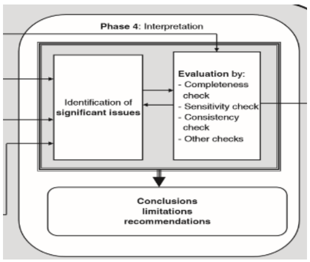
4.3 Life cycle Impact assessment (LCIA)

LCIA (as defined in Standard ISO 14040/14044) is the "phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system." LCIA is used to translate or convert inventory results obtained from the LCI into consequences.

Methods

4.4 Interpretation

The Interpretation is the phase of the life cycle assessment (LCA) where conclusions are drawn from the results of LCIA and LCI. Then the recommendations are made according to the objective of the study. The results from LCIA and LCI should be analyzed to assess the reliability and validity of the LCA. Then make conclusions, recommendation, and limitations of the study.



LCI can be evaluated based on three aspects: analysis of data sources, data quality, completeness and consistency checks. First the analysis of sources of used data in inventory to assess the reliability and validity of these resources. Second, check the data quality by evaluating the uncertainties and data of the data. Third sensitivity and consistency checks. Sensitivity check estimates the changes or uncertainties in the results due to cut – off criteria, data quality, choice of allocation rules and selection of impact categories. While in the consistency check determine if the assumptions, methods, and data are consistent with the goal and scope.

There are also other checks regards to get a better understanding of the LCA from the stakeholders like:

- Completeness check: check if all relevant information is available if there is a gap in the information the goal and scope can be adapted to the information provided.
- Uncertainty check: uncertain data occurs when the environmental performance of different suppliers varies under different conditions produce different emissions. The varying data must be collected and evaluated to examine their range and distribution.
- Comparative analysis: It is a systematic, simultaneous listing of the LCA results for different alternatives. A comparative analysis can be used, for example, to compare CO2 emissions corresponding to a functional unit of 1 kg produced aluminum in several countries, each having its own alternative national energy scenarios (Klöpffer, 2014, Education, 2009, Standardization, 2006b).

5 Methodology

This chapter is dedicated to present the selected methodology for this research project. First, it will be presented the research purpose, research approach, and data collection. Second, it will be presented methodology of Life cycle assessment LCA study in this research.

5.1 Research purpose

The purpose of the research is to find a solution for the main research question which is conducted in the introduction chapter: “*Do the new insulation composites have a lower environmental impact than the traditional insulation materials?* ”. Then the research problem is delimited to some research questions. These research questions (RQ) will be answered during the rapport. The research questions RQ1, RQ2 and RQ3 are answered in the literature review chapter, the RQ4 and R5 are answered in the material chapter, the RQ6 will be answered in methodology chapter, while the RQ7, RQ8, and RQ9 will be answered in chapter 5,6,7 and results in the chapter. The RQ 10 & 11 will be answered in the discussion chapter. Finally, the conclusion of the research.

5.2 Research approach

According to Bryman & Bell (2011), deductive research is used to understand the relationship between the theory and research, while, inductive research is to arrive at a theory from findings of the study (Bryman, 2007a). This research approach in this project was inductive based on comparing between the energy and CO_2 equivalent of the production of the new insulation composites materials with traditional insulation materials to find if these new composite materials are more environment-friendly as new theoretical findings.

5.3 Research method

The main idea of the project was to do LCA study of these new composites compared with the conventional insulation materials. The lack of data on the components of composites made it impossible to conduct LCA study. Therefore, the research project is changed to make energy and greenhouse gasses analysis of these new composites compared with conventional insulation materials. The used method to answer the research question is to compare energy and CO_2 equivalent between the new composites and the conventional insulation materials. The data of conventional insulation materials are retrieved from EPDs. The data of component materials in the composites are received from the producers. The analysis will follow the LCA standards, but it will consider only the energy consumption and CO_2 equivalent. The findings of this method will be discussed in the discussion chapter. Although, the lack of data will be discussed.

5.4 Data collection

Data for this research is collected from different sources to answer the research questions and meet the objectives of the research. The collected data include data from the literature and data from producers. The input and output data for the analysis of AIC and calcined clay – AIM is received from the producers. Some of the data weren't Absolut because some of the products are not produced commercially. The input and output data for LCA of MKP – FA- Aerogel are retrieved from databases in Simapro except for data for aerogel is received from some producers. The data for materials, energy, heat is based on databases from Simapro. The data of the materials in Simapro is adjusted based on the EPDs.

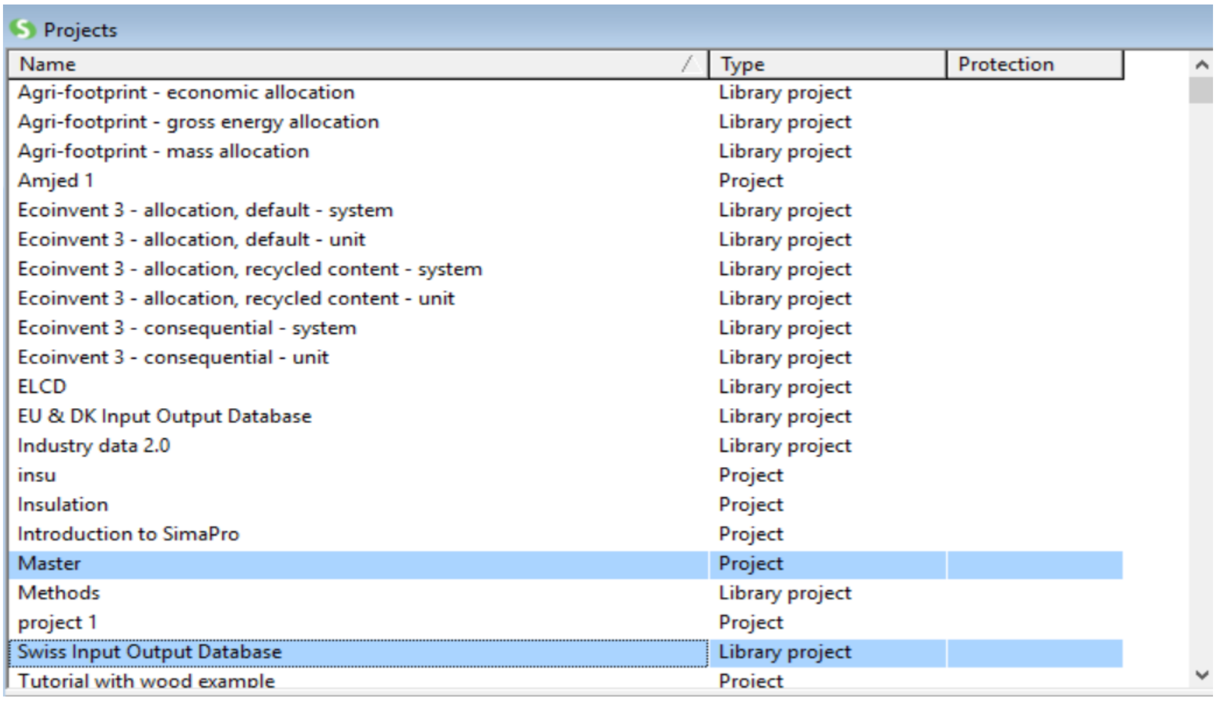
5.4.1 EPDs

EPDs are documentation of the previous done LCA studies. These studies are done after the LCA standards described in the previous chapter. The Epds ensure reliable data which can be used in these data. The data from EPDs are used to adjust the data of materials in Simapro to make a reliable analysis in Simapro (Sintef, 2018).

5.4.2 Simapro

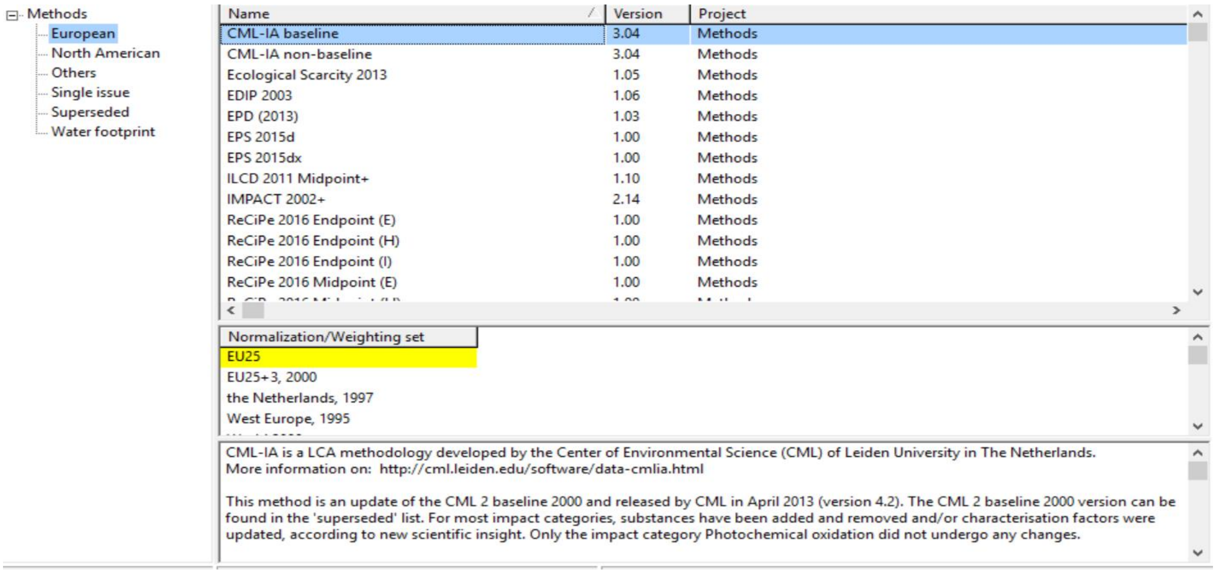
Simapro is the world's leading LCA software package for 25 years. Simapro is used by industry, research institutes and consultants in more than 80 countries (SimaPro, 2017). Simapro is used to do a systematic and transparent analysis of the Lifecycle of product or process. SimaPro follows the ISO 14044 standards (Standardization, 2006b). Simapro releases the results as a large table of emissions, waste, and disposal. Although, it illustrates the results in diagrams to explain the details (Consultants, 2013).

Simapro contains different databases (figure) like industry data 2.0, EU & DK input-output data, Ecoinvent (Centre, 2016, October 4) and European Life Cycle Database (ELCD) (Commission, 2016). The last two databases are the most popular and authoritative inventory databases in the world and were presented by European Commission. Another important database is USLCI which is "a publicly available database that allows users to objectively review and compare analysis results that are based on similar data collection and analysis methods."



Name	Type	Protection
Agri-footprint - economic allocation	Library project	
Agri-footprint - gross energy allocation	Library project	
Agri-footprint - mass allocation	Library project	
Amjed 1	Project	
Ecoinvent 3 - allocation, default - system	Library project	
Ecoinvent 3 - allocation, default - unit	Library project	
Ecoinvent 3 - allocation, recycled content - system	Library project	
Ecoinvent 3 - allocation, recycled content - unit	Library project	
Ecoinvent 3 - consequential - system	Library project	
Ecoinvent 3 - consequential - unit	Library project	
ELCD	Library project	
EU & DK Input Output Database	Library project	
Industry data 2.0	Library project	
insu	Project	
Insulation	Project	
Introduction to SimaPro	Project	
Master	Project	
Methods	Library project	
project 1	Project	
Swiss Input Output Database	Library project	
Tutorial with wood example	Project	

Figure 27 Databases in Simapro



Name	Version	Project
CML-IA baseline	3.04	Methods
CML-IA non-baseline	3.04	Methods
Ecological Scarcity 2013	1.05	Methods
EDIP 2003	1.06	Methods
EPD (2013)	1.03	Methods
EPS 2015d	1.00	Methods
EPS 2015dx	1.00	Methods
ILCD 2011 Midpoint+	1.10	Methods
IMPACT 2002+	2.14	Methods
ReCiPe 2016 Endpoint (E)	1.00	Methods
ReCiPe 2016 Endpoint (H)	1.00	Methods
ReCiPe 2016 Endpoint (I)	1.00	Methods
ReCiPe 2016 Midpoint (E)	1.00	Methods

Normalization/Weighting set
EU25
EU25+3, 2000
the Netherlands, 1997
West Europe, 1995

CML-IA is a LCA methodology developed by the Center of Environmental Science (CML) of Leiden University in The Netherlands.
More information on: http://cml.leiden.edu/software/data-cmlia.html

This method is an update of the CML 2 baseline 2000 and released by CML in April 2013 (version 4.2). The CML 2 baseline 2000 version can be found in the 'superseded' list. For most impact categories, substances have been added and removed and/or characterisation factors were updated, according to new scientific insight. Only the impact category Photochemical oxidation did not undergo any changes.

Figure 28 LCA Methods

5.4.3 LCIA methods

There are several available LCIA methods to provide environmental impact analysis such as ILCD 2011Midpoint (European Commission, 2012), EDIP 2003 (Dreyer et al., 2003), IMPACT 2002+ (Dreyer et al., 2003) and ReCiPe 2016 (Radboud University, 2016). These methods vary across areas such as assumptions made and regional relevancy, which may lead to different LCIA results. In this paper, tow single issue methods were used to conduct the energy consumption (IPCC 2013) and CO2 emissions (Cumulative Energy Demand (CED)) of the compared materials. IPCC 2013 contains the climate change factors of IPCC with a timeframe of 100 years. (Change., 2013). Cumulative Energy Demand (CED) calculate the energy demand of the whole system (ecoinvent, 2013).

5.5 Validity and reliability

According to Bryman & Bell (2011), there are four types of validity: Measurement validity, Internal validity, external validity, and Ecological validity (Bryman, 2007b). In this section, It will be presented the four types considering this research. Measurement validity controls "whether the measure being used measures what it claims" (Bryman, 2007b). The measurement validity of this research was based on the measures from other research or analysis. For thermal conductivity, the measured values are retrieved from the other research papers which are done in Sintef incorporated with NTNU. For environmental impact of materials, the measurement is presented by producers as (EPD) or databases in Simapro. Internal validity examines if the conclusions drawn from the research are a true reflection of causes (Bryman, 2007b). External validity examines if the results of the research can be generalized to other groups beyond the scope or context (Bryman, 2007b). The applied LCA methodology in this research include some new composites with new inorganic materials. The results are reliable for these composite. While in the discussion chapter, it is drawn some results of incorporating inorganic materials like aerogel into the composites. These results can be generalized for other composites. Ecological validity explores if the findings of the research apply to people's everyday life (Bryman, 2007b). The environmental impact of these new building composite materials is valuable for the life of human health and life.

Reliability is the degree to which the data collection, the analysis will allow consistent findings or (McKinnon, 1988) defines it as the trustworthiness of the collected data. The previous research is collected from academic journals with licensed access, open reports online. While the environmental impact data are retrieved from the producers and from databases in Simapro to ensure the trustworthiness of the data. The data of thermal conductivity of the studied materials are retrieved from the previous research of NTNU & Sintef.

6 Goal and scope

6.1 Goal

This project aims to compare the energy and CO_2 equivalent of the production of the new composites with some conventional insulation materials to conduct if these new composites are more environment – friendly solution.

There are several types of research focuses on the environmental performance of buildings based on thermal efficiency(Antoniadou et al., 2015, Schiavoni et al., 2016). Although, some researchers focus on the environmental impact of production (Pargana et al., 2014, Reidun Dahl Schlanbusch and Kristjansdottir, 2014). In this research, it will be a focus on environmental impact of the production of insulation materials.

6.2 Product system

The product system will be divided into a set of unit processes that are linked to one another by flows of intermediate products or waste. The dividing of the system will help to identify the input and output of the system.

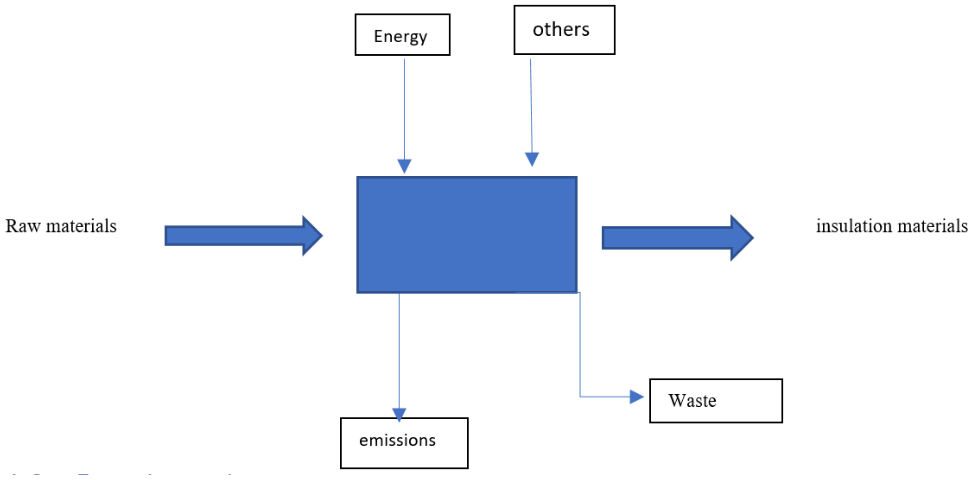


Figure 29 Insulation material unit process

6.3 System boundaries

The system considers the production phase of the compared materials, not the use phase of the end of life. The use phase eliminated since all used materials ensure the same R-value. The production phase includes (A1) raw material extraction and processing of raw materials, (A2) transportation of raw materials to the factory, (A3) production and product packaging. The scope of this system cradle – to – gate model after the LCA standards described in 2.4. Figure 30 presents the production phase.

The system boundary is defined as “cradle-to-gate” model (Education, 2009). The model includes the upstream processes such as raw material acquisition, transport, and production. The downstream processes such as operation, maintenance, and use are excluded from the LCA.

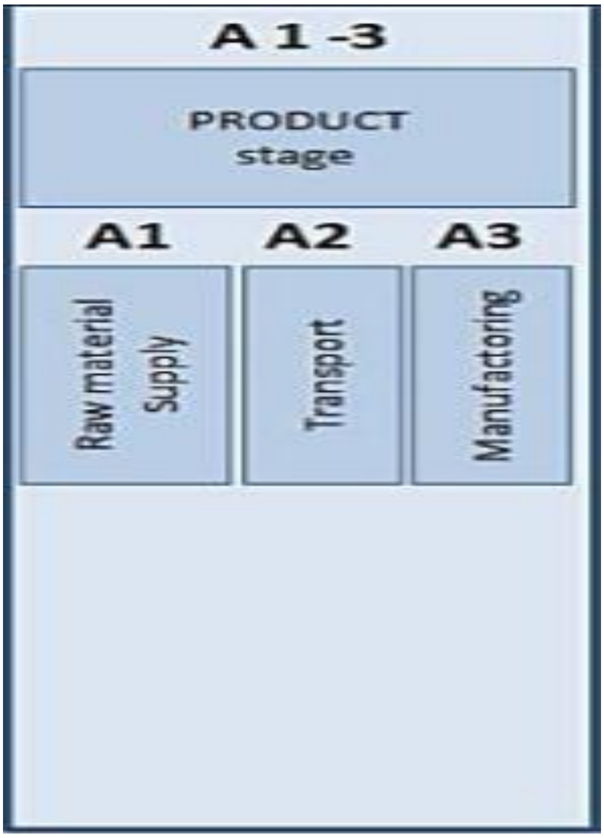


Figure 30 EN 15804 (European Committee for Standardization, 2012).

6.4 Function unit

The functional unit for this research is performed as it performed in the most life cycle assessment (LCA) studies of insulation solutions. The functional unit of insulation board that provides a thermal resistance R of 1 (m^2 K/W). The functional unit of this research is the "insulation for 1 m^2 area with a thickness ensure R-value (R = 1 m^2 K/ W)".

The functional unit equant mass (F.U) = R.λ.*p.A (Kg)*

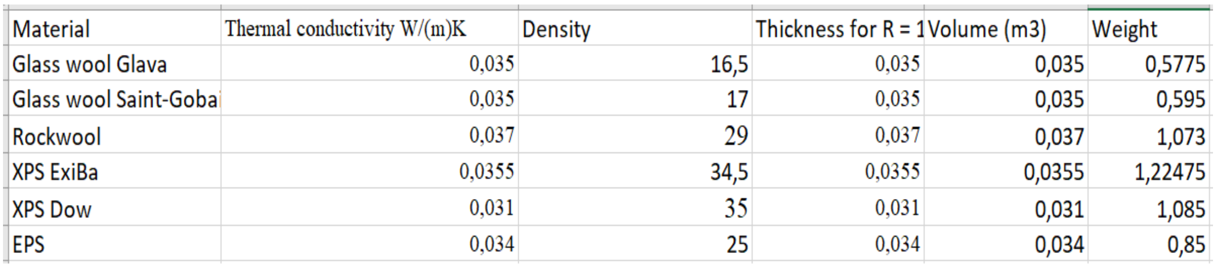
Where R represents the thermal resistance as 1 (m^2 K)/W, λ represents the thermal conductivity measured as W/(m*K), U represents the thermal transmittance as W/(m^2*K). A represents the defined area in the functional unit as 1 m^2, F.U corresponds to the used weight of the compared composite material, P represents the density of the insulation product in kg/m3, and V represents the volume of the compared composite in M^3.

Then in the next sections, it will be presented the calculations of the F.U (Kg) for the studied composite materials: conventional insulation materials, AIC, AIM and MKP – FA. The data of conventional insulation materials are retrieved from databases in Simapro adjusted by EPDs from the producers.

6.4.1 Conventional insulation materials

Table 2 presents the F.U of the conventional insulation materials based on the F.U formula.

Tabell 18

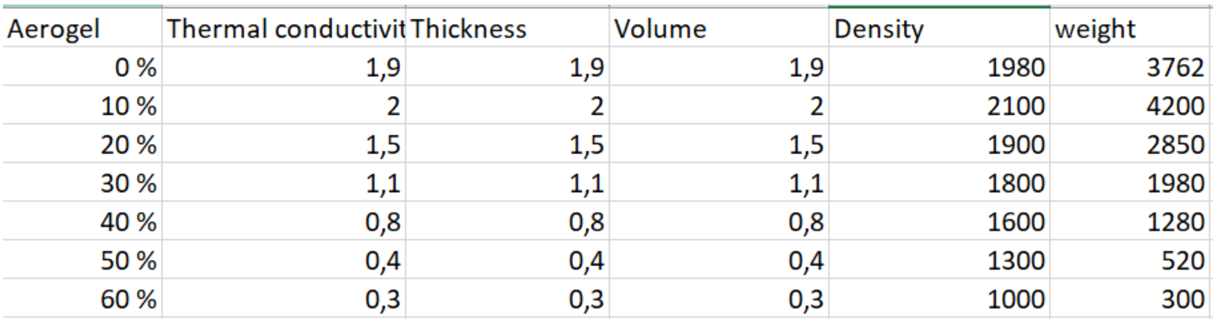


Material	Thermal conductivity W/(m)K	Density	Thickness for R = 1	Volume (m3)	Weight
Glass wool Glava	0,035	16,5	0,035	0,035	0,5775
Glass wool Saint-Goba	0,035	17	0,035	0,035	0,595
Rockwool	0,037	29	0,037	0,037	1,073
XPS ExiBa	0,0355	34,5	0,0355	0,0355	1,22475
XPS Dow	0,031	35	0,031	0,031	1,085
EPS	0,034	25	0,034	0,034	0,85

6.4.2 AIC

Table 1 presents the F.U of the AIC composites based on the F.U formula. The AIC composites are sett based on Aerogel content.

Tabell 19 F.U for AIC composites



Aerogel	Thermal conductivit	Thickness	Volume	Density	weight
0 %	1,9	1,9	1,9	1980	3762
10 %	2	2	2	2100	4200
20 %	1,5	1,5	1,5	1900	2850
30 %	1,1	1,1	1,1	1800	1980
40 %	0,8	0,8	0,8	1600	1280
50 %	0,4	0,4	0,4	1300	520
60 %	0,3	0,3	0,3	1000	300

6.4.3 AIM

Table 1 presents the F.U of the AIM composites based on the F.U formula. The AIC composites are sett based on Aerogel content. The AIM composites are AIM 0 % calcined clay, AIM 35% CS, AIM 65% CS, AIM 35% CK, AIM 65% CK.

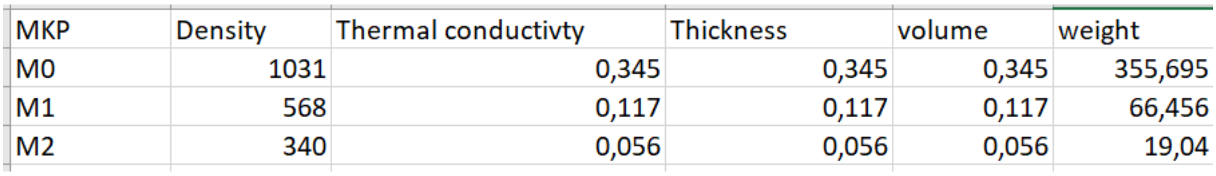
Table 1 F.U for AIM composites

AIM	Density	thermal conductivity	F.U
Concrete 0%	1379,96	1	1379,959819
Concrete 20%	1103,01	0,9	992,7095402
Concrete 40%	826,19	0,47	388,3098249
Concrete 50%	696,83	0,4	278,7325589
Concrete 60%	570,95	0,3	171,2857908
Concrete 70%	448,69	0,25	112,1722035
Concrete 80%	329,28	0,18	59,27030488
CS 35 40%	596,16	0,41	244,4267227
CS 35 50%	526,86	0,32	168,5949319
CS 35 60%	452,93	0,26	117,7613054
CS 35 70%	374,02	0,15	56,10355665
CS 35 80%	289,15	0,12	34,69854108
CS 65 40%	475,68	0,36	171,2456838
CS 65 50%	431,40	0,31	133,7329163
CS 65 60%	381,65	0,23	87,77888933
CS 65 70%	325,39	0,15	48,80902665
CS 65 80%	260,92	0,12	31,31062091
CK 35 40%	596,16	0,38	226,5418405
Ck 35 50%	526,86	0,32	168,5949319
Ck 35 60%	452,93	0,26	117,7613054
Ck 35 70%	374,02	0,19	71,06450509
Ck 35 80%	289,15	0,07	20,24081563
Ck 65 40%	475,68	0,39	185,5161575
Ck 65 50%	431,40	0,33	142,3608464
Ck 65 60%	381,65	0,25	95,41183622
Ck 65 70%	325,39	0,19	61,82476709
Ck 65 80%	260,92	0,07	18,26452887

6.4.4 MKP - FA

Table 1 presents the F.U of the MKP - FA composites based on the F.U formula. The MKP – FA composites are sett based on Aerogel content. The used MKP – FA composites are sett by aerogel contents

Table 2 MKP



MKP	Density	Thermal conductivty	Thickness	volume	weight
M0	1031	0,345	0,345	0,345	355,695
M1	568	0,117	0,117	0,117	66,456
M2	340	0,056	0,056	0,056	19,04

6.4.5 System tree

Fig. 31 represents the system tree of AIC

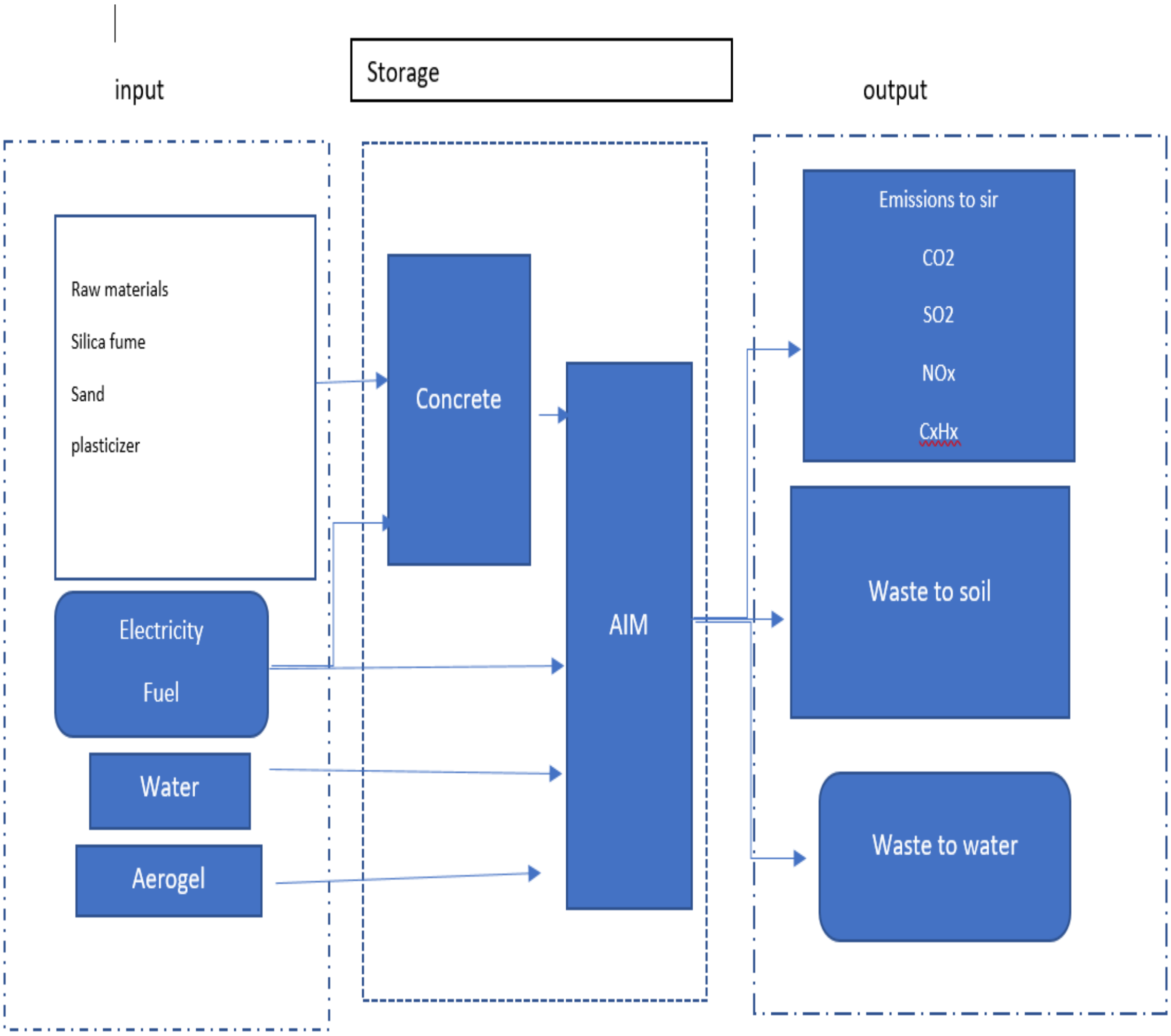


Figure 31 The system tree of AIC

32 represents the system tree of AIM

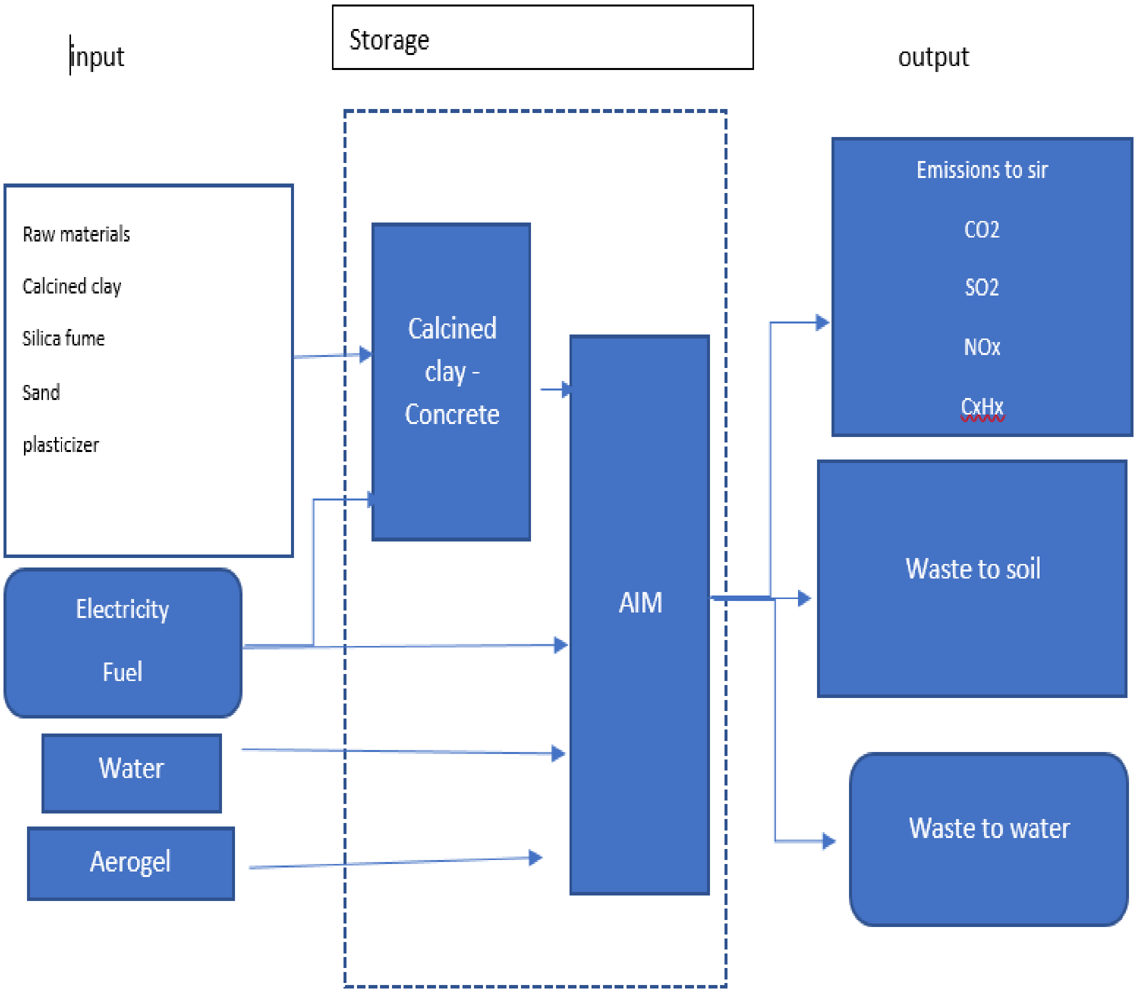


Figure 32 The system tree of AIM

Fig. 33 represents the system tree of MKP – FA

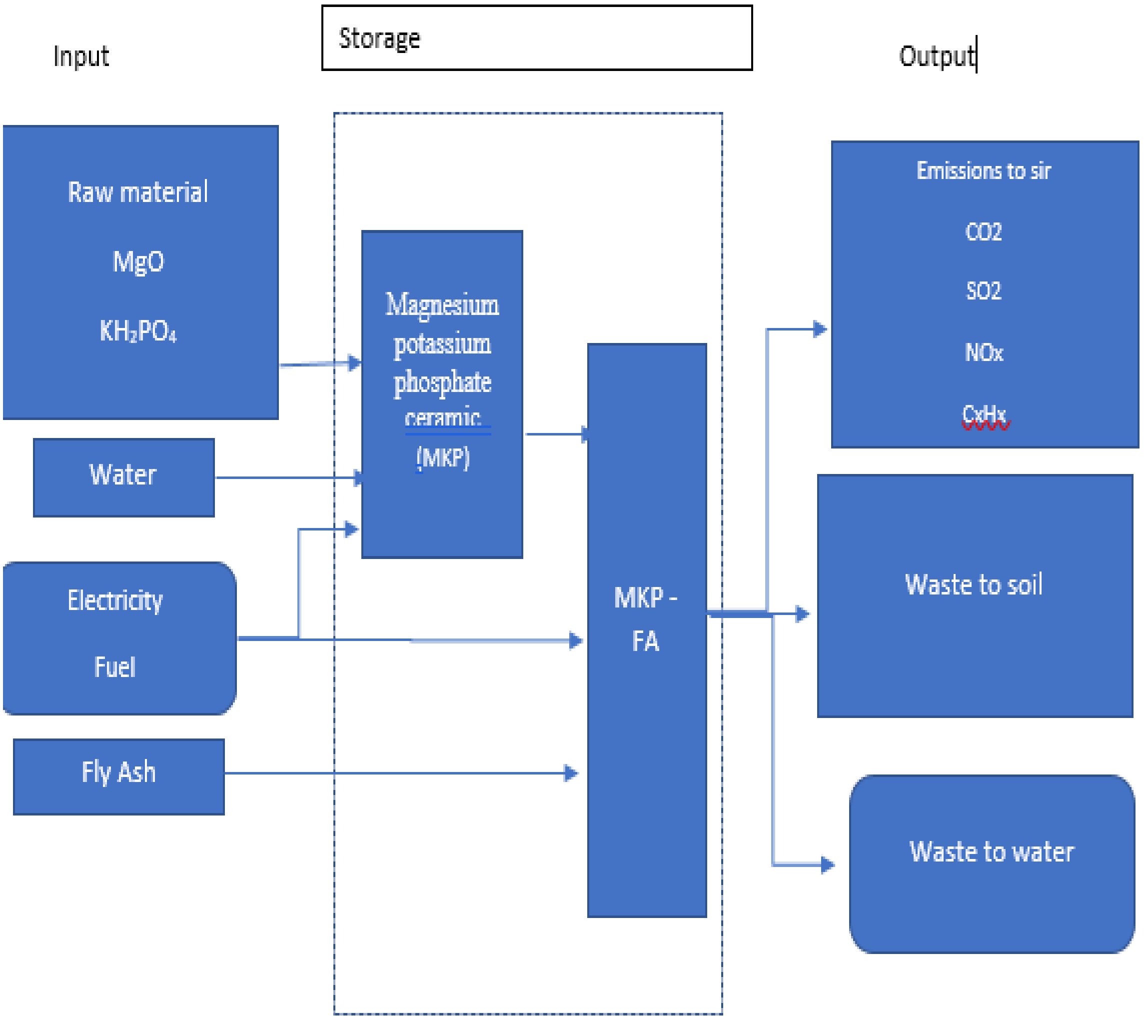


Figure 33 System tree of MKP - FA

7 Life cycle inventory analysis (LCI)

This chapter presents the life cycle inventory analysis (LCI) of The new composites

7.1 LCI of AIC

7.1.1 Acquisition and collection of AIC inventory data

As shown in the research paper, the components of the composites are received from several producers. The components are cement, sand, silica fume, water, superplasticizer, and aerogel particles. The cement used in Serine research was a CEM I 52.5R from (Norcem AS Brevik, Norway), Silica fume (Elkem Microsilica Grade 940), Superplasticizer (Dynamon SP130) from (Mapei, Norway), A natural sand from Finland (particle density: 2600 kg/m3), Hydrophobic aerogel granules from PCAS, France, Distilled water. The producers are contacted to get data about the environmental impact of their products (production) or environmental product declaration. The environmental impact's data of Cement, superplasticizer are retrieved from the EPDs of these products from producers. While the data of other materials such as water and sand are retrieved from some LCA databases. There are many LCA databases which can be used to get data like Ecoinvent (Centre, 2016, October 4), European Life Cycle Database (ELCD) (Commission, 2016). The last two databases are the most popular and authoritative inventory databases in the world and were presented by European Commission. There are also some data retrieved from previous studies and research. Simapro does the LCA based on the method (SimaPro, 2017). The data of mixing is retrieved from (UK, 2018) as 7,5 KW for mixing 1 m^3. The data of mixing AIC (5 min mixing) is estimated in Excel (Appendix c).

Aerogel

The data of silica aerogel is retrieved from the three manufacturers: Aspen, Cabot, and Svenska aerogel. There are few producers of aerogel granules in the world and they don't want to share the information about the production. Therefore, there is no EPD of aerogel production. The data of aerogel is received from the producers. Aspen claims that its production energy is 53.9 MJ/kg and its CO2 burden is 4.3 kgCO2/kg (Dowson et al., 2012).

The sustainability report of Cabot Aerogel (Appendix) presents the energy intensity and emissions intensity of their production. The data from the Cabot isn't a bit different from the data from Aspen which are mainly used in the LCA. The data are 63,9 MJ/ kg aerogel, 0,17 kg CO_2 / Kg aerogel (Corporation, 2016).

There is a gap in environmental impact data of Aerogel from the producers. The only available data is the energy consumption and CO_2 emissions from two producers: Cabot & Aspen. The used data for aerogel is data from Aspen (Dowson et al., 2012) but it is more reliable data than Cabot since it is claimed from Aspen. While the data from Cabot is conducted from the sustainability report of Cabot.

Silica Fume

The environmental impact of silica fume does not need to be included because the silica fume is a Co-product of the industrial silicon and ferroalloy production. The European silica fume producers allocate all greenhouse gas emissions to the main product silicon and ferrosilicon (Appendix B & D).

7.1.2 Acquisition and collection of conventional insulation materials inventory data

The environmental impact data of conventional insulation materials are retrieved from Environmental product declarations of these materials. The EPDs are done based on model “cradle to gate” which is considered in this analysis. The EPDs are attached in the appendixes.

Tabell 20 conventional insulation materials

Material	Producer	EPD part	Declaration nr	Reference
Glass wool	Glava	EPD- Norway	NEPD 221N	(Glava, 2013)
	Saint-Gobain	EPD- Norway	NEPD 00244E	(ISOVER, 2014)
Rockwool	Rockwool	EPD- Norway	NEPD 00131 revision 1	(Rockwool, 2013)
XPS	ExiBa	IBU	ECO-XPS-010101-1007	(Exiba, 2010)
	DOW	IBU	EPD-DOW-2013111-D	(Corporation, 2013)
EPS	EUMEPS	IBU	EPD-EPS-20130078-CBG1-EN	(EUMEPS, 2013)

7.1.3 Acquisition and collection of transport inventory data

The production location of AIC is defined as the same NTNU site here in Gjøvik. Because the AIC is still not a commercial produced. The environmental impact data of transport of the AIC components are retrieved from the Simapro.

Table 24 shows the distance between AIC production site (Gjøvik) and manufacturing location of the conventional insulation material.

Tabell 21 distance of conventional insulation materials to Gjøvik

Material	Location	Distance	Truck	skip	Total (Km)
Silica fume	Kristiansand	430	430	0	430
cement	Brevik / Norway	286	286	0	286
sand	Finland	1223	1223	0	1223
aerogel	Frankfurt	1418	1418	0	1418
water	Gjøvik	0	0	0	0
SP	Sagstua	107	107	0	107
aerogel aspen	Rhode island / USA	7624	1214	6410	7624

7.2 LCI of AIM

7.2.1 Acquisition and collection of AIM inventory data

As shown in the research paper, the components of the composites are received from several producers. The components are cement, silica fume, water, NRG - 700, and aerogel particles. The cement used in Serine research was CEM I 42.5R from (Norcem AS Brevik, Norway), Silica fume (Elkem Microsilica Grade 940), calcined clays (Saint-Gobain Weber from Oslo, Norway), NRG-700 from (Mapei, Norway), , Hydrophobic aerogel (Cabot Aerogel, Frankfurt am Main/Germany), Distilled water. The producers are contacted to get data about the environmental impact of their products (production) or environmental product declaration. The environmental impact's data of Cement, superplasticizer (appendix) is retrieved from the EPDs of these products from producers. While the data of other materials such as water and sand are retrieved from some LCA databases. There are many LCA databases which can be used to get data like Ecoinvent (Centre, 2016, October 4), European Life Cycle Database (ELCD) (Commission, 2016). The last two databases are the most popular and authoritative inventory databases in the world and presented by European Commission. There are also some data retrieved from previous studies and research. Simapro does the LCA based on the method (SimaPro, 2017). The data of mixing is retrieved from (UK, 2018) as 7,5 KW for mixing 1 m^3. The data of mixing AIM (5 min mixing) is estimated in Excel (Appendix c).

Aerogel

The data of silica aerogel is retrieved from the three manufacturers: Aspen, Cabot, and Svenska aerogel. There are few producers of aerogel granules in the world and they don't want to share the information about the production. Therefore, there is no EPD of aerogel production. The data of aerogel is received from the producers. Aspen claims that its production energy is 53.9 MJ/kg and its CO2 burden is 4.3 kgCO2/kg (Dowson et al., 2012). The sustainability report of Cabot Aerogel (Appendix) presents the energy intensity and emissions intensity of their production. The data from the Cabot isn't a bit different from the data from Aspen which are mainly used in the LCA. The data are 63,9 MJ/ kg aerogel, 0,17 kg CO_2 / Kg aerogel (Corporation, 2016). There is a gap in environmental impact data of Aerogel from the producers. The only available data is the energy consumption and CO_2 emissions from two producers: Cabot & Aspen. The used data for aerogel is data from Aspen (Dowson et al., 2012) but it is more reliable data than Cabot since it is claimed from Aspen. While the data from Cabot is conducted from the sustainability report of Cabot.

Silica Fume

The environmental impact of silica fume does not need to be included because the silica fume is a Co-product of the industrial silicon and ferroalloy production. The European silica fume producers allocate all greenhouse gas emissions to the main product silicon and ferrosilicon (Appendix B & D).

Calcined clay

The calcined clay isn't commercially produced. The producers claim that the one ton of Calcined clay release 300 – 400 kg CO_2. The environmental impact of Calcined clay was received from the producer (Appendix Email).

7.2.2 Acquisition and collection of conventional insulation materials inventory data

The environmental impact data of conventional insulation materials are retrieved from Environmental product declarations of these materials. The EPDs are done based on model "cradle to gate" which is considered in this analysis. The EPDs are attached in the appendixes.

Tabell 22 conventional insulation materials

Material	Producer	EPD part	Declaration nr	Reference
Glass wool	Glava	EPD- Norway	NEPD 221N	(Glava, 2013)
	Saint-Gobain	EPD- Norway	NEPD 00244E	(ISOVER, 2014)
Rockwool	Rockwool	EPD- Norway	NEPD 00131 revision 1	(Rockwool, 2013)
XPS	ExiBa	IBU	ECO-XPS-010101-1007	(Exiba, 2010)
	DOW	IBU	EPD-DOW-2013111-D	(Corporation, 2013)
EPS	EUMEPS	IBU	EPD-EPS-20130078-CBG1-EN	(EUMEPS, 2013)

7.2.3 Acquisition and collection of transport inventory data

The production location of AIC is defined as the same NTNU site here in Gjøvik. Because the AIM is still not a commercial produced. The environmental impact data of transport of the AIM components are retrieved from the Simapro.

Table 26 shows the distance between AIC production site (Gjøvik) and manufacturing location of the conventional insulation material.

Tabell 23 distance of conventional insulation materials to Gjøvik

Material	Location	Distance	Truck	skip	Total (Km)
Silica fume	Kristiansand	430	430	0	430
cement	Brevik/Norway	286	286	0	286
Calcined clay	Oslo/Norway	123	123	0	123
aerogel	Frankfurt	1418	1418	0	1418
water	Gjøvik	0	0	0	0
SP	Sagstua	107	107	0	107
aerogel aspen	Rhode island / USA	7624	1214	6410	7624

7.3 LCI of MKP - FA

7.3.1 Acquisition and collection of MKP -FA inventory data

The components of MKP – FA composites are Fly ash, magnesium oxide, phosphate salt, SP plasticizer and aerogel particles. The environmental impact data of magnesium oxide, water, and phosphate salt is retrieved from databases in Simapro. The producers are contacted to get data about the environmental impact of their products (production) or environmental product declaration. The most data of materials are retrieved from some LCA databased. There are many LCA databases which can be used to get data like Ecoinvent (Centre, 2016, October 4), European Life Cycle Database (ELCD) (Commission, 2016), Inventory of Carbon and Energy (ICE) (). The last two databases are the most popular and authoritative inventory databases in the world and were presented by European Commission. The data of mixing is retrieved from (UK, 2018) as 7,5 KW for mixing 1 m^3. The data of mixing MKP - FA (10 min mixing) is estimated in Excel (Appendix c).

Fly Ash

There are two views of the environmental impact of fly ash; first, the fly ash as a waste product which needs to be treated and in this case no need for the environmental impact data. The second, the Fly ash as co-products from power production. In this case, the environmental impact will be distributed based on the economic value. In this paper, the fly ash will be defined as waste because of the huge amount of fly ash from the power generation in the world today.

Aerogel

The data of silica aerogel is retrieved from the three manufacturers: Aspen, Cabot, and Svenska aerogel. There are few producers of aerogel granules in the world and they don't want to share the information about the production. Therefore, there is no EPD of aerogel production. The data of aerogel is received from the producers. Aspen claims that its production energy is 53.9 MJ/kg and its CO2 burden is 4.3 kgCO2/kg (Dowson et al., 2012).

The sustainability report of Cabot Aerogel presents the energy intensity and emissions intensity of their production. The data from the Cabot isn't a bit different from the data from Aspen which are mainly used in the LCA. The data are 63,9 MJ/ kg aerogel, 0,17 kg CO_2 / Kg aerogel (Corporation, 2016).

There is a gap in environmental impact data of Aerogel from the producers. The only available data is the energy consumption and CO_2 emissions from two producers: Cabot & Aspen. The used data for aerogel is data from Aspen (Dowson et al., 2012) but it is more reliable data than Cabot since it is claimed from Aspen. While the data from Cabot is conducted from the sustainability report of Cabot.

MKP

There was no available data of KH_2PO_4 in Simapro or EPDs. Several producers of KH_2PO_4 has been contacted without getting any data. Table 2 presents the contacted producers.

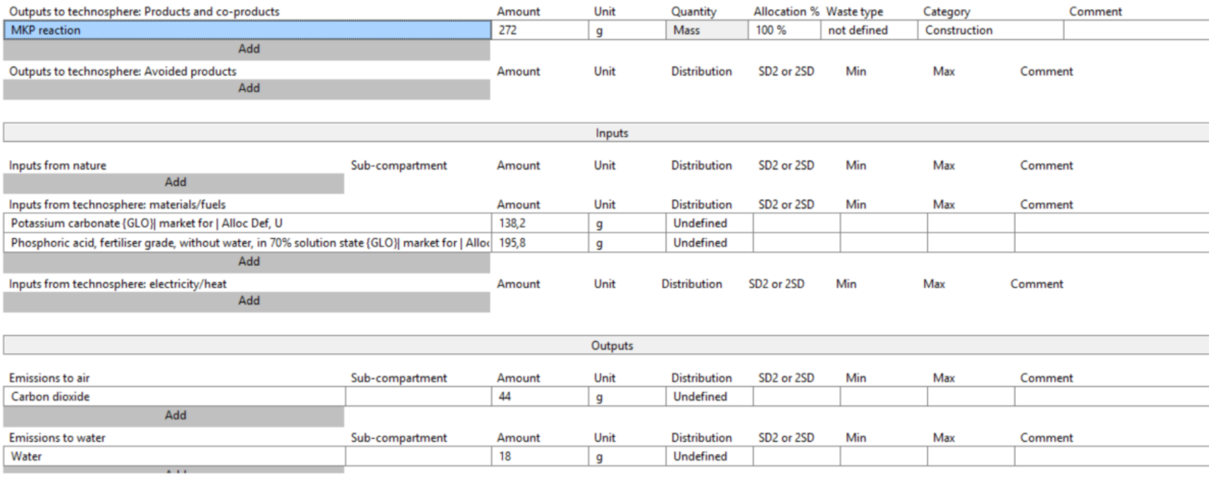
Table 3 Producers of KH_2PO_4

KH_2PO_4	**Contact**	**Data**
Greenway biotech	Email	No
Prayon	Email	No
Spectrumchemical	Email	No
Masteurope	Email	No
phosagro	Email	No
Permakem	Email	No
Sial	Email	No
Basf	Email	No
Sibelco	Email	No
Chiron	Email	No

The gap of any data of KH_2PO_4 was a big challenge to do this analysis. Therefore, the molar mass formula is used to solve the problem. The KH_2PO_4 is produced by the chemical reaction between the potassium carbonate and phosphoric acid. The formula of this chemical reaction (Chemiday, 2018) is:

$K_2CO_3 + 2H_3PO_4 \rightarrow 2KH_2PO_4 + H_2O + CO_2$ (Chemiday, 2018)

Then the molar mass formula is used to calculate the amount of each material in the reaction (appendix C Excel calculations). The mixing will be eliminated by cut off criteria since there no need for heat and energy for mixing (Chemiday, 2018). Then input the data of mass into Simapro as shown in the figure 34. Finally, the Simapro estimate the environmental impact of MKP based on materials in databases.



Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
MKP reaction	272	g	Mass	100 %	not defined	Construction	

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Potassium carbonate {GLO}| market for | Alloc Def, U	138,2	g	Undefined				
Phosphoric acid, fertiliser grade, without water, in 70% solution state {GLO}| market for | Alloc	195,8	g	Undefined				

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Emissions to air	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Carbon dioxide		44	g	Undefined				

Emissions to water	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Water		18	g	Undefined				

Figure 34 KH$_2$PO4 in Simapro

MgO

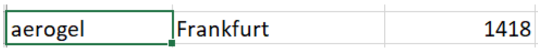
The data of MgO is retrieved from Simapro. Several producers were contacted to get data of these materials but no data was received. the table 4 present the contacted producers.

Table 4 Producers of MgO

MgO	Country	Contact	Data
Stb.rauschert	Germany	Email	No
Magnifin	Germany	Email	No
Magnesia		Email	No
Carlroth		Email	No
Basf	Germany	Email	No

7.3.2 Acquisition and collection of transport inventory data

The production location of MKP - FA is defined as the same NTNU site here in Gjøvik. Because the MKP- FA is still not a commercial produced. The used databases for transport inventory data is Ecoinvent. The components of MKP are retrieved from databases while the fly ash is available and cheap material. Because no producer replies about the environmental impact, it was not possible to estimate data of transport of KH_2PO_4 and MgO. There is no transport considered in this analysis. The aerogel is the only component where the transport data will be considered.



aerogel	Frankfurt	1418

Figure 35 transport of aerogel

7.3.3 Acquisition and collection of conventional insulation materials inventory data

The environmental impact data of conventional insulation materials are retrieved from Environmental product declarations of these materials. The EPDs are done based on model “cradle to gate” which is considered in this analysis. The EPDs are attached in the appendixes.

Tabell 24 conventional insulation materials

Material	Producer	EPD part	Declaration nr	Reference
Glass wool	Glava	EPD- Norway	NEPD 221N	(Glava, 2013)
	Saint-Gobain	EPD- Norway	NEPD 00244E	(ISOVER, 2014)
Rockwool	Rockwool	EPD- Norway	NEPD 00131 revison 1	(Rockwool, 2013)
XPS	ExiBa	IBU	ECO-XPS-010101-1007	(Exiba, 2010)
	DOW	IBU	EPD-DOW-2013111-D	(Corporation, 2013)
EPS	EUMEPS	IBU	EPD-EPS-20130078-CBG1-EN	(EUMEPS, 2013)

8 LCIA

There are several available LCIA methods to provide environmental impact analysis such as ILCD 2011Midpoint (European Commission, 2012), EDIP 2003 (Dreyer et al., 2003), IMPACT 2002+ (Dreyer et al., 2003) and ReCiPe 2016 (Radboud University, 2016). These methods vary across areas such as assumptions made and regional relevancy, which may lead to different LCIA results. But because of the gap of environmental impact's data of the AIC composites since they aren't commercially produced, it won't be used any of mentioned methods. The only available data of environmental impact of these composites is energy and emissions. Therefore these two parameters will be considered in this paper. It will be used two single issue methods conduct the energy consumption (IPCC 2013) and CO2 emissions (Cumulative Energy Demand (CED)) of the compared materials. IPCC 2013 contains the climate change factors of IPCC with a timeframe of 100 years. (Change., 2013). Cumulative Energy Demand (CED) calculate the energy demand of the whole system (ecoinvent, 2013). All calculations are done by Simapro. Results include the transport of components of the composites to Gjøvik as manufacturing's location. Also, the transport of conventional insulation materials to Gjøvik.

9 Results

In this chapter, it will be presented the results from Simapro calculations for the new composites. Although, the results show the comparison between the new composites and the conventional insulation materials. Finally, the comparison between the three composites. The results are presented in two categories Energy and CO_2 equivalent.

9.1 AIC

The results present the analysis of the AIC composites, then present the comparison of AIC composites with each insulation materials. Then compare the A60 (as multifunctional material) which content 60% Aerogel with conventional insulation materials.

9.1.1 Energy

AIC composites

The figure 36 and table 28 present the energy analysis of the AIC composites.

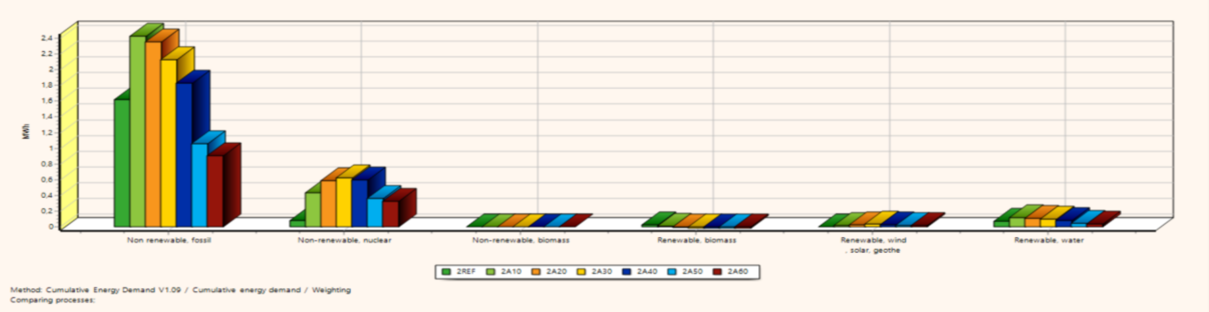
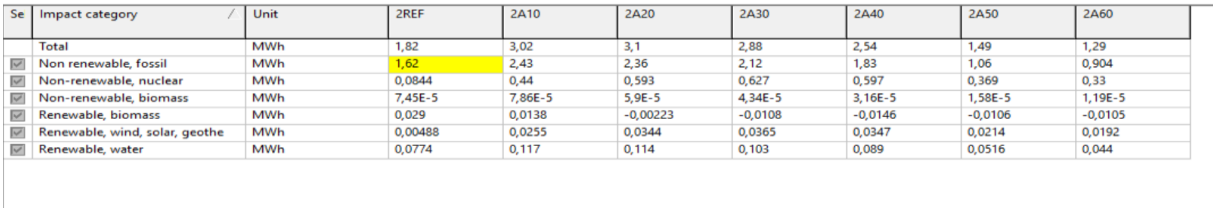


Figure 36 energy analysis of AIC

Tabell 25 energy analysis AIC composite



Se	Impact category	Unit	2REF	2A10	2A20	2A30	2A40	2A50	2A60
	Total	MWh	1,82	3,02	3,1	2,88	2,54	1,49	1,29
☑	Non renewable, fossil	MWh	1,62	2,43	2,36	2,12	1,83	1,06	0,904
☑	Non-renewable, nuclear	MWh	0,0844	0,44	0,593	0,627	0,597	0,369	0,33
☑	Non-renewable, biomass	MWh	7,45E-5	7,86E-5	5,9E-5	4,34E-5	3,16E-5	1,58E-5	1,19E-5
☑	Renewable, biomass	MWh	0,029	0,0138	-0,00223	-0,0108	-0,0146	-0,0106	-0,0105
☑	Renewable, wind, solar, geothe	MWh	0,00488	0,0255	0,0344	0,0365	0,0347	0,0214	0,0192
☑	Renewable, water	MWh	0,0774	0,117	0,114	0,103	0,089	0,0516	0,044

AIC & Glass wool Glava

The figure 37 and table 29 present the energy analysis of the AIC composites and glass wool Glava.

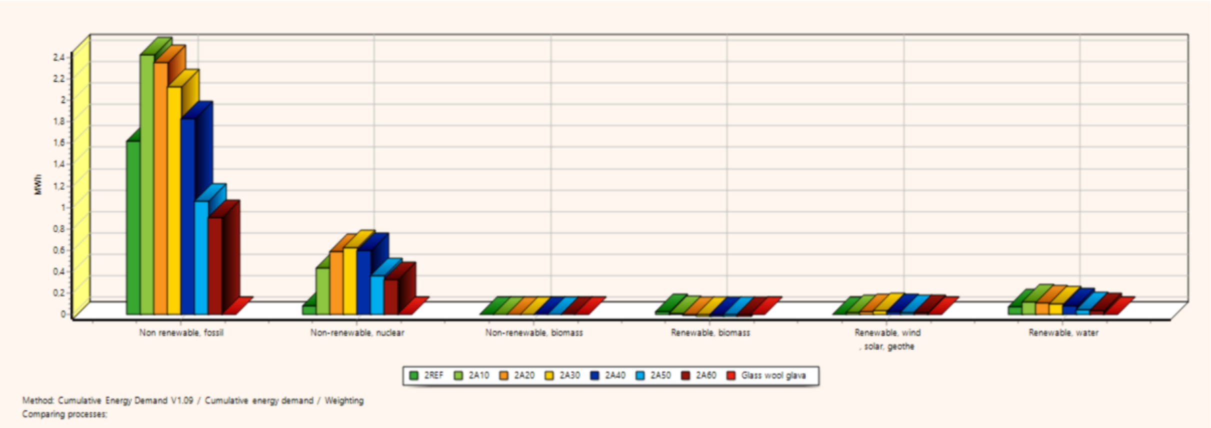
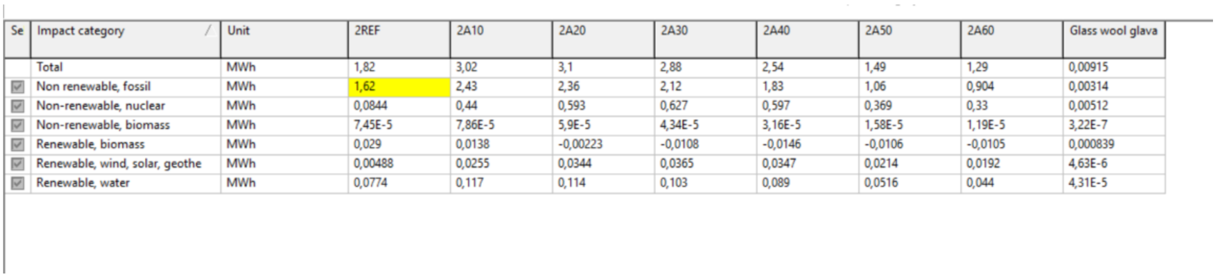


Figure 37 Comparison of AIC and glass wool Glava

Tabell 26 Comparison of AIC and glass wool Glava



Se	Impact category	Unit	2REF	2A10	2A20	2A30	2A40	2A50	2A60	Glass wool glava
	Total	MWh	1,82	3,02	3,1	2,88	2,54	1,49	1,29	0,00915
☑	Non renewable, fossil	MWh	1,62	2,43	2,36	2,12	1,83	1,06	0,904	0,00314
☑	Non-renewable, nuclear	MWh	0,0844	0,44	0,593	0,627	0,597	0,369	0,33	0,00512
☑	Non-renewable, biomass	MWh	7,45E-5	7,86E-5	5,9E-5	4,34E-5	3,16E-5	1,58E-5	1,19E-5	3,22E-7
☑	Renewable, biomass	MWh	0,029	0,0138	-0,00223	-0,0108	-0,0146	-0,0106	-0,0105	0,000839
☑	Renewable, wind, solar, geothe	MWh	0,00488	0,0255	0,0344	0,0365	0,0347	0,0214	0,0192	4,63E-6
☑	Renewable, water	MWh	0,0774	0,117	0,114	0,103	0,089	0,0516	0,044	4,31E-5

AIC & saint Geber Isover

The figure 38 and table 30 present the energy analysis of the AIC composites and glass wool Isover.

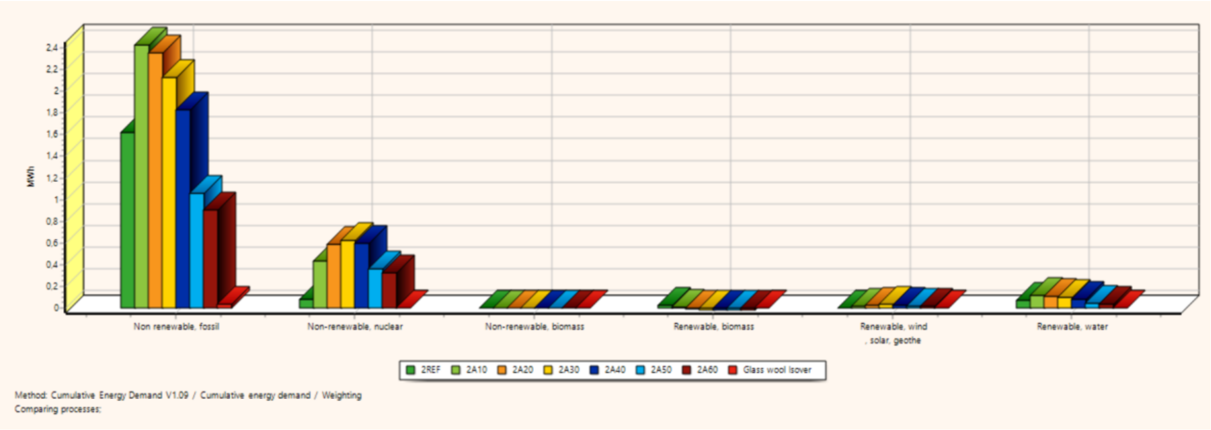
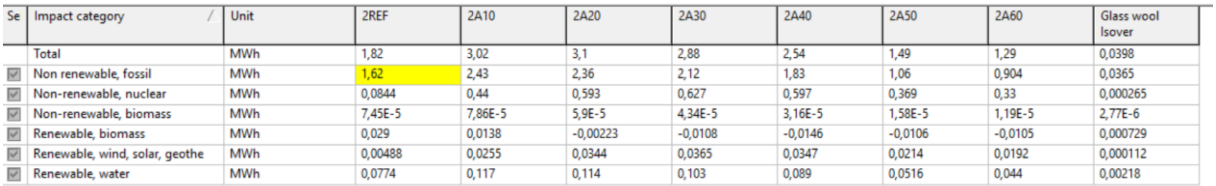


Figure 38 Comparison of AIC and glass wool Isover

Tabell 27 comparison of AIC and glass wool Isover



Se	Impact category	Unit	2REF	2A10	2A20	2A30	2A40	2A50	2A60	Glass wool Isover
	Total	MWh	1,82	3,02	3,1	2,88	2,54	1,49	1,29	0,0398
☑	Non renewable, fossil	MWh	1,62	2,43	2,36	2,12	1,83	1,06	0,904	0,0365
☑	Non-renewable, nuclear	MWh	0,0844	0,44	0,593	0,627	0,597	0,369	0,33	0,000265
☑	Non-renewable, biomass	MWh	7,45E-5	7,86E-5	5,9E-5	4,34E-5	3,16E-5	1,58E-5	1,19E-5	2,77E-6
☑	Renewable, biomass	MWh	0,029	0,0138	-0,00223	-0,0108	-0,0146	-0,0106	-0,0105	0,000729
☑	Renewable, wind, solar, geothe	MWh	0,00488	0,0255	0,0344	0,0365	0,0347	0,0214	0,0192	0,000112
☑	Renewable, water	MWh	0,0774	0,117	0,114	0,103	0,089	0,0516	0,044	0,00218

AIC & XPS Dow

The figure 39 and table 31 present the energy analysis of the AIC composites and XPS Dow

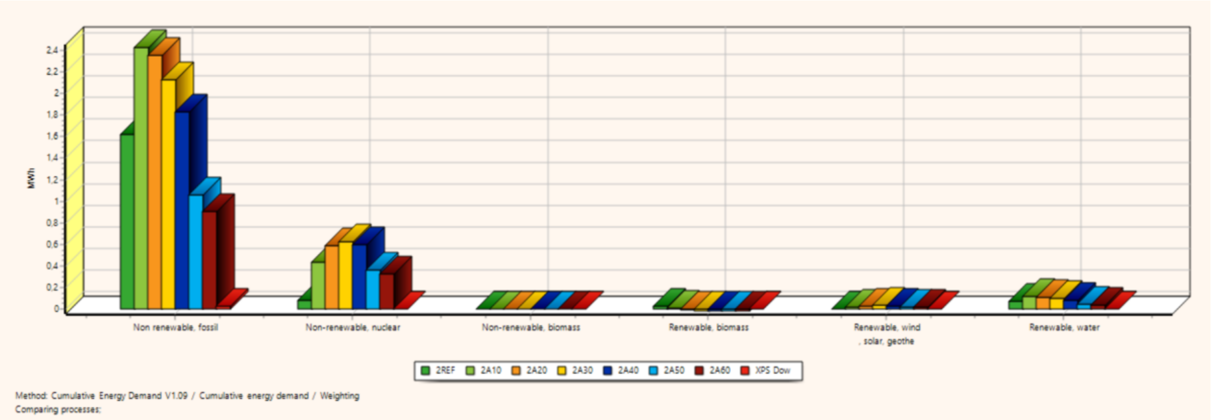
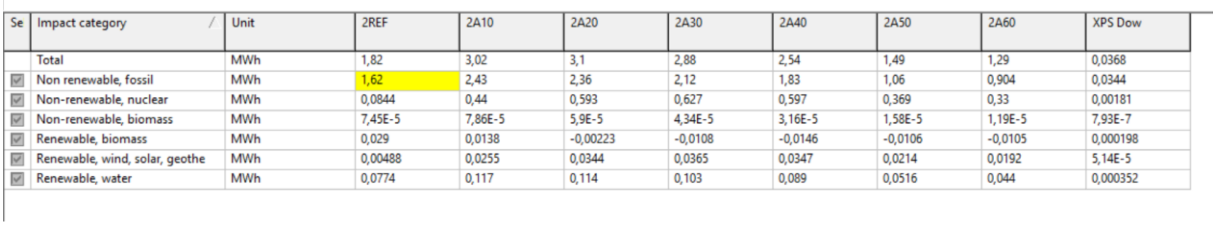


Figure 39 Comparison of AIC and XPS Dow

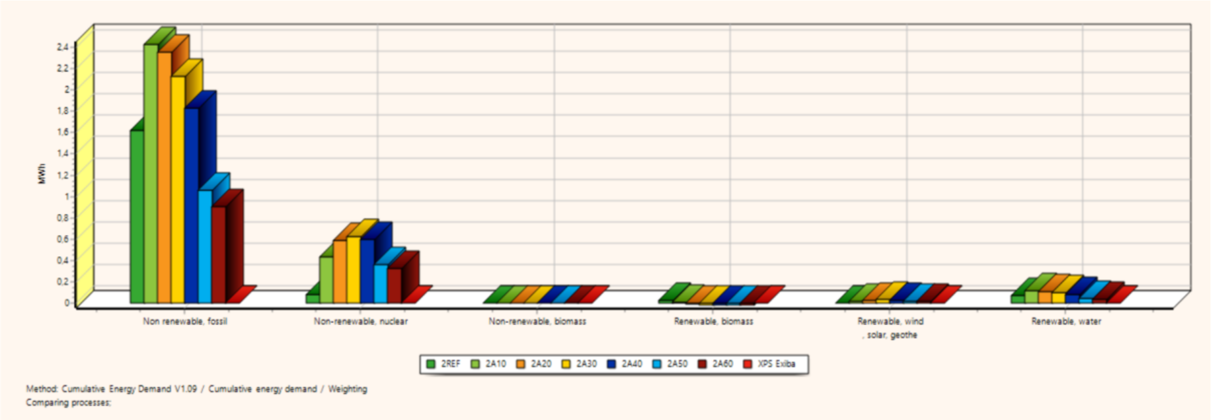
Tabell 28 comparison of AIC and XPS Dow



Se	Impact category	Unit	2REF	2A10	2A20	2A30	2A40	2A50	2A60	XPS Dow
	Total	MWh	1,82	3,02	3,1	2,88	2,54	1,49	1,29	0,0368
☑	Non renewable, fossil	MWh	1,62	2,43	2,36	2,12	1,83	1,06	0,904	0,0344
☑	Non-renewable, nuclear	MWh	0,0844	0,44	0,593	0,627	0,597	0,369	0,33	0,00181
☑	Non-renewable, biomass	MWh	7,45E-5	7,86E-5	5,9E-5	4,34E-5	3,16E-5	1,58E-5	1,19E-5	7,93E-7
☑	Renewable, biomass	MWh	0,029	0,0138	-0,00223	-0,0108	-0,0146	-0,0106	-0,0105	0,000198
☑	Renewable, wind, solar, geothe	MWh	0,00488	0,0255	0,0344	0,0365	0,0347	0,0214	0,0192	5,14E-5
☑	Renewable, water	MWh	0,0774	0,117	0,114	0,103	0,089	0,0516	0,044	0,000352

AIC & XPS ExiBa

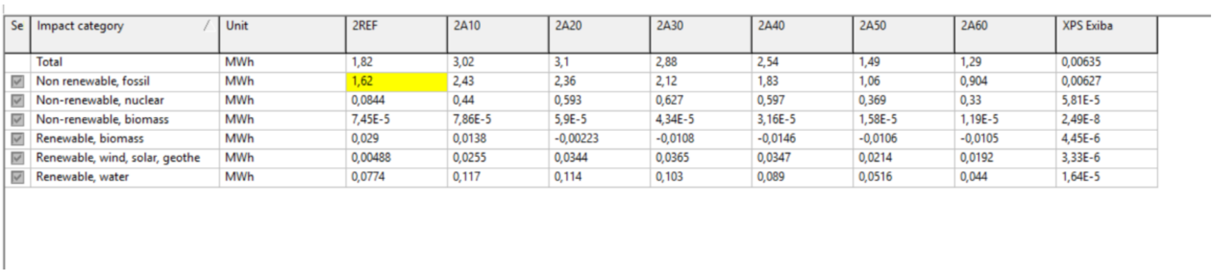
The figure 40 and table 32 present the energy analysis of the AIC composites and XPS ExiBa



Method: Cumulative Energy Demand V1.09 / Cumulative energy demand / Weighting
Comparing processes:

Figure 40 comparison of AIC and XPS ExiBa

Tabell 29 comparison of AIC and XPS ExiBa



Se	Impact category	Unit	2REF	2A10	2A20	2A30	2A40	2A50	2A60	XPS Exiba
	Total	MWh	1,82	3,02	3,1	2,88	2,54	1,49	1,29	0,00635
☑	Non renewable, fossil	MWh	1,62	2,43	2,36	2,12	1,83	1,06	0,904	0,00627
☑	Non-renewable, nuclear	MWh	0,0844	0,44	0,593	0,627	0,597	0,369	0,33	5,81E-5
☑	Non-renewable, biomass	MWh	7,45E-5	7,86E-5	5,9E-5	4,34E-5	3,16E-5	1,58E-5	1,19E-5	2,49E-8
☑	Renewable, biomass	MWh	0,029	0,0138	-0,00223	-0,0108	-0,0146	-0,0106	-0,0105	4,45E-6
☑	Renewable, wind, solar, geothe	MWh	0,00488	0,0255	0,0344	0,0365	0,0347	0,0214	0,0192	3,33E-6
☑	Renewable, water	MWh	0,0774	0,117	0,114	0,103	0,089	0,0516	0,044	1,64E-5

AIC & EPS

The figure 41 and table 33 present the energy analysis of the AIC composites and EPS

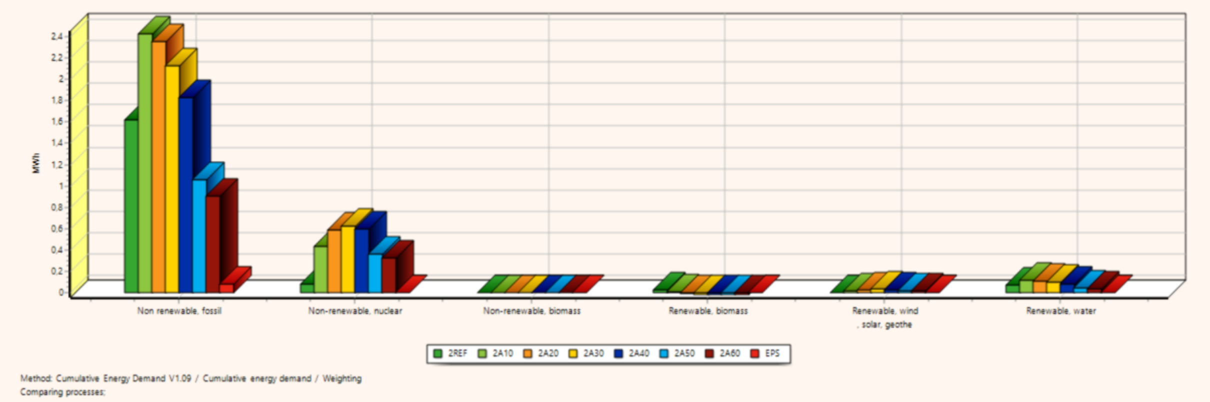
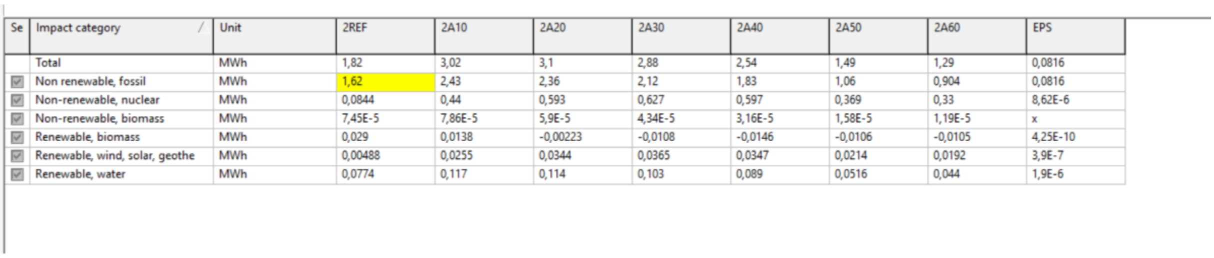


Figure 41 comparison of AIC and EPS

Tabell 30 comparison of AIC and EPS



Se	Impact category	Unit	2REF	2A10	2A20	2A30	2A40	2A50	2A60	EPS
	Total	MWh	1,82	3,02	3,1	2,88	2,54	1,49	1,29	0,0816
☑	Non renewable, fossil	MWh	1,62	2,43	2,36	2,12	1,83	1,06	0,904	0,0816
☑	Non-renewable, nuclear	MWh	0,0844	0,44	0,593	0,627	0,597	0,369	0,33	8,62E-6
☑	Non-renewable, biomass	MWh	7,45E-5	7,86E-5	5,9E-5	4,34E-5	3,16E-5	1,58E-5	1,19E-5	x
☑	Renewable, biomass	MWh	0,029	0,0138	-0,00223	-0,0108	-0,0146	-0,0106	-0,0105	4,25E-10
☑	Renewable, wind, solar, geothe	MWh	0,00488	0,0255	0,0344	0,0365	0,0347	0,0214	0,0192	3,9E-7
☑	Renewable, water	MWh	0,0774	0,117	0,114	0,103	0,089	0,0516	0,044	1,9E-6

AIC & Rockwool

The figure 42 and table 34 present the energy analysis of the AIC composites and Rock wool

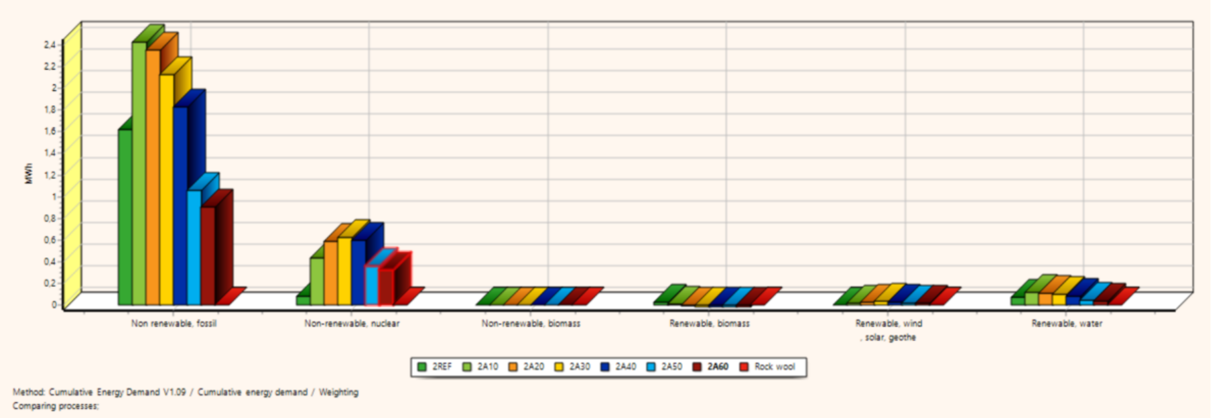
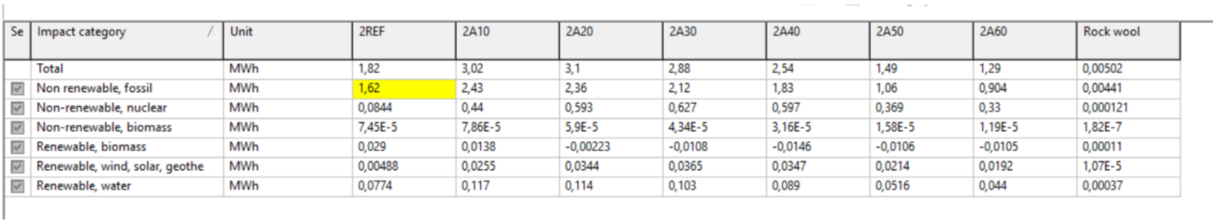


Figure 42 comparison AIC and Rockwool

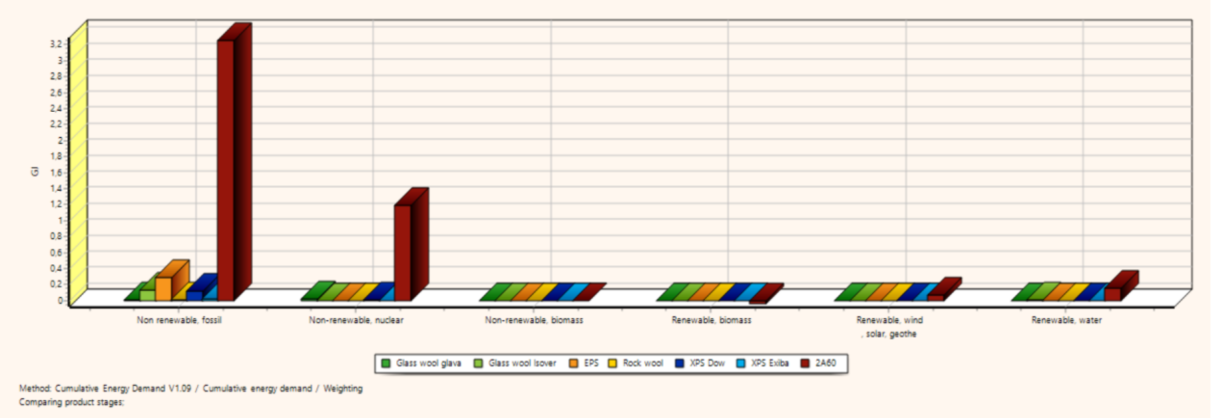
Tabell 31 comparison AIC and Rockwool



Se	Impact category	Unit	2REF	2A10	2A20	2A30	2A40	2A50	2A60	Rock wool
	Total	MWh	1,82	3,02	3,1	2,88	2,54	1,49	1,29	0,00502
☑	Non renewable, fossil	MWh	1,62	2,43	2,36	2,12	1,83	1,06	0,904	0,00441
☑	Non-renewable, nuclear	MWh	0,0844	0,44	0,593	0,627	0,597	0,369	0,33	0,000121
☑	Non-renewable, biomass	MWh	7,45E-5	7,86E-5	5,9E-5	4,34E-5	3,16E-5	1,58E-5	1,19E-5	1,82E-7
☑	Renewable, biomass	MWh	0,029	0,0138	-0,00223	-0,0108	-0,0146	-0,0106	-0,0105	0,00011
☑	Renewable, wind, solar, geothe	MWh	0,00488	0,0255	0,0344	0,0365	0,0347	0,0214	0,0192	1,07E-5
☑	Renewable, water	MWh	0,0774	0,117	0,114	0,103	0,089	0,0516	0,044	0,00037

AIC 60% & insulation materials

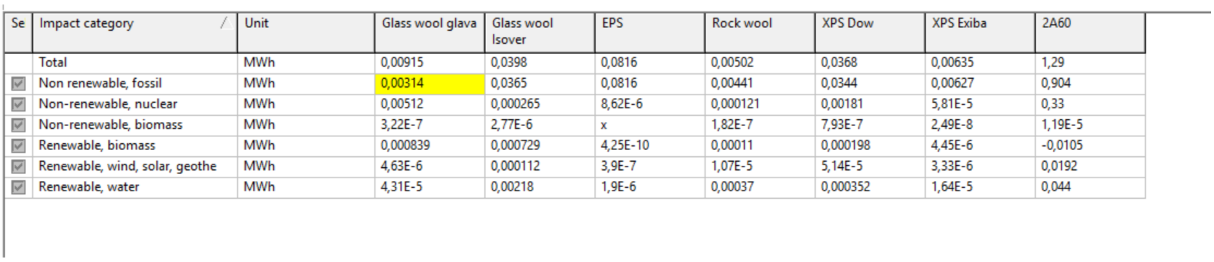
The figure 43 and table 35 present the energy analysis of the AIC A60 as multifunctional material and the conventional insulation materials.



Method: Cumulative Energy Demand V1.09 / Cumulative energy demand / Weighting
Comparing product stages:

Figure 43 A60 as multifunctional material

Tabell 32 A60 as multifunctional material



Se	Impact category	Unit	Glass wool glava	Glass wool Isover	EPS	Rock wool	XPS Dow	XPS Exiba	2A60
	Total	MWh	0,00915	0,0398	0,0816	0,00502	0,0368	0,00635	1,29
☑	Non renewable, fossil	MWh	0,00314	0,0365	0,0816	0,00441	0,0344	0,00627	0,904
☑	Non-renewable, nuclear	MWh	0,00512	0,000265	8,62E-6	0,000121	0,00181	5,81E-5	0,33
☑	Non-renewable, biomass	MWh	3,22E-7	2,77E-6	x	1,82E-7	7,93E-7	2,49E-8	1,19E-5
☑	Renewable, biomass	MWh	0,000839	0,000729	4,25E-10	0,00011	0,000198	4,45E-6	-0,0105
☑	Renewable, wind, solar, geothe	MWh	4,63E-6	0,000112	3,9E-7	1,07E-5	5,14E-5	3,33E-6	0,0192
☑	Renewable, water	MWh	4,31E-5	0,00218	1,9E-6	0,00037	0,000352	1,64E-5	0,044

9.1.2 CO2 emissions

AIC composites

The figure 44 and table 36 present the CO_2 equivalent analysis of the AIC composites.

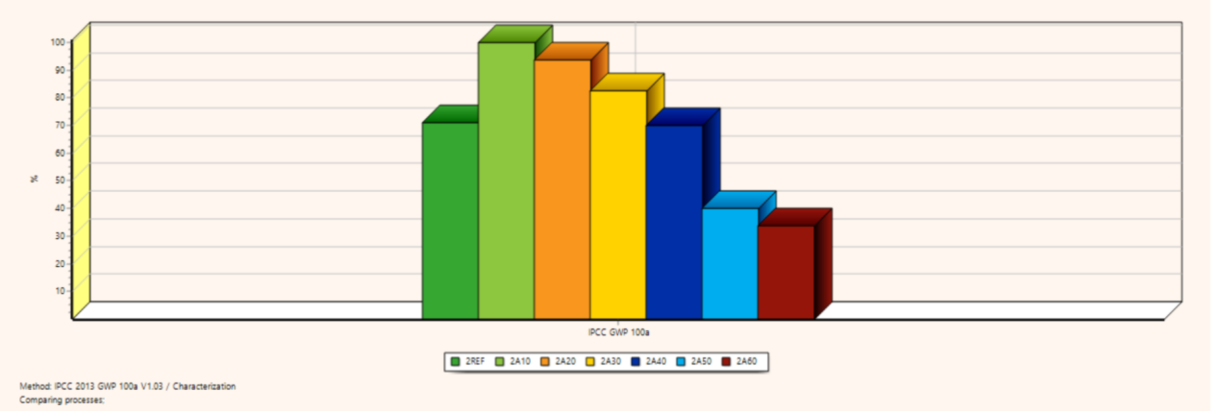
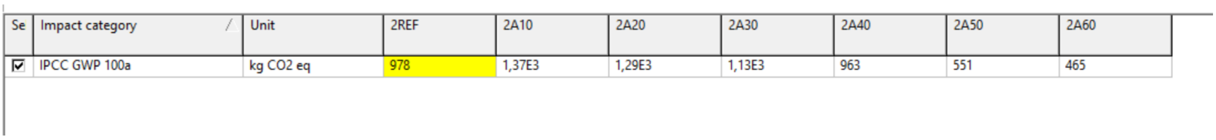


Figure 44 CO_2 equivalent analysis of AIC

Tabell 33 CO_2 equivalent analysis of AIC



Se	Impact category	Unit	2REF	2A10	2A20	2A30	2A40	2A50	2A60
☑	IPCC GWP 100a	kg CO2 eq	978	1,37E3	1,29E3	1,13E3	963	551	465

AIC & Glass wool Glava

The figure 45 and table 37 present the energy analysis of the AIC composites and glass wool Glava.

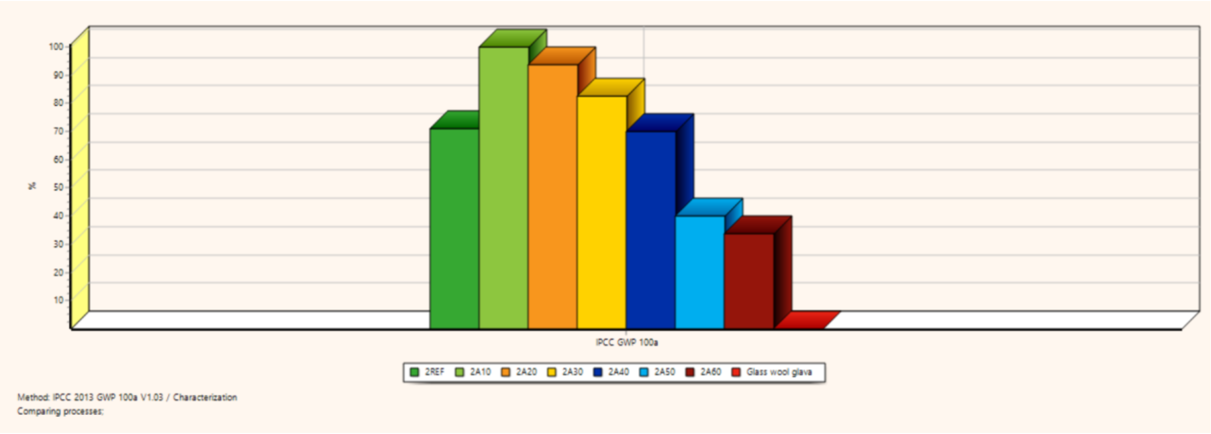
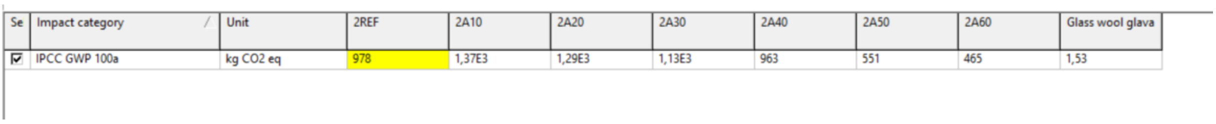


Figure 45 comparison of AIC and glass wool Glava

Tabell 34 comparison of AIC and glass wool Glava



Se	Impact category	Unit	2REF	2A10	2A20	2A30	2A40	2A50	2A60	Glass wool glava
☑	IPCC GWP 100a	kg CO2 eq	978	1,37E3	1,29E3	1,13E3	963	551	465	1,53

AIC & saint Geber Isover

The figure 46 and table 38 present the energy analysis of the AIC composites and glass wool Isover.

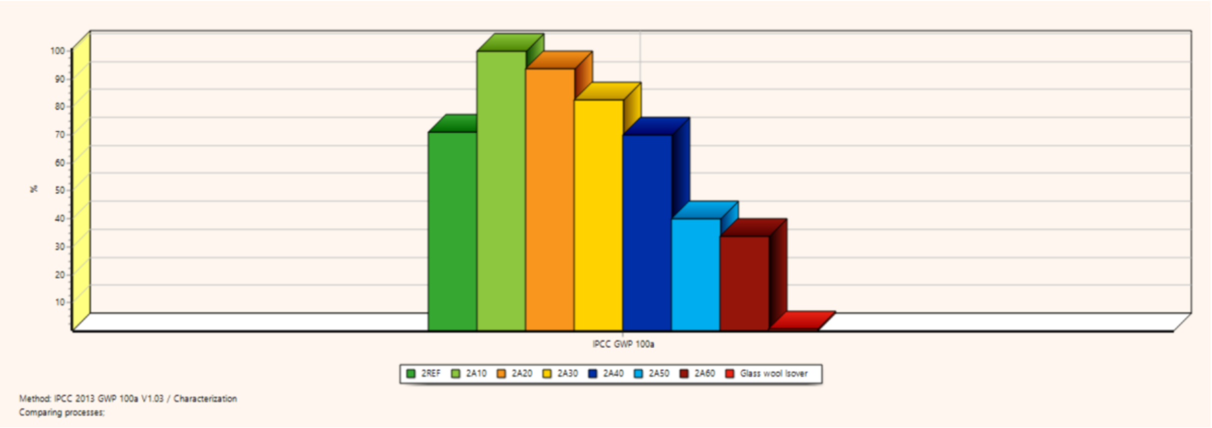
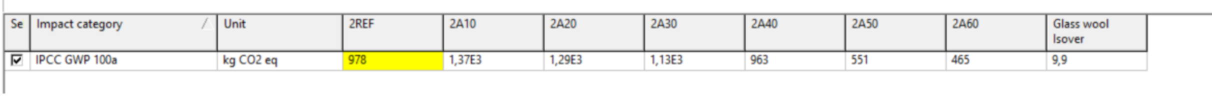


Figure 46 comparison of AIC and glass wool Isover

Tabell 35 comparison of AIC and glass wool Isover



Se	Impact category	Unit	2REF	2A10	2A20	2A30	2A40	2A50	2A60	Glass wool Isover
☑	IPCC GWP 100a	kg CO2 eq	978	1,37E3	1,29E3	1,13E3	963	551	465	9,9

AIC & Rockwool

The figure 47 and table 39 present the energy analysis of the AIC composites and Rock wool

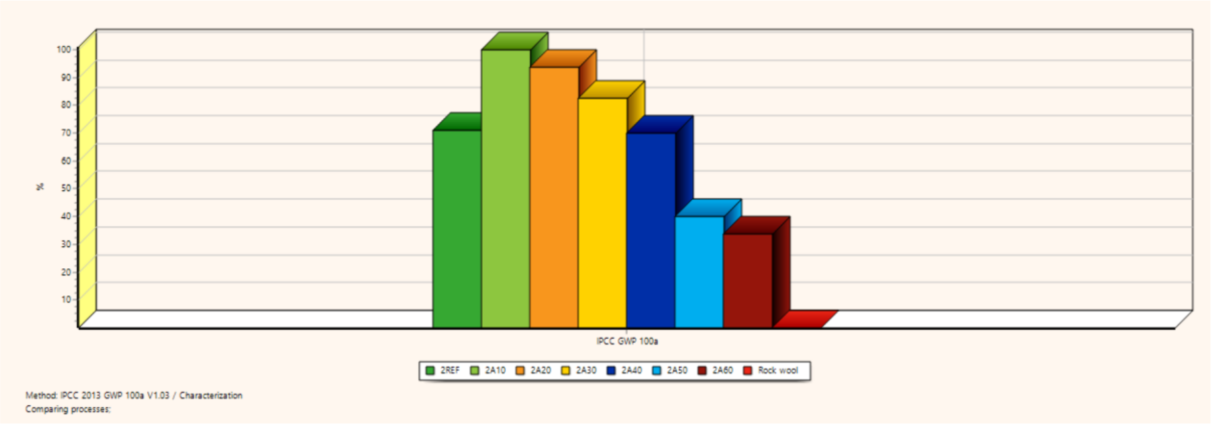
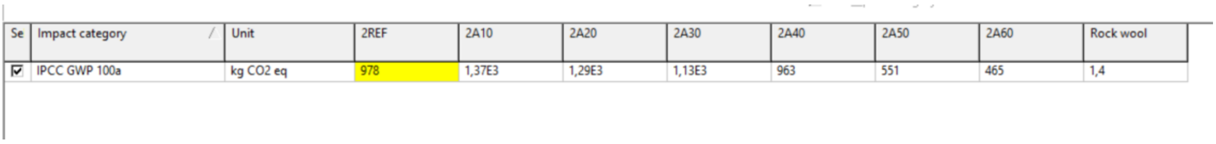


Figure 47 comparison of AIC and Rockwool

Tabell 36 comparison of AIC and Rockwool



Se	Impact category	Unit	2REF	2A10	2A20	2A30	2A40	2A50	2A60	Rock wool
☑	IPCC GWP 100a	kg CO2 eq	978	1,37E3	1,29E3	1,13E3	963	551	465	1,4

AIC & XPS Dow

The figure 48 and table 40 present the energy analysis of the AIC composites and XPS Dow

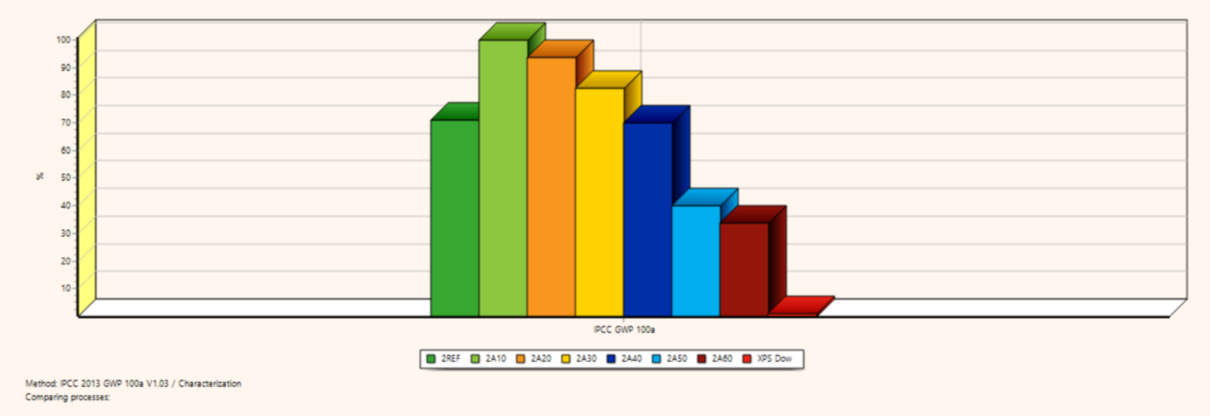
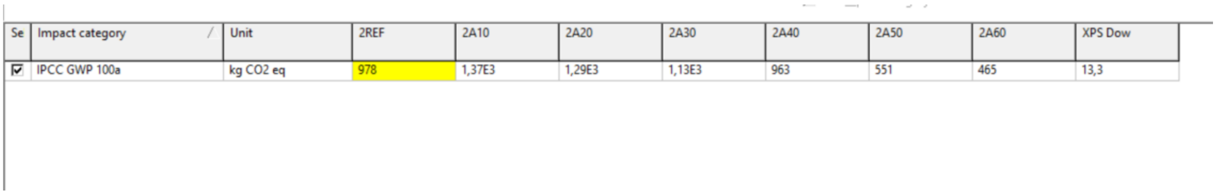


Figure 48 comparison of AIC and XPS Dow

Tabell 37 comparison of AIC and XPS Dow



Se	Impact category	Unit	2REF	2A10	2A20	2A30	2A40	2A50	2A60	XPS Dow
☑	IPCC GWP 100a	kg CO2 eq	978	1,37E3	1,29E3	1,13E3	963	551	465	13,3

AIC & XPS ExiBa

The figure 49 and table 41 present the energy analysis of the AIC composites and XPS ExiBa

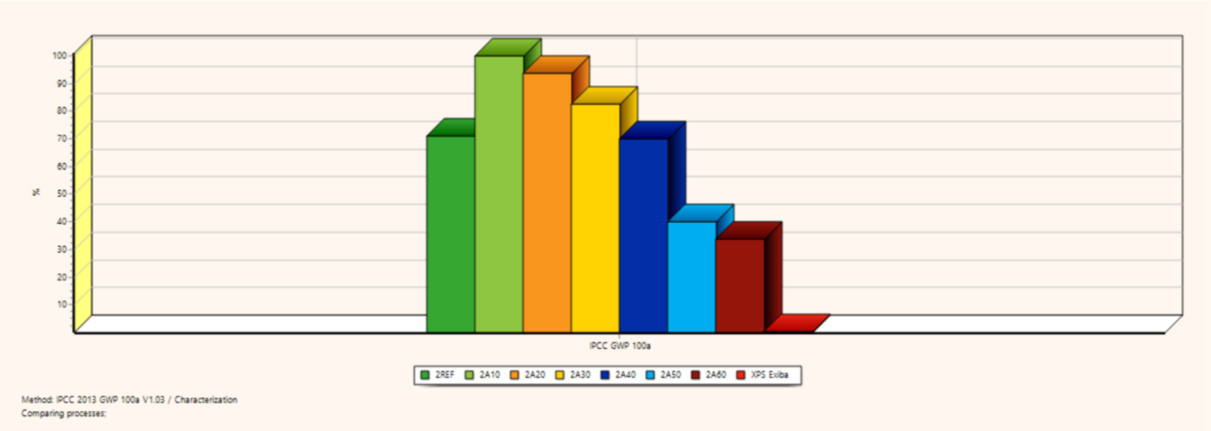
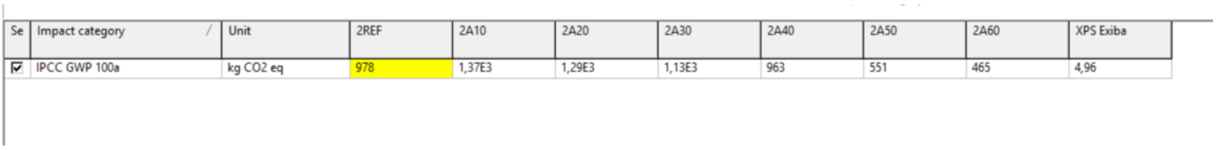


Figure 49 comparison of AIC and XPS ExiBa

Tabell 38 comparison of AIC and XPS ExiBa



Se	Impact category	Unit	2REF	2A10	2A20	2A30	2A40	2A50	2A60	XPS Exiba
☑	IPCC GWP 100a	kg CO2 eq	978	1,37E3	1,29E3	1,13E3	963	551	465	4,96

AIC 60% & insulation materials

The figure 50 and table 42 present the energy analysis of the AIC A60 as multifunctional material and the conventional insulation materials.

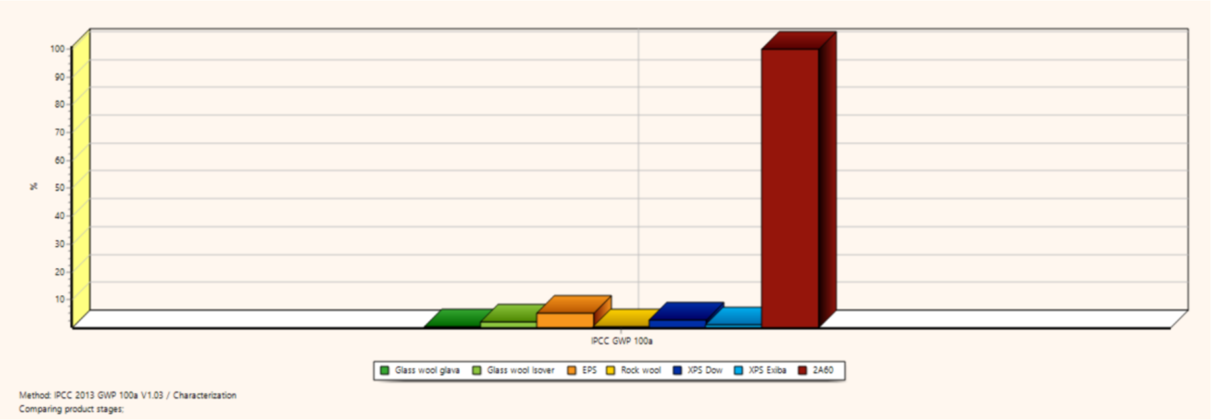
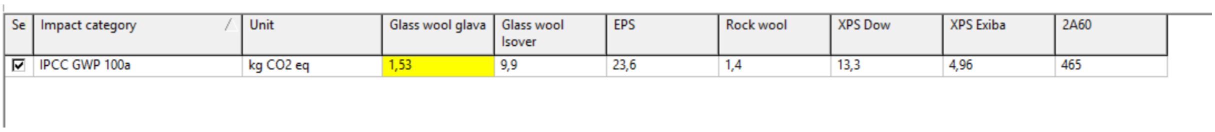


Figure 50 comparison of A60 and conventional insulation materials

Tabell 39 comparison of A60 and conventional insulation materials



Se	Impact category	Unit	Glass wool glava	Glass wool Isover	EPS	Rock wool	XPS Dow	XPS Exiba	2A60
☑	IPCC GWP 100a	kg CO2 eq	1,53	9,9	23,6	1,4	13,3	4,96	465

9.2 AIM

The results present the analysis of the AIM composites. First, AIM without calcined clay, second AIM with 35% replacement of calcined clay CS, AIM with 65% replacement of calcined clay CS, AIM with 35% replacement of calcined clay CK, and AIM with 35% replacement of calcined clay CK. Then present the comparison of AIM composites with each insulation materials. Then compare the AIM 60 & 70 (as multifunctional materials) with conventional insulation materials.

9.2.1 Energy

AIM without calcined clay

The figure 51 and table 49 present the energy analysis of the AIM composites.

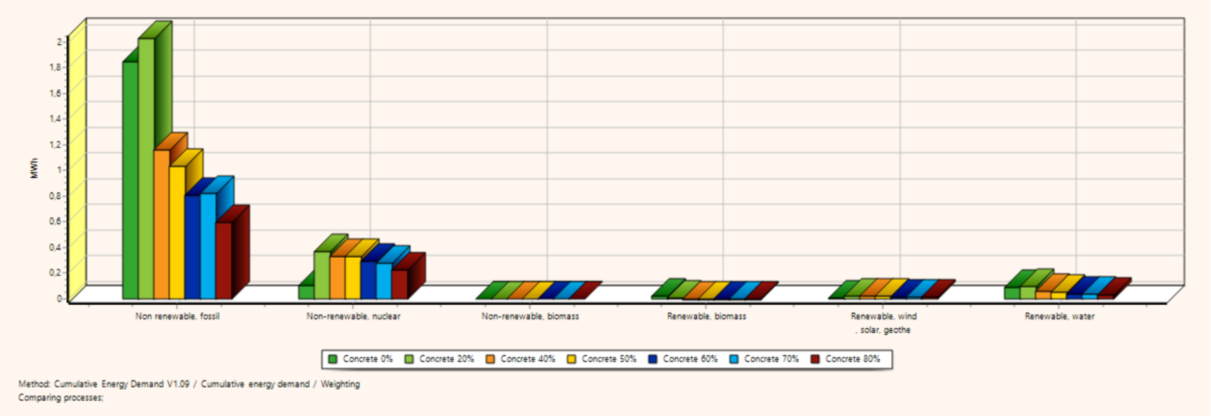
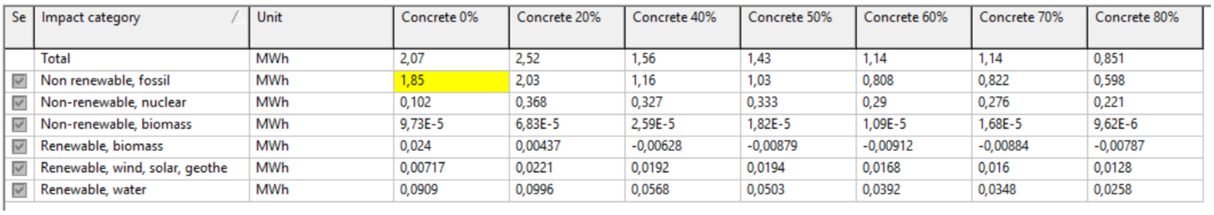


Figure 51 Energy analysis of AIM without calcined clay

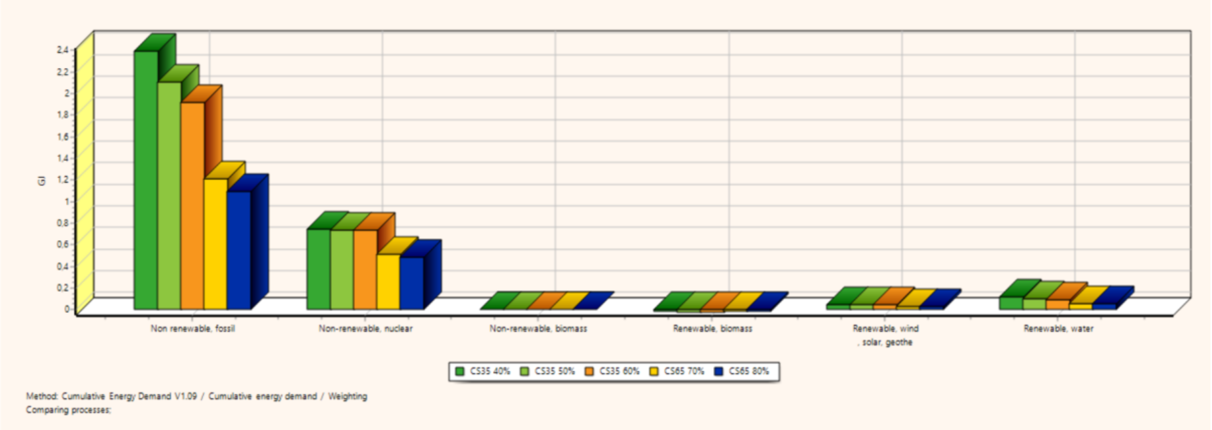
Tabell 40 Energy analysis of AIM without calcined clay



Se	Impact category	Unit	Concrete 0%	Concrete 20%	Concrete 40%	Concrete 50%	Concrete 60%	Concrete 70%	Concrete 80%
	Total	MWh	2,07	2,52	1,56	1,43	1,14	1,14	0,851
☑	Non renewable, fossil	MWh	1,85	2,03	1,16	1,03	0,808	0,822	0,598
☑	Non-renewable, nuclear	MWh	0,102	0,368	0,327	0,333	0,29	0,276	0,221
☑	Non-renewable, biomass	MWh	9,73E-5	6,83E-5	2,59E-5	1,82E-5	1,09E-5	1,68E-5	9,62E-6
☑	Renewable, biomass	MWh	0,024	0,00437	-0,00628	-0,00879	-0,00912	-0,00884	-0,00787
☑	Renewable, wind, solar, geothe	MWh	0,00717	0,0221	0,0192	0,0194	0,0168	0,016	0,0128
☑	Renewable, water	MWh	0,0909	0,0996	0,0568	0,0503	0,0392	0,0348	0,0258

AIM CS 35%

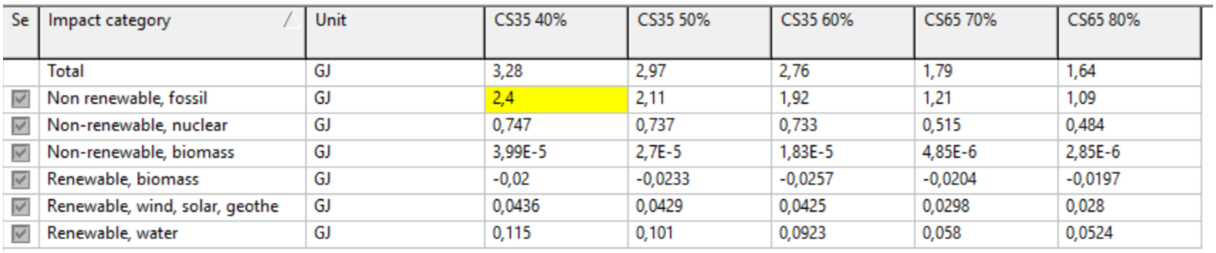
The figure 52 and table 44 present the energy analysis of the AIM composites.



Method: Cumulative Energy Demand V1.09 / Cumulative energy demand / Weighting
Comparing processes:

Figure 52 Energy analysis of AIM CS 35%

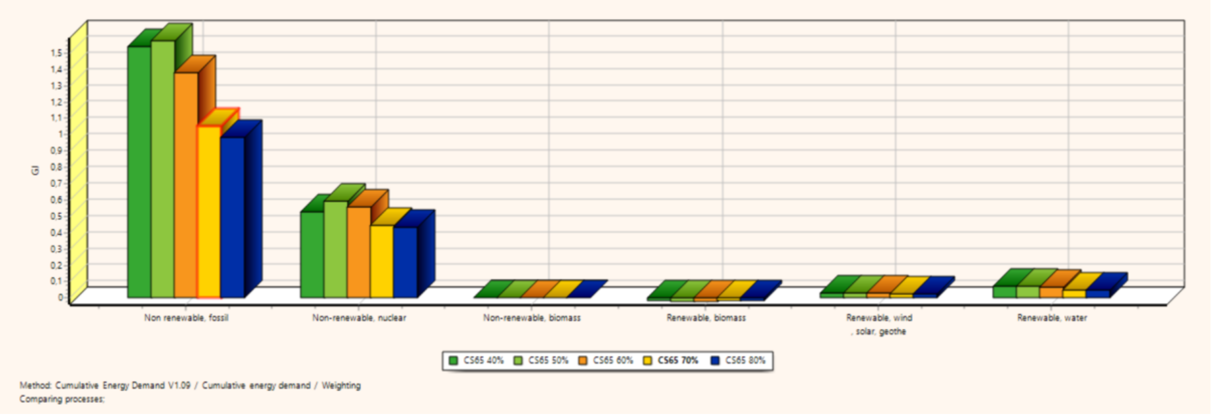
Tabell 41 Energy analysis of AIM CS 35%



Se	Impact category /	Unit	CS35 40%	CS35 50%	CS35 60%	CS65 70%	CS65 80%
	Total	GJ	3,28	2,97	2,76	1,79	1,64
☑	Non renewable, fossil	GJ	2,4	2,11	1,92	1,21	1,09
☑	Non-renewable, nuclear	GJ	0,747	0,737	0,733	0,515	0,484
☑	Non-renewable, biomass	GJ	3,99E-5	2,7E-5	1,83E-5	4,85E-6	2,85E-6
☑	Renewable, biomass	GJ	-0,02	-0,0233	-0,0257	-0,0204	-0,0197
☑	Renewable, wind, solar, geothe	GJ	0,0436	0,0429	0,0425	0,0298	0,028
☑	Renewable, water	GJ	0,115	0,101	0,0923	0,058	0,0524

AIM CS 65%

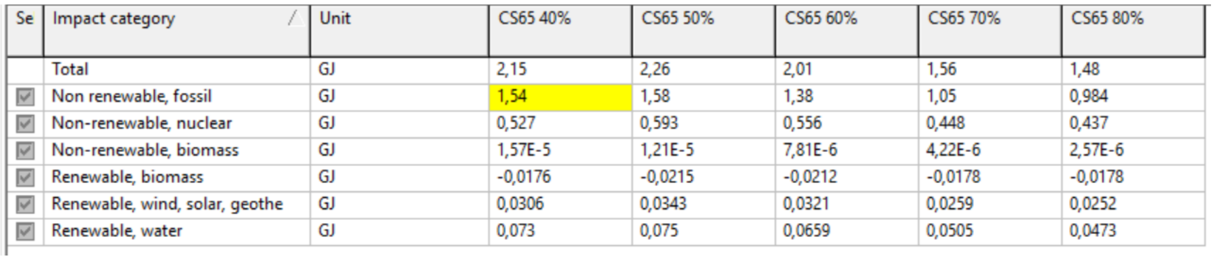
The figure 53 and table 45 present the energy analysis of the AIM composites.



Method: Cumulative Energy Demand V1.09 / Cumulative energy demand / Weighting
Comparing processes;

Figur 53 Energy analysis of AIM CS 65%

Tabell 42 Energy analysis of AIM CS 65%



Se	Impact category	Unit	CS65 40%	CS65 50%	CS65 60%	CS65 70%	CS65 80%
	Total	GJ	2,15	2,26	2,01	1,56	1,48
☑	Non renewable, fossil	GJ	1,54	1,58	1,38	1,05	0,984
☑	Non-renewable, nuclear	GJ	0,527	0,593	0,556	0,448	0,437
☑	Non-renewable, biomass	GJ	1,57E-5	1,21E-5	7,81E-6	4,22E-6	2,57E-6
☑	Renewable, biomass	GJ	-0,0176	-0,0215	-0,0212	-0,0178	-0,0178
☑	Renewable, wind, solar, geothe	GJ	0,0306	0,0343	0,0321	0,0259	0,0252
☑	Renewable, water	GJ	0,073	0,075	0,0659	0,0505	0,0473

AIM CK 35%

The figure 54 and table 46 present the energy analysis of the AIM composites.

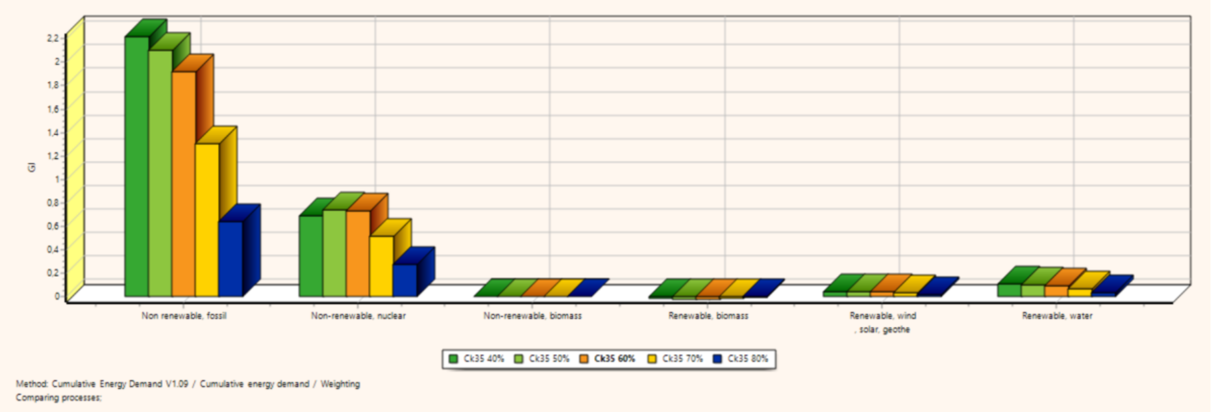
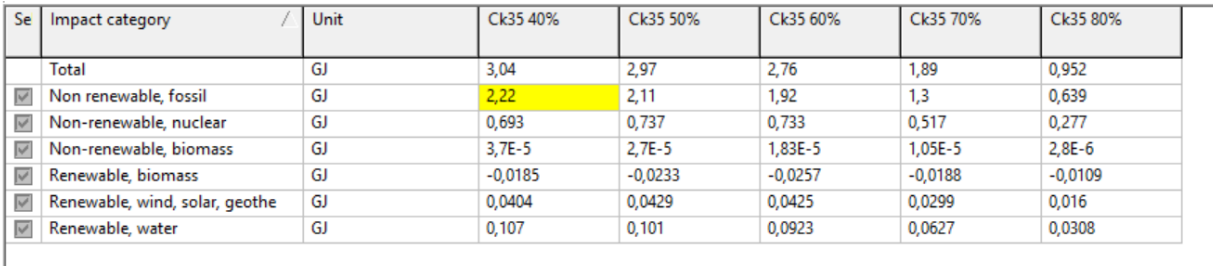


Figure 54 Energy analysis of AIM CK 35%

Tabell 43 Energy analysis of AIM CK 35%



Se	Impact category	Unit	Ck35 40%	Ck35 50%	Ck35 60%	Ck35 70%	Ck35 80%
	Total	GJ	3,04	2,97	2,76	1,89	0,952
☑	Non renewable, fossil	GJ	2,22	2,11	1,92	1,3	0,639
☑	Non-renewable, nuclear	GJ	0,693	0,737	0,733	0,517	0,277
☑	Non-renewable, biomass	GJ	3,7E-5	2,7E-5	1,83E-5	1,05E-5	2,8E-6
☑	Renewable, biomass	GJ	-0,0185	-0,0233	-0,0257	-0,0188	-0,0109
☑	Renewable, wind, solar, geothe	GJ	0,0404	0,0429	0,0425	0,0299	0,016
☑	Renewable, water	GJ	0,107	0,101	0,0923	0,0627	0,0308

AIM CK 65%

The figure 55 and table 47 present the energy analysis of the AIM composites.

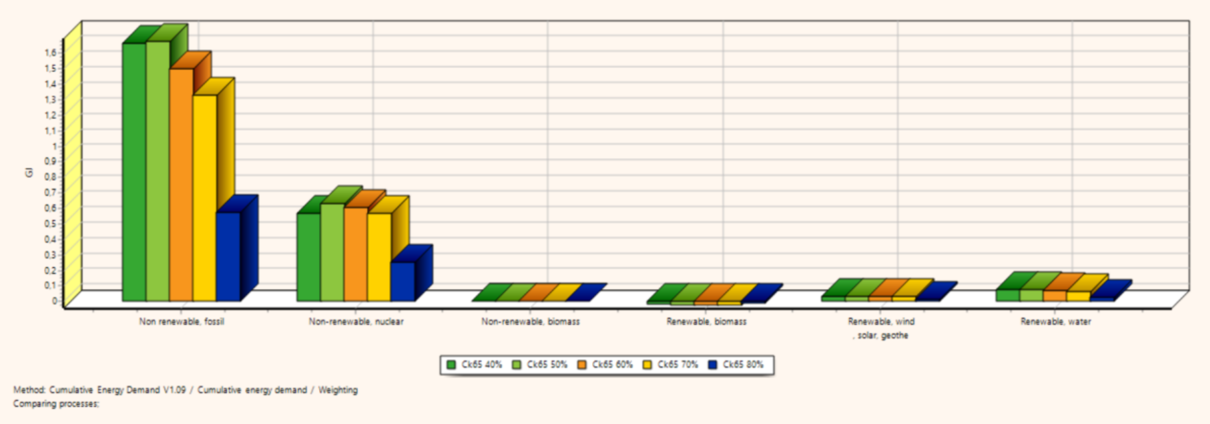
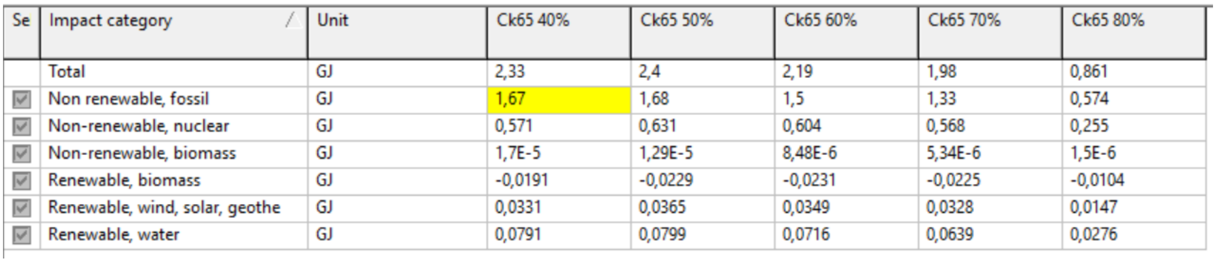


Figure 55 Energy analysis of AIM CK 65%

Tabell 44 Energy analysis of AIM CK 65%



Se	Impact category	Unit	Ck65 40%	Ck65 50%	Ck65 60%	Ck65 70%	Ck65 80%
	Total	GJ	2,33	2,4	2,19	1,98	0,861
☑	Non renewable, fossil	GJ	1,67	1,68	1,5	1,33	0,574
☑	Non-renewable, nuclear	GJ	0,571	0,631	0,604	0,568	0,255
☑	Non-renewable, biomass	GJ	1,7E-5	1,29E-5	8,48E-6	5,34E-6	1,5E-6
☑	Renewable, biomass	GJ	-0,0191	-0,0229	-0,0231	-0,0225	-0,0104
☑	Renewable, wind, solar, geothe	GJ	0,0331	0,0365	0,0349	0,0328	0,0147
☑	Renewable, water	GJ	0,0791	0,0799	0,0716	0,0639	0,0276

AIM 60 %

The figure 56 and table 48 present the energy analysis of the AIM composites with and without calcined clay.

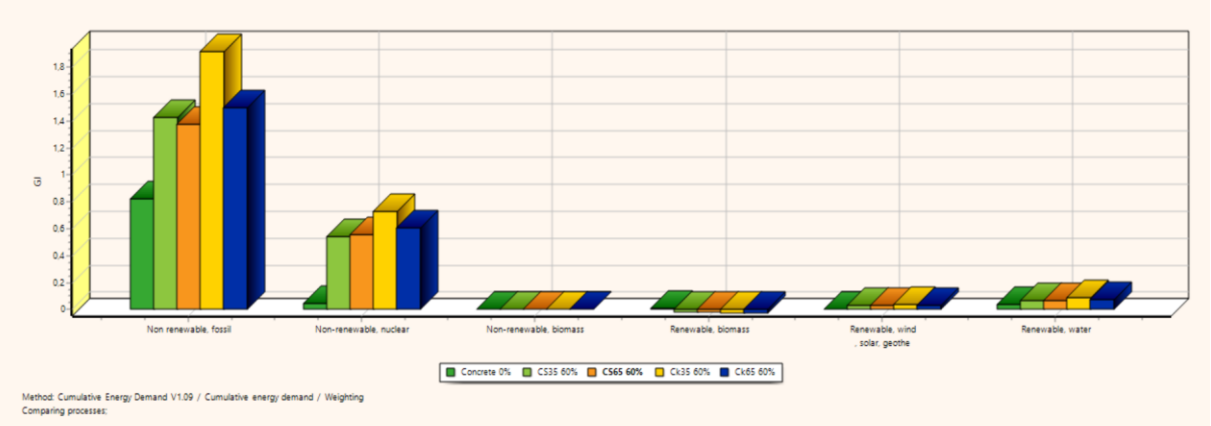
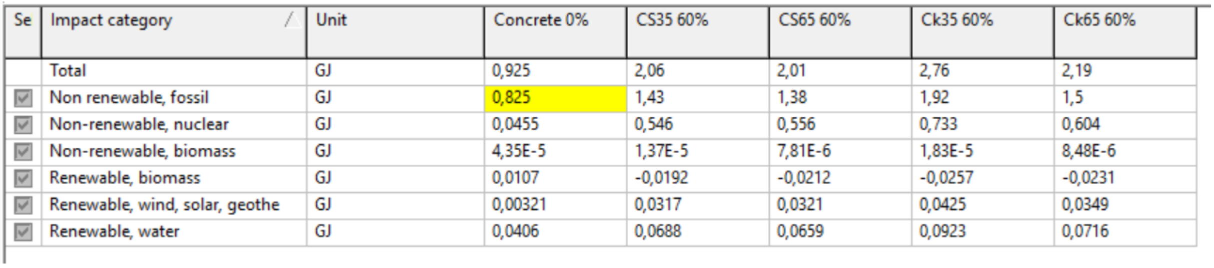


Figure 56 Energy analysis of AIM 60%

Tabell 45 Energy analysis of AIM 60%



Se	Impact category	Unit	Concrete 0%	CS35 60%	CS65 60%	Ck35 60%	Ck65 60%
	Total	GJ	0,925	2,06	2,01	2,76	2,19
☑	Non renewable, fossil	GJ	0,825	1,43	1,38	1,92	1,5
☑	Non-renewable, nuclear	GJ	0,0455	0,546	0,556	0,733	0,604
☑	Non-renewable, biomass	GJ	4,35E-5	1,37E-5	7,81E-6	1,83E-5	8,48E-6
☑	Renewable, biomass	GJ	0,0107	-0,0192	-0,0212	-0,0257	-0,0231
☑	Renewable, wind, solar, geothe	GJ	0,00321	0,0317	0,0321	0,0425	0,0349
☑	Renewable, water	GJ	0,0406	0,0688	0,0659	0,0923	0,0716

AIM & conventional insulation materials

AIM 60%

The figure 57 and table 49 present the energy analysis of the AIM 60% composites with and without calcined clay compared with conventional insulation materials.

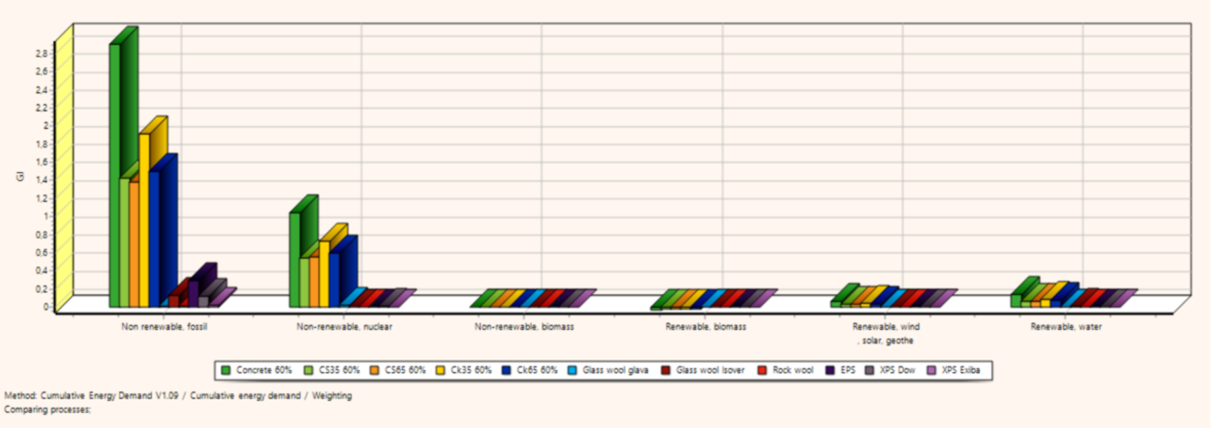
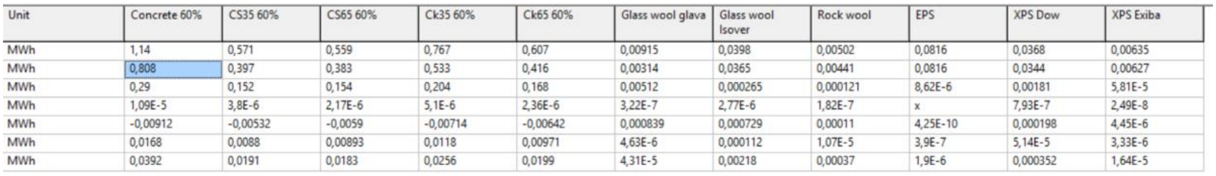


Figure 57 comparison of AIM 60 % and conventional insulation materials

Tabell 46 comparison of AIM 60 % and conventional insulation materials



Unit	Concrete 60%	CS35 60%	CS65 60%	Ck35 60%	Ck65 60%	Glass wool glava	Glass wool Isover	Rock wool	EPS	XPS Dow	XPS Exiba
MWh	1,14	0,571	0,559	0,767	0,607	0,00915	0,0398	0,00502	0,0816	0,0368	0,00635
MWh	0,808	0,397	0,383	0,533	0,416	0,00314	0,0365	0,00441	0,0816	0,0344	0,00627
MWh	0,29	0,152	0,154	0,204	0,168	0,00512	0,000265	0,000121	8,62E-6	0,00181	5,81E-5
MWh	1,09E-5	3,8E-6	2,17E-6	5,1E-6	2,36E-6	3,22E-7	2,77E-6	1,82E-7	x	7,93E-7	2,49E-8
MWh	-0,00912	-0,00532	-0,0059	-0,00714	-0,00642	0,000839	0,000729	0,00011	4,25E-10	0,000198	4,45E-6
MWh	0,0168	0,0088	0,00893	0,0118	0,00971	4,63E-6	0,000112	1,07E-5	3,9E-7	5,14E-5	3,33E-6
MWh	0,0392	0,0191	0,0183	0,0256	0,0199	4,31E-5	0,00218	0,00037	1,9E-6	0,000352	1,64E-5

AIM 70%

The figure 58 and table 55 present the energy analysis of the AIM composites 70 % with and without calcined clay compared with conventional insulation materials.

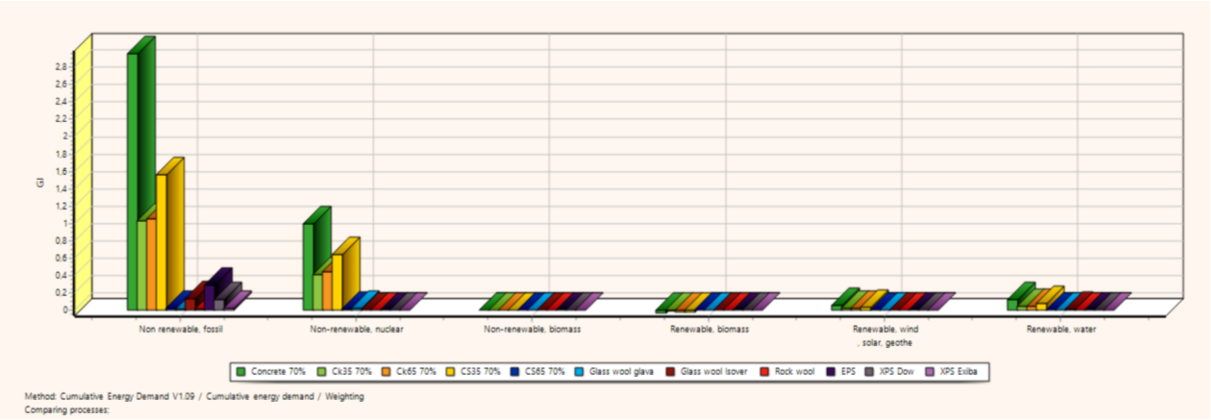
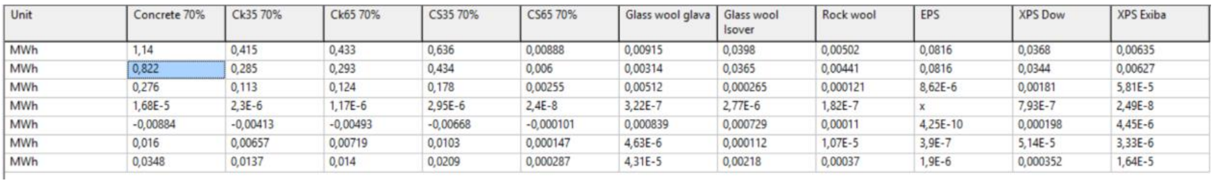


Figure 58 comparison of AIM 70 % and conventional insulation materials

Tabell 47 comparison of AIM 70 % and conventional insulation materials



Unit	Concrete 70%	Ck35 70%	Ck65 70%	CS35 70%	CS65 70%	Glass wool glava	Glass wool Isover	Rock wool	EPS	XPS Dow	XPS Exiba
MWh	1,14	0,415	0,433	0,636	0,00888	0,00915	0,0398	0,00502	0,0816	0,0368	0,00635
MWh	0,822	0,285	0,293	0,434	0,006	0,00314	0,0365	0,00441	0,0816	0,0344	0,00627
MWh	0,276	0,113	0,124	0,178	0,00255	0,00512	0,000265	0,000121	8,62E-6	0,00181	5,81E-5
MWh	1,68E-5	2,3E-6	1,17E-6	2,95E-6	2,4E-8	3,22E-7	2,77E-6	1,82E-7	x	7,93E-7	2,49E-8
MWh	-0,00884	-0,00413	-0,00493	-0,00668	-0,000101	0,000839	0,000729	0,00011	4,25E-10	0,000198	4,45E-6
MWh	0,016	0,00657	0,00719	0,0103	0,000147	4,63E-6	0,000112	1,07E-5	3,9E-7	5,14E-5	3,33E-6
MWh	0,0348	0,0137	0,014	0,0209	0,000287	4,31E-5	0,00218	0,00037	1,9E-6	0,000352	1,64E-5

9.2.2 CO_2 emissions

AIM without calcined clay

The figure 59 and table 51 present the CO_2 equivalent analysis of the AIM without calcined clay

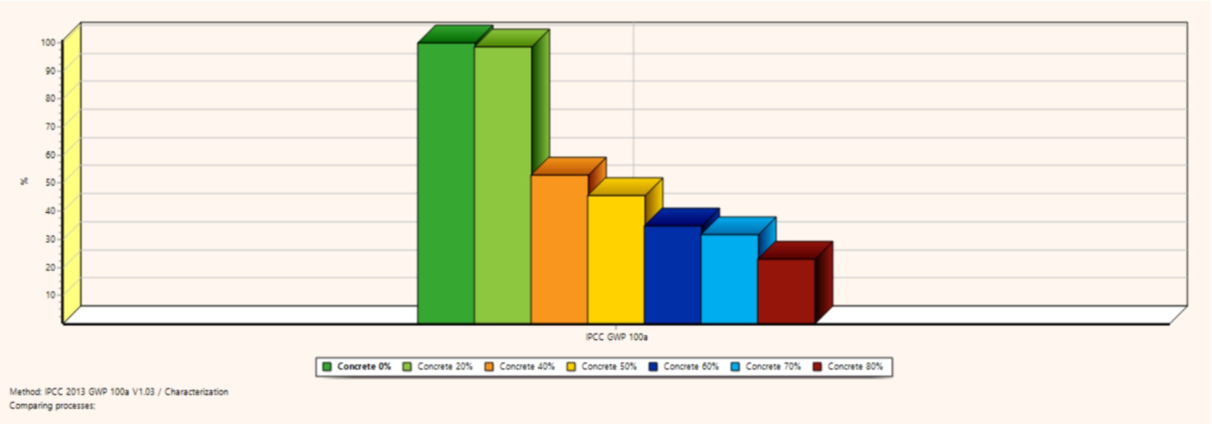
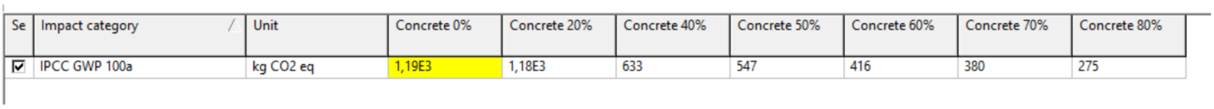


Figure 59 CO_2 equivalent analysis of the AIM without calcined clay

Tabell 48 CO_2 equivalent analysis of the AIM without calcined clay



Se	Impact category	Unit	Concrete 0%	Concrete 20%	Concrete 40%	Concrete 50%	Concrete 60%	Concrete 70%	Concrete 80%
☑	IPCC GWP 100a	kg CO2 eq	1,19E3	1,18E3	633	547	416	380	275

AIM CS 35%

The figure 60 and table 52 present the CO_2 equivalent analysis of the AIM CS 35%

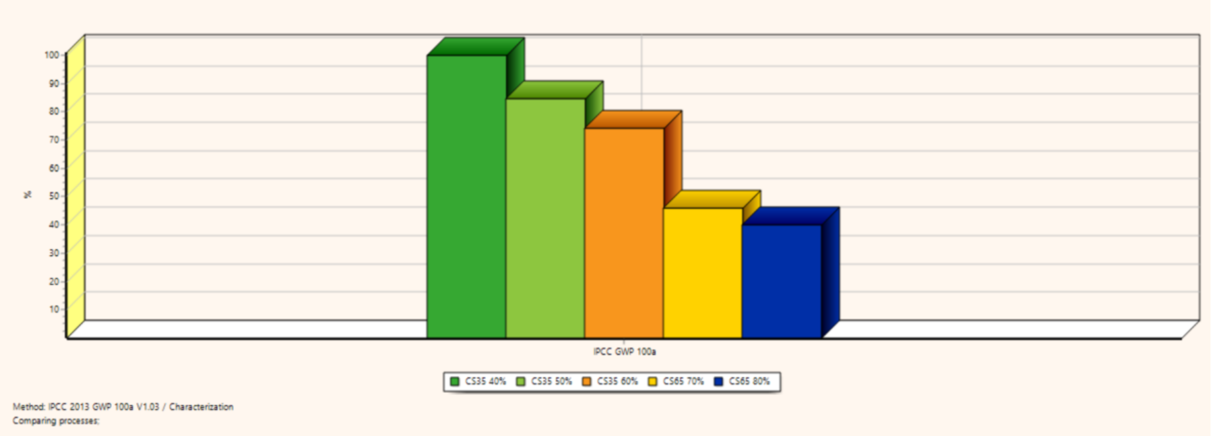
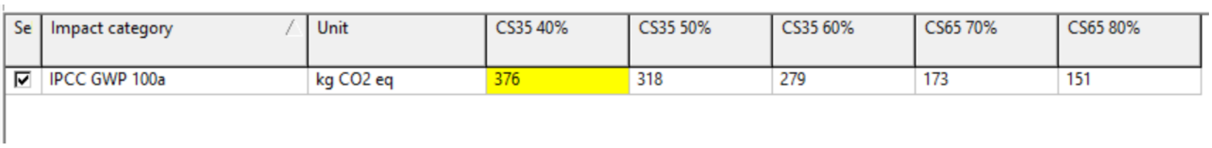


Figure 60 CO_2 equivalent analysis of the AIM CS 35%

Tabell 49 CO_2 equivalent analysis of the AIM CS 35%



Se	Impact category	Unit	CS35 40%	CS35 50%	CS35 60%	CS65 70%	CS65 80%
☑	IPCC GWP 100a	kg CO2 eq	376	318	279	173	151

AIM CS 65%

The figure 61 and table 53 present the CO_2 equivalent analysis of the AIM CS 65%

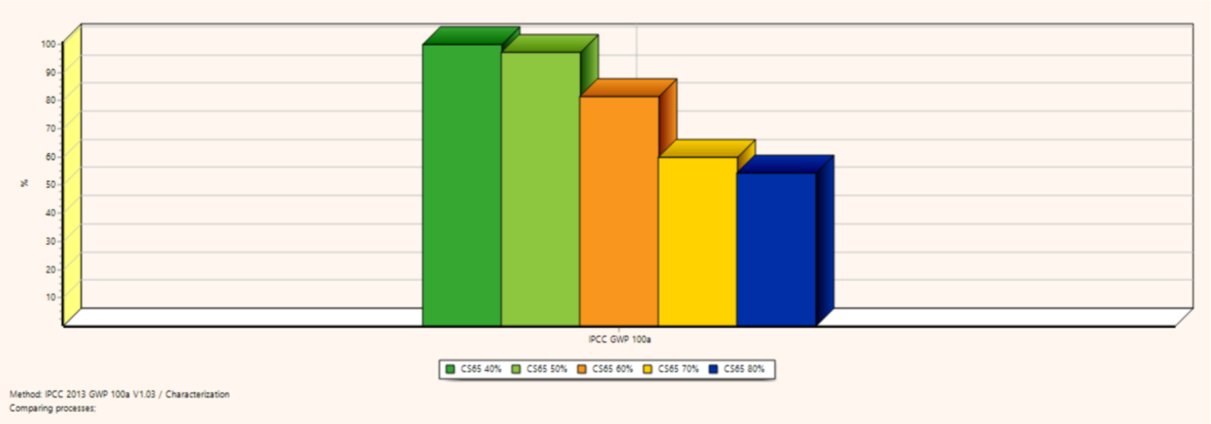
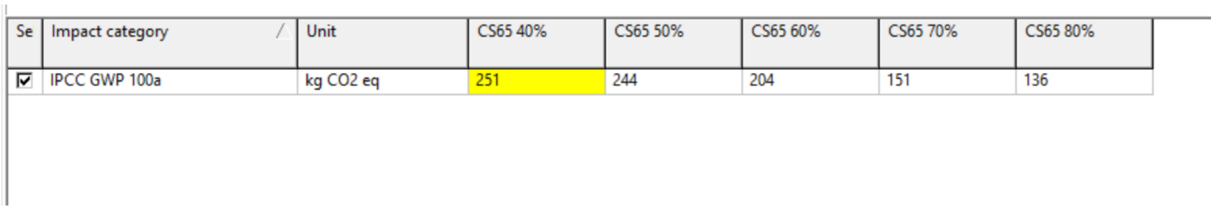


Figure 61 CO_2 equivalent analysis of the AIM CS 65%

Tabell 50 CO_2 equivalent analysis of the AIM CS 65%



Se	Impact category	Unit	CS65 40%	CS65 50%	CS65 60%	CS65 70%	CS65 80%
☑	IPCC GWP 100a	kg CO2 eq	251	244	204	151	136

AIM CK 35%

The figure 62 and table 54 present CO_2 equivalent analysis of the AIM CK 35%

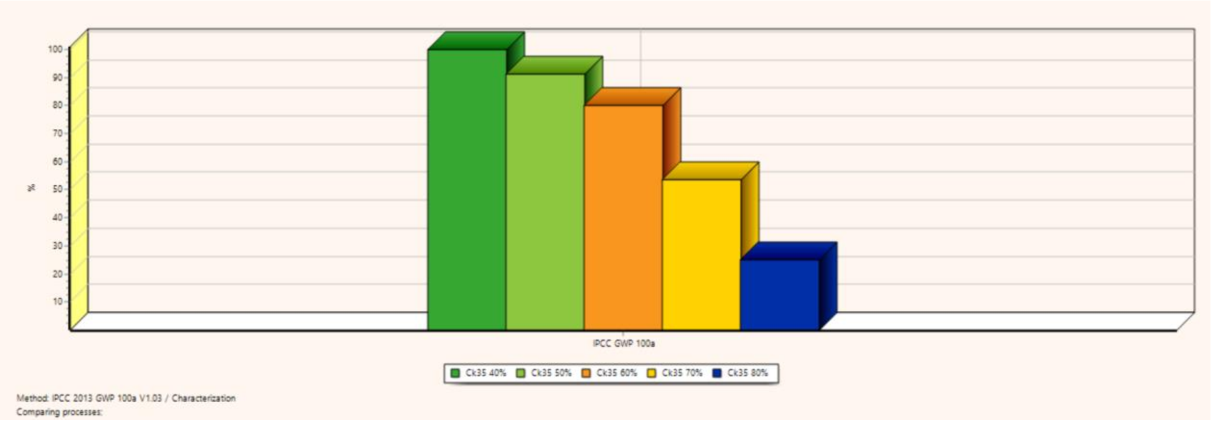
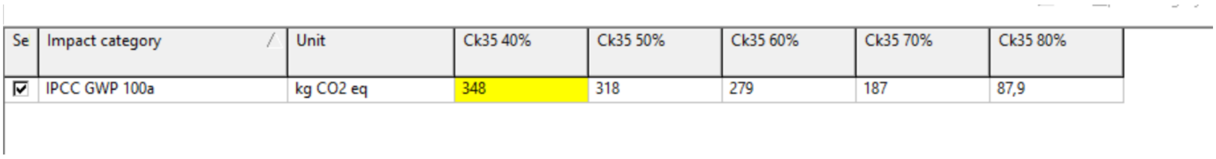


Figure 62 CO_2 equivalent analysis of the AIM CK 35%

Tabell 51 CO_2 equivalent analysis of the AIM CK 35%



Se	Impact category	Unit	Ck35 40%	Ck35 50%	Ck35 60%	Ck35 70%	Ck35 80%
☑	IPCC GWP 100a	kg CO2 eq	348	318	279	187	87,9

AIM CK 65%

The figure 63 and table present the CO_2 equivalent analysis of the AIM CK 65%.

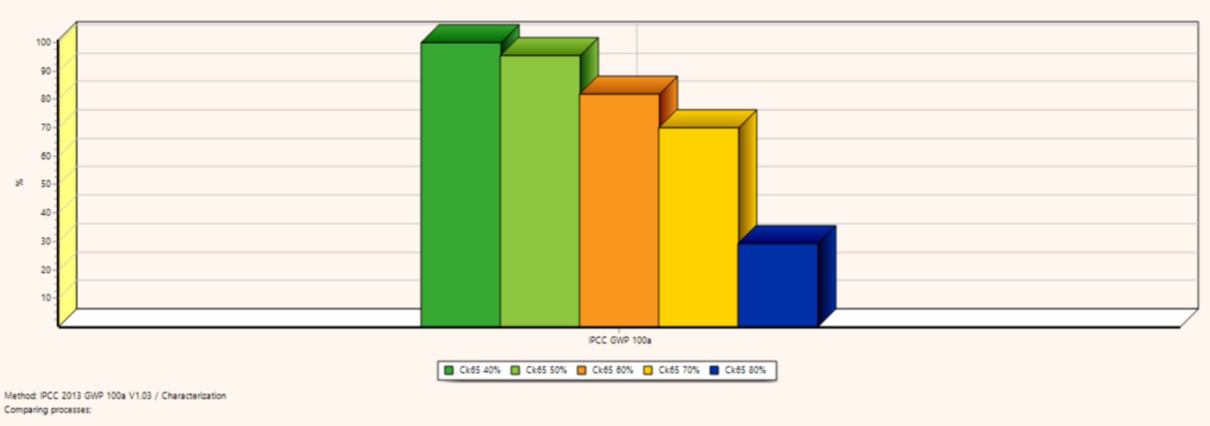
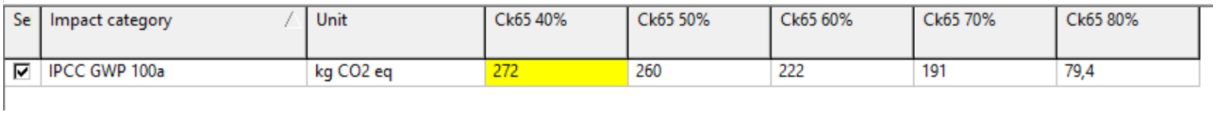


Figure 63 CO_2 equivalent analysis of the AIM CK 65%

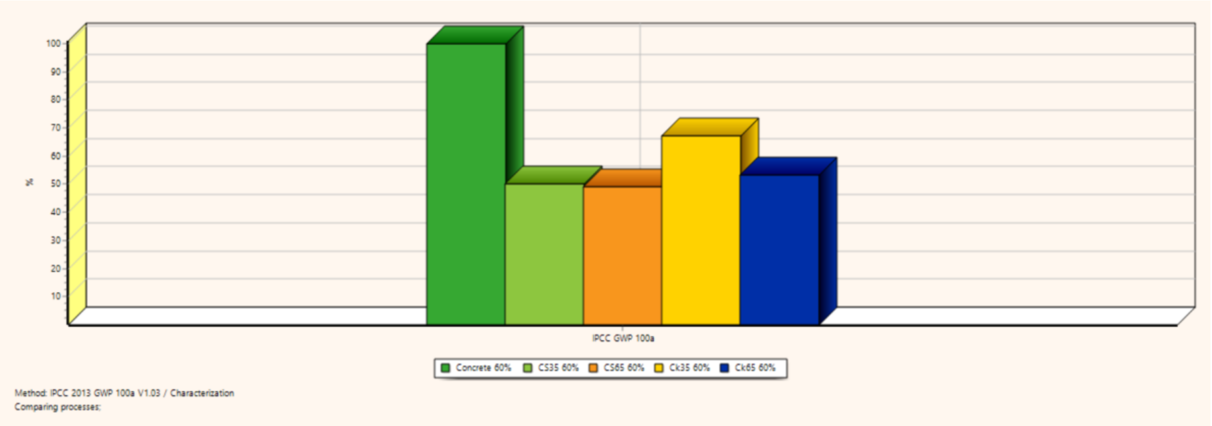
Tabell 52 CO_2 equivalent analysis of the AIM CK 65%



Se	Impact category	Unit	Ck65 40%	Ck65 50%	Ck65 60%	Ck65 70%	Ck65 80%
☑	IPCC GWP 100a	kg CO2 eq	272	260	222	191	79,4

AIM 60 %

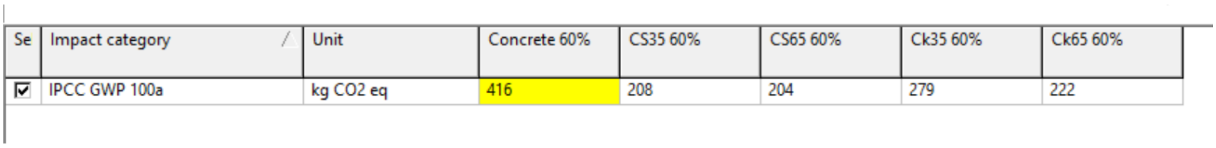
The figure 64 and table 56 present the CO_2 equivalent analysis of the AIM 60% aerogel.



Method: IPCC 2013 GWP 100a V1.03 / Characterization
Comparing processes:

Figure 64 CO_2 equivalent analysis of the AIM 60%

Tabell 53 CO_2 equivalent analysis of the AIM 60%



Se	Impact category	Unit	Concrete 60%	CS35 60%	CS65 60%	Ck35 60%	Ck65 60%
☑	IPCC GWP 100a	kg CO2 eq	416	208	204	279	222

AIM 70%

The figure 65 and table 57 present CO_2 equivalent analysis of the AIM 70%.

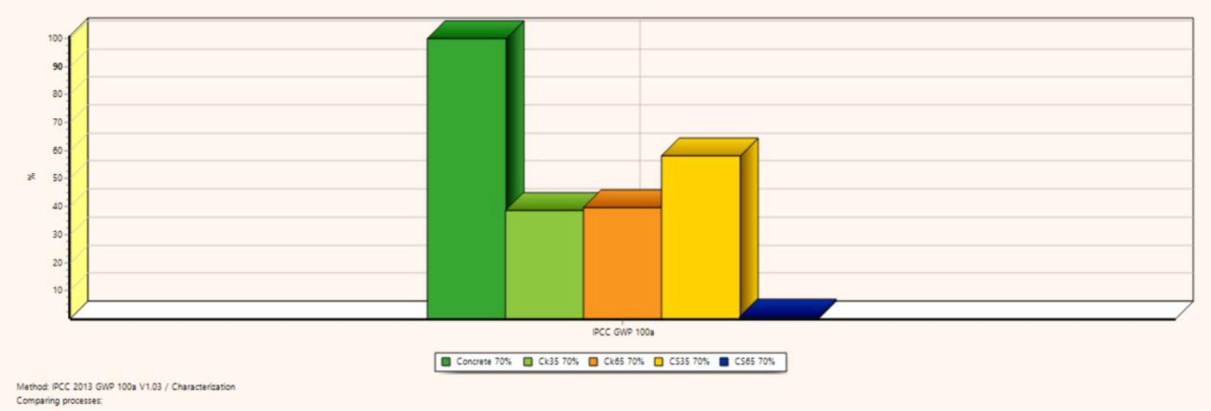
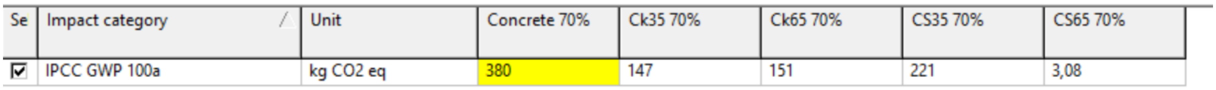


Figure 65 CO_2 equivalent analysis of the AIM 70%

Tabell 54 CO_2 equivalent analysis of the AIM 70%

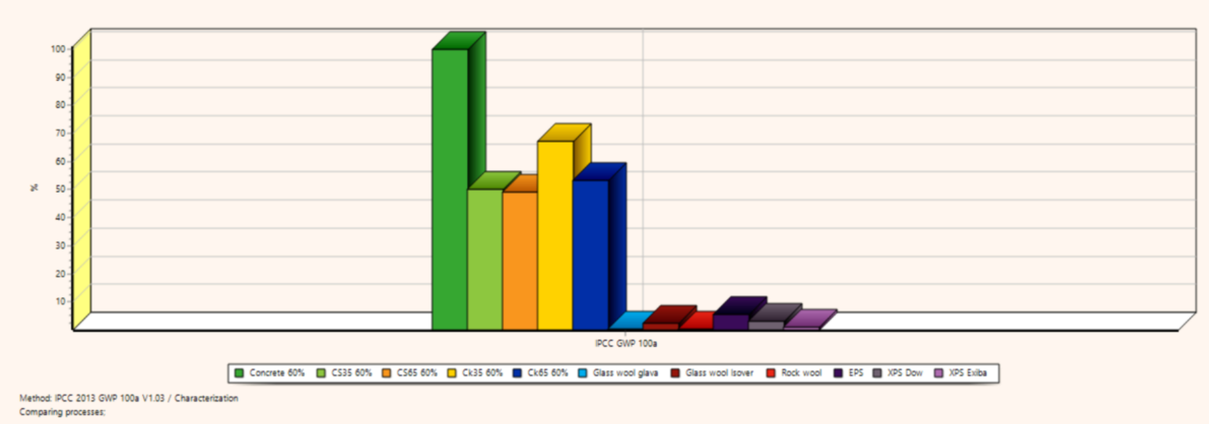


Se	Impact category	Unit	Concrete 70%	Ck35 70%	Ck65 70%	CS35 70%	CS65 70%
☑	IPCC GWP 100a	kg CO2 eq	380	147	151	221	3,08

AIM & conventional insulation materials

AIM 60%

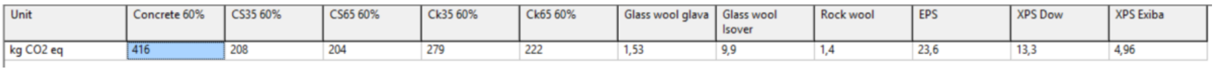
The figure 66 and table 58 present the CO_2 equivalent analysis of the AIM 60% composites compared with conventional insulation materials.



Method: IPCC 2013 GWP 100a V1.03 / Characterization
Comparing processes:

Figure 66 CO_2 equivalent analysis of the AIM 60% compared with conventional insulation materials

Tabell 55 CO_2 equivalent analysis of the AIM 60% compared with conventional insulation materials



Unit	Concrete 60%	CS35 60%	CS65 60%	Ck35 60%	Ck65 60%	Glass wool glava	Glass wool Isover	Rock wool	EPS	XPS Dow	XPS Exiba
kg CO2 eq	416	208	204	279	222	1,53	9,9	1,4	23,6	13,3	4,96

AIM 70%

The figure 67 and table 59 present the CO_2 equivalent analysis of the AIM 70% composites compared with conventional insulation materials.

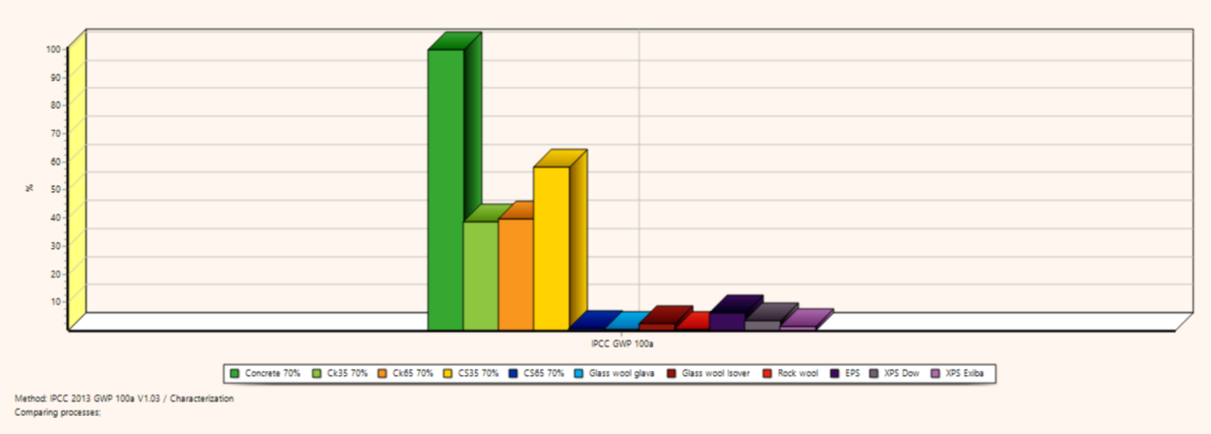
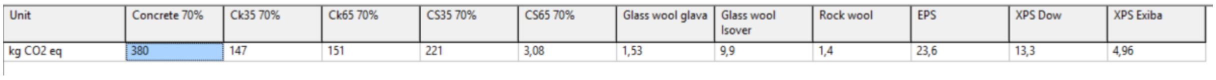


Figure 67 CO_2 equivalent analysis of the AIM 70% compared with conventional insulation materials

Tabell 56 CO_2 equivalent analysis of the AIM 70% compared with conventional insulation materials



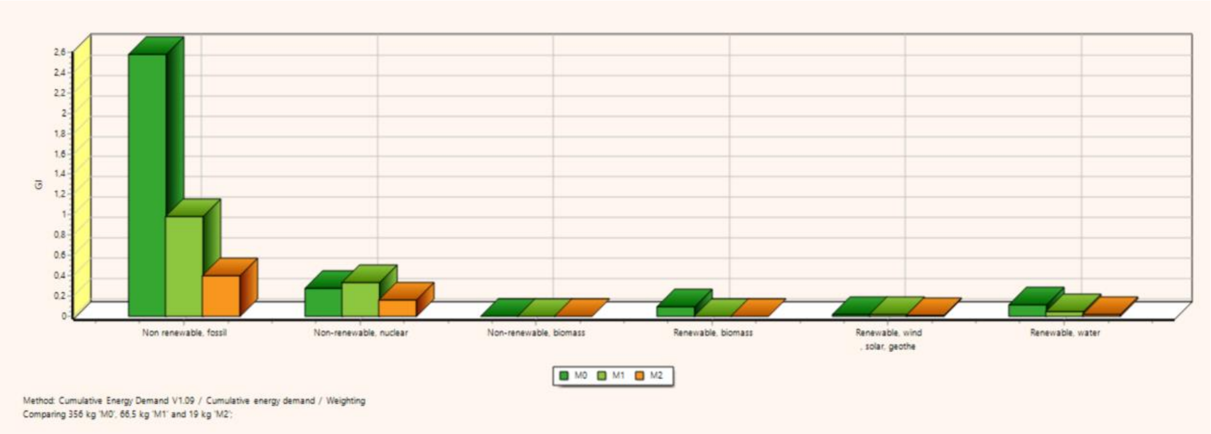
Unit	Concrete 70%	Ck35 70%	Ck65 70%	CS35 70%	CS65 70%	Glass wool glava	Glass wool Isover	Rock wool	EPS	XPS Dow	XPS Exiba
kg CO2 eq	380	147	151	221	3,08	1,53	9,9	1,4	23,6	13,3	4,96

9.3 MKP

The results present the analysis of the MKP composites. Then present the comparison of MKP composites with insulation materials.

9.3.1 Energy

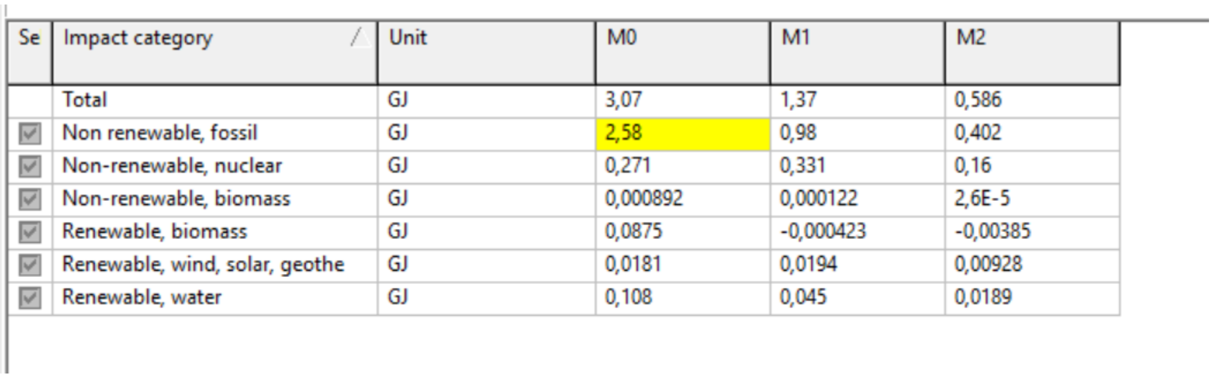
The figure 68 and table 60 present the energy analysis of the MKP composites.



Method: Cumulative Energy Demand V1.09 / Cumulative energy demand / Weighting
Comparing 356 kg 'M0', 66,5 kg 'M1' and 19 kg 'M2';

Figure 68 Energy analysis of the MKP

Tabell 57 Energy analysis of the MKP



Se	Impact category	Unit	M0	M1	M2
	Total	GJ	3,07	1,37	0,586
☑	Non renewable, fossil	GJ	2,58	0,98	0,402
☑	Non-renewable, nuclear	GJ	0,271	0,331	0,16
☑	Non-renewable, biomass	GJ	0,000892	0,000122	2,6E-5
☑	Renewable, biomass	GJ	0,0875	-0,000423	-0,00385
☑	Renewable, wind, solar, geothe	GJ	0,0181	0,0194	0,00928
☑	Renewable, water	GJ	0,108	0,045	0,0189

MKP & insulation materials

The figure 69 and table 61 present the energy analysis of MKP composites compared with conventional insulation materials.

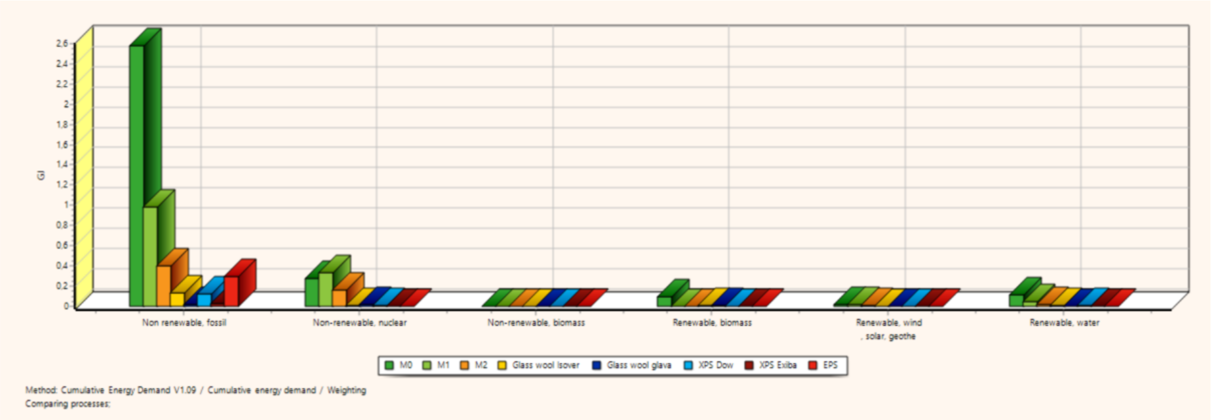
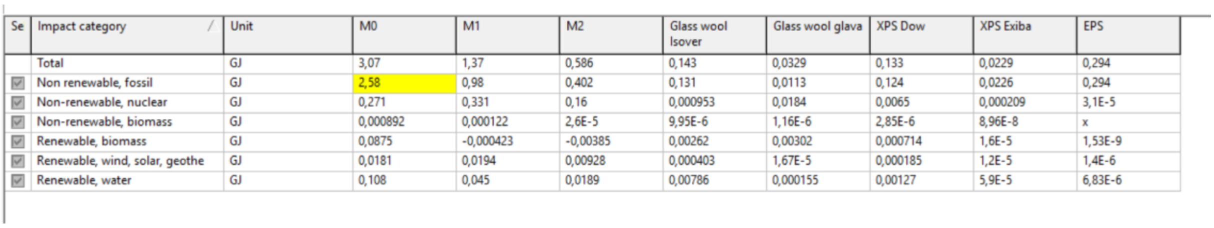


Figure 69 comparison of MKP and conventional insulation materials

Tabell 58 comparison of MKP and conventional insulation materials



Se	Impact category	Unit	M0	M1	M2	Glass wool Isover	Glass wool glava	XPS Dow	XPS Exiba	EPS
	Total	GJ	3,07	1,37	0,586	0,143	0,0329	0,133	0,0229	0,294
☑	Non renewable, fossil	GJ	2,58	0,98	0,402	0,131	0,0113	0,124	0,0226	0,294
☑	Non-renewable, nuclear	GJ	0,271	0,331	0,16	0,000953	0,0184	0,0065	0,000209	3,1E-5
☑	Non-renewable, biomass	GJ	0,000892	0,000122	2,6E-5	9,95E-6	1,16E-6	2,85E-6	8,96E-8	x
☑	Renewable, biomass	GJ	0,0875	-0,000423	-0,00385	0,00262	0,00302	0,000714	1,6E-5	1,53E-9
☑	Renewable, wind, solar, geothe	GJ	0,0181	0,0194	0,00928	0,000403	1,67E-5	0,000185	1,2E-5	1,4E-6
☑	Renewable, water	GJ	0,108	0,045	0,0189	0,00786	0,000155	0,00127	5,9E-5	6,83E-6

9.3.2 CO2

MKP composites

The figure 70 and table 62 present the CO_2 equivalent analysis of the MKP composites.

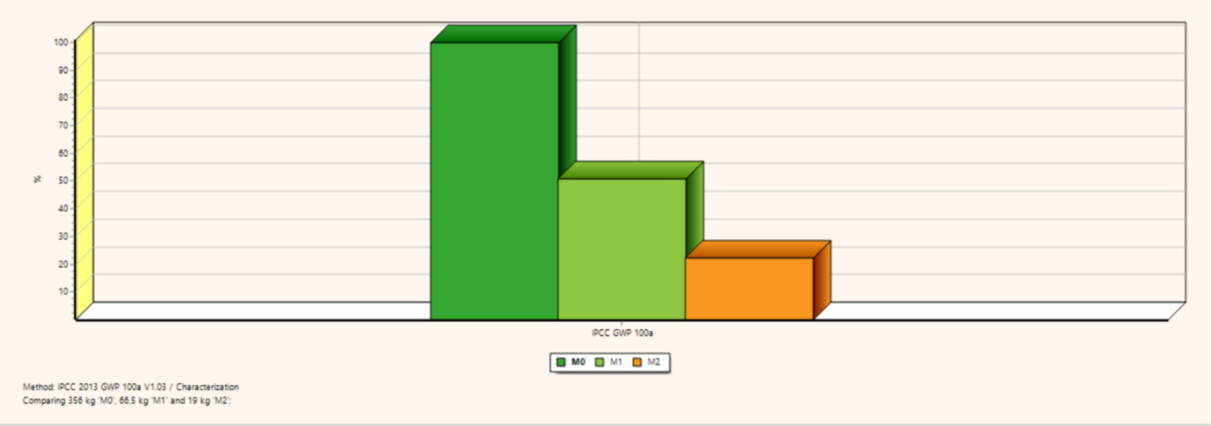
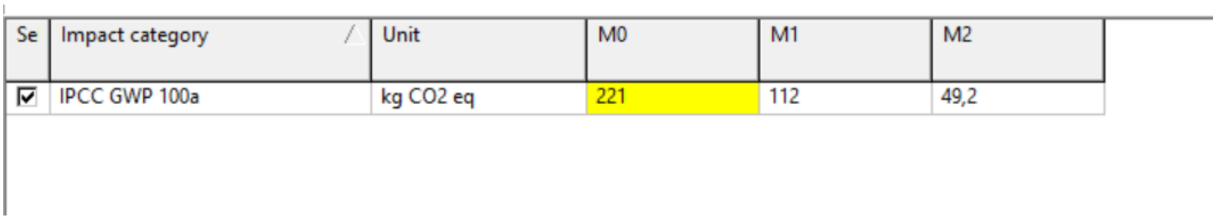


Figure 70 CO_2 equivalent analysis of the MKP

Tabell 59 CO_2 equivalent analysis of the MKP



Se	Impact category	Unit	M0	M1	M2
☑	IPCC GWP 100a	kg CO2 eq	221	112	49,2

MKP & insulation materials

The figure 71 and table 63 present the CO_2 equivalent analysis of the MKP composites compared with conventional insulation materials.

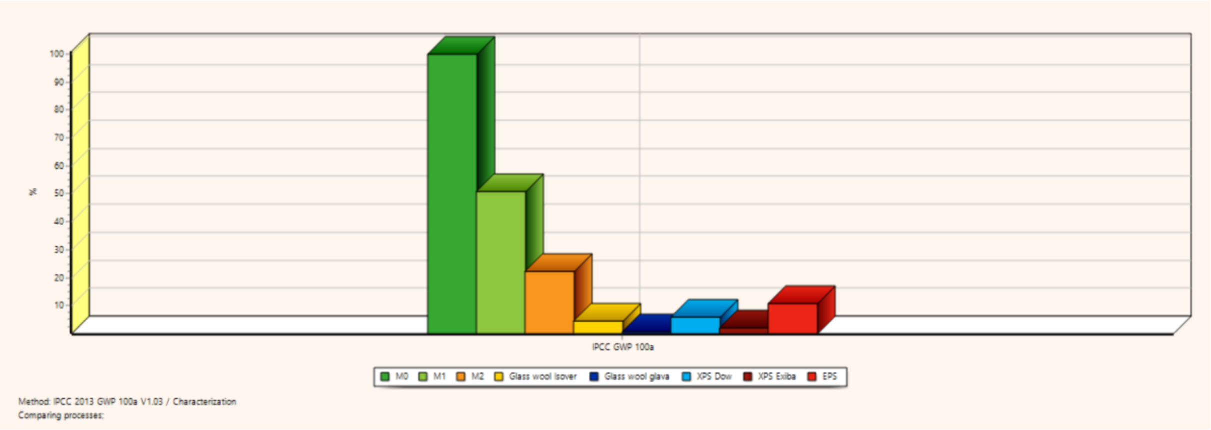
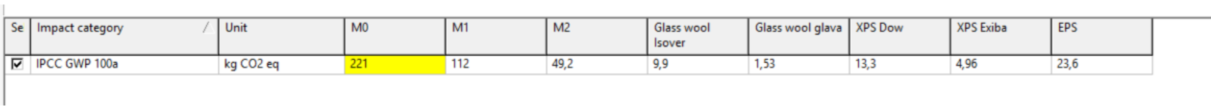


Figure 71 comparison of MKP and conventional insulation materials

Tabell 60 comparison of MKP and conventional insulation materials



Se	Impact category	Unit	M0	M1	M2	Glass wool Isover	Glass wool glava	XPS Dow	XPS Exiba	EPS
☑	IPCC GWP 100a	kg CO2 eq	221	112	49,2	9,9	1,53	13,3	4,96	23,6

9.4 Comparison between the composites

In this section, it will be presented the comparison between the three composites AIC, AIM, and MKP. The comparison includes the composites which can be used as a multifunctional material: AIC 60%, AIM 60%, and MKP 1&2.

9.4.1 Energy

The figure 72 and table 64 present the energy analysis of the three composites.

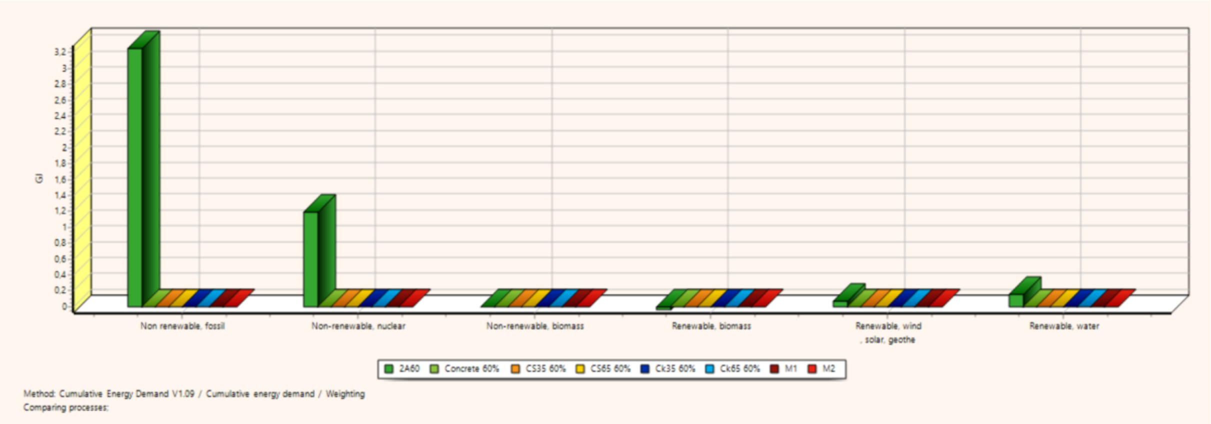
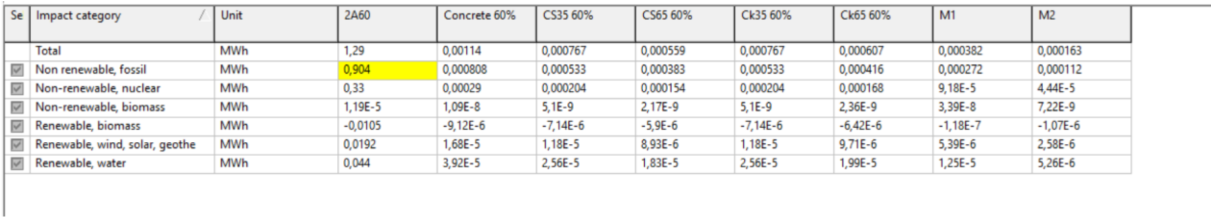


Figure 72 Energy analysis of the three composites

Tabell 61 Energy analysis of the three composites



Se	Impact category	Unit	2A60	Concrete 60%	CS35 60%	CS65 60%	Ck35 60%	Ck65 60%	M1	M2
	Total	MWh	1,29	0,00114	0,000767	0,000559	0,000767	0,000607	0,000382	0,000163
☑	Non renewable, fossil	MWh	0,904	0,000808	0,000533	0,000383	0,000533	0,000416	0,000272	0,000112
☑	Non-renewable, nuclear	MWh	0,33	0,00029	0,000204	0,000154	0,000204	0,000168	9,18E-5	4,44E-5
☑	Non-renewable, biomass	MWh	1,19E-5	1,09E-8	5,1E-9	2,17E-9	5,1E-9	2,36E-9	3,39E-8	7,22E-9
☑	Renewable, biomass	MWh	-0,0105	-9,12E-6	-7,14E-6	-5,9E-6	-7,14E-6	-6,42E-6	-1,18E-7	-1,07E-6
☑	Renewable, wind, solar, geothe	MWh	0,0192	1,68E-5	1,18E-5	8,93E-6	1,18E-5	9,71E-6	5,39E-6	2,58E-6
☑	Renewable, water	MWh	0,044	3,92E-5	2,56E-5	1,83E-5	2,56E-5	1,99E-5	1,25E-5	5,26E-6

9.4.2 CO_2 equivalent

The figure 73 and table 65 present the CO_2 equivalent analysis of the three composites.

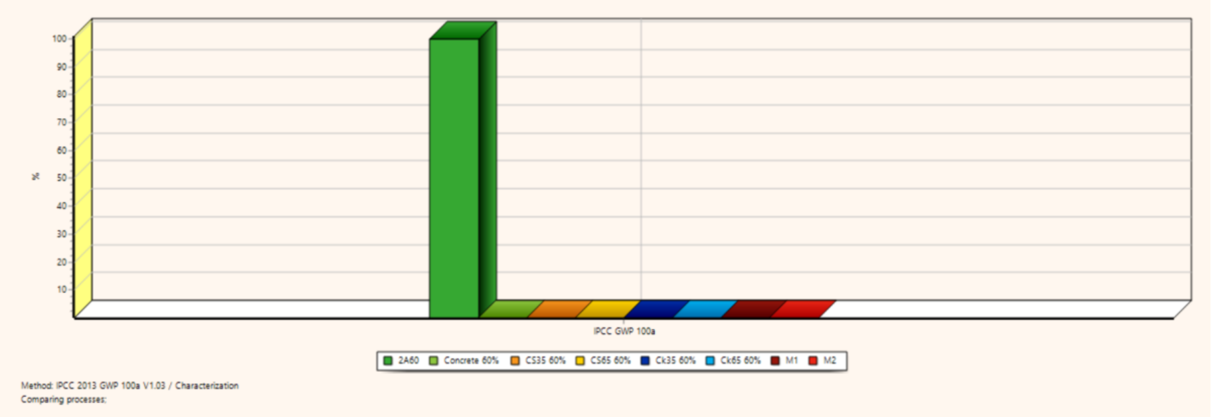
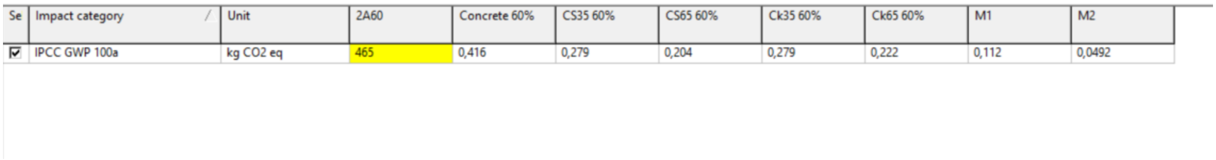


Figure 73 CO_2 equivalent analysis of the three composites

Tabell 62 CO_2 equivalent analysis of the three composites



Se	Impact category	Unit	2A60	Concrete 60%	CS35 60%	CS65 60%	Ck35 60%	Ck65 60%	M1	M2
☑	IPCC GWP 100a	kg CO2 eq	465	0,416	0,279	0,204	0,279	0,222	0,112	0,0492

10 Discussion

In this chapter, it will be discussed the results of the LCA studies of the studied new composites: AIC, MKP – FA considering the energy and CO_2 equivalent. The discussion will include parts: presentation of the results, check of the results, the need of the research, discussion of used methodology in this research, multifunctional materials, limitation of this research, the incorporating of inorganic materials or additives in the building materials. First, the need of the research section will present the need of this research in the building sector. Second, presentation of the results of the research in this project. Then, discussion of the methodology discusses the used methodology in this research such as functional unit, system boundaries, scope. Then, discuss some check of the results as completeness, consistency and sensitive checks, discuss the new composites as multifunctional materials. Then, discuss the limitations of the research in this paper. Then, discuss the drawn conclusions from this research which can be generalized to other building materials. Finally, discuss the sustainable performance of these composites as a need for commercial production of these composites.

10.1 Results

AIC

The comparison between the AIC and conventional insulation materials is based on defined functional unit 1 m^2 area insulation and R-value equal 1. The results from LCIA show that incorporating of aerogel into lightweight concrete will reduce the environmental impact of the concrete aggregates. Although, the results from LCIA show that AIC composites have a higher environmental impact than conventional insulation materials.

AIM

The comparison between the AIM composites is based on defined functional unit 1 m^2 area insulation and R-value equal 1. The results from LCIA show that incorporating of aerogel into concrete mortars will reduce the energy consumption and CO_2 equivalent of the concrete aggregates. Although, the results show that the calcined clay reduces the CO_2 equivalent and energy consumption of AIM.

The comparison between the AIM and conventional insulation materials is based on defined functional unit 1 m^2 area insulation and R-value equal 1. the results from LCIA show that AIM composites have higher CO_2 equivalent than conventional insulation materials. Although, the

AIM composites have higher energy consumption and CO_2 equivalent than conventional insulation materials.

MKP

The comparison between the MKP - FA and conventional insulation materials with defined functional unit 1 m^2 area insulation and U – value equal 1. The results from LCIA show that incorporating of aerogel into MKP - FA will reduce the environmental impact of the concrete aggregates. Although, the results from LCIA show that MKP - FA composites have higher environmental impact than conventional insulation materials.

Comparison of the new composites

The comparison between the MKP - FA and conventional insulation materials with defined functional unit 1 m^2 area insulation and U – value equal 1. The results show at AIC composite with 60 % has the highest CO_2 equivalent compared with other composites. While the M2 has the lowest CO2 compared with other composites.

10.2 Completeness check

There is a gap in environmental impact data of Aerogel from the producers. The only available data is the energy consumption and CO_2 emissions from two producers: Cabot & Aspen. The used data for aerogel is data from Aspen (Dowson et al., 2012) but it is more reliable data than Cabot since it is claimed from Aspen. While the data from Cabot is conducted from the sustainability report of Cabot. The author has contacted several producers to get new data but didn’t get a result.

10.3 Consistency checks

The data of used traditional insulation material for comparison are retrieved from databases in Simapro and adjusted based on the EPDs. The data from the databases is ideal and don’t cover the difference between the producers regards the energy mix, waste treatment or environmental-friendly technology. While the data from EPDs are more reliable and precise data on the production.

The environmental impact data of chemical components (MgO, KH_2PO_4) of MKP are retrieved from the databases. The data from the databases is ideal and don’t cover the difference between the producers regards the energy mix, waste treatment or environmental-friendly technology.

The calcined clay in this research isn’t commercially produced. Therefore, the producer considers only the CO_2 emissions of production. The replacement of cement by calcined clay will reduce the energy consumption of the production since there is no data of energy. Consequently, the energy analysis of AIM isn't reliable. While the CO_2 equivalent analysis is more reliable since the CO_2 data of all components are available. The calcined clay reduces the CO_2 equivalent of the production of AIM.

10.4 Sensitivity check

The allocation of emissions from the production of Silica fume will affect the result. As shown in the LCI, The European silica fume producers allocate all greenhouse gas emissions to the main product silicon and ferrosilicon since the entire Si / FeSi include by-products are covered by EU carbon leakage list. The silica fume is co-product of silicon production and has lower economic value. In the other hand, the silica fume as a commercial product can be considered environmentally based on the distribution of economic value. In this paper, the allocation of emissions and energy consumption follow the allocation rules in EU.

There are two views of allocation of the environmental impact of fly ash; first, the fly ash as a waste product which needs to be treated and in this case no need for the environmental impact data. The second(Mukherjee et al., 2008), the Fly ash as co-products from power production. In this case, the environmental impact will be distributed based on the economic value. If the consumption of fly ash becomes too high that it becomes necessary to produce it for replacement of Portland cement, then its sustainability advantages are lost, because then the impacts of the production of fly ash become nearly equal to the production of Portland cement.

10.5 The need of the research

The research in this paper will cover a gap in the research field. The previous research focuses on developing alternative building material with low thermal conductivity. In this paper, the research will go further in this field by studying the environmental impact of some of these alternative materials. It will be considered only the energy consumption and CO_2 equivalent analysis. Then compare the environmental impact of these alternative materials to the traditional insulation materials. The environmental impact has been a very important factor for the building industry when they choose the materials because the environmental legislation takes stronger place in many countries. Examples of that are EU environment regulation (Appendix). Many countries require environmental product declaration (Sintef, 2018) for the commercial products. This paper will support the commercial production of the studied alternative materials because it presents a basic knowledge of the environmental impact of these materials.

The research in this paper focuses on using these composite materials as more sustainable alternatives to the traditional insulation materials. The main idea of this research project is to compare the environmental impact between the insulation composite material which is studied in NTNU and Sintef with traditional insulation materials as organic like Polyurethane (EPS) or polystyrene (XPS) or inorganic like glass wool or rock wool. The main aim is to find if this new insulation composite has a less environmental impact than the traditional insulation materials which achieve the same thermal insulation. The conventional thermal insulation materials like cellulose, EPS, polystyrene foam, cork foam are organic materials which have a negative environmental impact during their production phase. In this paper, it will be a comparison of the energy consumption and CO_2 equivalent during their production phase of these traditional materials with the new composites.

10.6 Discussion of Methodology

The choice of the principles to be applied in the LCA of each insulation material, following the guidelines defined in ISO 14040 (Standardization, 2006a) and 14044 (Standardization, 2006b) standards, were important to guarantee the scientific validity of the results presented in this paper. This paper is not a full LCA of the new composites but follows the LCA standards in other LCA studies of insulation materials that were based on the same standardized methodological approach (Sintef, 2018, Pargana et al., 2014).

10.6.1 The scope

This paper doesn’t include any case study scenario for the environmental impact of the compared materials during the production phase. Because the comparison is based on R – the value of compared materials. The LCA exclusive the environmental impact of the use phase. The thickness and weight of the materials in the walls are calculated to achieve the considered functional unit.

The functional unit is 1 m^2 insulation material in the building envelope with the desired R-value equal 1. The used functional unit is to ensure that the compared materials have the same thermal efficiency in the use phase. That will provide a fair and reliable comparison. Although, the functional unit has been used in several types of research (Pargana et al., 2014, Reidun Dahl Schlanbusch and Kristjansdottir, 2014).

In fact, the significant part of the environmental impact of thermal insulation materials comes from their use in buildings as energy savings that result from their installation in the envelope of a building. The compared materials desire equal R -values, based on that the insulation materials ensure equal insulation effect for the buildings. Consequently, there is no value of adding the use phase to the comparison between the environmental impact of the compared materials in this research.

It is necessary to have the density to calculate the weight of the compared material. First, it was calculated the thickness which achieves desired R – values. Then, calculate the volume and multiply it by the density to calculate the weight of the material. Finally conduct the LCA by Simapro based on the composite mix, data, and calculated weight. The chosen composites were AIC retrieved from (Gao et al., 2014) and MKP – FA. The compared amount of material is the amount which achieves the desired of R – value.

10.6.1.1 Importance of Density

The density was an important factor in this LCA study. The materials with high density usually have higher thermal conductivity. Therefore, the Functional unit equant mass (F.U) will be bigger than materials with low thermal conductivity. The AIC composites with high density have a higher energy consumption and CO_2 equivalent than conventional insulation materials.

10.7 Multifunctional material

The new composites which achieve the good mechanical strength and low thermal conductivity can be used as multifunctional materials which are used for both walls buildings and insulation of buildings. The most composites don't ensure the requirements of mechanical strength of the building. Therefore, they can't be used in the columns and grounds of constructions. While they can be used in the walls because based on measured mechanical strength and thermal conductivity of these composites. In this case, the new composites will be an insulator and building bricks. The new composites which combine both insulation and mechanical strength are composites with aerogel content 60%. These new composites can be used as multifunctional materials. The results from the analysis show that the production of new composites AIC, AIM, and MKP have higher energy consumption and CO_2 equivalent than traditional insulation materials. Although, few of them ensure low thermal conductivity. Therefore, they aren't a sustainable alternative for the conventional insulation panels in the walls from the insulation view.

While from the building view, some of these composites ensure minimum mechanical strength and low thermal conductivity. Although, their production has lower energy consumption and CO_2 equivalent than plain concrete. Therefore, They can be used as blocks in the walls as an environment-friendly alternative to the plain concrete. Furthermore, they are also an environment-friendly alternative to plain concrete in the use phase since they have a lower thermal conductivity which ensures energy saving for the building in heating or cooling as shown in section 2.1.

10.8 Limitation of the research

In this section, it will be discussed some limitations of this research which affect the results.

10.8.1 Lack of properties data in the previous research

The functional unit is the insulation of 1 m^2 area which ensures R-value equal 1. The comparison will be based the difference between the materials to insulate 1 m^2 area. There are several research papers in the databases in the field of this research. The research papers present experiments of new composites with low thermal conductivity. The main challenge was the gap of data for some properties of these experimental composites. It is necessary to have the density to calculate the weight of the compared material. First, it was calculated the thickness which achieves desired R-value by thermal resistance and R – values formula. Then calculate the volume and multiply it by the density to calculate the weight of the material. Finally, conduct the LCA by Simapro based on the composite components, data, and calculated weight. The chosen composites were AIC retrieved from (Gao et al., 2014) and MKP – FA. These composites were chosen because the properties data include density, thermal conductivity, mix and mechanical strength were available from their research papers. There were several research papers of different composites such as (Fickler et al., 2015). But they didn't include a study of density which is required for this research. Therefore, they aren't included in this research.

10.8.2 Lack of environmental impact data from the producer

The environmental impact data of the components of composites are retrieved from the databases in Simapro, technician data from producers or the environment product declaration (EPD) of these materials. The EPD is published from producers and follow the European standards. The EPD is reliable data from the producer and is good value for the research. In fact, it was not possible to get the EPD from all producers. For Aerogel, it was no EPD published by producers. The producers published some data which are used in this research. But they aren't done by the third party as the principles of LCA in ISO standard 140144 (Mark DOWSON, 2011).

One of the producers of aerogel insulation product in Norway replied that: "Will you find EPD for aerogel only?, I think you will struggle, there are two factories in the world that manage to produce aerogel in large enough volume to be commercially viable. Our aerogel, Lumira, comes from Cabot Corporation's factory in Frankfurt. The other is Aspen in the United States. Both keep careful not to tell how they can produce their aerogel.” (appendix B).

The calcined clay isn’t commercially produced. Therefore, there isn’t data of energy analysis of the calcined clay. The available data is only the CO_2 emissions of the ton calcined clay. There was no available data of KH_2PO_4 in Simapro or EPDs. It was contacted several producers of KH_2PO_4. Therefore, the molar mass formula is used to estimate the environmental impact of MKP based on materials in Simapro databases (appendix C Excel calculations).

10.8.3 Different views of allocation

There are different views of the allocation of the environmental impact of some components of the composites. The research in this paper follows the default view of the allocation of these materials. While the increase of the production of these materials to meet the demand caused by the commercial production of the new composites can change the view of the allocation to include the environmental impact.

The European silica fume producers allocate all greenhouse gas emissions to the main product silicon and ferrosilicon since the entire Si / FeSi include co-products are covered by EU carbon leakage list. The silica fume is co-product of silicon production and has lower economic value. In the other hand, the silica fume as a commercial product can be considered environmentally based on the distribution of economic value. In this paper, the allocation of emissions and energy consumption follow the allocation rules in EU. By increasing of the demand of Silica fume to cover the need of the commercial production of these composites, the allocation of the environmental impact of silica fume can be changed as discussed in the section (silica fume).

Another case is the Fly Ash; there are two views of the environmental impact of fly ash; first, the fly ash as a waste product which needs to be treated and in this case no need for the environmental impact data. The second, the Fly ash as co-products from power production. In this case, the environmental impact will be distributed based on the economic value. If the consumption of fly ash becomes too high. the environmental impact of Fly Ash will be distributed based on the economic value

10.9 Incorporating of materials into building composite materials

In this section, it will be discussed the incorporating of inorganic materials or additive into the composite building material. This discussion aims to draw conclusions of the environmental impact of incorporating of these materials into the building composite materials. The studied incorporated materials are MKP, Calcined clay, aerogel, silica fume, Fly ash and Portland cement.

10.9.1 Incorporating of MKP

The mass of MgO and KH_2PO_4 in the MKP - FA – Aerogel composite is defined as cement mass in the concrete preparation. The main advantages of using MKP as an alternative to cement is the low thermal conductivity. The low thermal conductivity will reduce the need for insulation in the building. The need for insulation in the building cause energy consumption of the climate condition regulation systems and building operation of insulation panels. The energy consumption and building operations release a lot of negative environmental impact as emissions or waste. The MKP will reduce this environmental impact. Consequently, improving the sustainable performance of the buildings. Figure 71 shows the comparison of the environmental impact of the mass of (MgO and KH_2PO_4) and Portland cement based on data from databases in Simapro. The production of MKP components has a lower environmental impact than cement. This low environmental impact of MKP production is an additional advantage to the main advantage as ow thermal conductivity.

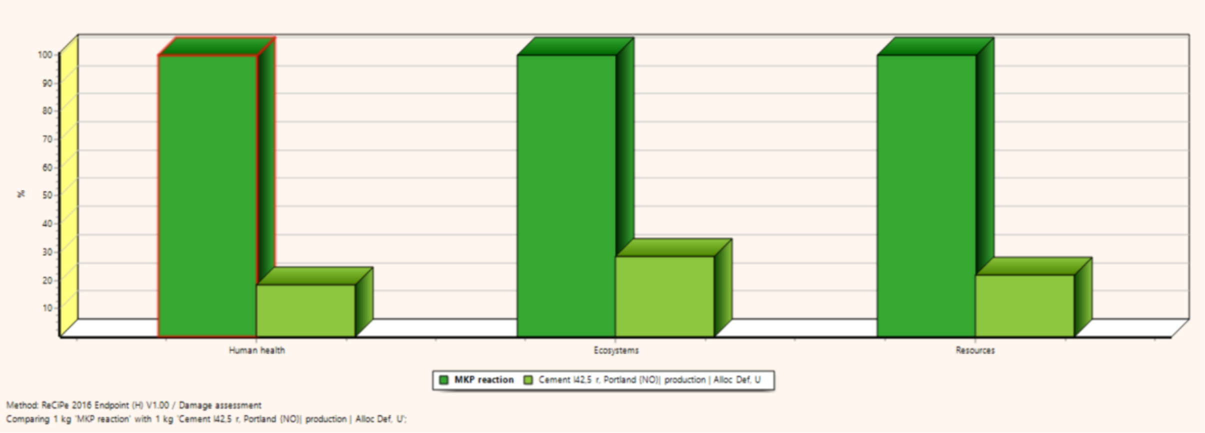


Figure 74 Comparison of MKP & cement

10.9.2 Incorporating of Calcined clay

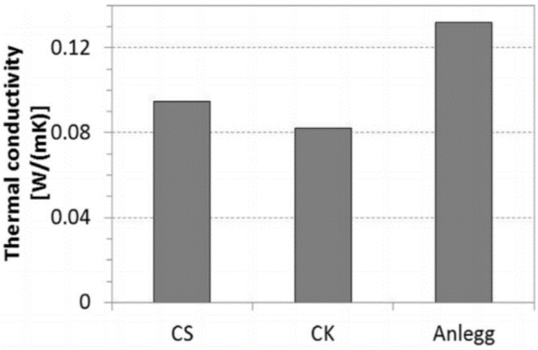
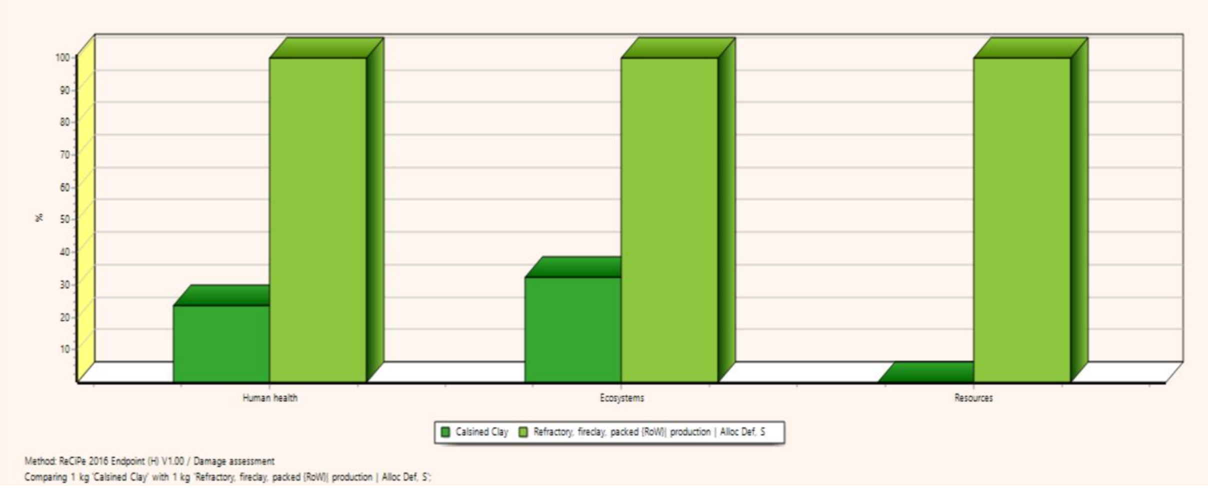


Figure 75 thermal conductivity of the CS, CK &Anlegg cement. Retrieved from(Ng et al., 2016)

The partial replacement of Portland cement with calcined clay decrease thermal conductivity of the AIM. The main reason for this decreasing of thermal conductivity is that the calcined clay has lower thermal conductivity than anlegg cement (Ng et al., 2016). Figure 72 shows the thermal conductivity of the used two types calcined clay and the cement.

The main advantages of replacement of Portland cement by calcined clay as an alternative to cement are the low thermal conductivity. The low thermal conductivity will reduce the need for insulation in the building. The need for insulation in the building cause energy consumption of the climate condition regulation systems and building's operations. The energy consumption and building operations release a lot of negative environmental impact as emissions or waste.

Figure 73 shows the difference in environmental impact between the calcined clay from the databases in Simapro and the calcined clay from the producer. The data from the producer isn't absolute because they don't produce the calcined clay as commercial product yet. The available data from producer include just CO_2 emissions. The producer plans to reduce the CO_2 to zero.



Method: ReCiPe 2016 Endpoint (H) V1.00 / Damage assessment
Comparing 1 kg 'Calsined Clay' with 1 kg 'Refractory, fireclay, packed {RoW}| production | Alloc Def, S';

Figure 76 Comparison between cement and MKP

The figure 35 present the comparison of the CO_2 equivalent of the used calcined clay in this research and the used cement in this research. The figure 74 shows the calcined clay has the lower CO_2 equivalent comparing with Portland cement. That explains why the partial replacement of Portland cement by calcined clay will decrease the CO_2 equivalent of the AIM composites.

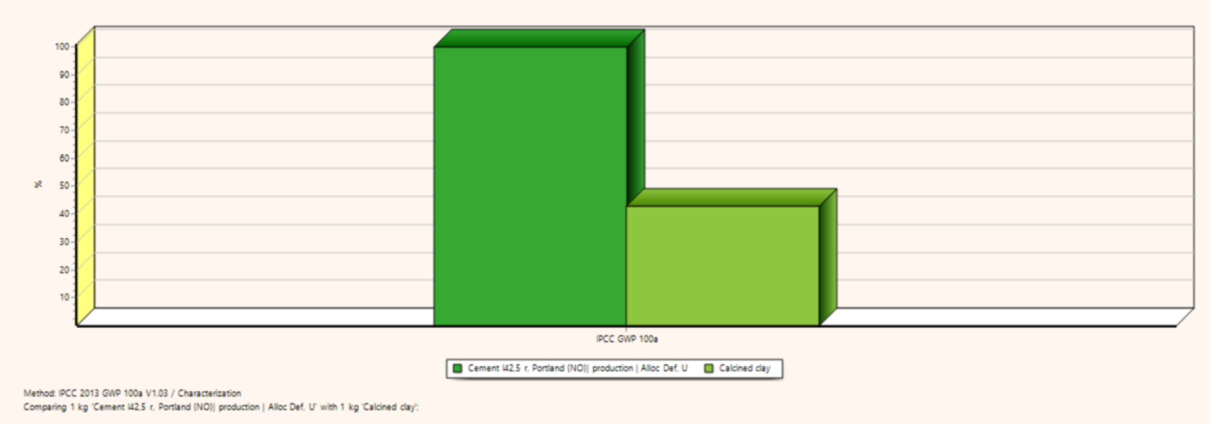


Figure 77 LCA calcined clay & cement

10.9.3 Aerogel Incorporating

The aerogel has low thermal conductivity around 0.015 $W.m^{-1}.K^{-1}$ (Pierre and Rigacci, 2011). Because of that, it is defined as a very good insulator, but the lack of the mechanical strength makes a big challenge to use it as an alternative to the insulation panels (Prassas, 2011). Incorporating aerogel to the building materials will make a composite with low thermal conductivity and mechanical strength as well good. These alternative composites can be used to replace the insulation panels. The aerogel concrete composites with amount aerogel over 60 % show very low thermal conductivity as well as low mechanical strength (Gao et al., 2014, Ng et al., 2016, Fickler et al., 2015, Júlio et al., 2016). Based on that, these composites can substitute the traditional insulation panels in the walls.

Aerogel production technology is a challenge for this research. Because the production of Aerogel has a high environmental impact. In this section, it will be a focus on this challenge. The aerogel is still produced in batch-wise in the most companies. The progress from batch-wise to the continuous wise will bring a significant advantage regarding the economic and environmental effects of the production (Smirnova and Gurikov, 2018).

The main challenge from the sustainable view is to use the studied composites in this paper commercially as an alternative to traditional insulation panels is the huge environmental impact of these composites. The aerogel based on the available data from producers has responsibly high emissions and energy consumption compared with traditional insulation materials based on previous research (Mark DOWSON, 2011). Figure 36 & 37 presents the comparison between the aerogel, organic insulation material as EPS and inorganic insulation materials as glass wool and rock wool. The production of EPS has the highest energy consumption and CO_2 equivalent compared with others. The figures that the production of Aerogel Aspen which is used in this study has high energy consumption and CO_2 equivalent. While the Aerogel Cabot has lower energy consumption and CO_2 equivalent compared with Aspen. The data of Cabot is new updated compared Aspen because of the Cabot data is retrieved from the Cabot sustainability report 2017. Therefore, it is shown that there is progress in the technology of Aerogel production.

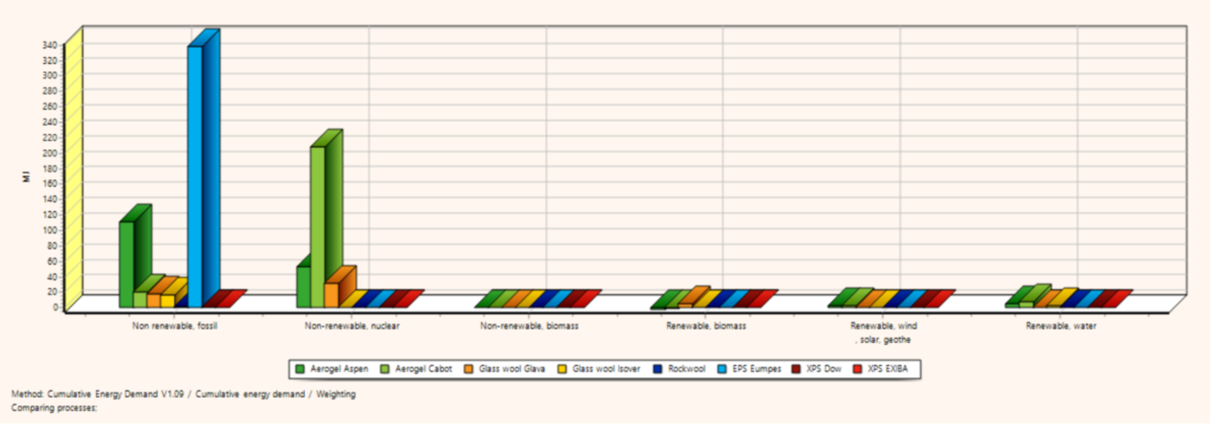


Figure 78 comparison between aerogel and insulation materials. Energy

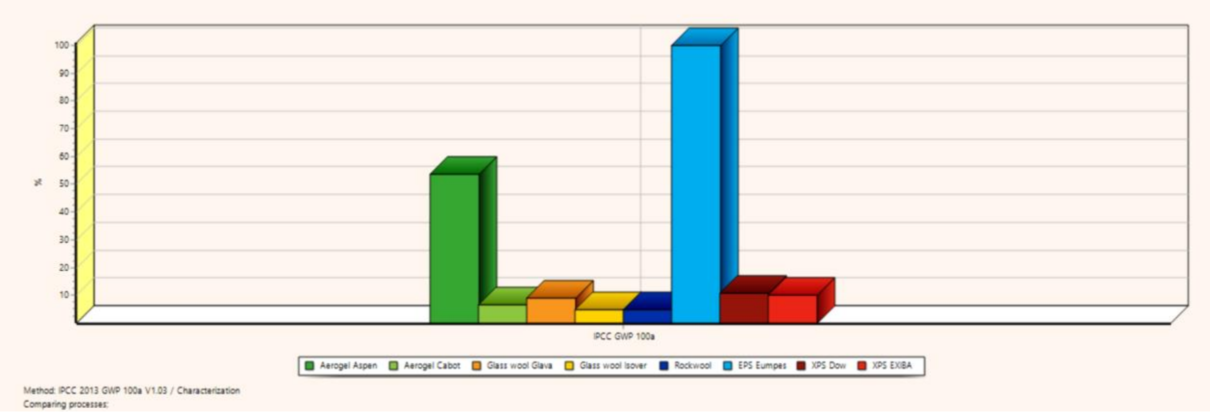


Figure 79 comparison between aerogel and insulation materials. CO_2 equivalent

In this case, the composites with aerogel contents 60 % or more will not be comparable with conventional insulation materials. The progress in developing environmental friendly production of aerogel is critical for commercial using of these composites as alternatives to insulation walls.

According to Svenska Aerogel: "*No negative environmental impact. In production, large amounts of water are used. The production of wastewater has a somewhat higher salinity. The waste water is circulated and reused in further production*" (Aerogel, 2018). Svenska Aerogel is another producer of Aerogel assumes that there are no emissions of there Aerogel production and the main waste is water which will be recycled (Aerogel, 2018). By utilizing these data in the LCA affect the LCA of these composites. The Aerogel won't have any emissions.

The sustainability report of Cabot Aerogel presents the energy intensity and emissions intensity of their production. The data from the Cabot isn't a big difference from the data from Aspen which are mainly used in the LCA. The data are 63,9 MJ/ kg aerogel, 0,17 kg CO_2 / Kg aerogel, 0,0208 kg SO_2 / Kg aerogel and 0,075 Kg Nitrogen oxides / Kg aerogel (Corporation, 2016).

Aspen is a producer of aerogel. Aspen claims that its production energy is 53.9 MJ/kg and its CO2 burden is 4.3 kgCO2/kg (Dowson et al., 2012).

Figure 77 shows the difference in the CO_2 equivalent of production between three producers based on available data from producers.

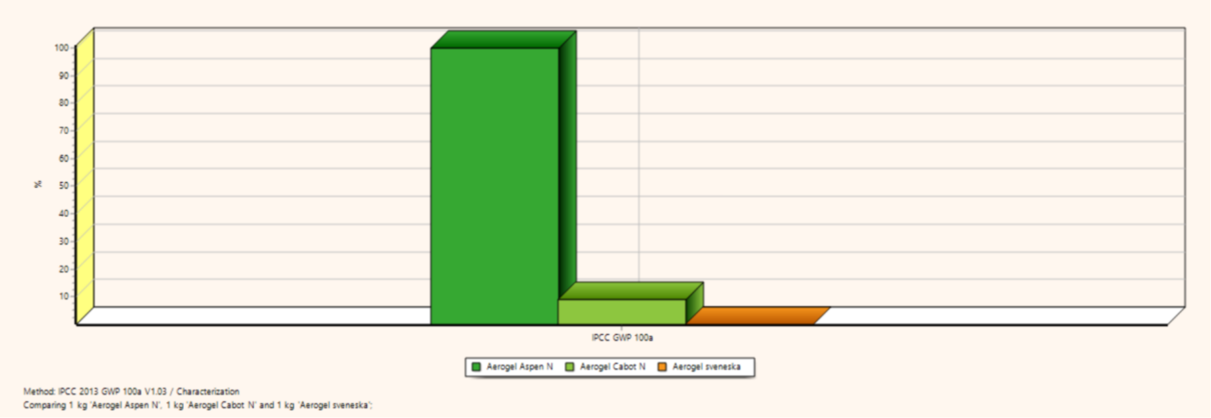
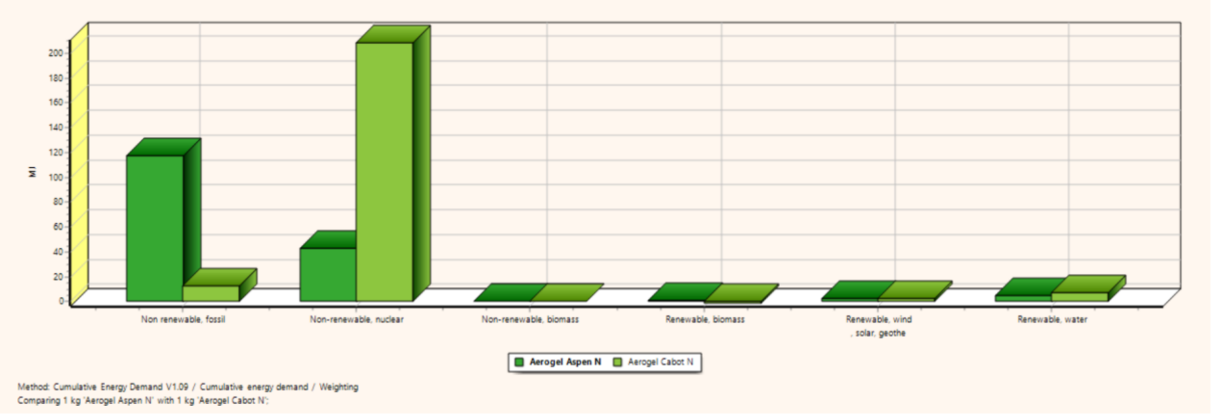


Figure 80 CO2 emissions of Aerogel production based on data from producers

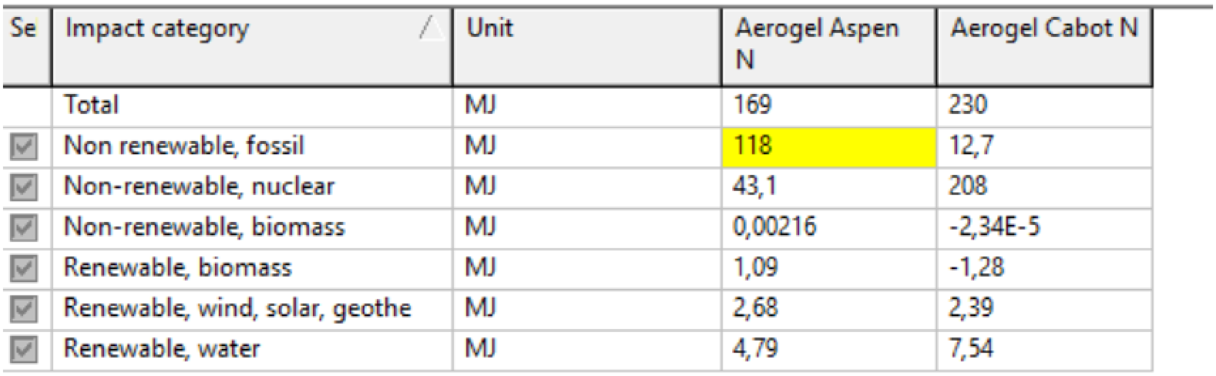
Figure 77 shows the difference in energy consumption of Aerogel production between two producers based on available data from producers.



Method: Cumulative Energy Demand V1.09 / Cumulative energy demand / Weighting
Comparing 1 kg 'Aerogel Aspen N' with 1 kg 'Aerogel Cabot N';

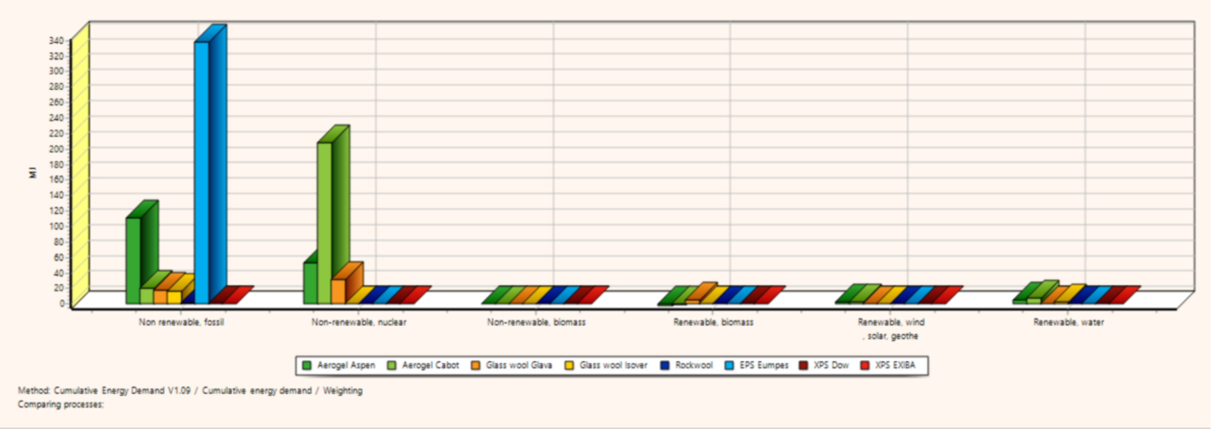
Figure 81 comparison between the Aspen & Cabot

Tabell 63 comparison between the Aspen & Cabot



Se	Impact category	Unit	Aerogel Aspen N	Aerogel Cabot N
	Total	MJ	169	230
☑	Non renewable, fossil	MJ	118	12,7
☑	Non-renewable, nuclear	MJ	43,1	208
☑	Non-renewable, biomass	MJ	0,00216	-2,34E-5
☑	Renewable, biomass	MJ	1,09	-1,28
☑	Renewable, wind, solar, geothe	MJ	2,68	2,39
☑	Renewable, water	MJ	4,79	7,54

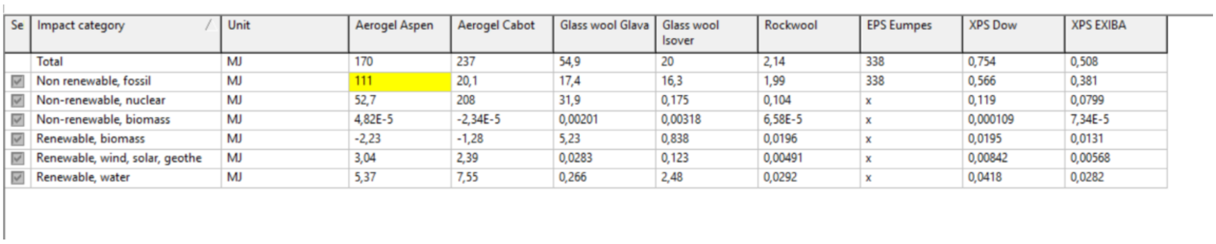
The figure 79 and Table 67 present the comparison of aerogel and some conventional insulation materials. The figure 79 shows that aerogel has a high environmental impact compared conventional insulation materials retrieved from EPD for production of each 1 kg of the insulation material. The EPS have responsible highest energy consumption compared with other insulation materials.



Method: Cumulative Energy Demand V1.09 / Cumulative energy demand / Weighting
Comparing processes;

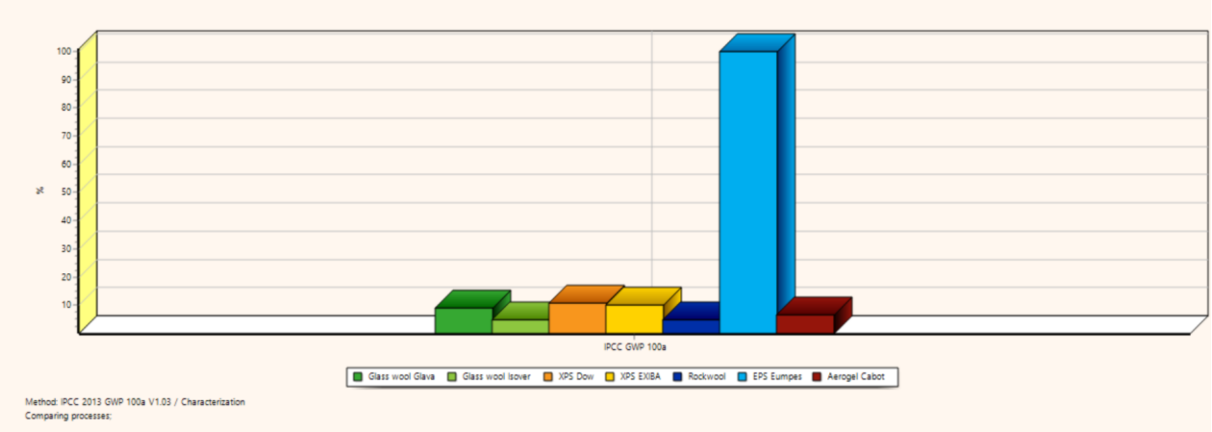
Figure 82 Comparison of aerogel and conventional insulation materials

Table 64 Comparison of aerogel and conventional insulation materials



Se	Impact category	Unit	Aerogel Aspen	Aerogel Cabot	Glass wool Glava	Glass wool Isover	Rockwool	EPS Eumpes	XPS Dow	XPS EXIBA
	Total	MJ	170	237	54,9	20	2,14	338	0,754	0,508
☑	Non renewable, fossil	MJ	111	20,1	17,4	16,3	1,99	338	0,566	0,381
☑	Non-renewable, nuclear	MJ	52,7	208	31,9	0,175	0,104	x	0,119	0,0799
☑	Non-renewable, biomass	MJ	4,82E-5	-2,34E-5	0,00201	0,00318	6,58E-5	x	0,000109	7,34E-5
☑	Renewable, biomass	MJ	-2,23	-1,28	5,23	0,838	0,0196	x	0,0195	0,0131
☑	Renewable, wind, solar, geothe	MJ	3,04	2,39	0,0283	0,123	0,00491	x	0,00842	0,00568
☑	Renewable, water	MJ	5,37	7,55	0,266	2,48	0,0292	x	0,0418	0,0282

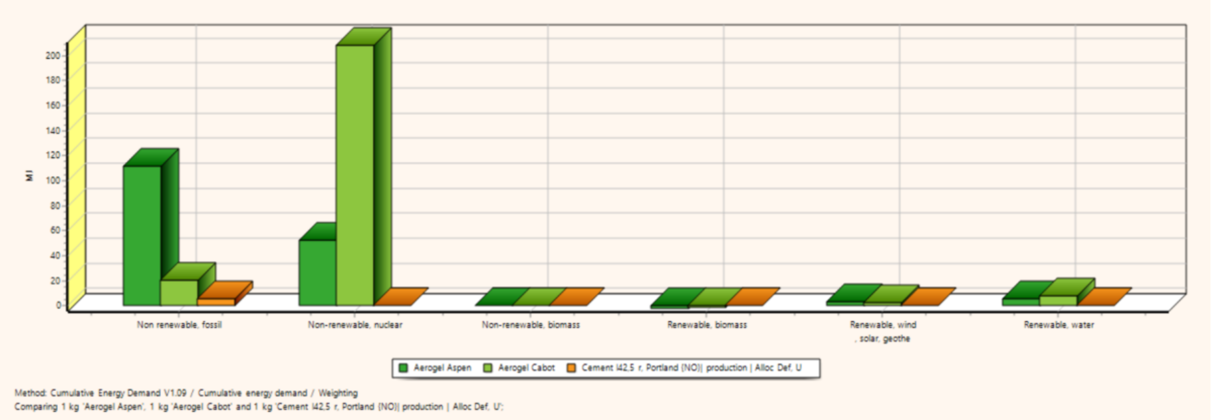
The figure 80 present the CO_2 equivalent between aerogel and some conventional insulation materials.



Method: IPCC 2013 GWP 100a V1.03 / Characterization
Comparing processes;

Figure 83 comparison of aerogel and conventional insulation materials

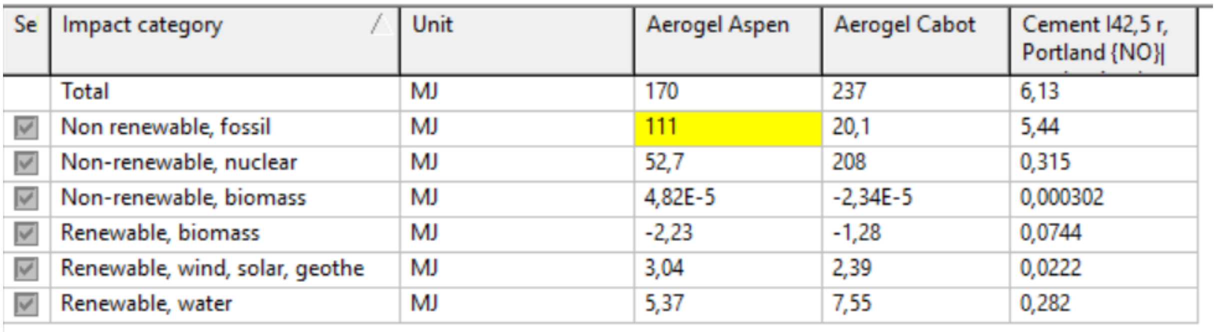
Figure 81 presents the comparison of the environmental impact of the aerogel from Aspen and Cabot in this research and the used cement in this research. The figure 81 and table 68 show Portland cement has the lowest environmental impact compared with used Portland cement in this research and aerogel.



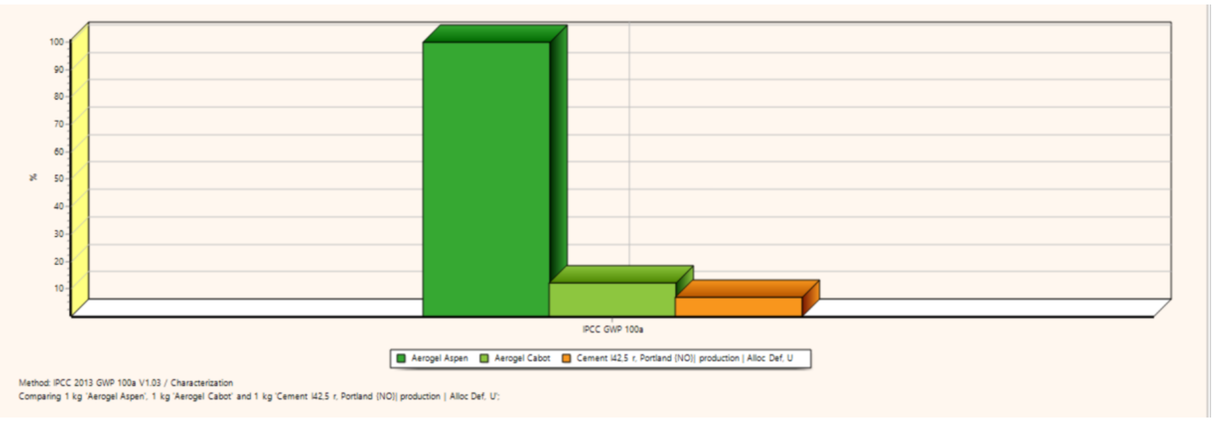
Method: Cumulative Energy Demand V1.09 / Cumulative energy demand / Weighting
Comparing 1 kg 'Aerogel Aspen', 1 kg 'Aerogel Cabot' and 1 kg 'Cement I42,5 r, Portland {NO}| production | Alloc Def, U';

Figure 84 Comparison of aerogel and cement

Table 65 Comparison of aerogel and cement



Se	Impact category	Unit	Aerogel Aspen	Aerogel Cabot	Cement I42,5 r, Portland {NO}|
	Total	MJ	170	237	6,13
☑	Non renewable, fossil	MJ	111	20,1	5,44
☑	Non-renewable, nuclear	MJ	52,7	208	0,315
☑	Non-renewable, biomass	MJ	4,82E-5	-2,34E-5	0,000302
☑	Renewable, biomass	MJ	-2,23	-1,28	0,0744
☑	Renewable, wind, solar, geothe	MJ	3,04	2,39	0,0222
☑	Renewable, water	MJ	5,37	7,55	0,282



Method: IPCC 2013 GWP 100a V1.03 / Characterization
Comparing 1 kg 'Aerogel Aspen', 1 kg 'Aerogel Cabot' and 1 kg 'Cement I42,5 r, Portland {NO}| production | Alloc Def, U';

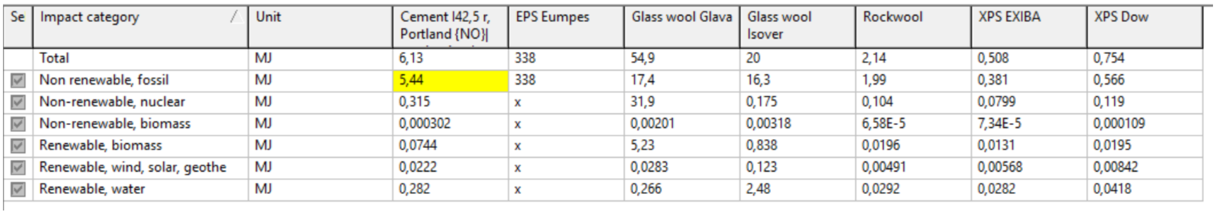
Figure 85 Comparison of aerogel and cement

Figure 82 presents the comparison of the CO_2 equivalent of the aerogel from Aspen and Cabot in this research and the used cement in this research. The figure 82 show Portland cement has the lowest environmental impact compared with used aerogel used in this research. That explains why the partial replacement of Portland cement by aerogel will decrease the environmental impact of the Aerogel – concrete. Also, the replacement of cement by aerogel will reduce the need for large amounts of cements in the aggregates as shown in the material chapter.

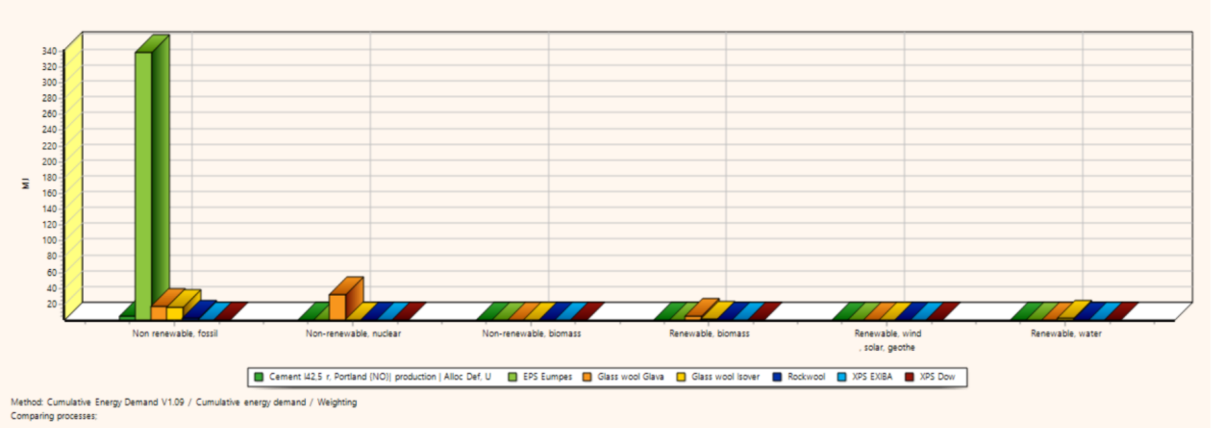
10.9.4 Incorporating of Portland cement

The Portland cement has a lower environmental impact compared with conventional insulation materials. Figure 83 shows the comparison between Portland cement, EPS, and conventional insulation materials. The Portland cement has the lowest energy consumption and CO_2 equivalent. While the EPS has the highest energy consumption and CO_2 equivalent. Although, it has a lower environmental impact than the most conventional insulation material. Because of that the incorporating of Portland cement in the composite building material will reduce the environmental impact

Tabell 66 comparison of cement and conventional insulation materials



Se	Impact category	Unit	Cement I42,5 r, Portland {NO}|	EPS Eumpes	Glass wool Glava	Glass wool Isover	Rockwool	XPS EXIBA	XPS Dow
	Total	MJ	6,13	338	54,9	20	2,14	0,508	0,754
☑	Non renewable, fossil	MJ	5,44	338	17,4	16,3	1,99	0,381	0,566
☑	Non-renewable, nuclear	MJ	0,315	x	31,9	0,175	0,104	0,0799	0,119
☑	Non-renewable, biomass	MJ	0,000302	x	0,00201	0,00318	6,58E-5	7,34E-5	0,000109
☑	Renewable, biomass	MJ	0,0744	x	5,23	0,838	0,0196	0,0131	0,0195
☑	Renewable, wind, solar, geothe	MJ	0,0222	x	0,0283	0,123	0,00491	0,00568	0,00842
☑	Renewable, water	MJ	0,282	x	0,266	2,48	0,0292	0,0282	0,0418



Method: Cumulative Energy Demand V1.09 / Cumulative energy demand / Weighting
Comparing processes;

Figure 86 Comparison of cement and conventional insulation materials

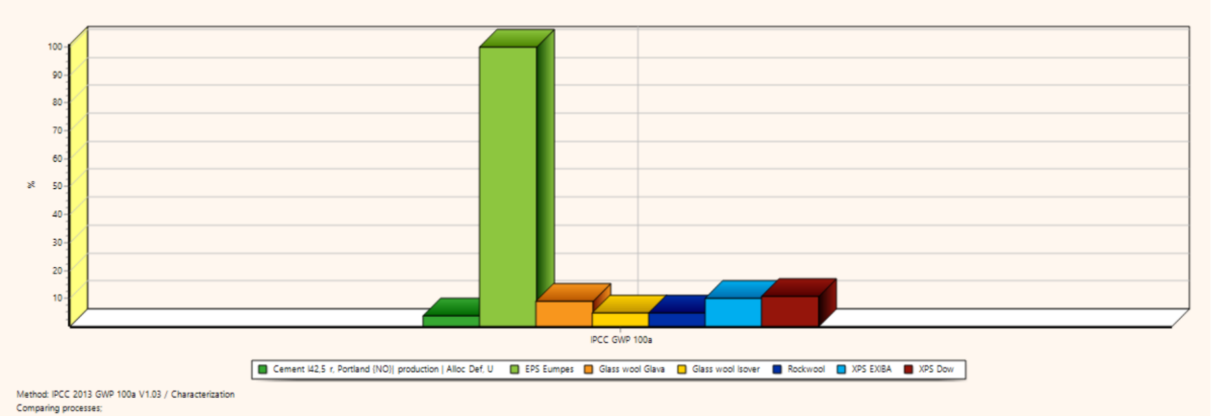
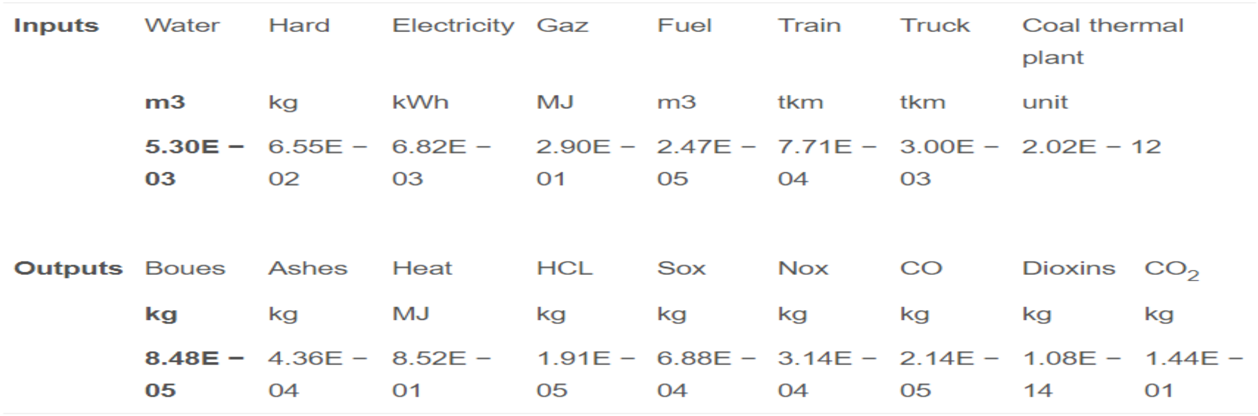


Figure 87 Comparison of Portland cement, aerogel and organic insulation material (EPS)

10.9.5 Fly Ash – incorporating

There are two views of the environmental impact of fly ash; first, the fly ash as a waste product which needs to be treated and in this case no need for the environmental impact data. The second, the Fly ash as co-products from power production. In this case, the environmental impact will be distributed based on the economic value. Table 70 shows the input and output from the Fly Ash when the environmental impact of fly ash is distributed based on the economic value. Figure 85 shows the comparison between the fly ash as waste product & Fly ash where the environmental impact is distributed based on the economic value.

Tabell 67 environmental impact of fly ash is distributed based on the economic value



Inputs	Water	Hard	Electricity	Gaz	Fuel	Train	Truck	Coal thermal plant	
	m3	kg	kWh	MJ	m3	tkm	tkm	unit	
	5.30E − 03	6.55E − 02	6.82E − 03	2.90E − 01	2.47E − 05	7.71E − 04	3.00E − 03	2.02E − 12	
Outputs	Boues	Ashes	Heat	HCL	Sox	Nox	CO	Dioxins	CO_2
	kg	kg	MJ	kg	kg	kg	kg	kg	kg
	8.48E − 05	4.36E − 04	8.52E − 01	1.91E − 05	6.88E − 04	3.14E − 04	2.14E − 05	1.08E − 14	1.44E − 01

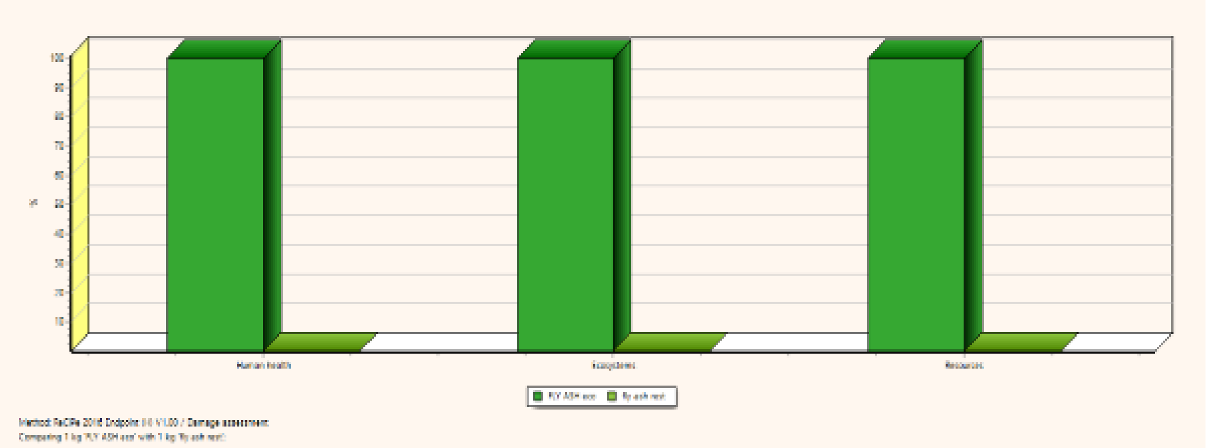


Figure 88 environmental impact of fly ash in the two views

If the consumption of fly ash becomes too high that it becomes necessary to produce it for replacement of Portland cement, then its sustainability advantages are lost, because then the impacts of the production of fly ash become higher than Portland cement. Figure 48 shows the comparison between the environmental impacts of fly ash (based on the economic value) & Portland cement. Consequently, the incorporating of fly ash as a waste in the building composite materials will reduce the environmental impact of these composite. While the incorporating of fly ash with economic view in the building composite materials will increase the environmental impact of these composite.

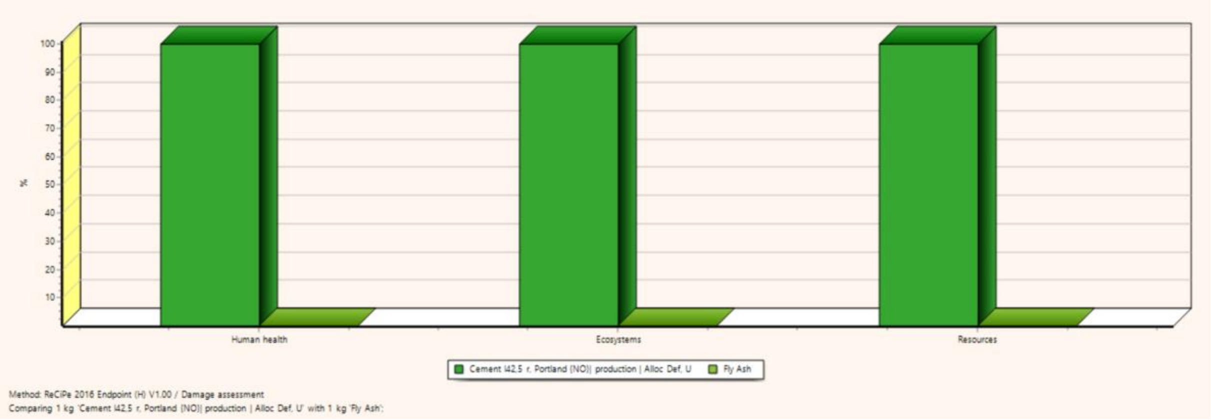
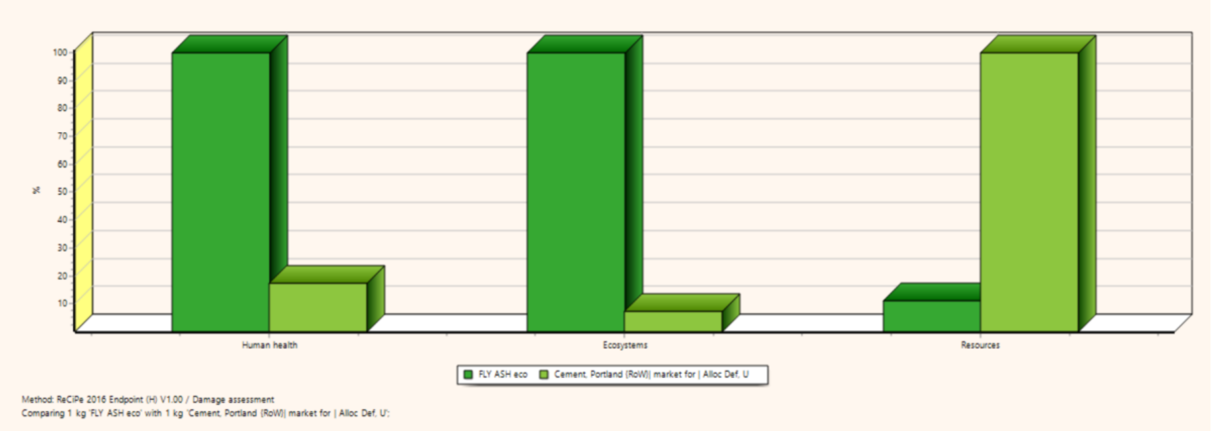


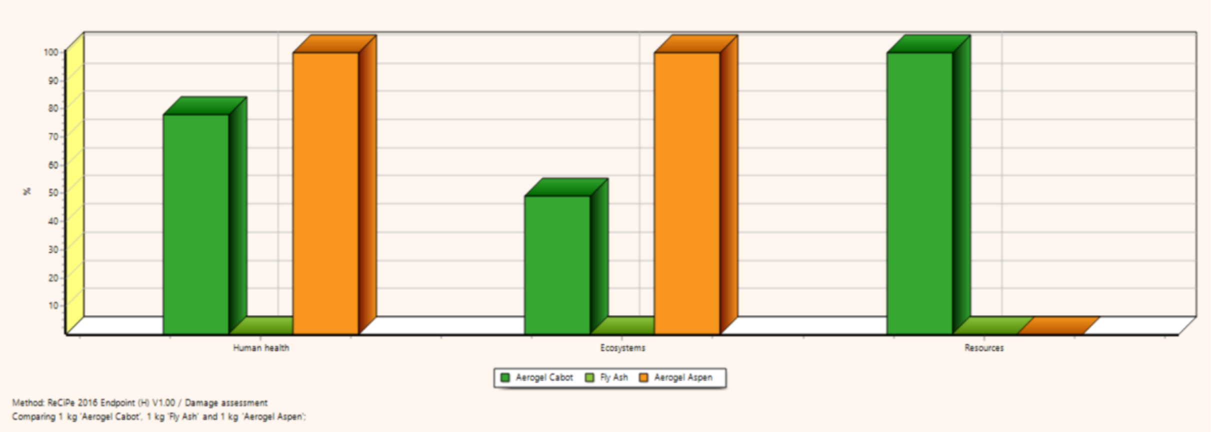
Figure 89 Comparison between the Fly Ash & Portland cement



Method: ReCiPe 2016 Endpoint (H) V1.00 / Damage assessment
Comparing 1 kg 'FLY ASH eco' with 1 kg 'Cement, Portland {RoW}| market for | Alloc Def, U';

Figure 90 Comparison between the Fly Ash & Portland cement

From an environmental view, the incorporating of fly ash as waste into building composite materials is better than incorporating of aerogel, because the aerogel has high environmental impact. While the fly ash as waste has no environmental impact (figure 88).



Method: ReCiPe 2016 Endpoint (H) V1.00 / Damage assessment
Comparing 1 kg 'Aerogel Cabot', 1 kg 'Fly Ash' and 1 kg 'Aerogel Aspen';

Figure 91 aerogel & fly ash

Although, the incorporating of fly ash based on economic value into building composite materials is better than incorporating of aerogel because the aerogel has higher environmental impact than fly ash (Economic value). The figure 89 present the environmental impact of aerogel from Cabot, aerogel from Aspen and fly ash eco.

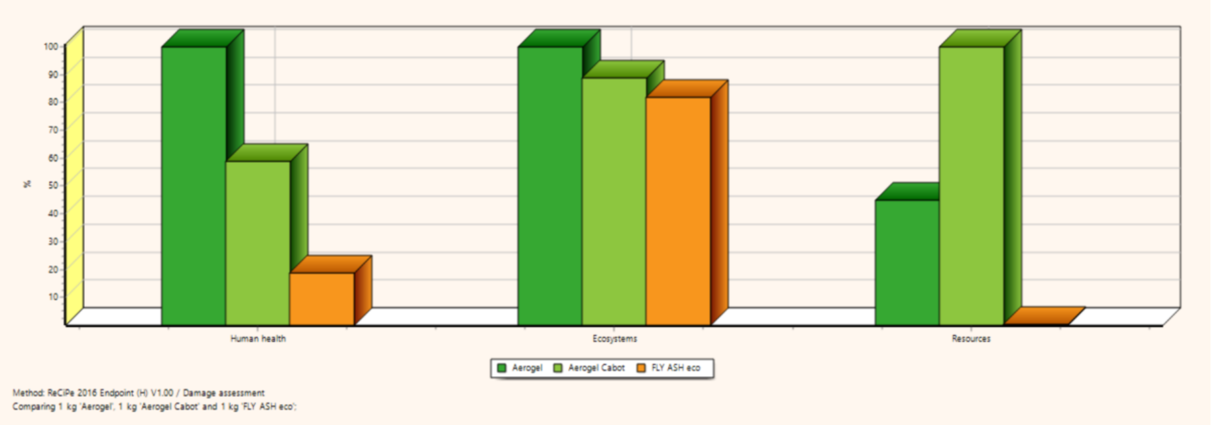
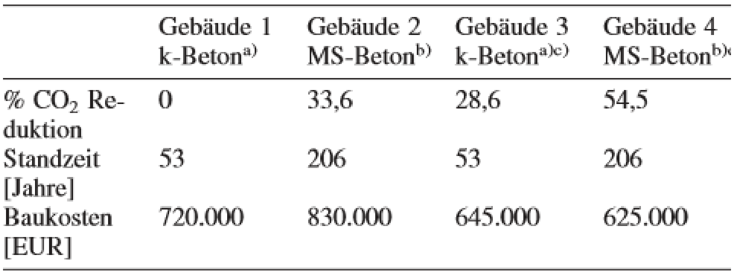


Figure 92 aerogel & fly ash eco

10.9.6 Incorporating of Silica Fume

Silica fume is a by-product of silicon and ferrosilicon production. The silica fume has special chemical and physical properties. The incorporating of silica fume into the concrete ensure higher compressive strength, chemical resistance, and erosion resistance. This allows for a lighter construction and increases the life of the structure. CO2 emissions are reduced up to 50% by using micro silica – content in concrete compared to conventional construction. The Concrete constructions cause 5-10% of global CO2 emissions.



	Gebäude 1 k-Beton$^{a)}$	Gebäude 2 MS-Beton$^{b)}$	Gebäude 3 k-Beton$^{a)c)}$	Gebäude 4 MS-Beton$^{b)}$
% CO_2 Reduktion	0	33,6	28,6	54,5
Standzeit [Jahre]	53	206	53	206
Baukosten [EUR]	720.000	830.000	645.000	625.000

Figure 93 reduction of CO_2 emissions by incorporating silica fume

The environmental impact of silica fume does not need to be included because the silica fume is a by-product of the industrial silicon and ferroalloy production. The European silica fume producers allocate all greenhouse gas emissions to the main product silicon and ferrosilicon.

The allocation of emissions from the production of Silica fume will affect the result. As shown in the LCI, The European silica fume producers allocate all greenhouse gas emissions to the main product silicon and ferrosilicon since the entire Si / FeSi include by-products are covered by EU carbon leakage list. The silica fume is co-product of silicon production and has lower economic value. In the other hand, the silica fume as a commercial product can be considered environmentally based on the distribution of economic value. In this paper, the allocation of emissions and energy consumption follow the allocation rules in EU. Figure 91 shows the comparison of the two views of silicon fume based on databases in Simapro.

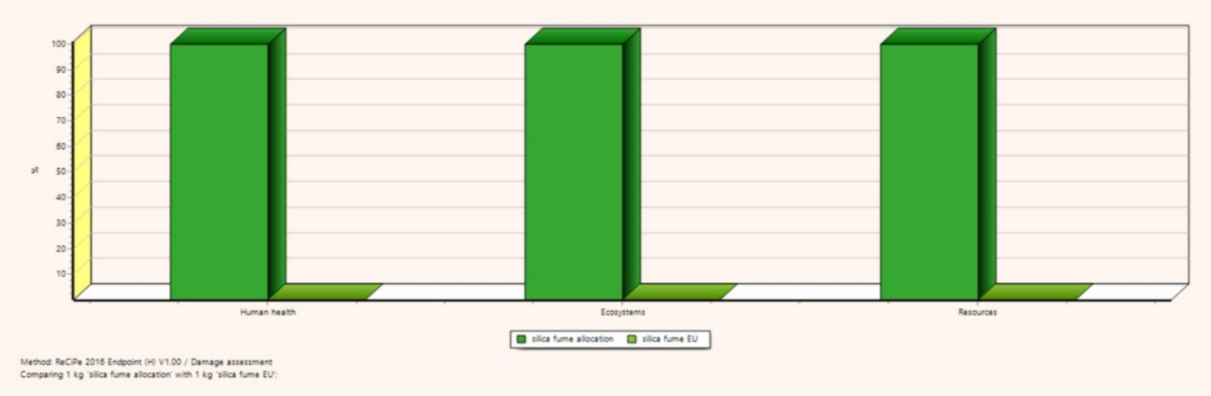


Figure 94 Comparison of the two-different view of silicon fume

10.10 Sustainable performance

The research in this paper focuses on the environmental impact of the new composites. This research will be the basis for environmental product declaration (EPD) of these new composites as commercial products. This research will contribute to the research about the sustainable performance of these new composites. The sustainability is based on three basic dimensions or views economic, social and environmental. The environmental view considers the reduction of the negative environmental impact which affects the possibility of this current generation to meet their needs without compromising the possibility of the next generations to meet their needs (Brundtland, 1987). The LCA is an approach to define these negative environmental impacts from a product, process or a system. Further research to determine the sustainable performance of these new composite is to research in the economic and social views of the new composites. The economic view of sustainability includes studying the economic performance (Ann Brockett, 2012) of the new composites and the commercial production. The social view includes the social responsibility (Ann Brockett, 2012) of the new composites as commercial products.

11 Conclusion

In this thesis, further research is done to study the new building composite materials with low thermal conductivity developed in NTNU & Sintef. The production of some new insulation composite materials has been studied to conduct the environmental impact of the production of these materials. The main aim was to conduct a LCA of these new composites compared to traditional insulation materials. Because of the lack of data from several components of these composites such as Aerogel and calcined clay, it wasn't possible to do an LCA consist with LCA standards. Therefore, the aim is changed to do an energy and greenhouse climate analysis based on the available data in EPDs and Simapro. While for the components where there is no available LCA data, the claimed energy and CO_2 equivalent from the producers were used. The production of some new insulation composite materials has been studied to estimate the CO_2 equivalent and energy consumption of the production of these materials. The analysis considers the functional unit as "the insulation for 1 m^2 area with a thickness ensure R-value R = 1 m2 K/ W.". The FU equant mass was calculated by excel based on the formula from previous research F.U = R.λ.p.A (Kg). It has been used two single issue methods conduct the energy consumption (IPCC 2013) and CO2 emissions (Cumulative Energy Demand (CED)) of the compared materials. The results show that the new composites have high energy consumption and CO_2 equivalent compared with conventional insulation materials concerning the functional unit. The main reason for that is at the high density and high thermal conductivity of most of them compared to the traditional insulation materials. While they have low thermal conductivity and low density compared to plain concrete samples in the research. These materials also don't meet requirements of compressive strength of concrete. Therefore, they can't be used in the building basis, but they can be used in the walls as blocks instead of installation of thermal insulation panels. The research considered the composites from AIC and AIM with 60 % aerogel content as multifunctional building materials which combine the low thermal conductivity and applicable strength to walls.

Even if the thesis couldn't make life cycle assessment (LCA) of these new composites because of the lack of the reliable data of the environmental impact of these composites. The thesis presents the energy consumption and CO_2 equivalent of production of these composites. Then compare them with the energy consumption and CO_2 equivalent of production of the traditional insulation materials. By this comparing, it was possible to get a partial knowledge if these new composites are more environment - friendly solution to use in the thermal insulation in the walls than the traditional insulation panels. These materials have high energy consumption and CO_2 equivalent than the traditional insulation materials.

This thesis will cover the gap in the research of the environmental impact of these composite materials. It wasn’t done any research about comparing the Aerogel – composites with the traditional insulation materials before. The study considered the composites: Aerogel incorporated concrete (AIC), calcined clay – aerogel incorporated mortars (AIM) and The Magnesium potassium phosphate ceramic incorporated with Fly Ash and Aerogel (MKP – FA - Aerogel).

This thesis has also made some conclusions which can be generalized to other composites. First, the aerogel reduces the energy consumption and CO_2 of the production of Aerogel concrete aggregates because it reduces the density of the aggregate which reduces the amount of cement in the aggregate. Second, the replacement of cement by calcined clay will reduce the CO_2 equivalent since the calcined clay low CO_2 equivalent compared with cement. Then, the Silica fume has no environmental impact as co-product to the ferrosilicon. Therefore, Silica fume reduces the environmental impact of concrete aggregates. The production of MKP has a higher environmental impact than the production of Portland cement. Therefore, the use of MKP as cement mass in the aggregates will increase the environmental impact of the aggregates. But it can reduce the environmental impact of the aggregate in the use phase by as energy saving based on their improved properties as strength and thermal conductivity. Finally, the fly ash will reduce the environmental impact of the aggregates since it defines as waste with no environmental impact.

11.1 Limitations

The limitations of this research were the lack of data of environmental impact for these composites. The estimated data of environmental impact of these new composites are done based on summarising the environmental impact of the components. The main challenge here was that not all the data of the components were available from producers or even in the databases.

12 Future research

The development of new composite as multifunctional materials combine mechanical strength and low thermal conductivity is a new research area. Research on following areas is recommended for future research.

- Make LCA studies of the component materials which isn't commercially produced as calcined clay and aerogel.
- Development of environment-friendly technology to produce Aerogel. As shown in the discussion, another aerogel producer assumes that is no environmental impact of the aerogel production and recycle the water.
- Utilizing the waste additives (such as FA or clay) in concrete aggregates to improve the mechanical strength.
- The sustainability performance of these composites. Since the LCA conduct the environmental impact analysis, the other views as the economy and society could be studied. For the economic view, life cycle costs analysis (LCCA) of these new composites. It includes studying the economic performance (Ann Brockett, 2012) of the new composites and the commercial production. The social view includes the social responsibility (Ann Brockett, 2012) of the new composites as commercial products. It could be conducted by social life cycle analysis (SLCA). Finally, Sustainable assessment of these composites

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14 Appendix A drafts of scientific papers considered from this research

15 Appendix B Emails

16 Appendix C Excel calculations

17 Appendix D EPDs

This appendix includes all used EPDs and environmental impact reports in this research.

Energy and greenhouse gas assessment of Aerogel incorporated concrete (AIC)

Abstract

The Aerogel incorporated concrete (AIC) is developed as an alternative material to the traditional concrete. AIC is a new composite material with low thermal conductivity. Based on that the AIC will reduce energy consumption of the buildings because of thermal conductivity of the concrete. This paper will present life cycle assessment of the AIC to declare the environment impact of this new composite in production phase. Then compare the environmental impact of AIC with traditional insulation materials which achieve the same thermal insulation. The aim of this LCA is to assess if the AIC is more sustainable solution than traditional insulation materials.

Keywords: thermal insulation, Life cycle assessment, Aerogel incorporated concrete, Aerogel,

1 Introduction

The thermal insulation is very important concept for the building industry. The buildings consume a lot of energy to regulate the inside climate of the building. The thermal insulation will hinder the thermal transfer between the inside and outside climate (1, 2). Consequently, the thermal insulation reduces the energy consumption of the buildings (3). The reduction of energy consumption will reduce the resources consumption and emissions from power generation. Based on that the thermal insulation support the sustainable development approach in building industry. The sustainable development is defined in (our common future report) as *development which meets the needs of the current generation without compromising the need of the next generations* (4). The Sustainable development concept has got more attention today, because of the increasing of risks on the future of this world (4). The building industry is one of the important sectors which consider the sustainable development of their business. The building industry has made huge progress forward to achieve the sustainable development. It has been developed some approaches to make the buildings more sustainable like smart grid, low- emissions housing and zero emissions house. The aim is to reduce the energy consumption and emissions of the buildings.

Thermal insulation is the protection of buildings from thermal loss outwardly. It can be used to hold the temperature inside the building (either cold or hot). It can be used in many countries with different weather. The thermal loss causes when it happens a temperature difference over material or construction; then it becomes a heat transfer between the hot side to the cold side. That main way to the insulation of building is to set a suitably thick layer of material which has low thermal conductivity (3) . That will reduce thermal transfer outward or inward. The building materials were mainly focused in this field because the properties and the specifications of these materials (1) have a high influence on the sustainability performance of buildings. Materials which have low thermal conductivity are more sustainable than materials with high thermal conductivity. The low thermal conductivity will reduce the need for the inside climate regulation (heating or cooling). The energy consumption of inside climate regulation will be reduced (3).

The thermal insulation can be defined as sustainable technology because of this reducing of energy consumption. Although it is possible to improve the sustainable performance of choose an Eco or recycle material, an environment-friendly productions method and secure social workers.

There were previous attempts to develop building materials with low thermal conductivity to reduce the negative environmental impact of the buildings (5). NTNU & Sintef have corporate in research to develop new construction composite materials with low thermal conductivity by incorporating inorganic materials and other additives to the traditional concrete. The main focus was to develop materials which have a low thermal conductivity and meet the mechanical strength requirements of concrete as well (6).

The AIC composite in the NTNU research consist of traditional components of concrete such as water, cement, and sand. Then incorporate the Aerogel in the concrete samples. The contents of aerogel in samples will be increased gradually from 10 % to 60%. After preparing the samples in a standard Hobart 2-litre mixer. The samples will be scanned the structure of particles. Then some tests will be done to measure the density, thermal conductivity, compressive strength and flexural strength of the samples. Finally draw graphs which show the change in the characterization based on the increasing of aerogel content of sample.

Further, the research in this paper focus on using these composite materials as more sustainable alternatives to the traditional insulation materials. The main idea of this research project is to compare the environmental impact between the insulation composite material AIC which are studied in NTNU and Sintef with traditional insulation materials as organic like Polyurethane (EPS) or polystyrene (XPS) or inorganic like mineral wool. The main aim is to find if this new insulation composite has a less environmental impact than the traditional insulation materials which achieve the same thermal insulation. The traditional thermal insulation materials like cellulose, EXPs, polystyrene foam, urethane foam are organic materials which has negative environmental impact during their production phase. In this paper, it will be comparison of the energy and CO_2 equivalent during their production phase of these traditional materials with the new composite AIC.

This paper conduct LCA of AIC to compare it with conventional insulation materials. The LCA will consider only the energy and CO_2 equivalent because of the lack of data for the AIC since it isn’t commercial produced.

2 Literature review

The corresponding literature can be divided into two areas: previous literature focusing of environmental impact of insulation materials, A study of Aerogel and previous literature focusing on research of Aerogel – concrete.

2.1 Literature focusing of environmental impact of insulation materials

There are several LCA studies of insulation materials to determine the environmental impact of the insulation materials. Pargana at university of Lisboa presented a comparative environmental life cycle assessment of thermal insulation materials of buildings (7). The study is based on the LCA ISO standards (8) and compare many types of insulation materials like Expanded cork agglomerate (ICB), Extruded polystyrene (XPS) and Expanded polystyrene (EPS). The study results are preformed in “cradle to gate” (9). Another research is a LCA study of transparent aerogel analyze the environmental impact of aerogel done by Mark DOWSON at the University of Bath. The study shows that aerogel as a good insulation material and has responsibly high emissions and energy consumption of their production than traditional insulation materials (10). Although, Other LCA studies include the inorganic materials. Schiavoni at University of Perugia include the aerogel and stone wool as a good insulation material to their LCA study (11). There are also other researches presents composite materials like chemically bonded phosphate ceramics (12), permafrost cement as a new phosphate based cement for using in very cold countries (13).

2.2 A study of Aerogel

Aerogel is a synthetic porous ultralight material. Aerogels are formed by removing the liquid from a gel under special drying conditions, bypassing the shrinkage and cracking experienced during ambient evaporation. Aerogel was invented as quite revolutionary solid-state materials contents 90 % air. The aerogel have extremely low density and better physical properties (14), especially for many applications of aerogel like thermal insulation, acoustical insulation (15), or transparent to light or solar radiation (16, 17). The material can be produced in monolithic or granular form (10, 15). There are different types of aerogel: silica aerogel, carbon aerogel, and metal oxide aerogel. The aerogel is the most used type of insulation composite materials (15).

Silica aerogels are lightweight and highly porous materials, with a three-dimensional network of silica particles. The silica aerogel produces by extracting the liquid phase of silica gels under supercritical conditions (15, 18). Silica has promising characteristics, such as extremely low thermal conductivity, low density, high porosity and high specific surface area (15, 18, 19). Based on these characteristics, the aerogel has excellent potential application for thermal insulation (6, 20-22). Silica aerogels are known as the best known thermal insulating materials with thermal conductivity around 0.015 $W.m^{-1}.K^{-1}$ at ambient temperature and pressure (23). Additionally, Silica aerogels present further advantages such as good fire, acoustic resistance(15), resistance to moisture, waterproofing and self-cleaning properties, corrosion protection, UV reflection, durability (15, 22, 24).

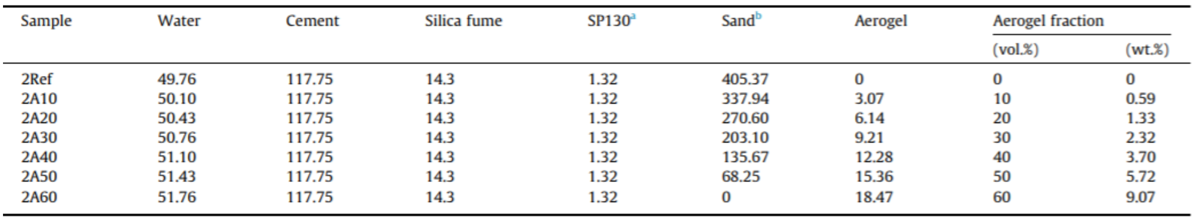
2.3 Literature focusing on research of Aerogel – concrete

There are several studies of incorporating aerogel to concrete to reduce the thermal conductivity. The main aim of this research field is to make a concrete which has low thermal conductivity and meet the mechanical strength requirements (6, 21, 22, 25, 26). Julio at university of Lisboa presented the Silica-based aerogels as aggregates for cement-based thermal renders. the results of the study are that the replacement of silica sand by a subcritical hybrid aerogel synthesized by design lead to successfully produce lightweight and low thermal conductivity cement based renders. incorporate aerogel to Lightweight concrete (22). Fickler at university presented the incorporating of aerogel to high performance concrete mixtures. The results of the study show that Aerogel concrete is optimized Based on concrete formulas of HPC, UHPC and LC. The goal of that study to increase the compressive strength while maintaining good heat insulating properties (25).

3 Material

According to the paper: The AIC consist of traditional concrete components, Aerogel hydrophobic granules. Then a Superplasticizer (Dynamon SP130) which is modified acrylic polymer solution for precast concrete was added during the stirring stage to increase cohesion and homogeneity of the concrete mixture. The mixture is formed in samples (40 mm - 40 mm - 160 mm). the table show the mix proportion of the AIC samples.

Tabell 1 AIC composition



Sample	Water	Cement	Silica fume	SP130[a]	Sand[b]	Aerogel	Aerogel fraction	
							(vol.%)	(wt.%)
2Ref	49.76	117.75	14.3	1.32	405.37	0	0	0
2A10	50.10	117.75	14.3	1.32	337.94	3.07	10	0.59
2A20	50.43	117.75	14.3	1.32	270.60	6.14	20	1.33
2A30	50.76	117.75	14.3	1.32	203.10	9.21	30	2.32
2A40	51.10	117.75	14.3	1.32	135.67	12.28	40	3.70
2A50	51.43	117.75	14.3	1.32	68.25	15.36	50	5.72
2A60	51.76	117.75	14.3	1.32	0	18.47	60	9.07

The graphs show the change in the thermal conductivity and density of AIC samples based on increasing of aerogel content in the composite. The graph 1 show the decreasing of density with increasing of aerogel content. The measured density of 60 % aerogel incorporated aerogel is about 100 kg/m^3 compared to the density sample 1980 kg/m^3 of reference plain concrete. The aerogel is porous ultralight material and has extremely low density (density: 100 kg/m3), therefore replacing normal aggregates (i.e. sand with density of 2600 kg/ m3) in the plain concrete by aerogel particles results in a lightweight concrete.

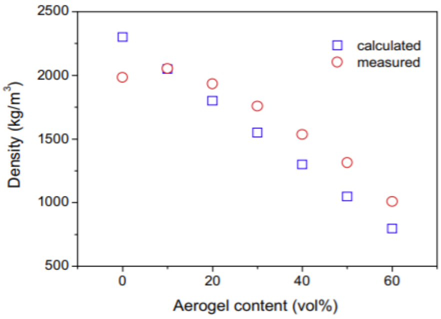


Figure 1 AIC density

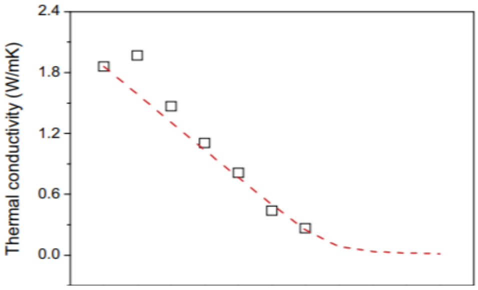


Figure 2 AIC Thermal conductivity

The graphs show the change in the thermal conductivity and density of AIC samples based on increasing of aerogel content in the composite. The graph 1 show the decreasing of thermal conductivity with increasing of aerogel content. The measured thermal conductivity of 60 % aerogel incorporated aerogel is about 0.26 W/mK compared to the density sample 1.86 W/mK of reference plain concrete. The aerogel is has low thermal conductivity of about 0.01–0.02 W/mK, therefore incorporation of aerogel particles to concrete will result in a thermal insulating composite.

4 Method

Life cycle assessment (LCA) is a method to analyze environmental aspects and impacts of product systems. LCA aims at comparing and analyzing the potential environmental impacts of given products and services at every stage of their life. The ISO 14040 and 14044 are related standards to preform LCA (27). The methodology in this part is based on these standards. The framework of LCA is shown in the figure 1.

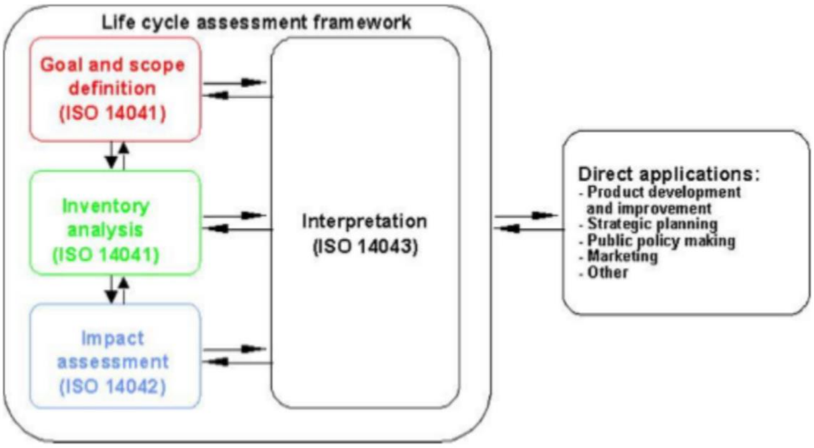


Figure 3 Life cycle assessment framework

4.1 Goal & Scope

The goal and scope definition phase, it is important to define AIC utility (function) and the functional unit. In agreement with ISO statement of functional unit, “A functional unit is ‘a quantified performance of a product system for use as a reference unit’”(8). The function of AIC is defined as insulating the building from outside climate. The functional unit is The functional unit “*is 1 m^2 insulation material in the building envelope with the desired R-value*”

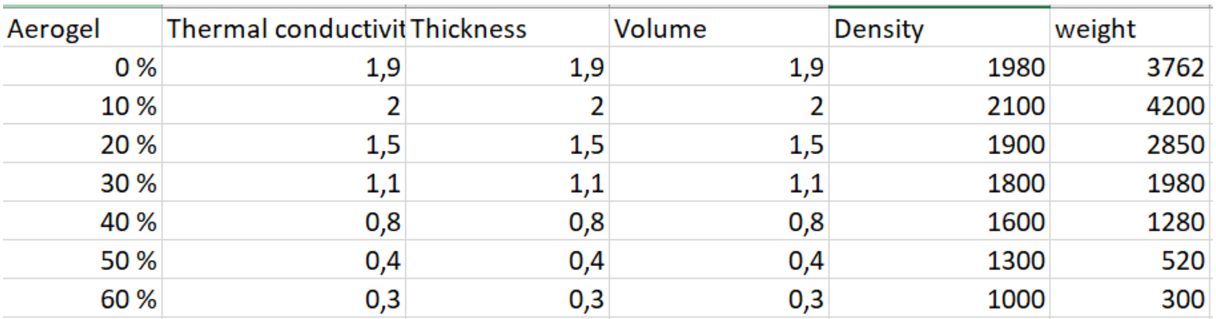
The system considers the production phase of the compared materials, not the use phase of the end of life. The use phase eliminated since all used materials ensure the same R-value. The production phase includes (A1) raw material extraction and processing of raw materials, (A2) transportation of raw materials to the factory, (A3) production and product packaging. The scope of this system cradle – to – gate model after the LCA standards described in 2.4. Figure 4 presents the production phase.

The functional unit equant mass is

$F.U = R.\lambda.p.A$

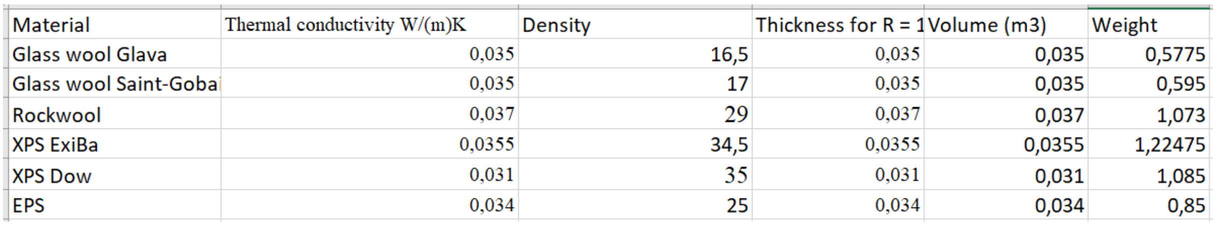
Where R represents the thermal resistance as 1 (m2 K)/W, λ represents the thermal conductivity measured as W/(m*K), U represents the thermal transmittance as W/(m^2*K). A represent the defined area in the functional unit as 1 m^2, F.U corresponds to the used weight of compared composite material, P represent the density of the insulation product in kg/m3 and V represent the volume of the compared composite in M^3.

Tabell 2



Aerogel	Thermal conductivit	Thickness	Volume	Density	weight
0 %	1,9	1,9	1,9	1980	3762
10 %	2	2	2	2100	4200
20 %	1,5	1,5	1,5	1900	2850
30 %	1,1	1,1	1,1	1800	1980
40 %	0,8	0,8	0,8	1600	1280
50 %	0,4	0,4	0,4	1300	520
60 %	0,3	0,3	0,3	1000	300

Tabell 3



Material	Thermal conductivity W/(m)K	Density	Thickness for R = 1	Volume (m3)	Weight
Glass wool Glava	0,035	16,5	0,035	0,035	0,5775
Glass wool Saint-Goba	0,035	17	0,035	0,035	0,595
Rockwool	0,037	29	0,037	0,037	1,073
XPS ExiBa	0,0355	34,5	0,0355	0,0355	1,22475
XPS Dow	0,031	35	0,031	0,031	1,085
EPS	0,034	25	0,034	0,034	0,85

The product system is defined as “cradle-to-gate” model (9). The model includes the upstream processes such as raw material acquisition, transport, and production. The downstream processes such as operation, maintenance and use are excluded from the LCA. 4 represents the system tree of AIC.

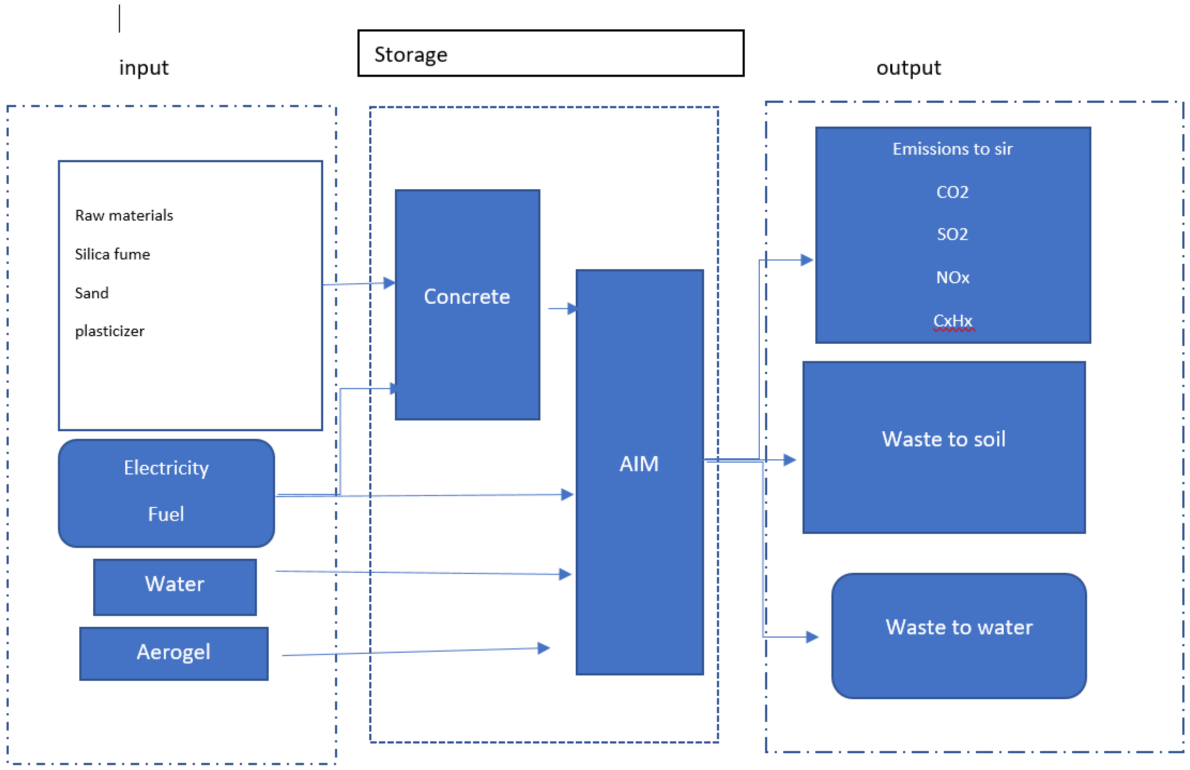


Figure 4 system boundary

4.2 Life cycle inventory analysis (LCI)

4.2.1 Acquisition and collection of AIC inventory data

As shown in the research paper, the components of the composites are received from several producers. The components are cement, sand, silica fume, water, superplasticizer, and aerogel particles. The cement used in Serine research was a CEM I 52.5R from (Norcem AS Brevik, Norway), Silica fume (Elkem Microsilica Grade 940), Superplasticizer (Dynamon SP130) from (Mapei, Norway), A natural sand from Finland (particle density: 2600 kg/m3), Hydrophobic aerogel granules from PCAS, France, Distilled water. The producers are contacted to get data about environmental impact of their products (production) or environmental product declaration. The environmental impact’s data of Cement, superplasticizer are retrieved from the EPDs of these products from producers. While the data of other materials such as water and sand are retrieved from some LCA databases. There are many LCA databases which can be used to get data like Ecoinvent (28), European Life Cycle Database

(ELCD) (29). The last two databases are the most popular and authoritative inventory databases in the world and was presented by European Commission. There are also some data retrieved from previous studies and research. The LCA is done by Simapro based on method (30).

The data of silica aerogel is retrieved from the three manufacturer: Aspen, Cabot and Svenska aerogel. There are few producers of aerogel granules in the world and they don't want to share the information about the production. Therefore, there is no EPD of aerogel production. the data of aerogel is received from the producers. Aspen claims that its production energy is 53.9 MJ/kg and its CO2 burden is 4.3 kgCO2/kg (31).

The sustainability report of Cabot Aerogel presents the energy intensity and emissions intensity of their production. The data from the Cabot isn't a big different from the data from Aspen which are mainly used in the LCA. The data are 63,9 MJ/ kg aerogel, 0,17 kg CO_2 / Kg aerogel, 0,0208 kg SO_2 / Kg aerogel and 0,075 Kg Nitrogen oxides / Kg aerogel (32).

According to Svenska Aerogel: "*No negative environmental impact. In production, large amounts of water are used. The production waste water has a somewhat higher salinity. The waste water is circulated and reused in further production*" (33). Svenska Aerogel is another producer of Aerogel assumes that there is no emissions of there Aerogel production and the main waste is water which will be recycled (33)

The environmental impact of silica fume does not need to be included because the silica fume is a by-product of the industrial silicon and ferroalloy production. The European silica fume producers allocate all greenhouse gas emissions to the main product silicon and ferrosilicon (Appendix).

4.2.2 Acquisition and collection of conventional insulation materials inventory data

The environmental impact data of conventional insulation materials are retrieved from Environmental product declarations of these materials. The EPDs are done based on model "cradle to gate" which is considered in this analysis. The EPDs are attached in the appendixes.

Tabell 4 conventional insulation materials

Material	Producer	EPD part	Declaration nr	Reference
Glass wool	Glava	EPD- Norway	NEPD 221N	(34)
	Saint-Gobain	EPD- Norway	NEPD 00244E	(35)
Rockwool	Rockwool	EPD- Norway	NEPD 00131 revisjon 1	(36)
XPS	ExiBa	IBU	ECO-XPS-010101-1007	(37)
	DOW	IBU	EPD-DOW-2013111-D	(38)
EPS	EUMEPS	IBU	EPD-EPS-20130078-CBG1-EN	(39)

4.2.3 Acquisition and collection of transport inventory data

The production location of AIC is defined as the same NTNU site here in Gjøvik. Because the AIC is still not a commercial produced. The environmental impact data of transport of the AIC components are retrieved from Simapro.

Tabell 5 distance of conventiona insulation materials to Gjøvik

Material	Location	Distanse	Truck	skip	Total (Km)
Silica fume	Kristiansand	430	430	0	430
cement	Brevik / Norway	286	286	0	286
sand	Finland	1223	1223	0	1223
aerogel	Frankfurt	1418	1418	0	1418
water	Gjøvik	0	0	0	0
SP	Sagstua	107	107	0	107
aerogel aspen	Rhode island / USA	7624	1214	6410	7624

4.3 Life cycle impact assessment

There are several available LCIA methods to provide environmental impact analysis such as ILCD 2011Midpoint (40), EDIP 2003 (41), IMPACT 2002+ (41) and ReCiPe 2016 (42). These methods vary across areas such as assumptions made and regional relevancy, which may lead to different LCIA results. But because of gap of environmental impact's data of the AIC composites since they aren't commercial produced, it won't be used any of mentioned methods. The only available data of environmental impact of these composites is energy and emissions. Therefore, these two parameters will be considered in this paper. It will be used two single issue methods conduct the energy consumption (IPCC 2013) and CO2 emissions (Cumulative Energy Demand (CED)) of the compared materials. IPCC 2013 contains the climate change factors of IPCC with a timeframe of 100 years. (43). Cumulative Energy Demand (CED) calculate the energy demand of the whole system (44). All calculations are done by excel. Results include the transport of components of AIC to Gjøvik as manufacturing's location. Also, the transport of conventional insulation materials to Gjøvik.

5 Results

Figure 5 presents the energy consumption of AIC composites based on aerogel conten

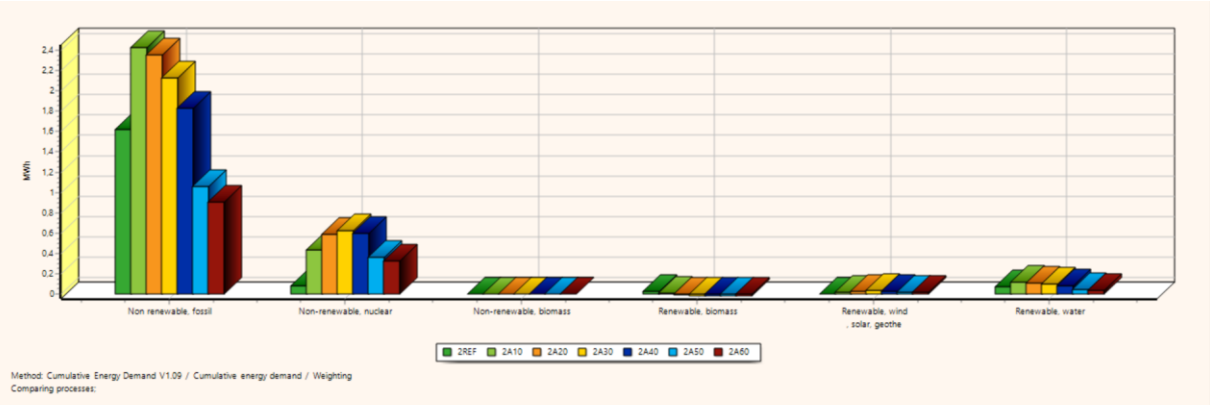
AIC

The results present the analysis of the AIC composites, then present the comparison of AIC composites with each insulation materials. Then compare the A60 (as multifunctional material) which content 60% Aerogel with conventional insulation materials.

Energy

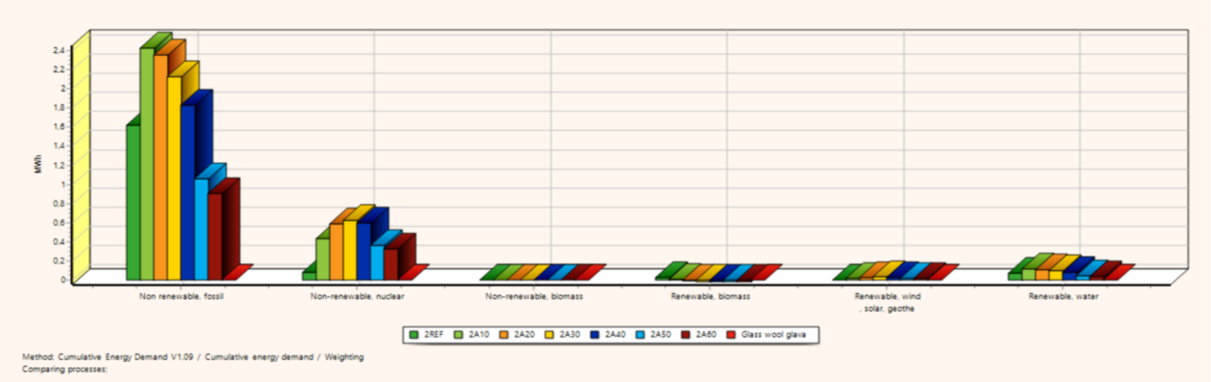
AIC composites

The figure and table present the energy analysis of the AIC composites.



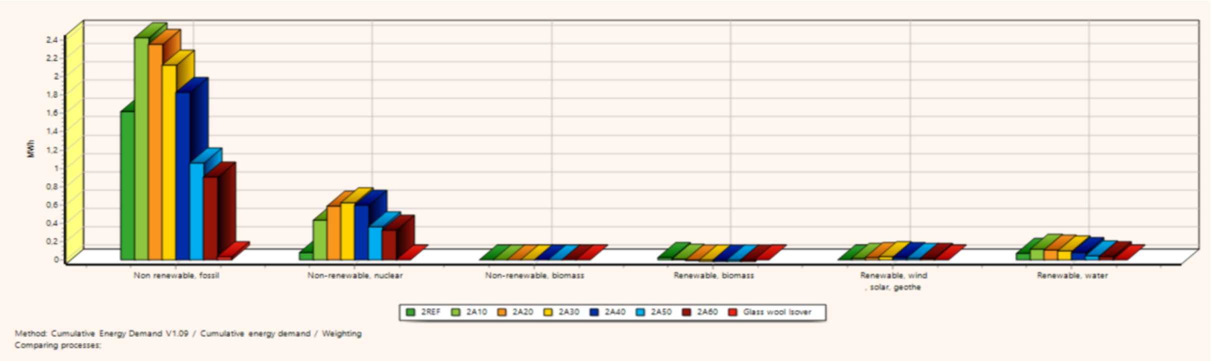
AIC & Glass wool Glava

The figure and table present the energy analysis of the AIC composites and glass wool glava.



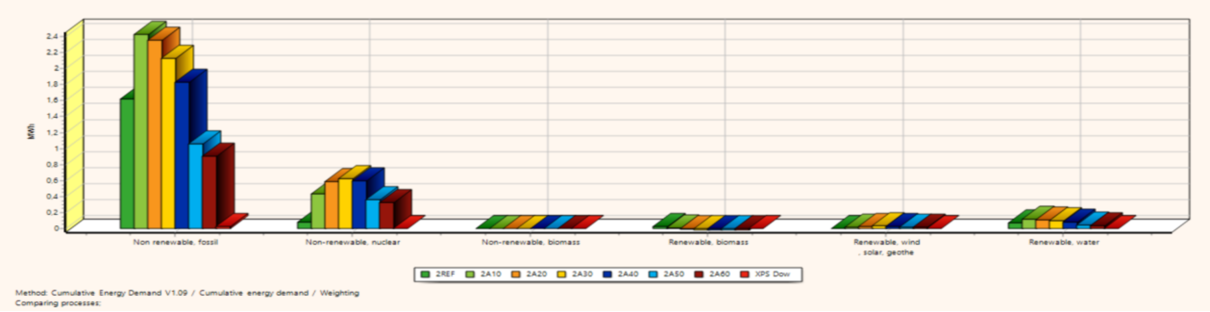
AIC & saint Isover

The figure and table present the energy analysis of the AIC composites and glass wool Isover.



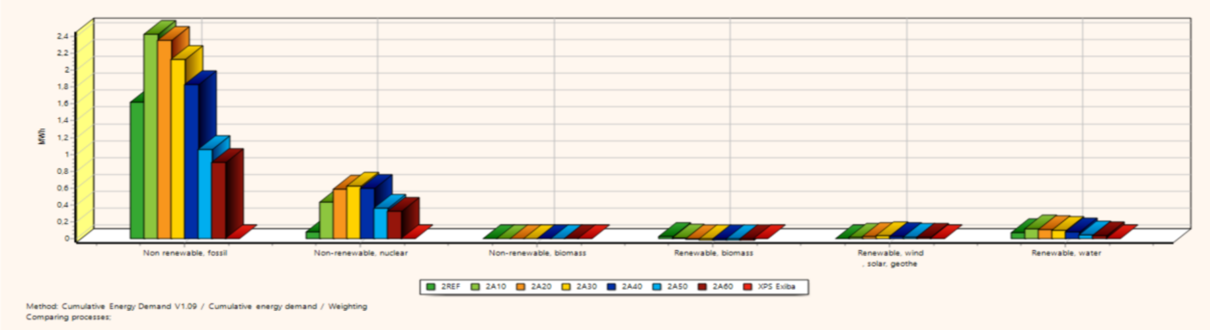
AIC & XPS Dow

The figure and table present the energy analysis of the AIC composites and XPS Dow



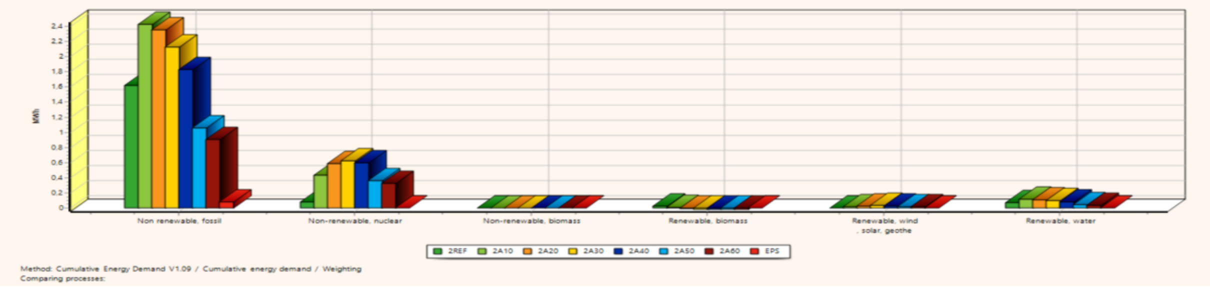
AIC & XPS ExiBa

The figure and table present the energy analysis of the AIC composites and XPS ExiBa



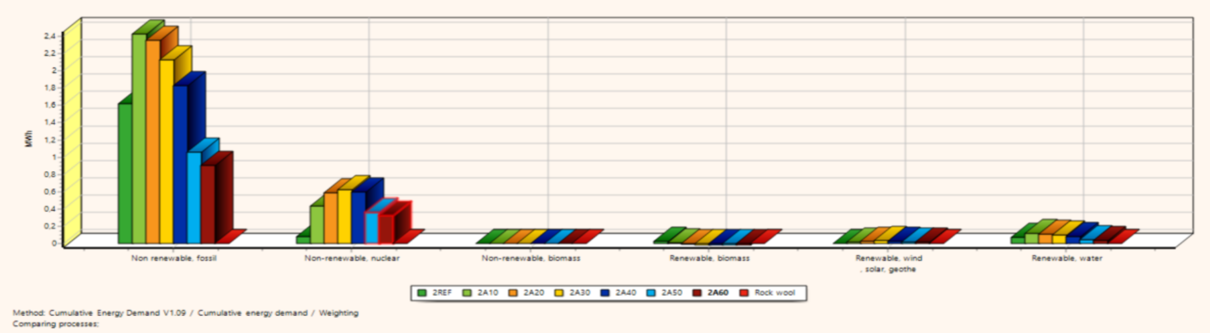
AIC & EPS

The figure and table present the energy analysis of the AIC composites and EPS



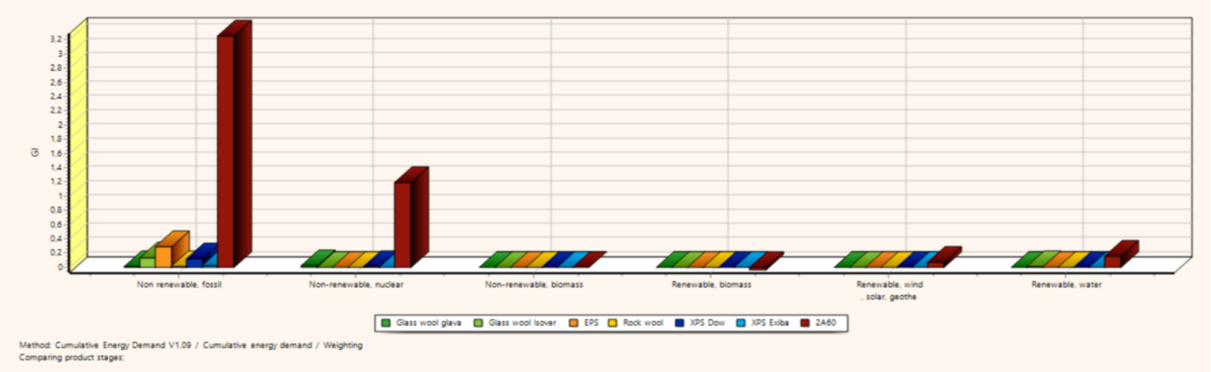
AIC & Rockwool

The figure and table present the energy analysis of the AIC composites and Rock wool



AIC 60% & insulation materials

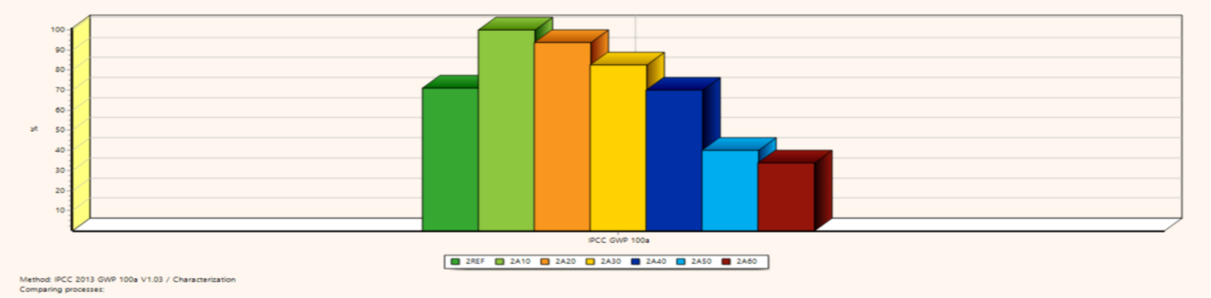
The figure and table present the energy analysis of the AIC A60 as multifunctional material and the conventional insulation materials.



CO2 emissions

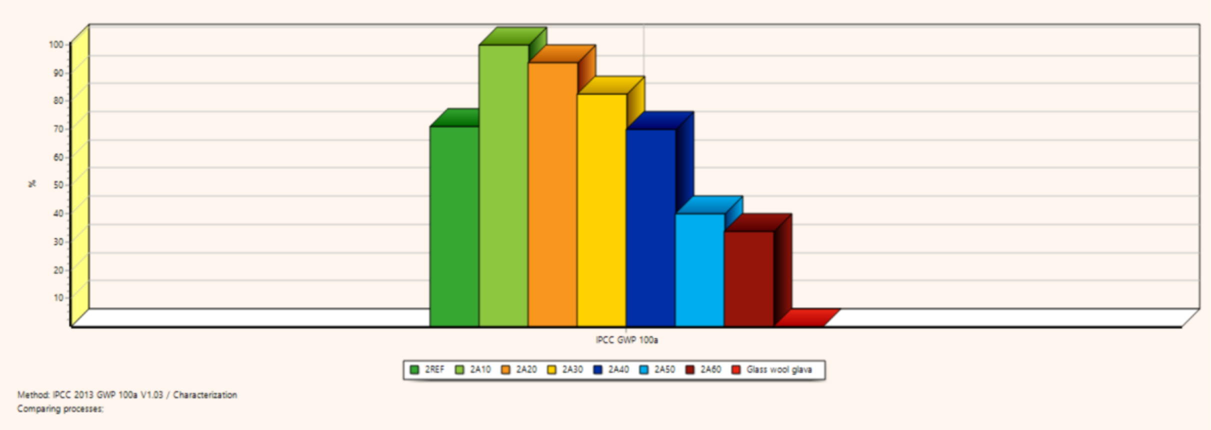
AIC composites

The figure and table present the CO_2 equivalent analysis of the AIC composites.



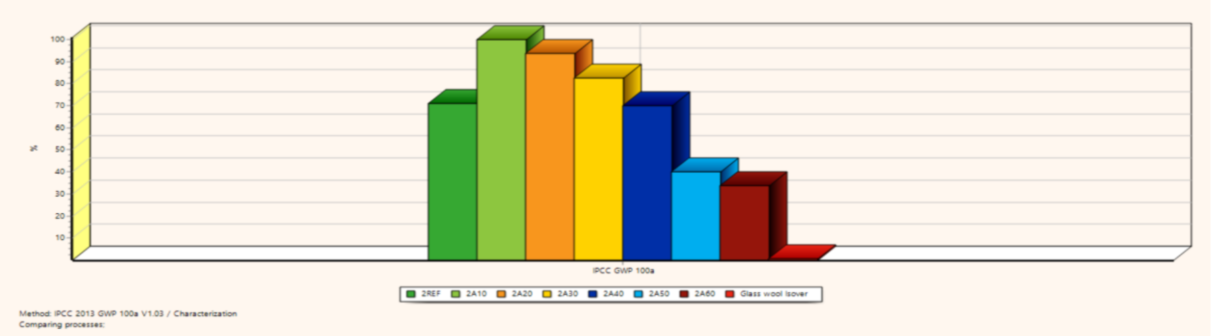
AIC & Glass wool Glava

The figure and table present the energy analysis of the AIC composites and glass wool glava.



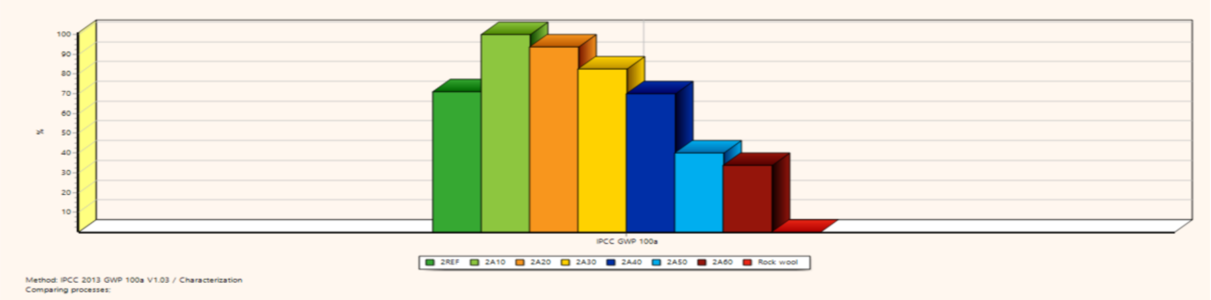
AIC & saint Isover

The figure and table present the energy analysis of the AIC composites and glass wool Isover.



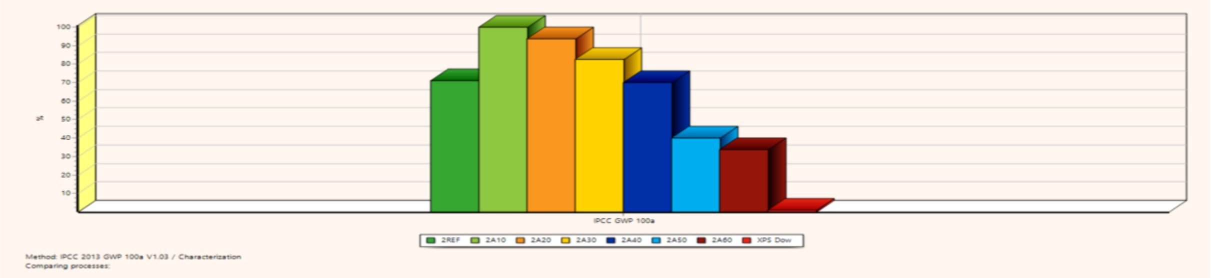
AIC & Rockwool

The figure and table present the energy analysis of the AIC composites and Rock wool



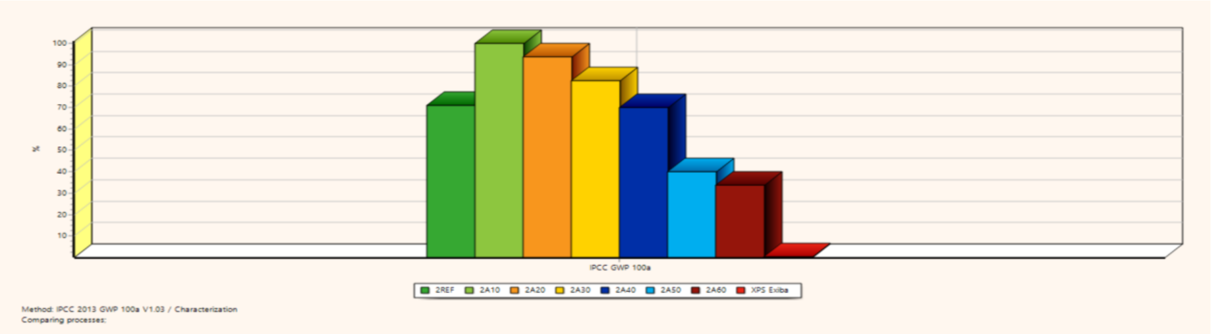
AIC & XPS Dow

The figure and table present the energy analysis of the AIC composites and XPS Dow



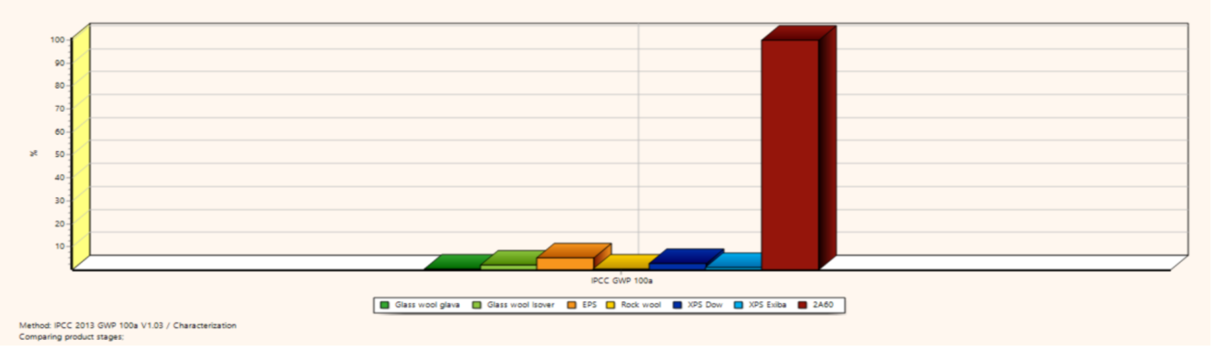
AIC & XPS ExiBa

The figure and table present the energy analysis of the AIC composites and XPS ExiBa



AIC 60% & insulation materials

The figure and table present the energy analysis of the AIC A60 as multifunctional material and the conventional insulation materials.



6 Discussion

The results from LCIA show that incorporating of aerogel into lightweight concrete will reduce the environmental impact of the concrete aggregates.

The comparison between the AIC and conventional insulation materials with defined functional unit 1 m2 area insulation and U – value equal 1.

The results from LCA show that AIC is still not comparable with traditional insulation regards the energy consumption and CO_2 emissions. The difference in environmental impact is high because of the huge amount of AIC composites to ensure the (R = 1) as shown in the functional unit compared to the conventional insulation materials. The AIC composites with aerogel content 60 % or higher have better thermal conductivity than concrete, but the environmental impact increase extremely.

6.1 Completeness check

The energy mix is based on hydropower which is used in Norway (45). The energy consumption data in the LCA should be inserted based on this mix.

There is gap in environmental impact data of Aerogel from the producers. The only available data is the energy consumption and CO_2 emissions from one producer. The data is old and isn't updated (31). The author has contacted several producers to get new data, but didn't get result.

6.2 Consistency checks

The data of used traditional insulation material for comparison are retrieved from the EPDs. the data from the databases is ideal and don't cover the difference between the producers regards the energy mix, waste treatment or environmental-friendly technology. While the data from EPDs are more reliable and presis data of the production

6.3 Sensitivity check

The allocation of emissions from production of Silica fume will affect the result. As shown in the LCI, The European silica fume producers allocate all greenhouse gas emissions to the main product silicon and ferrosilicon since the entire Si / FeSi include by – products are covered by EU carbon leakage list. The silica fume is co - product of silicon production and has lower economic value. In the other hand, the silica fume as commercial product can be considered environmentally based on the distribution of economic value. In this paper, the allocation of emissions and energy consumption follow the allocation rules in EU.

6.4 Aerogel incorporating

The aerogel has low thermal conductivity around 0.015 $W.m^{-1}.K^{-1}$. Because of that it is defined as very good insulator but the luck of the mechanical strength makes a big challenge to use it as alternative to the insulation panels. Incorporating aerogel to the concrete will make a composite with higher mechanical strength which can be used to replace the insulation panels and low thermal conductivity as well. The aerogel concrete composites with amount aerogel over 60 % show very low thermal conductivity as well as low mechanical strength. Based on that, these composites can substitute the traditional insulation panels in the walls.

The main challenge from the sustainable view is to use AIC commercially as alternative to traditional insulation panels is the huge environmental impact of these composites. The production of concrete in general has lower negative impact than production of conventional insulation materials, but the aerogel based on the available data from producers has responsibly high emissions and energy consumption than traditional insulation materials (10) (Figure).

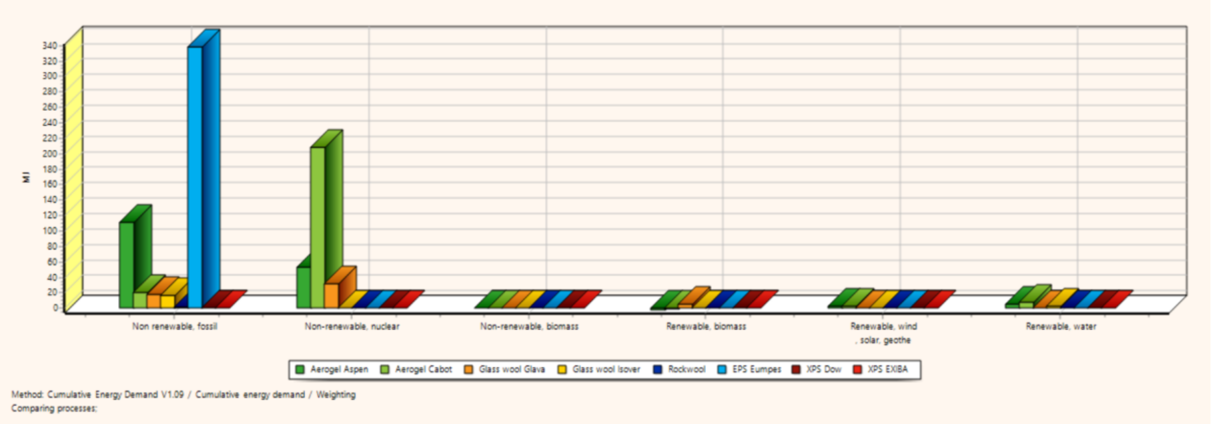


Figure 5 comparison of aerogel and conventional insulation materials

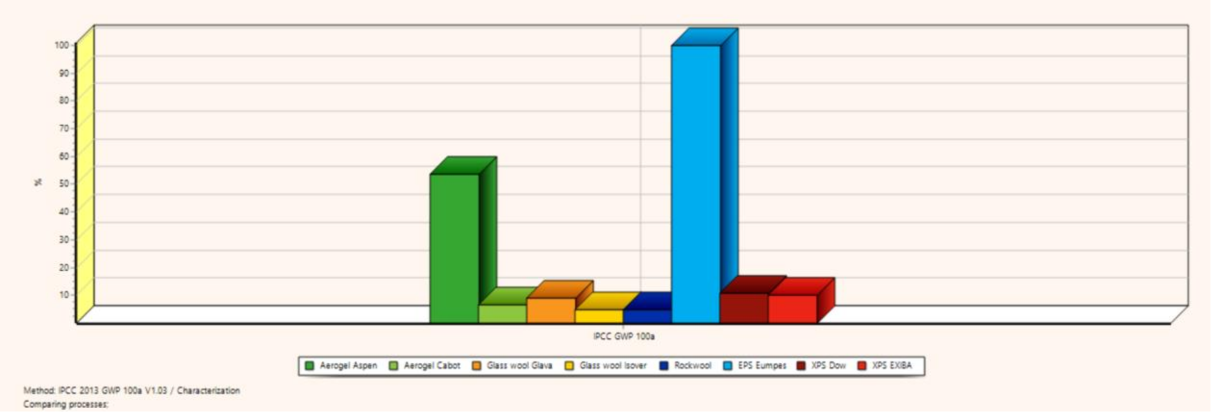


Figure 6 comparison of aerogel and conventional insulation materials

In this case, the composites with aerogel contents 60 % or more will not be comparable with conventional insulation materials. The figure show that the main effect of aerogel production to the human health is from the electricity consumption in the manufacturing processes. Because of that the resource of electricity is critical for assessment of environmental impact of aerogel production. The progress in developing environmental friendly production of aerogel is critical for commercial using of these composites as alternatives to insulation walls. Another producer of Aerogel assumes that there is no emissions of there Aerogel production and the main waste is water which will be recycled (33).

7 Conclusion

The AIC composites have higher environmental impact than traditional insulation materials. The main cause for this difference of environmental impact is the high energy consumption and CO_2 emissions of aerogel production. The progress in developing environmental friendly production of aerogel is critical for commercial using of these composites as alternatives to insulation walls.

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Environmental impact of Aerogel incorporated mortars as multifunctional building material with calcined clay as binder

Abstract

The Aerogel incorporated concrete (AIM) is developed as an alternative material with a low thermal conductivity to the traditional concrete. The previous research shows that the partial replacement of Portland cement with calcined clay as binder to the Aerogel incorporated mortars (AIM) will decrease the thermal conductivity of the AIM. This paper will present life cycle assessment of the calcined clay – aerogel concrete to declare the environment impact of this new composite in production phase. Then compare the environmental impact of calcined clay - AIM with plain concrete. The LCA will consider only the CO_2 equivalent because the AIM composites isn't commercial produced, therefore there is lack of data of the environmental impact of these composites. The aim of this LCA is to assess if the AIM is more sustainable solution than traditional building materials in the walls.

Keywords: thermal insulation, Aerogel incorporated mortars, calcined clay, Aerogel, life cycle assessment

1 Introduction

The thermal insulation is very important concept for the building industry. The buildings consume a lot of energy to regulate the inside climate of the building. The thermal insulation will hinder the thermal transfer between the inside and outside climate (1, 2). Consequently, the thermal insulation reduces the energy consumption of the buildings. The reduction of energy consumption will reduce the resources consumption and emissions from power generation. Based on that the thermal insulation support the sustainable development approach in building industry. The sustainable development is defined in (our common future report) as *development which meets the needs of the current generation without compromising the need of the next generations* (3). The Sustainable development concept has got more attention today, because of the increasing of risks on the future of this world (3). The building industry is one of the important sectors which consider the sustainable development of their business. The building industry has made huge progress forward to achieve the sustainable development. It has been developed some approaches to make the buildings more sustainable like smart grid, low- emissions housing and zero emissions house. The aim is to reduce the energy consumption and emissions of the buildings.

Thermal insulation is the protection of buildings from thermal loss outwardly. It can be used to hold the temperature inside the building (either cold or hot). It can be used in many countries with different weather. The thermal loss causes when it happens a temperature difference over material or construction; then it becomes a heat transfer between the hot side to the cold side. That main way to the insulation of building is to set a suitably thick layer of material which has low thermal conductivity. That will reduce thermal transfer outward or inward. The building materials were mainly focused in this field because the properties and the specifications of these materials (1) have a high influence on the sustainability performance of buildings. Materials which have low thermal conductivity are more sustainable than materials with high thermal conductivity. The low thermal conductivity will reduce the need for the inside climate regulation (heating or cooling). The energy consumption of inside climate regulation will be reduced (3).

The thermal insulation can be defined as sustainable technology because of this reducing of energy consumption. Although it is possible to improve the sustainable performance of choose an Eco or recycle material, an environment-friendly productions method and secure social workers.

There were previous attempts to develop building materials with low thermal conductivity to reduce the negative environmental impact of the buildings (4). NTNU & Sintef have corporate in research to develop new construction composite materials with low thermal conductivity by incorporating inorganic materials and other additives to the traditional concrete. The main focus was to develop materials which have a low thermal conductivity and meet the mechanical strength requirements of concrete as well (5).

The AIC composite in the NTNU research consist of traditional components of concrete such as water, cement, and sand. Then incorporate the Aerogel in the concrete samples. The contents of aerogel in samples will be increased gradually from 10 % to 60%. After preparing the samples in a standard Hobart 2-litre mixer. The samples will be scanned the structure of particles. Then some tests will be done to measure the density, thermal conductivity, compressive strength and flexural strength of the samples. Finally draw graphs which show the change in the characterization based on the increasing of aerogel content of sample (5).

Further, the research in this paper focus on using these composite materials as more sustainable alternatives to the traditional insulation materials. The main idea of this research project is to compare the environmental impact between the insulation composite material AIC which are studied in NTNU and Sintef with traditional insulation materials as organic like Polyurethane (EPS) or polystyrene (XPS) or inorganic like mineral wool. The main aim is to find if this new insulation composite has a less environmental impact than the traditional insulation materials which achieve the same thermal insulation. The traditional thermal insulation materials like cellulose, EXPs, polystyrene foam, urethane foam are organic materials which has negative environmental impact during their production phase. In this paper, it will be comparison of the environmental impact during their production phase of these traditional materials with the new composite AIC.

2 Literature review

The corresponding literature can be divided into two areas: previous literature focusing of environmental impact of insulation materials, A study of components: Aerogel & Calcined clay and previous literature focusing on research of Aerogel – concrete.

2.1 A study of Aerogel

Aerogel is a synthetic porous ultralight material. Aerogels are formed by removing the liquid from a gel under special drying conditions, bypassing the shrinkage and cracking experienced during ambient evaporation. Aerogel was invented as quite revolutionary solid-state materials contents 90 % air. The aerogel have extremely low density and better physical properties (6), especially for many applications of aerogel like thermal insulation, acoustical insulation (7), or transparent to light or solar radiation (8, 9). The material can be produced in monolithic or granular form (7, 10). There are different types of aerogel: silica aerogel, carbon aerogel, and metal oxide aerogel. The aerogel is the most used type of insulation composite materials (7).

Silica aerogels are lightweight and highly porous materials, with a three-dimensional network of silica particles. The silica aerogel produces by extracting the liquid phase of silica gels under supercritical conditions (7, 11). Silica has promising characteristics, such as extremely low thermal conductivity, low density, high porosity and high specific surface area (7, 11, 12). Based on these characteristics, the aerogel has excellent potential application for thermal insulation (5, 13-15). Silica aerogels are known as the best known thermal insulating materials with thermal conductivity around 0.015 $W.m^{-1}.K^{-1}$ at ambient temperature and pressure (16). Additionally, Silica aerogels present further advantages such as good fire, acoustic resistance(7), resistance to moisture, waterproofing and self-cleaning properties, corrosion protection, UV reflection, durability (7, 15, 17).

2.2 Study of Calcined clay

Clay is a naturally occurring material composed primarily of fine-grained minerals, which is plastic at appropriate water contents and will harden with dried or fired"(18). Clay can be found in great abundance all around the world, and it has been found that. The clay minerals can be divided into three main classes 28: ƒ Kaolin Group (e.g., Kaolinite, Dickite, Nacrite) ƒ Smectite Group (e.g., Montmorillonite, Nontronite, Beidellite) ƒ Illite Group (e.g., Illite, Glauconite).

Although the structure and compositions of the three minerals are very different, the fundamental building blocks are the same. The two basic units describing the atomic structure of all clay minerals are an octahedral and a tetrahedral sheet. The calcined clay is clay which has been treated with calcination process. The clay heats to drive out volatile materials; a natural abrasive. Calcined clay can be used as a replacement of the cement (5).

2.3 Literature focusing of environmental impact of insulation materials

There are several LCA studies of insulation materials to determine the environmental impact of the insulation materials. Pargana at university of Lisboa presented a comparative environmental life cycle assessment of thermal insulation materials of buildings (19). The study is based on the LCA ISO standards (20) and compare many types of insulation materials like Expanded cork agglomerate (ICB), Extruded polystyrene (XPS) and Expanded polystyrene (EPS). The study results are preformed in "cradle to gate" (21). Another research is a LCA study of transparent aerogel analyze the environmental impact of aerogel done by Mark DOWSON at the University of Bath. The study shows that aerogel as a good insulation material and has responsibly high emissions and energy consumption of their production than traditional insulation materials (10). Although, Other LCA studies include the inorganic materials. Schiavoni at University of Perugia include the aerogel and stone wool as a good insulation material to their LCA study (22). There are also other researches presents composite materials like chemically bonded phosphate ceramics (23), permafrost cement as a new phosphate based cement for using in very cold countries (24).

2.4 Literature focusing on research of Aerogel – concrete

There are several studies of incorporating aerogel to concrete to reduce the thermal conductivity. The main aim of this research field is to make a concrete which has low thermal conductivity and meet the mechanical strength requirements (5, 13, 15, 25, 26). Julio at university of Lisboa presented the Silica-based aerogels as aggregates for cement-based thermal renders. the results of the study are that the replacement of silica sand by a subcritical hybrid aerogel synthesized by design lead to successfully produce lightweight and low thermal conductivity cement based renders. incorporate aerogel to Lightweight concrete (15). Fickler at university presented the incorporating of aerogel to high performance concrete mixtures. The results of the study show that Aerogel concrete is optimized Based on concrete formulas of HPC, UHPC and LC. The goal of that study to increase the compressive strength while maintaining good heat insulating properties (25).

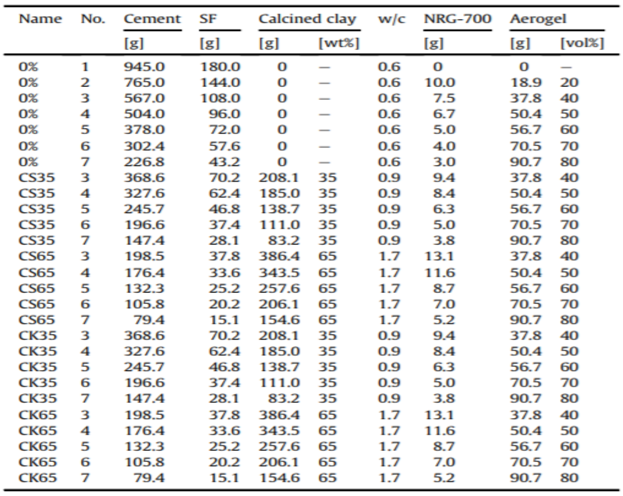
3 Material

Serine has researched the replacement of cement with calcined clay in aerogel incorporated mortars (AIM) to decrease the thermal conductivity. Serine has tested samples of aerogel incorporated concrete with cement as a binder. These samples contents aerogel from 20 % to 80 %. Then tested samples aerogel incorporated concrete with calcined clays as a binder (replacement of cement). The replaced calcined clay has two types of CS (mainly contain smectite) and CK (mainly contain kaolinite). The replacement of ordinary Portland cement with calcined clay as a binder was in two contents 65% and 35%.

3.1 Thermal conductivity

The samples with calcined clay were tested and the result compared with the first samples. Serina found that at an aerogel loading of between 40 vol% and 80 vol%, replacement of cement with calcined clay lowered the thermal conductivity by up to 20% when <70 vol% aerogel was present (0.410 W/(mK) to 0.370 W/(mK)), and by up to 40% with >70 vol% aerogel (0.164 W/(mK) to 0.145 W/(mK)), driven mainly by the innate thermal conductivity of the binders. At replacement level of up to ~30% by weight of binder (%bwob), the properties of the mortar were independent of clay types. When the replacement increased to above 40%bwob, calcined smectite enriched clays were favored for lowering the thermal conductivities of the mortars as compared to those containing kaolinite. The figure show conducted measured thermal conductivity of the different samples based on the increasing of aerogel contents (3).

Tabell 1 AIM compositions



Name	No.	Cement	SF	Calcined clay		w/c	NRG-700	Aerogel	
		[g]	[g]	[g]	[wt%]		[g]	[g]	[vol%]
0%	1	945.0	180.0	0	–	0.6	0	0	–
0%	2	765.0	144.0	0	–	0.6	10.0	18.9	20
0%	3	567.0	108.0	0	–	0.6	7.5	37.8	40
0%	4	504.0	96.0	0	–	0.6	6.7	50.4	50
0%	5	378.0	72.0	0	–	0.6	5.0	56.7	60
0%	6	302.4	57.6	0	–	0.6	4.0	70.5	70
0%	7	226.8	43.2	0	–	0.6	3.0	90.7	80
CS35	3	368.6	70.2	208.1	35	0.9	9.4	37.8	40
CS35	4	327.6	62.4	185.0	35	0.9	8.4	50.4	50
CS35	5	245.7	46.8	138.7	35	0.9	6.3	56.7	60
CS35	6	196.6	37.4	111.0	35	0.9	5.0	70.5	70
CS35	7	147.4	28.1	83.2	35	0.9	3.8	90.7	80
CS65	3	198.5	37.8	386.4	65	1.7	13.1	37.8	40
CS65	4	176.4	33.6	343.5	65	1.7	11.6	50.4	50
CS65	5	132.3	25.2	257.6	65	1.7	8.7	56.7	60
CS65	6	105.8	20.2	206.1	65	1.7	7.0	70.5	70
CS65	7	79.4	15.1	154.6	65	1.7	5.2	90.7	80
CK35	3	368.6	70.2	208.1	35	0.9	9.4	37.8	40
CK35	4	327.6	62.4	185.0	35	0.9	8.4	50.4	50
CK35	5	245.7	46.8	138.7	35	0.9	6.3	56.7	60
CK35	6	196.6	37.4	111.0	35	0.9	5.0	70.5	70
CK35	7	147.4	28.1	83.2	35	0.9	3.8	90.7	80
CK65	3	198.5	37.8	386.4	65	1.7	13.1	37.8	40
CK65	4	176.4	33.6	343.5	65	1.7	11.6	50.4	50
CK65	5	132.3	25.2	257.6	65	1.7	8.7	56.7	60
CK65	6	105.8	20.2	206.1	65	1.7	7.0	70.5	70
CK65	7	79.4	15.1	154.6	65	1.7	5.2	90.7	80

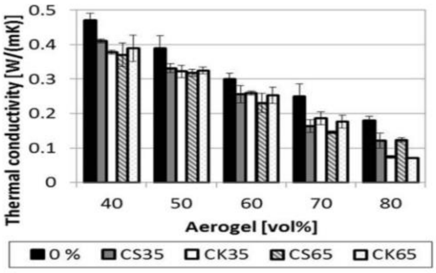


Figure 1 AIM Thermal conductivity

4 Method

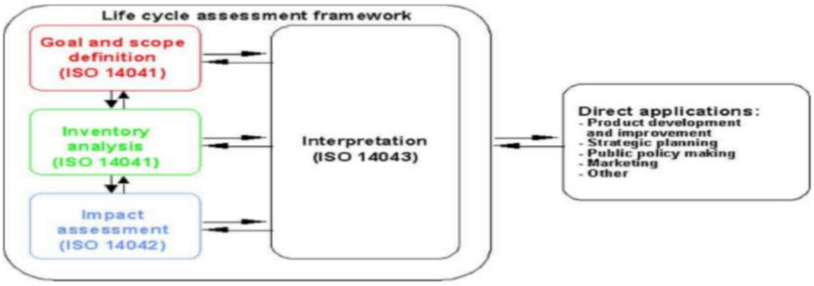


Figure 2 Lifecycle assessment framework

4.1 Goal and scope

This analysis aims to compare the production of the AIM composites with some conventional insulation materials to conduct which insulation material is the best environment – friendly. The AIM composites are AIM 0 % calcined clay, AIM 35% CS, AIM 65% CS, AIM 35% CK, AIM 65% CK.

There are many research focuses on the environmental performance of buildings based on thermal efficiency. Although some researches focus on environmental impact of production. In this analysis, it will be focus on environmental impact of production of insulation materials.

The functional unit for this research is performed as it performed in the most life cycle assessment (LCA) studies of insulation solutions. the functional unit (f.u.) was defined as the mass (kg) of insulation board that provides a thermal resistance R of 1 (m2 K/W)

The functional unit of this research is the mass of the insulation material for 1 m^2 area with a thickness ensure R-value R = 1 m^2 K/ W.

$$F.U = R.\lambda.p.A\ (Kg)$$

Where R represents the thermal resistance as 1 (m^2 K)/W, λ represents the thermal conductivity measured as W/(m*K), U represents the thermal transmittance as W/(m^2*K). A represents the defined area in the functional unit as 1 m^2, F.U corresponds to the used weight of the compared composite material, P represents the density of the insulation product in kg/m3, and V represents the volume of the compared composite in M^3.

Then in the next sections it will be presented the calculations of the F.U (Kg) for the studied composite materials: conventional insulation materials, AIC, AIM and MKP – FA. The data of conventional insulation materials are retrieved from EPDs and also from databases in Simapro.

The system boundary is defined as "cradle-to-gate" model (21). The model includes the upstream processes such as raw material acquisition, transport, and production. The downstream processes such as operation, maintenance and use are excluded from the LCA. Fig. 2 represents the system boundary of Calcined clay – Aerogel concrete.

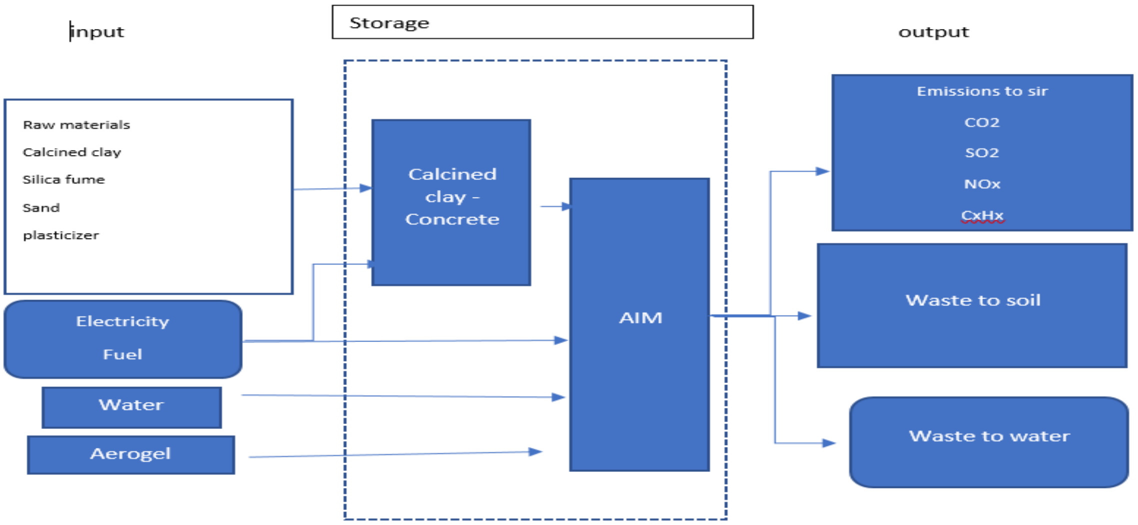


Figure 3 system tree of AIM

4.2 LCI

4.2.1 Acquisition and collection of AIM inventory data

As shown in the research paper, the components of the composites are received from several producers. The components are cement, silica fume, water, NRG - 700, and aerogel particles. The cement used in Serine research was CEM I 42.5R from (Norcem AS Brevik, Norway), Silica fume (Elkem Microsilica Grade 940), calcined clays (SaintGobain Weber from Oslo, Norway), NRG-700 from (Mapei, Norway), , Hydrophobic aerogel (Cabot Aerogel, Frankfurt am Main/Germany), Distilled water. The producers are contacted to get data about environmental impact of their products (production) or environmental product declaration. The environmental impact's data of Cement, superplasticizer is retrieved from the EPDs of these products from producers. While the data of other materials such as water and sand are retrieved from some LCA databases. There are many LCA databases which can be used to get data like Ecoinvent (27), European Life Cycle Database (ELCD) (28). The last two databases are the most popular and authoritative inventory databases in the world and was presented by European Commission. There are also some data retrieved from previous studies and research. The LCA is done by Simapro based on method (29).

The data of silica aerogel is retrieved from the three manufacturer: Aspen, Cabot and Svenska aerogel. There are few producers of aerogel granules in the world and they don't want to share the information about the production. Therefore, there is no EPD of aerogel production. the data of aerogel is received from the producers. Aspen claims that its production energy is 53.9 MJ/kg and its CO2 burden is 4.3 kgCO2/kg (30).

The sustainability report of Cabot Aerogel presents the energy intensity and emissions intensity of their production. The data from the Cabot isn't a big different from the data from Aspen which are mainly used in the LCA. The data are 63,9 MJ/ kg aerogel, 0,17 kg CO_2 / Kg aerogel, 0,0208 kg SO_2 / Kg aerogel and 0,075 Kg Nitrogen oxides / Kg aerogel (31).

According to Svenska Aerogel: "*No negative environmental impact. In production, large amounts of water are used. The production waste water has a somewhat higher salinity. The waste water is circulated and reused in further production*" (32). Svenska Aerogel is another producer of Aerogel assumes that there is no emissions of there Aerogel production and the main waste is water which will be recycled (32)

The environmental impact of silica fume does not need to be included because the silica fume is a by-product of the industrial silicon and ferroalloy production. The European silica fume producers allocate all greenhouse gas emissions to the main product silicon and ferrosilicon (Appendix).

The environmental impact of Calcined clay was received from the producer.

4.2.1 Acquisition and collection of conventional insulation materials inventory data

The environmental impact data of conventional insulation materials are retrieved from Environmental product declarations of these materials. The EPDs are done based on model "cradle to gate" which is considered in this analysis. The EPDs are attached in the appendixes.

Tabell 2 conventional insulation materials

Material	Producer	EPD part	Declaration nr	Reference
Glass wool	Glava	EPD- Norway	NEPD 221N	(33)
	Saint-Gobain	EPD- Norway	NEPD 00244E	(34)
Rockwool	Rockwool	EPD- Norway	NEPD 00131 revisjon 1	(35)
XPS	ExiBa	IBU	ECO-XPS-010101-1007	(36)
	DOW	IBU	EPD-DOW-2013111-D	(37)
EPS	EUMEPS	IBU	EPD-EPS-20130078-CBG1-EN	(38)

4.2.3 Acquisition and collection of transport inventory data

The production location of AIC is defined as the same NTNU site here in Gjøvik. Because the AIC is still not a commercial produced. The environmental impact data of transport of the AIC components are retrieved from the Simapro. The table 4 show the distance between AIC production site (Gjøvik) and manufacturing location of the conventional insulation material.

Tabell 3 distance of conventiona insulation materials to Gjøvik

Material	Location	Distanse	Truck	skip	Total (Km)
Silica fume	Kristiansand	430	430	0	430
cement	Brevik/Norway	286	286	0	286
Calcined clay	Oslo/Norway	123	123	0	123
aerogel	Frankfurt	1418	1418	0	1418
water	Gjøvik	0	0	0	0
SP	Sagstua	107	107	0	107
aerogel aspen	Rhode island / USA	7624	1214	6410	7624

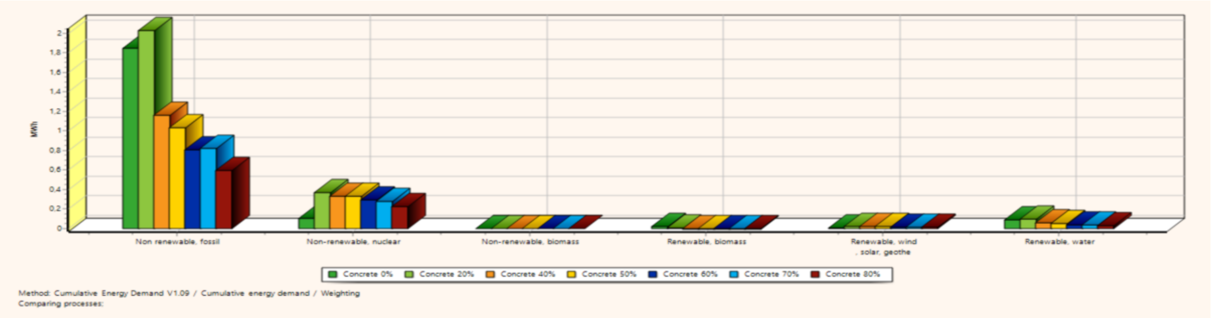
Results

The results present the analysis of the AIM composites, first AIM without calcined clay, second AIM with 35% replacement of calcined clay CS, AIM with 65% replacement of calcined clay CS, AIM with 35% replacement of calcined clay CK, and AIM with 35% replacement of calcined clay CK. Then present the comparison of AIM composites with each insulation materials. Then compare the A60 and A70 (as multifunctional materials) with conventional insulation materials.

Energy

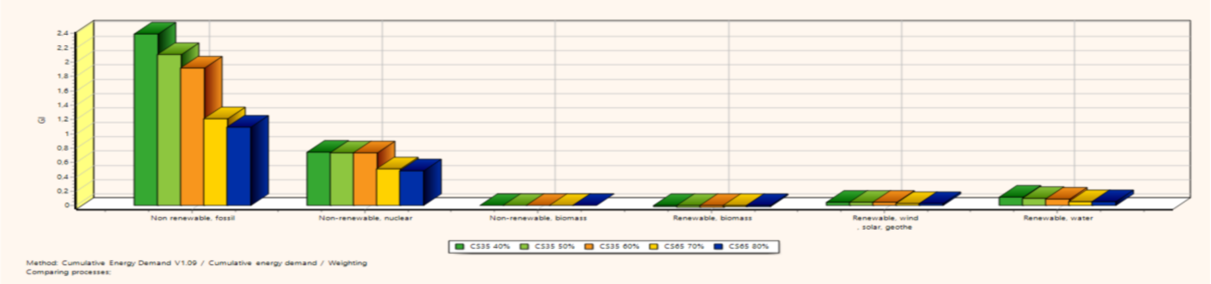
AIM without calcined clay

The figure and table present the energy analysis of the AIM composites.



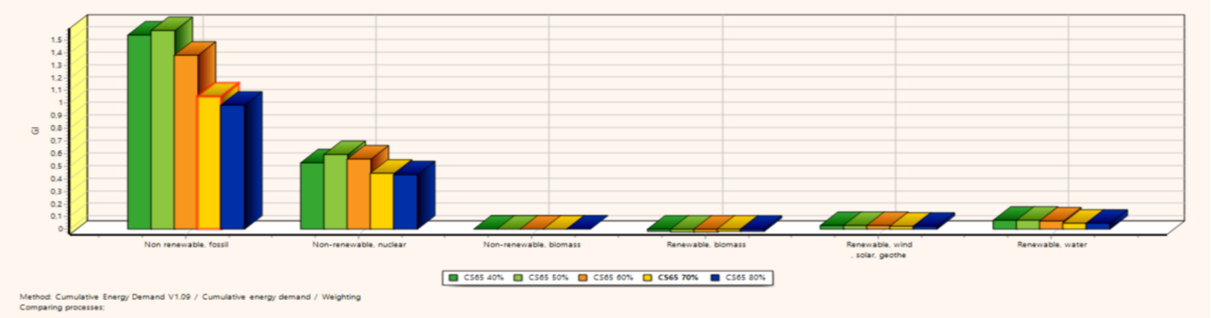
AIM CS 35%

The figure and table present the energy analysis of the AIM composites.



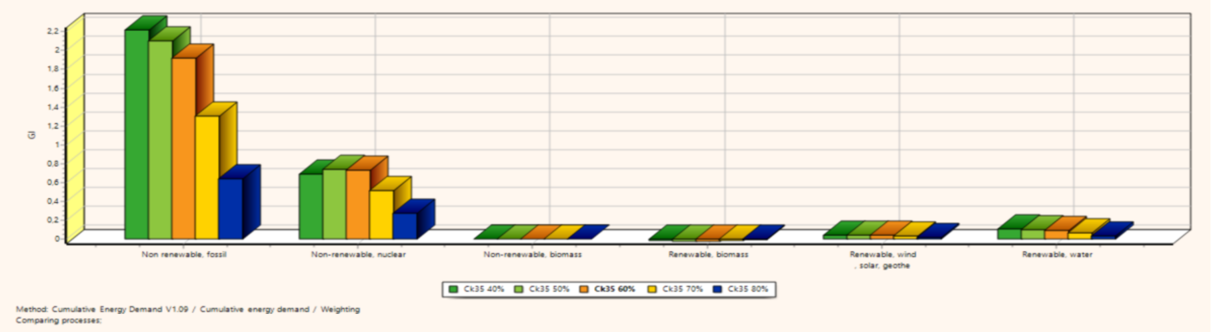
AIM CS 65%

The figure and table present the energy analysis of the AIM composites.



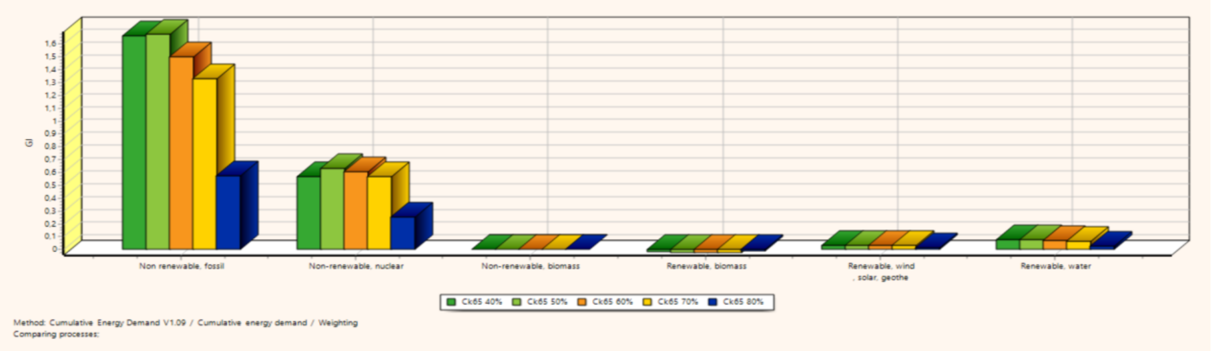
AIM CK 35%

The figure and table present the energy analysis of the AIM composites.



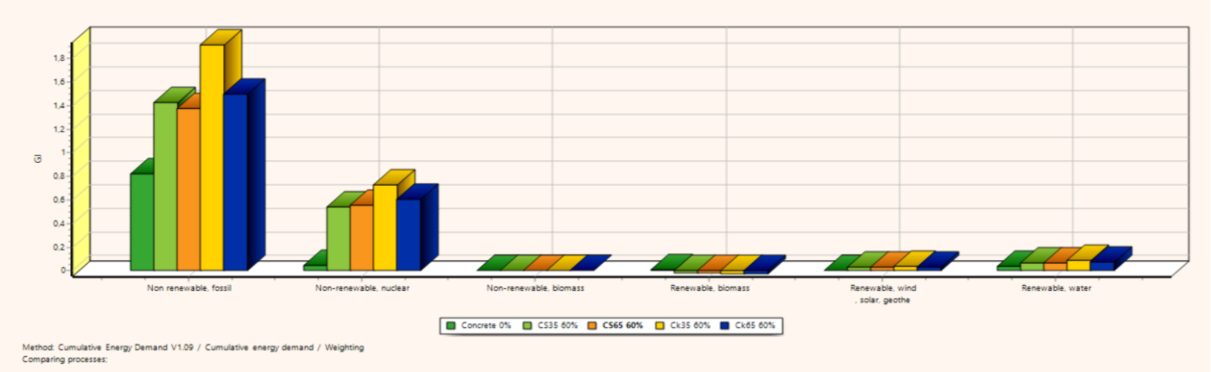
AIM CK 65%

The figure and table present the energy analysis of the AIM composites.



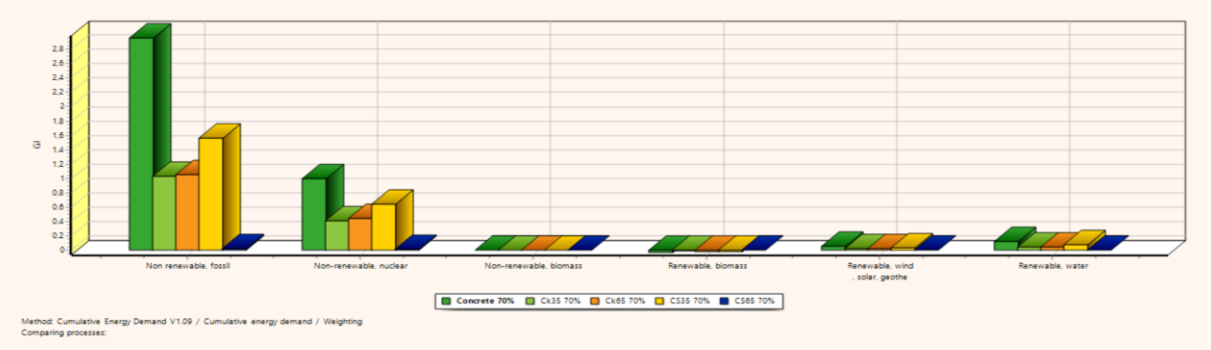
AIM 60 %

The figure and table present the energy analysis of the AIM composites with and without calcined clay.



AIM 70 %

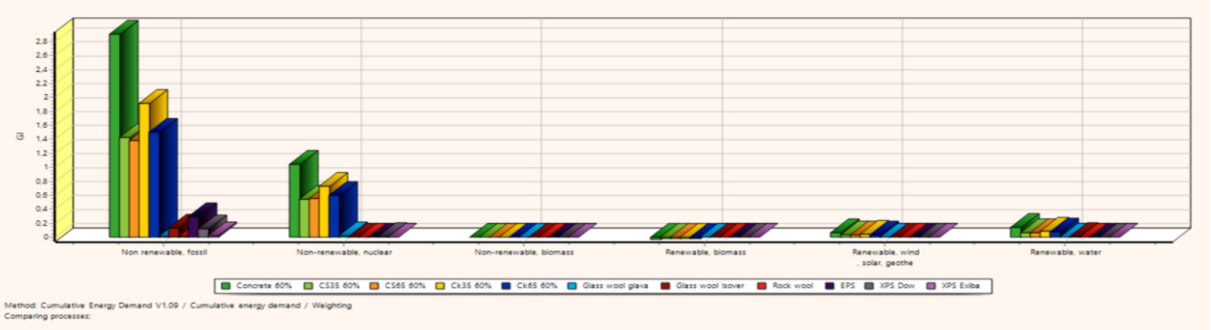
The figure and table present the energy analysis of the AIM composites with and without calcined clay.



AIM & conventional insulation materials

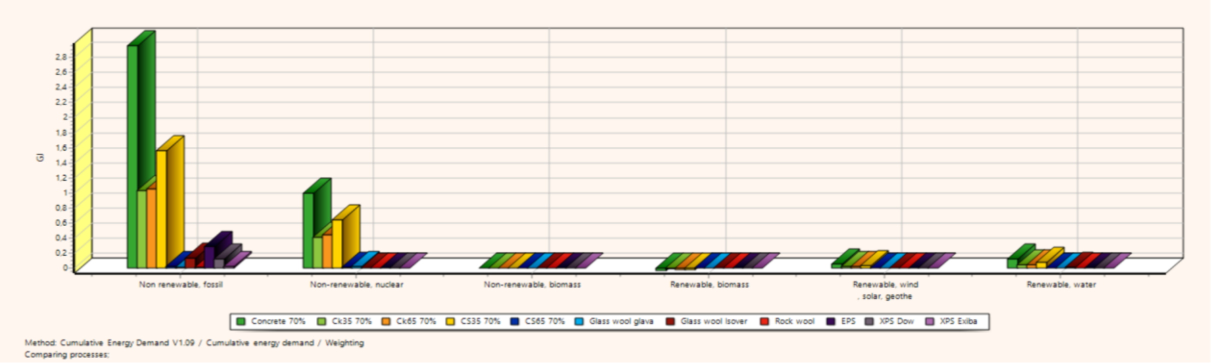
AIM 60%

The figure and table present the energy analysis of the AIM 60% composites with and without calcined clay compared with conventional insulation materials.



AIM 70%

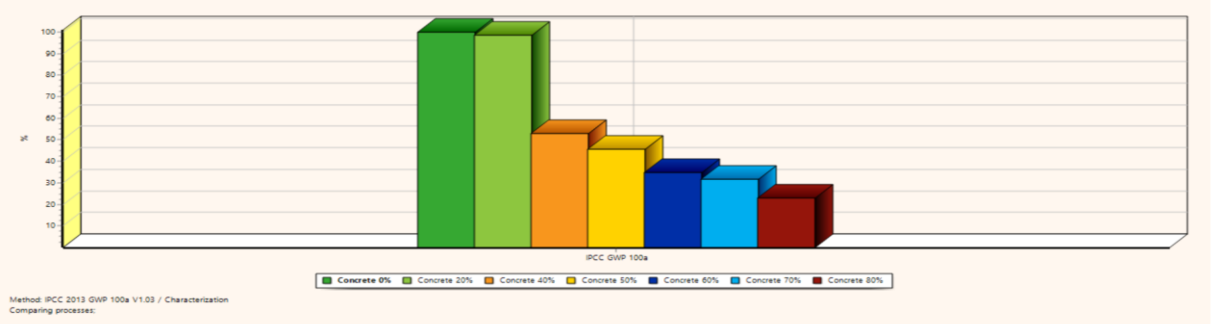
The figure and table present the energy analysis of the AIM composites 70 % with and without calcined clay compared with conventional insulation materials.



CO$_2$ emissions

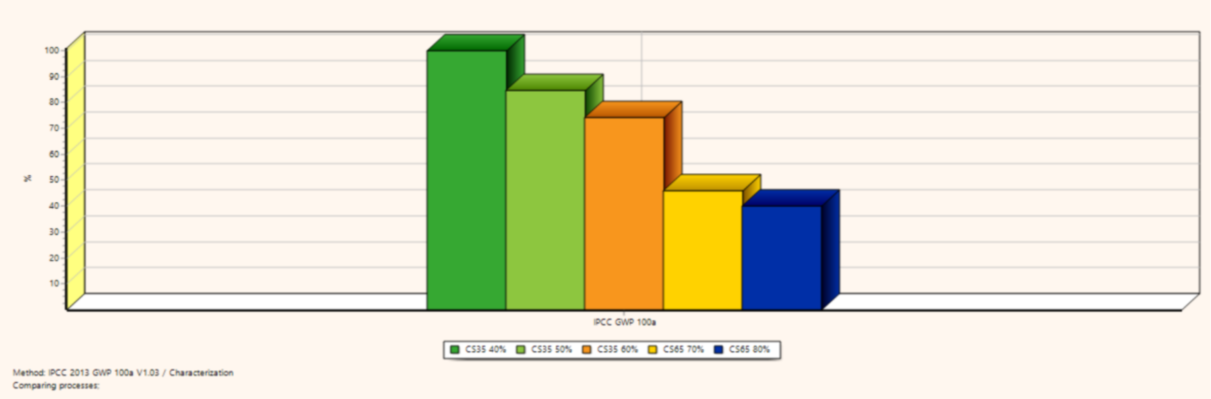
AIM without calcined clay

The figure and table present the energy analysis of the AIM composites



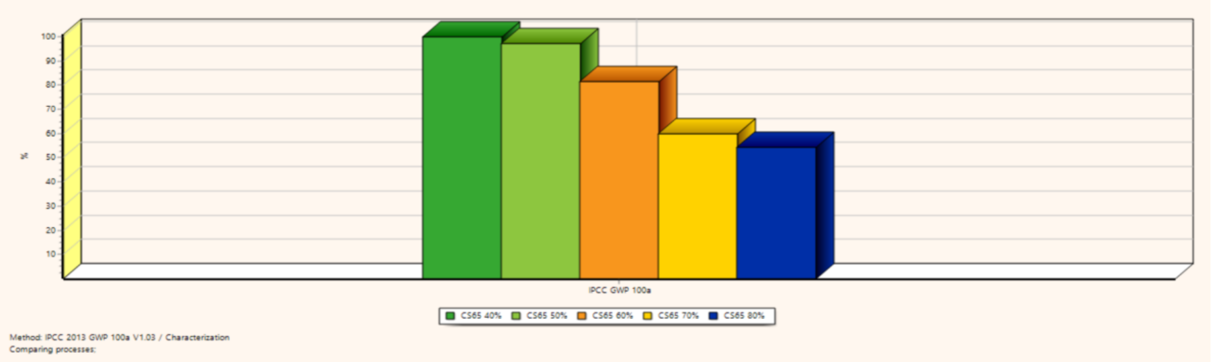
AIM CS 35%

The figure and table present the energy analysis of the AIM composites



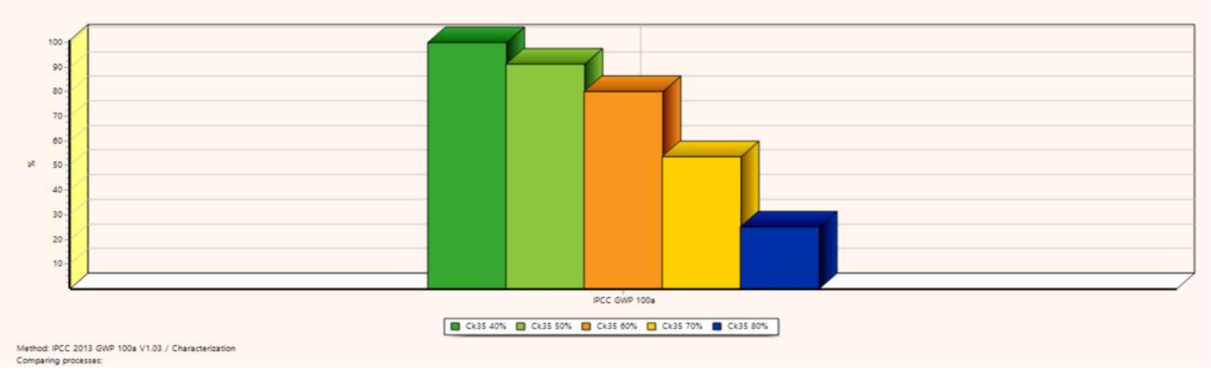
AIM CS 65%

The figure and table present the energy analysis of the AIM composites



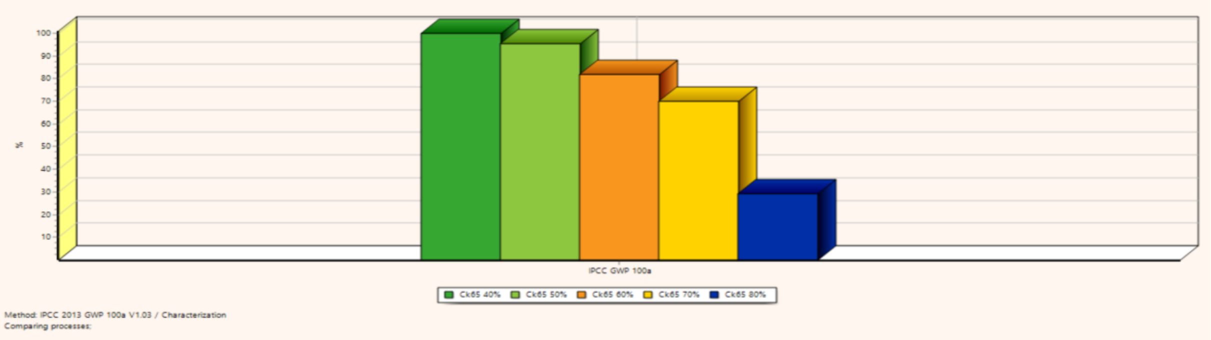
AIM CK 35%

The figure and table present the energy analysis of the AIM composites



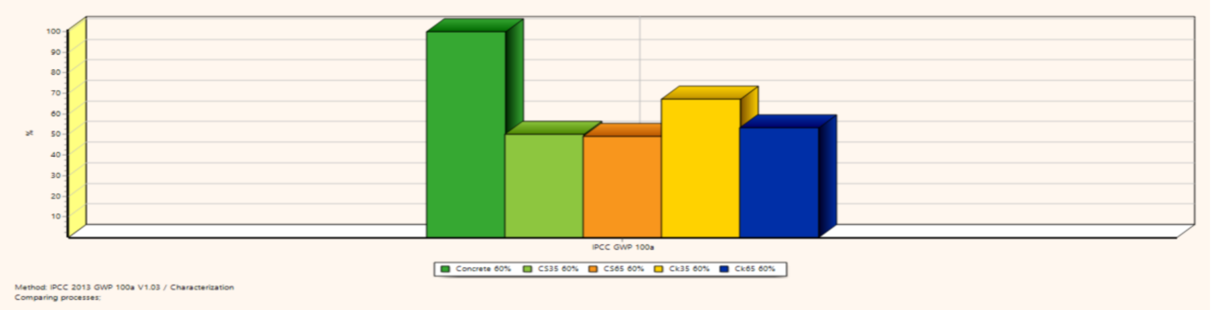
AIM CK 65%

The figure and table present the co2 equivalent analysis of the AIM composites



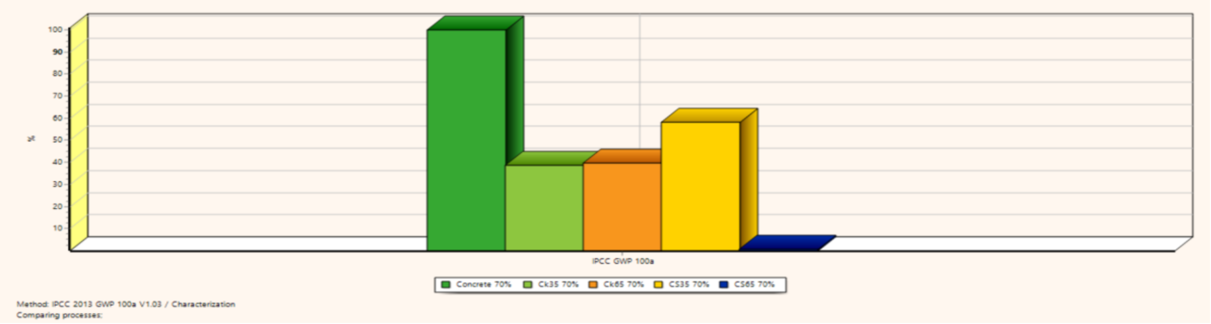
AIM 60 %

The figure and table present the CO_2 equivalent analysis of the AIM composites



AIM 70%

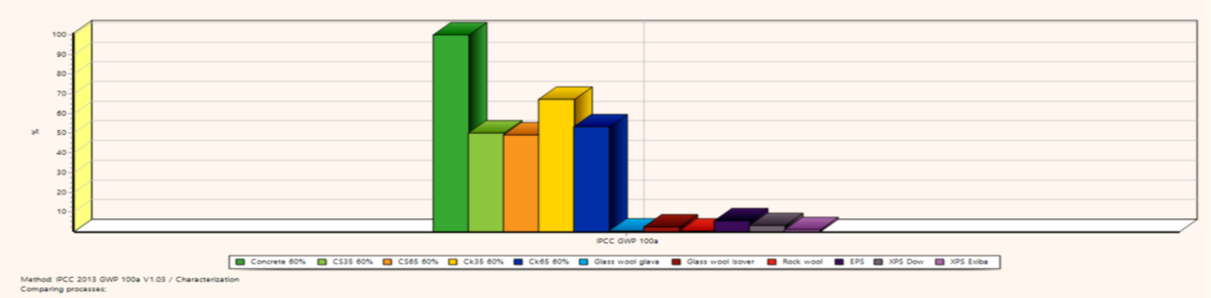
The figure and table present the CO_2 equivalent analysis of the AIM composites



AIM & conventional insulation materials

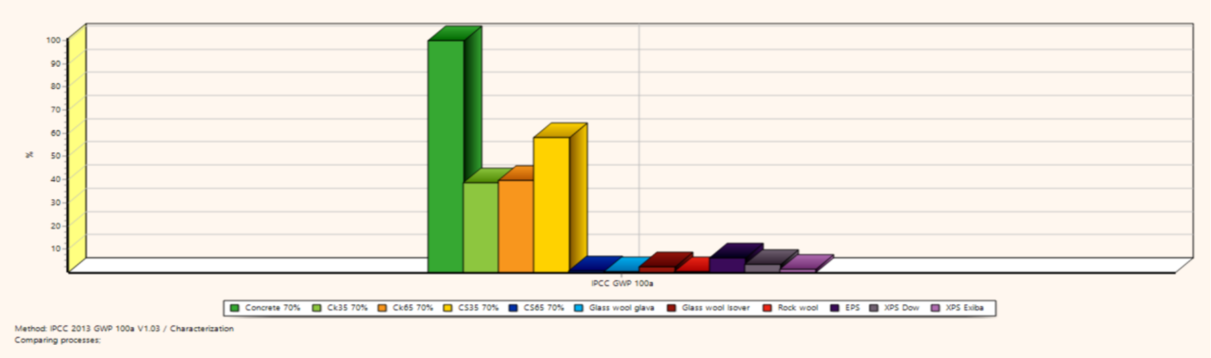
AIM 60%

The figure and table present the CO_2 equivalent analysis of the AIM 60% composites compared with conventional insulation materials.



AIM 70%

The figure and table present the CO_2 equivalent analysis of the AIM 70% composites compared with conventional insulation materials.



4.3 Life cycle impact assessment

There are several available LCIA methods to provide environmental impact analysis such as ILCD 2011Midpoint (39), EDIP 2003 (40), IMPACT 2002+ (40) and ReCiPe 2016 (41). These methods vary across areas such as assumptions made and regional relevancy, which may lead to different LCIA results. But because of gap of environmental impact's data of the AIC composites since they aren't commercial produced, it wont be used any of mentioned methods. The only available data of environmental impact of these composites is energy and emissions. Therefore these two parameters will be considered in this paper. It will be used two single issue methods conduct the energy consumption (IPCC 2013) and CO2 emissions (Cumulative Energy Demand (CED)) of the compared materials. IPCC 2013 contains the climate change factors of IPCC with a timeframe of 100 years. (42). Cumulative Energy Demand (CED) calculate the energy demand of the whole system (43). All calculations are done by excel. Results include the transport of components of AIC to Gjøvik as manufacturing's location. Also, the transport of conventional insulation materials to Gjøvik.

5 Results

6 Discussion

The comparison between the AIM and conventional insulation materials with defined functional unit 1 m2 area insulation and U – value equal 1. The results from LCIA show that incorporating of aerogel into concrete mortars will reduce the energy consumption and CO_2 emissions of the concrete aggregates. The results show that the calcined clay reduce the CO_2 and energy consumption of AIM.

The results from LCIA show that AIM composites have higher CO_2 Emissions than conventional insulation materials. While the AIM composites have lower energy consumption than conventional insulation materials. The AIM is still not comparable with traditional insulation regards the environmental impact. The difference in environmental impact is high because of the high environmental impact compared to the traditional insulation materials. The AIM composites with aerogel content 70 % or higher have better thermal conductivity than concrete, but the environmental impact increase extremely.

6.1 Completeness check

The energy mix is based on hydropower which is used in Norway (44). The energy consumption data in the LCA should be inserted based on this mix.

The calcined clay which is used in this study isn't commercial product. Because of that it has no environment product declaration. The used environmental impact data of calcined clay is theoretical data received from the supplier of this material. The received data is 3 / 400 kg CO_2 emissions each ton of calcined clay. It is not exact value but can be used in research. The producer will try reducing the CO_2 emissions to zero. There is no data about other waste or emissions from the producer. The lack of data about other emissions or waste of calcined clay will affect the reliability of the results of this study. Because the comparison will not cover all parameters of the materials.

There is gap in environmental impact data of Aerogel from the producers. The only available data is the energy consumption and CO_2 emissions from one producer. The data is old and isn't updated. The author has contacted several producers to get new data, but didn't get result.

6.2 Consistency checks

The data of used traditional insulation material for comparison are retrieved from the EPDs. the data from the databases is ideal and don't cover the difference between the producers regards the energy mix, waste treatment or environmental-friendly technology. While the data from EPDs are more reliable and presis data of the production

6.3 Sensitivity check

The allocation of emissions from production of Silica fume will affect the result. As shown in the LCI, The European silica fume producers allocate all greenhouse gas emissions to the main product silicon and ferrosilicon since the entire Si / FeSi include by – products are covered by EU carbon leakage list. The silica fume is co - product of silicon production and has lower economic value. In the other hand, the silica fume as commercial product can be considered environmentally based on the distribution of economic value. In this paper, the allocation of emissions and energy consumption follow the allocation rules in EU.

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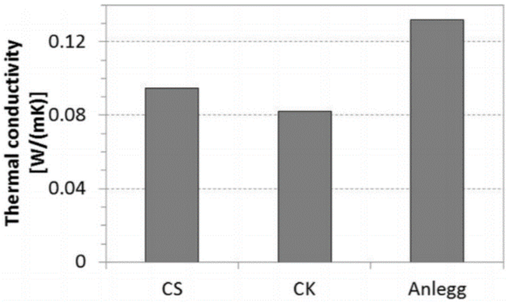

6.4 Replacement of calcined clay

The partial replacement of Portland cement with calcined clay decrease thermal conductivity of the AIM, While It increase environmental impact of AIM. The main reason for this decreasing of thermal conductivity is that the calcined clay has lower thermal conductivity than anlegg cement (5). The figure shows the thermal conductivity of the used two types calcined clay and the cement.

6.5 The incorporating of Aerogel

Aerogel incorporating

The aerogel has low thermal conductivity around 0.015 $W.m^{-1}.K^{-1}$. Because of that it is defined as very good insulator but the luck of the mechanical strength makes a big challenge to use it as alternative to the insulation panels. Incorporating aerogel to the concrete will make a composite with higher mechanical strength which can be used to replace the insulation panels and low thermal conductivity as well. The aerogel concrete composites with amount aerogel over 60 % show very low thermal conductivity as well as low mechanical strength. Based on that, these composites can substitute the traditional insulation panels in the walls.

The main challenge from the sustainable view is to use AIC commercially as alternative to traditional insulation panels is the huge environmental impact of these composites. The production of concrete in general has lower negative impact than production of conventional insulation materials, but the aerogel based on the available data from producers has responsibly high emissions and energy consumption than traditional insulation materials (10) (Figure).

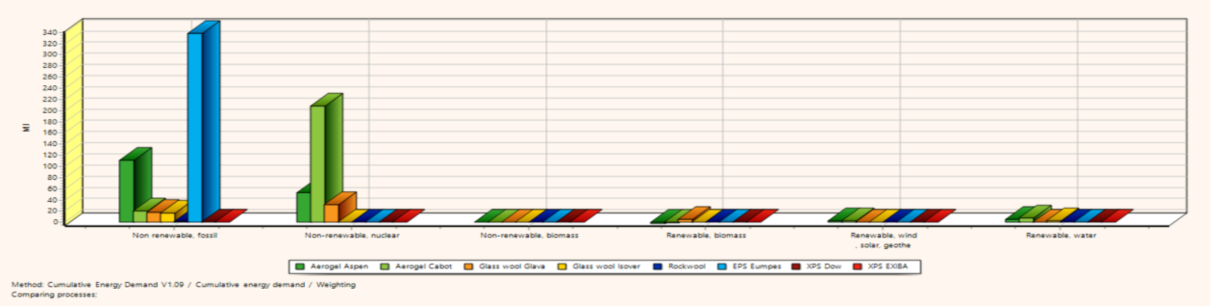

Figure 4 comparison of aerogel and conventional insulation materials

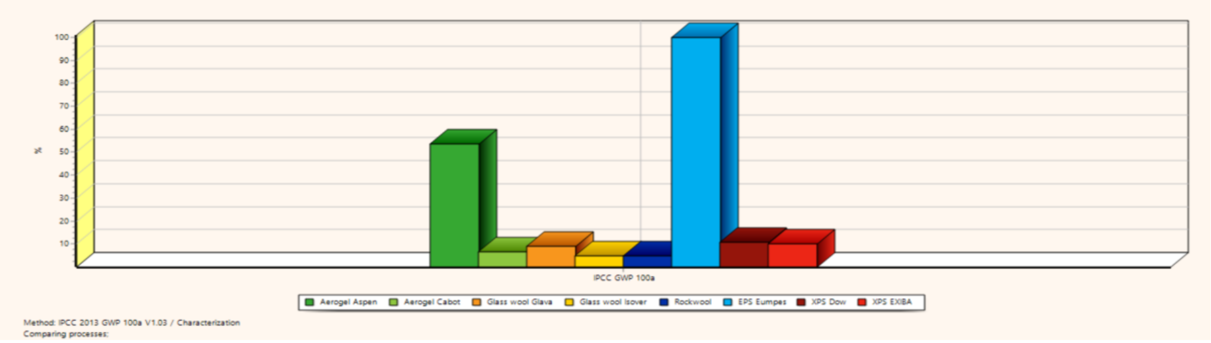

Figure 5 comparison of aerogel and conventional insulation materials

In this case, the composites with aerogel contents 60 % or more will not be comparable with conventional insulation materials. The figure show that the main effect of aerogel production to the human health is from the electricity consumption in the manufacturing processes. Because of that the resource of electricity is critical for assessment of environmental impact of aerogel production. The progress in developing environmental friendly production of aerogel is critical for commercial using of these composites as alternatives to insulation walls. Another producer of Aerogel assumes that there is no emissions of there Aerogel production and the main waste is water which will be recycled (32)

Conclusion

The Calcined clay - AIM composites have higher environmental impact than traditional insulation materials. The main cause for this difference of environmental impact is the high energy consumption and CO_2 emissions of aerogel production. The progress in developing environmental friendly production of aerogel is critical for commercial using of these composites as alternatives to insulation walls.

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Energy and greenhouse gas assessment of MKP as multifunctional building material

Abstract

The Magnesium potassium phosphate ceramic (MKP) as a chemical bounded phosphate ceramic has low thermal conductivity and god mechanical strength. The research in chemical bounded phosphate ceramic show that by adding the Fly Ash to this phosphate ceramic will make a new composite with better mechanical strength. The Magnesium potassium phosphate ceramic – Fly Ash (MKP - FA) as a material with god mechanical strength and low thermal conductivity can substitute the insulation panels in the walls. The incorporating of aerogel will decrease the thermal conductivity to be comparable with insulation materials. In this paper, it is going to do a life cycle assessment of the (MKP – FA - Aerogel) and compare it with traditional insulation material. The (MKP – FA) can be more sustainable alternative for traditional insulation materials if It has lower environmental impact than traditional insulation materials.

Keywords: Monopotassium phosphate, Life cycle assessment, thermal conductivity, Aerogel, Fly ash,

1 Introduction

The thermal insulation is very important concept for the building industry. The buildings consume a lot of energy to regulate the inside climate of the building. The thermal insulation will hinder the thermal transfer between the inside and outside climate (1, 2). Consequently, the thermal insulation reduces the energy consumption of the buildings (3). The reduction of energy consumption will reduce the resources consumption and emissions from power generation. Based on that the thermal insulation support the sustainable development approach in building industry. The sustainable development is defined in (our common future report) as *development which meets the needs of the current generation without compromising the need of the next generations* (4). The Sustainable development concept has got more attention today, because of the increasing of risks on the future of this world (4). The building industry is one of the important sectors which consider the sustainable development of their business. The building industry has made huge progress forward to achieve the sustainable development. It has been developed some approaches to make the buildings more sustainable like smart grid, low- emissions housing and zero emissions house. The aim is to reduce the energy consumption and emissions of the buildings.

Thermal insulation is the protection of buildings from thermal loss outwardly. It can be used to hold the temperature inside the building (either cold or hot). It can be used in many countries with different weather. The thermal loss causes when it happens a temperature difference over material or construction; then it becomes a heat transfer between the hot side to the cold side. That main way to the insulation of building is to set a suitably thick layer of material which has low thermal conductivity (3) . That will reduce thermal transfer outward or inward. The building materials were mainly focused in this field because the properties and the specifications of these materials (1) have a high influence on the sustainability performance of buildings. Materials which have low thermal conductivity are more sustainable than materials with high thermal conductivity. The low thermal conductivity will reduce the need for the inside climate regulation (heating or cooling). The energy consumption of inside climate regulation will be reduced (3).

The thermal insulation can be defined as sustainable technology because of this reducing of energy consumption. Although it is possible to improve the sustainable performance of choose an Eco or recycle material, an environment-friendly productions method and secure social workers.

There were previous attempts to develop building materials with low thermal conductivity to reduce the negative environmental impact of the buildings (5). NTNU & Sintef have corporate in research to develop new construction composite materials with low thermal conductivity by incorporating inorganic materials and other additives to the traditional concrete. The main focus was to develop materials which have a low thermal conductivity and meet the mechanical strength requirements of concrete as well (6).

The AIC composite in the NTNU research consist of traditional components of concrete such as water, cement, and sand. Then incorporate the Aerogel in the concrete samples. The contents of aerogel in samples will be increased gradually from 10 % to 60%. After preparing the samples in a standard Hobart 2-litre mixer. The samples will be scanned the structure of particles. Then some tests will be done to measure the density, thermal conductivity, compressive strength and flexural strength of the samples. Finally draw graphs which show the change in the characterization based on the increasing of aerogel content of sample.

Further, the research in this paper focus on using these composite materials as more sustainable alternatives to the traditional insulation materials. The main idea of this research project is to compare the environmental impact between the insulation composite material AIC which are studied in NTNU and Sintef with traditional insulation materials as organic like Polyurethane (EPS) or polystyrene (XPS) or inorganic like mineral wool. The main aim is to find if this new insulation composite has a less environmental impact than the traditional insulation materials which achieve the same thermal insulation. The traditional thermal insulation materials like cellulose, EXPs, polystyrene foam, urethane foam are organic materials which has negative environmental impact during their production phase. In this paper, it will be comparison of the environmental impact during their production phase of these traditional materials with the new composite AIC.

2 Literature review

The corresponding literature can be divided into two areas: previous LCA of insulation materials, study of inorganic materials Aerogel & Fly Ash, the previous literature of CBPS.

2.1 Literature focusing of environmental impact of insulation materials

There are several LCA studies of insulation materials to determine the environmental impact of the insulation materials. Pargana at university of Lisboa presented a comparative environmental life cycle assessment of thermal insulation materials of buildings (7). The study is based on the LCA ISO standards (8) and compare many types of insulation materials like Expanded cork agglomerate (ICB), Extruded polystyrene (XPS) and Expanded polystyrene (EPS). The study results are preformed in “cradle to gate” (9). Another research is a LCA study of transparent aerogel analyze the environmental impact of aerogel done by Mark DOWSON at the University of Bath. The study shows that aerogel as a good insulation material and has responsibly high emissions and energy consumption of their production than traditional insulation materials (10). Although, Other LCA studies include the inorganic materials. Schiavoni at University of Perugia include the aerogel and stone wool as a good insulation material to their LCA study (11). There are also other researches presents composite materials like chemically bonded phosphate ceramics (12), permafrost cement as a new phosphate based cement for using in very cold countries (13).

2.2 A Study of inorganic materials

2.2.1 A study of Aerogel

Aerogel is a synthetic porous ultralight material. Aerogels are formed by removing the liquid from a gel under special drying conditions, bypassing the shrinkage and cracking experienced during ambient evaporation. Aerogel was invented as quite revolutionary solid-state materials contents 90 % air. The aerogel have extremely low density and better physical properties (14), especially for many applications of aerogel like thermal insulation, acoustical insulation (15), or transparent to light or solar radiation (16, 17). The material can be produced in monolithic or granular form (10, 15). There are different types of aerogel: silica aerogel, carbon aerogel, and metal oxide aerogel. The aerogel is the most used type of insulation composite materials (15).

Silica aerogels are lightweight and highly porous materials, with a three-dimensional network of silica particles. The silica aerogel produces by extracting the liquid phase of silica gels under supercritical conditions (15, 18). Silica has promising characteristics, such as extremely low thermal conductivity, low density, high porosity and high specific surface area (15, 18, 19). Based on these characteristics, the aerogel has excellent potential application for thermal insulation (6, 20-22). Silica aerogels are known as the best known thermal insulating materials with thermal conductivity around 0.015 $W.m^{-1}.K^{-1}$ at ambient temperature and pressure (23). Additionally, Silica aerogels present further advantages such as good fire, acoustic resistance(15), resistance to moisture, waterproofing and self-cleaning properties, corrosion protection, UV reflection, durability (15, 22, 24).

2.2.1 A study of Fly ash

Fly Ash is the finely divided residue from the combustion of pulverized coal in the power generation or factories. The most amounts of Fly ash in the world today is a waste from a coal-fired electric and steam generating plants (25). The huge consumption of coal in the power generation release million tons of Fly ash. Because of that The fly ash is the world's fifth largest raw material resource (26). Fly ash consists primarily of oxides of silicon, aluminum iron and calcium. Magnesium, potassium, sodium, titanium, and sulfur (27). Fly ash has significant environmental benefits when its incorporates to concrete as: Increasing the life of concrete by improving concrete durability, reduction in energy use and greenhouse gas when fly ash is used to replace or displace manufactured cement, reduction in amount of coal combustion products that must be disposed in landfills, and conservation of natural resources and materials (28), (29).

2.3 Chemically bonded phosphate ceramic

The chemically bonded phosphate ceramics (CBPCs) combine some advantages from both types of cement and conventional ceramics. CBPCs are synthesized by chemical reactions, most of them at ambient conditions. The main types are magnesium phosphate, aluminum phosphate, and iron phosphate ceramics.

The CBPCs is developed as materials which have middle properties between the sintered ceramics and the cement. The sintered ceramics have superior mechanical properties and ceramics are far more stable in acidic and high-temperature environments. While the traditional cement like Portland cement is an inexpensive product and be used in high volumes, however. The CBPCs can fulfill this need. The

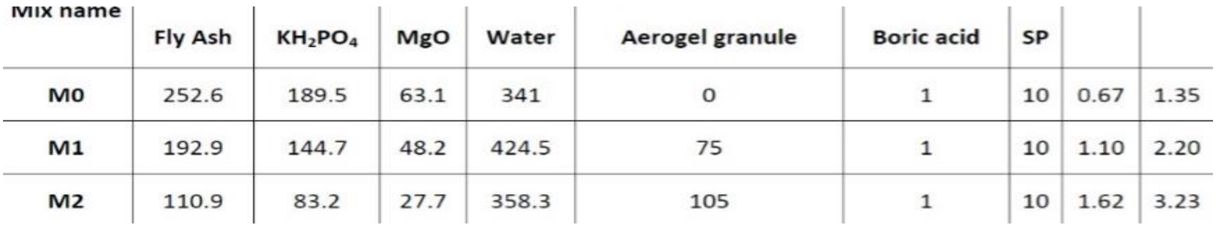
CBPC is produced by controlling the solubility of the oxide in the acid-phosphate solution. Oxides or oxide minerals of low solubility are the best candidates to form CBPCs because their solubility can be controlled easily (8).

Wagh and his research group developed the new composite Magnesium potassium phosphate ceramic by reacting the oxide with monopotassium phosphate in an aqueous solution.

3 Material

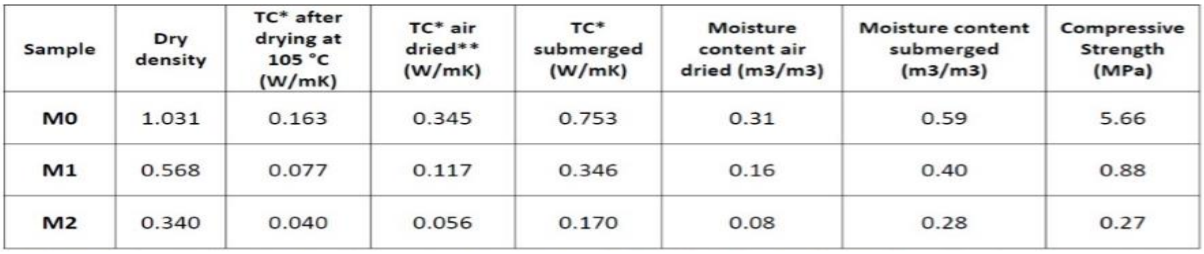
Wagh and his research group developed the new composite Magnesium potassium phosphate ceramic by reacting the oxide with monopotassium phosphate in an aqueous solution. Then the composite can have better mechanical strength by mixing the fly ash within the mixture. The compressive strength of this new composite is in range from 55 to 83 MP. While the new composite has high thermal conductivity. Further more to get a composite with lower thermal conductivity, the Aerogel was incorporated to the new composite research as shown in the table.

Tabell 1 MKP compositions



Mix name	Fly Ash	KH_2PO_4	MgO	Water	Aerogel granule	Boric acid	SP		
M0	252.6	189.5	63.1	341	0	1	10	0.67	1.35
M1	192.9	144.7	48.2	424.5	75	1	10	1.10	2.20
M2	110.9	83.2	27.7	358.3	105	1	10	1.62	3.23

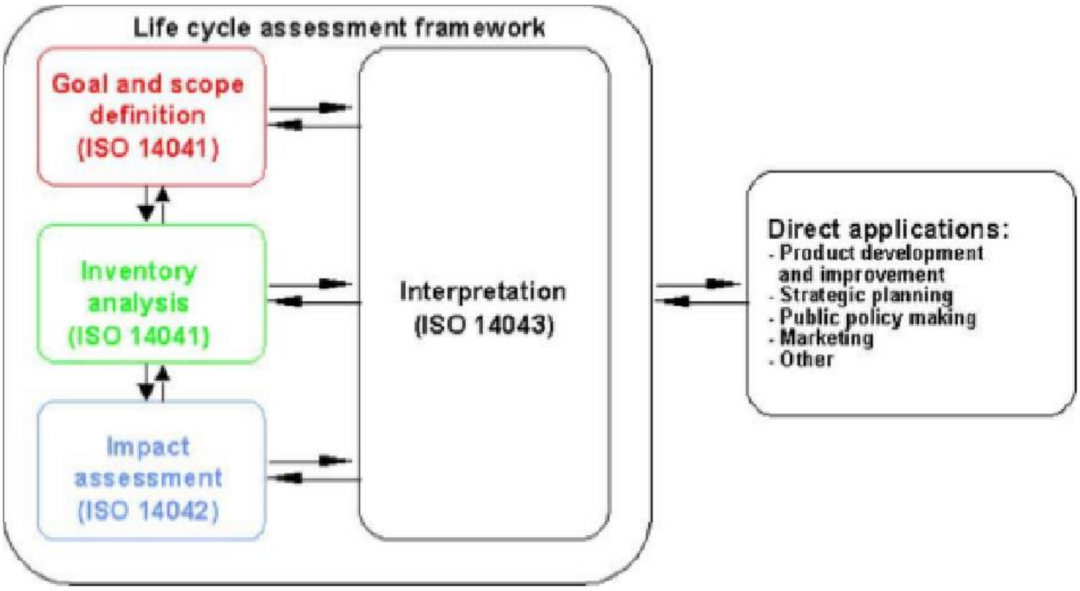
Tabell 2 MKP Density & thermal conductivity



Sample	Dry density	TC* after drying at 105 °C (W/mK)	TC* air dried** (W/mK)	TC* submerged (W/mK)	Moisture content air dried (m3/m3)	Moisture content submerged (m3/m3)	Compressive Strength (MPa)
M0	1.031	0.163	0.345	0.753	0.31	0.59	5.66
M1	0.568	0.077	0.117	0.346	0.16	0.40	0.88
M2	0.340	0.040	0.056	0.170	0.08	0.28	0.27

4 Method

Life cycle assessment (LCA) is a method to analyze environmental aspects and impacts of product systems. LCA aims at comparing and analyzing the potential environmental impacts of given products and services at every stage of their life. The ISO 14040 and 14044 are related standards to preform LCA. The methodology in this part is based on these standards.



4.1 Goal and scope

This analysis aims to compare the production of the MKP - FA composites with some conventional insulation materials to conduct which insulation material is the best environment – friendly.

There are many research focuses on the environmental performance of buildings based on thermal efficiency. Although some researches focus on environmental impact of production. In this analysis, it will be focus on environmental impact of production of insulation materials.

The functional unit for this research is performed as it performed in the most life cycle assessment (LCA) studies of insulation solutions. the functional unit (f.u.) was defined as the mass (kg) of insulation board that provides a thermal resistance R of 1 (m2 K/W)

The functional unit of this research is the mass of the insulation material for 1 m^2 area with a thickness ensure R-value R = 1 m^2 K/ W.

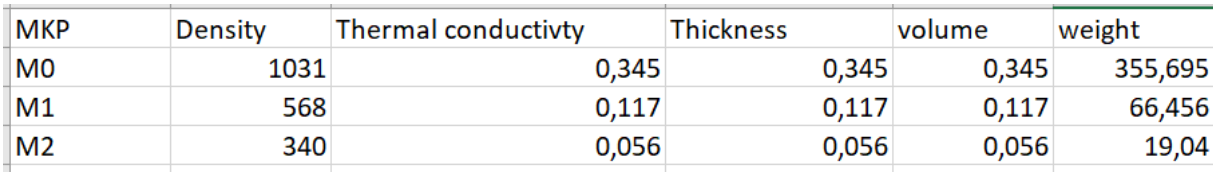
F.U = R.λ.*p.A (Kg)*

Where R represents the thermal resistance as 1 (m^2 K)/W, λ represents the thermal conductivity measured as W/(m*K), U represents the thermal transmittance as W/(m^2*K). A represents the defined area in the functional unit as 1 m^2, F.U corresponds to the used weight of the compared composite material, P represents the density of the insulation product in kg/m3, and V represents the volume of the compared composite in M^3.

Then in the next sections it will be presented the F.U (Kg) for the studied composite materials: conventional insulation materials, MKP – FA. The data of conventional insulation materials are retrieved from EPDs and also from databases in Simapro

The retrieved data for conventional insulation material required R = 1. By substitution with the formula 1,2,3, the U . value will be defined as 1. Then the thickness of AIC material calculates by formula (1). Then the volume of the AIC material will be calculated by formula (2). Then the weight will be calculated by the formula (3). The calculation is done on excel sheet and the table dawn show the results.

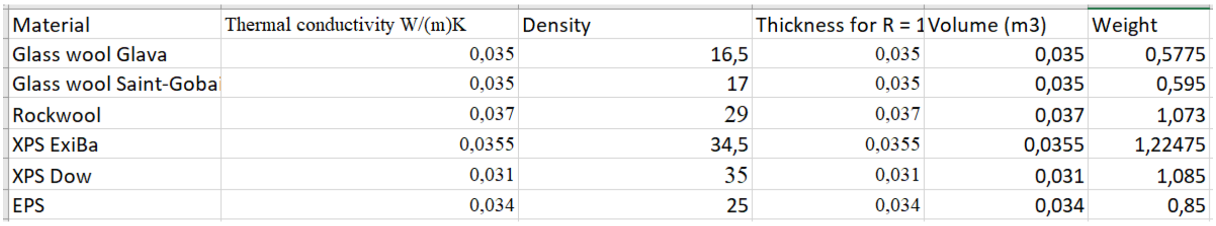
Tabell 3 MKP Air dry



MKP	Density	Thermal conductivty	Thickness	volume	weight
M0	1031	0,345	0,345	0,345	355,695
M1	568	0,117	0,117	0,117	66,456
M2	340	0,056	0,056	0,056	19,04

The weight of the conventional insulation materials will be calculated by the formula (2) and (3). The table down show the results

Tabell 4



Material	Thermal conductivity W/(m)K	Density	Thickness for R = 1	Volume (m3)	Weight
Glass wool Glava	0,035	16,5	0,035	0,035	0,5775
Glass wool Saint-Goba	0,035	17	0,035	0,035	0,595
Rockwool	0,037	29	0,037	0,037	1,073
XPS ExiBa	0,0355	34,5	0,0355	0,0355	1,22475
XPS Dow	0,031	35	0,031	0,031	1,085
EPS	0,034	25	0,034	0,034	0,85

The system boundary is defined as “cradle-to-gate” model (9). The model includes the upstream processes such as raw material acquisition, transport, and production. The downstream processes such as operation, maintenance and use are excluded from the LCA. Fig. 2 represents the system boundary of MKP - FA.

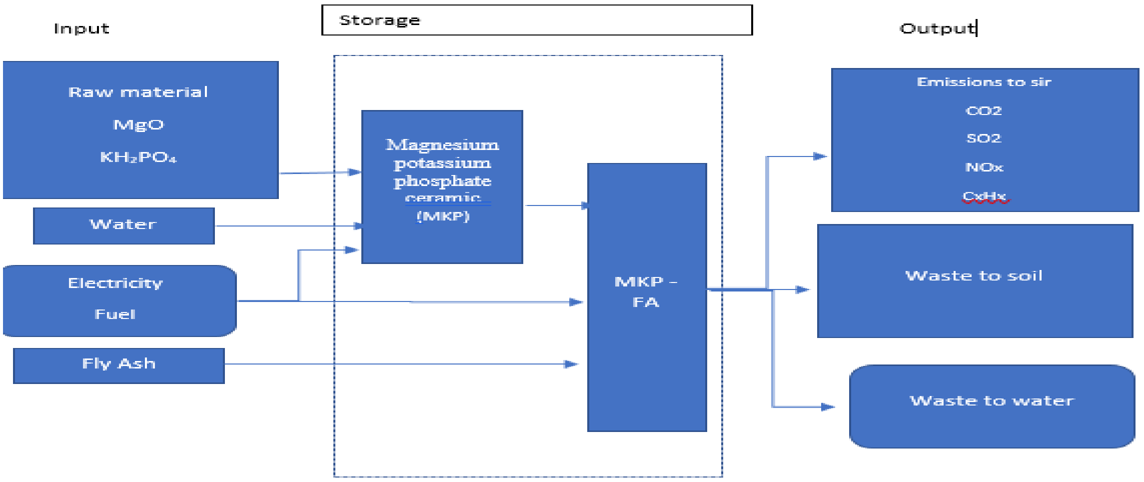


Figure 1 system tree of MKP

4.2 Life Cycle inventory of MKP - FA

4.2.1 Acquisition and collection of MKP -FA inventory data

The components of MKP – FA composites are Fly ash, magnesium oxide, phosphate salt, SP plasticizer and aerogel particles. The environmental impact data of magnesium oxide, water and phosphate salt is retrieved from databases in Simapro. The producers are contacted to get data about environmental impact of their products (production) or environmental product declaration. The most data of materials are received from the companies while the data of other materials are retrieved from some LCA databases based on availability and replies from the companies. There are many LCA databases which can be used to get data like Ecoinvent (30), European Life Cycle Database (ELCD) (31), Inventory of Carbon and Energy (ICE) (). The last two databases are the most popular and authoritative inventory databases in the world and was presented by European Commission. There are also some data retrieved from previous studies and research. The LCA is done by Simapro based on method (32).

There are two views of the environmental impact of fly ash; first, the fly ash as a waste product which needs to be treated and in this case no need for the environmental impact data. the second, the Fly ash as co-products from power production. In this case, the environmental impact will be distributed based on the economic value. In this paper, the fly ash will be defined as waste because of the huge amount of fly ash from the power generation in the world to day.

The data of silica aerogel is retrieved from the three manufacturers: Aspen, Cabot and Svenska aerogel. There are few producers of aerogel granules in the world and they don't want to share the information about the production. Therefore, there is no EPD of aerogel production. the data of aerogel is received from the producers. Aspen claims that its production energy is 53.9 MJ/kg and its CO2 burden is 4.3 kgCO2/kg (33).

The sustainability report of Cabot Aerogel presents the energy intensity and emissions intensity of their production. The data from the Cabot isn't a big different from the data from Aspen which are mainly used in the LCA. The data are 63,9 MJ/ kg aerogel, 0,17 kg CO_2 / Kg aerogel (34).

According to Svenska Aerogel: "*No negative environmental impact. In production, large amounts of water are used. The production waste water has a somewhat higher salinity. The waste water is circulated and reused in further production*" (35). Svenska Aerogel is another producer of Aerogel assumes that there is no emissions of there Aerogel production and the main waste is water which will be recycled (35).

4.2.2 Acquisition and collection of transport inventory data

The production location of MKP - FA is defined as the same NTNU site here in Gjøvik. Because the MKP- FA is still not a commercial produced. The used databases for transport inventory data is Ecoinvent. The components of MKP are retrieved from databases while the fly ash is available and cheap material, therefore it won't be considered any transport data for them. The aerogel is the only component where the transport data will be considered.

aerogel	Frankfurt	1418

Figure 2 transport of aerogel

4.2.3 Acquisition and collection of conventional insulation materials inventory data

The environmental impact data of conventional insulation materials are retrieved from Environmental product declarations of these materials. The EPDs are done based on model "cradle to gate" which is considered in this analysis. The EPDs are attached in the appendixes.

Tabell 5 conventional insulation materials

Material	Producer	EPD part	Declaration nr	Reference
Glass wool	Glava	EPD- Norway	NEPD 221N	(36)
	Saint-Gobain	EPD- Norway	NEPD 00244E	(37)
Rockwool	Rockwool	EPD- Norway	NEPD 00131 revisjon 1	(38)
XPS	ExiBa	IBU	ECO-XPS-010101-1007	(39)
	DOW	IBU	EPD-DOW-2013111-D	(40)
EPS	EUMEPS	IBU	EPD-EPS-20130078-CBG1-EN	(41)

4.2.4 Acquisition and collection of transport inventory data

The production location of AIC is defined as the same NTNU site here in Gjøvik. Because the AIC is still not a commercial produced. The environmental impact data of transport of the AIC components are retrieved from the Simapro. The table 7 show the distance between AIC production site (Gjøvik) and manufacturing location of the conventional insulation material.

Tabell 6 distance of conventiona insulation materials to Gjøvik

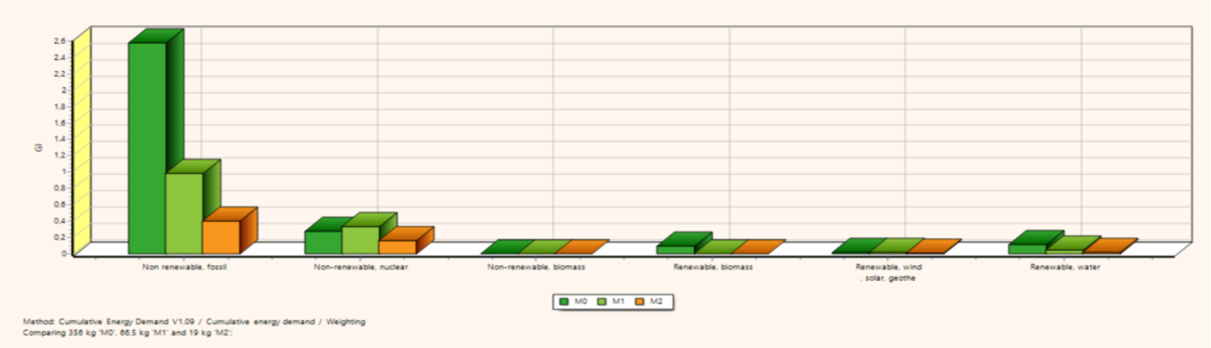
Material	Location	Distanse	Truck	skip	Total (Km)
Silica fume	Kristiansand	430	430	0	430
cement	Brevik / Norway	286	286	0	286
sand	Finland	1223	1223	0	1223
aerogel	Frankfurt	1418	1418	0	1418
water	Gjøvik	0	0	0	0
SP	Sagstua	107	107	0	107
aerogel aspen	Rhode island / USA	7624	1214	6410	7624

4.3 Life cycle impact assessment

There are several available LCIA methods to provide environmental impact analysis such as ILCD 2011Midpoint (42), EDIP 2003 (43), IMPACT 2002+ (43) and ReCiPe 2016 (44). These methods vary across areas such as assumptions made and regional relevancy, which may lead to different LCIA results. But because of gap of environmental impact's data of the AIC composites since they aren't commercial produced, it wont be used any of mentioned methods. The only available data of environmental impact of these composites is energy and emissions. Therefore these two parameters will be considered in this paper. It will be used two single issue methods conduct the energy consumption (IPCC 2013) and CO2 emissions (Cumulative Energy Demand (CED)) of the compared materials. IPCC 2013 contains the climate change factors of IPCC with a timeframe of 100 years. (45). Cumulative Energy Demand (CED) calculate the energy demand of the whole system (46). All calculations are done by excel. Results include the transport of components of MKP - FA to Gjøvik as manufacturing's location. Also, the transport of conventional insulation materials to Gjøvik.

5 Results

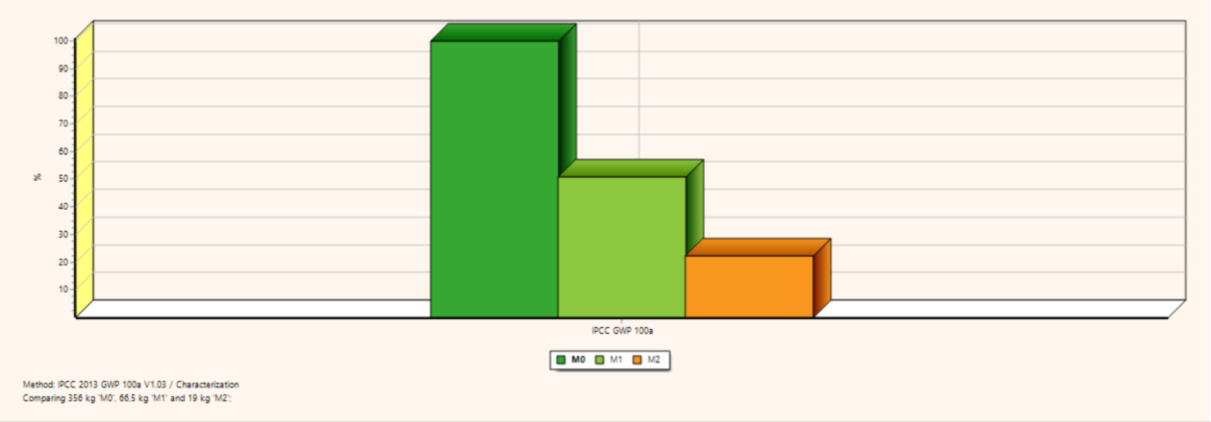
Figure 4 presents the energy consumption of MKP - FA composites based on aerogel content.



Method: Cumulative Energy Demand V1.09 / Cumulative energy demand / Weighting
Comparing 356 kg 'M0', 66,5 kg 'M1' and 19 kg 'M2';

Figure 3 the required energy consumption to produce the F.U amount of MKP - FA

Figure 5 presents the CO_2 emissions of MKP - FA composites based on aerogel content.



Method: IPCC 2013 GWP 100a V1.03 / Characterization
Comparing 356 kg 'M0', 66,5 kg 'M1' and 19 kg 'M2';

Figure 4 The released CO_2 emissions of production of the F.U amount

Figure 4 presents required energy consumption to produce the F.U amount (Kg) of compared materials

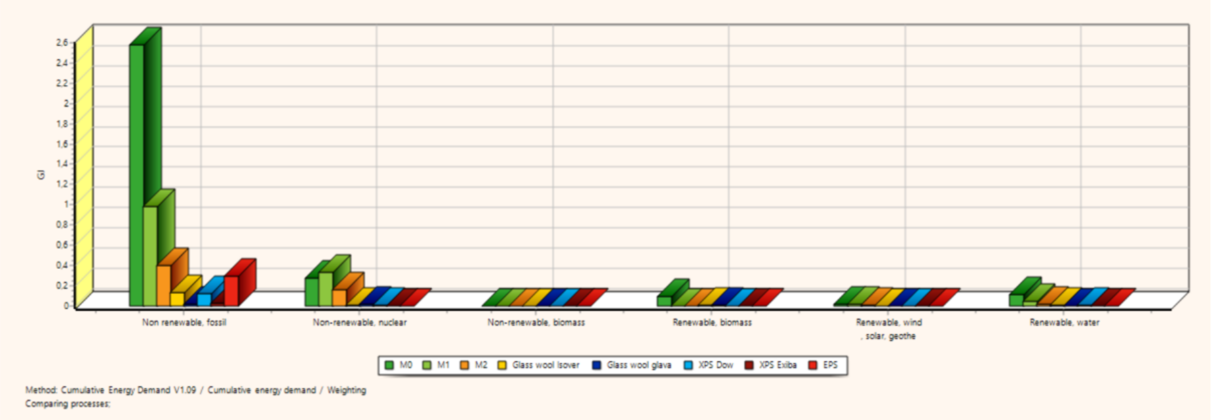


Figure 7 the required energy consumption to produce the F.U amount of compared materials

Figure 8 presents the CO_2 emissions of to production of the F.U amount (Kg) of compared materials.

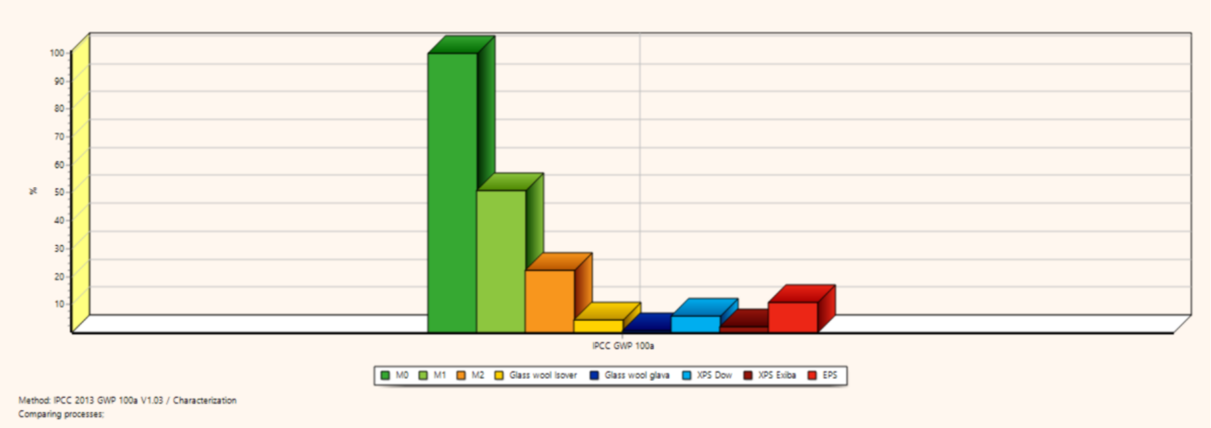


Figure 5 the CO_2 emissions of to production of the F.U amount (Kg) of compared materials.

6 Discussion

The comparison between the MKP - FA and conventional insulation materials with defined functional unit 1 m2 area insulation and U – value equal 1. The results from LCIA show that incorporating of aerogel into MKP - FA will reduce the environmental impact of the concrete aggregates. The results from LCIA show that MKP - FA composites have higher environmental impact than conventional insulation materials.

6.1 Completeness check

The energy mix is based on hydropower which is used in Norway (47). The energy consumption data in the LCA should be inserted based on this mix.

There is gap in environmental impact data of Aerogel from the producers. The only available data is the energy consumption and CO_2 emissions from one producer. The data is old and isn't updated (33). The author has contacted several producers to get new data, but didn't get result.

6.2 Consistency checks

The data of used traditional insulation material for comparison are retrieved from the EPDs. the data from the databases is ideal and don't cover the difference between the producers regards the energy mix, waste treatment or environmental-friendly technology. While the data from EPDs are more reliable and paresis data of the production.

The environmental impact data of chemical components (MgO, KH_2PO_4) of MKP are retrieved from the databases. the data from the databases is ideal and don't cover the difference between the producers regards the energy mix, waste treatment or environmental-friendly technology.

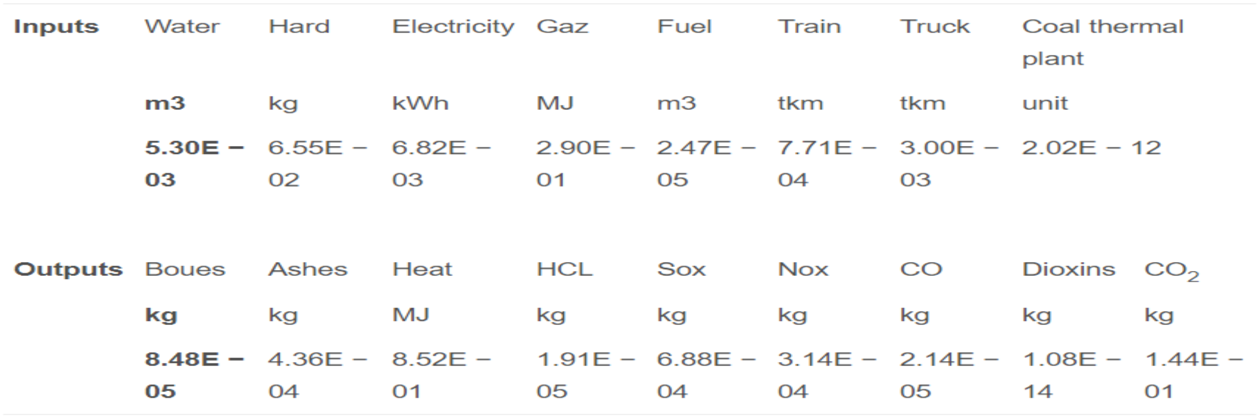
6.3 Sensitivity check

There are two views of allocation of the environmental impact of fly ash; first, the fly ash as a waste product which needs to be treated and in this case no need for the environmental impact data. the second(26), the Fly ash as co-products from power production. In this case, the environmental impact will be distributed based on the economic value. If the consumption of fly ash becomes too high that it becomes necessary to produce it for replacement of Portland cement, then its sustainability advantages are lost, because then the impacts of the production of fly ash becomes nearly equal to the production of Portland cement.

6.4 Fly Ash – incorporating

There are two views of the environmental impact of fly ash; first, the fly ash as a waste product which needs to be treated and in this case no need for the environmental impact data. the second, the Fly ash as co-products from power production. In this case, the environmental impact will be distributed based on the economic value. The table 2 show the input and output from the Fly Ash when the environmental impact of fly ash is distributed based on the economic value. Figure 5 show the comparison between the fly ash as waste product & Fly ash where the environmental impact is distributed based on the economic value.

Tabell 7 environmental impact of fly ash is distributed based on the economic value



Inputs	Water	Hard	Electricity	Gaz	Fuel	Train	Truck	Coal thermal plant	
	m3	kg	kWh	MJ	m3	tkm	tkm	unit	
	5.30E – 03	6.55E – 02	6.82E – 03	2.90E – 01	2.47E – 05	7.71E – 04	3.00E – 03	2.02E – 12	
Outputs	Boues	Ashes	Heat	HCL	Sox	Nox	CO	Dioxins	CO_2
	kg	kg	MJ	kg	kg	kg	kg	kg	kg
	8.48E – 05	4.36E – 04	8.52E – 01	1.91E – 05	6.88E – 04	3.14E – 04	2.14E – 05	1.08E – 14	1.44E – 01

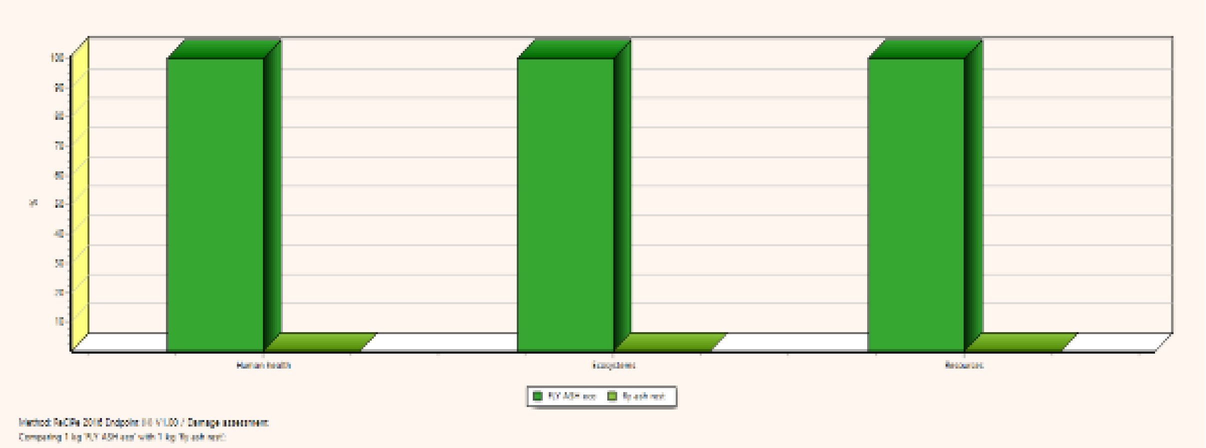


Figure 6 environmental impact of fly ash i the two views

If the consumption of fly ash becomes too high that it becomes necessary to produce it for replacement of Portland cement, then its sustainability advantages are lost, because then the impacts of the production of fly ash becomes higher than Portland cement. The figure 15 shows the comparison between the environmental impacts of fly ash (based on the economic value) & Portland cement. Consequently, the incorporating of fly ash as a waste in the building composite materials will reduce the environmental impact of these composite. While the incorporating of fly ash with economic view in the building composite materials will increase the environmental impact of these composite.

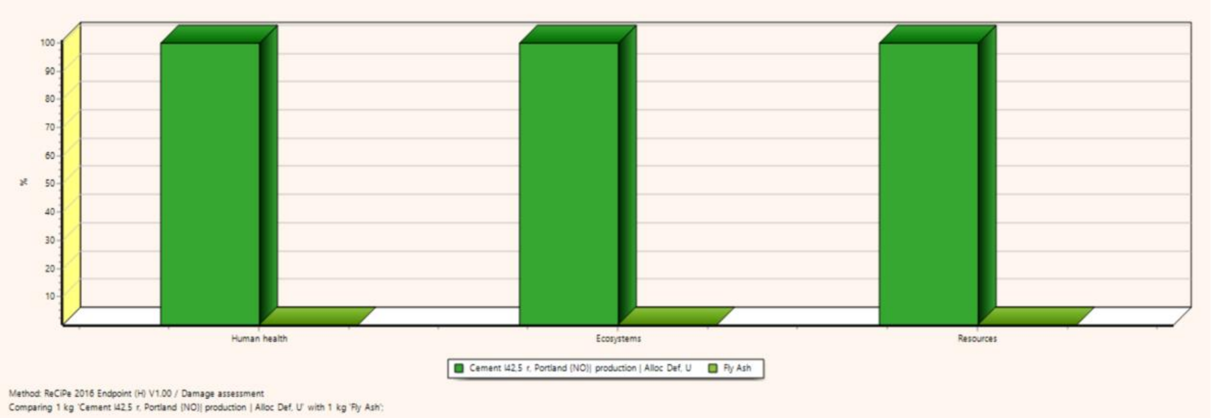


Figure 7 Comparison between the Fly Ash & Portland cement

6.5 Incorporating of Aerogel

The aerogel has low thermal conductivity around 0.015 W.m^{-1}.K^{-1}. Because of that it is defined as very good insulator but the luck of the mechanical strength makes a big challenge to use it as alternative to the insulation panels. Incorporating aerogel to the concrete will make a composite with higher mechanical strength which can be used to replace the insulation panels and low thermal conductivity as well. The aerogel concrete composites with amount aerogel over 60 % show very low thermal conductivity as well as low mechanical strength. Based on that, these composites can substitute the traditional insulation panels in the walls.

The main challenge from the sustainable view is to use MKP commercially as alternative to traditional insulation panels is the huge environmental impact of these composites. The production of concrete in general has lower negative impact than production of conventional insulation materials, but the aerogel based on the available data from producers has responsibly high emissions and energy consumption than traditional insulation materials (10) (Figure).

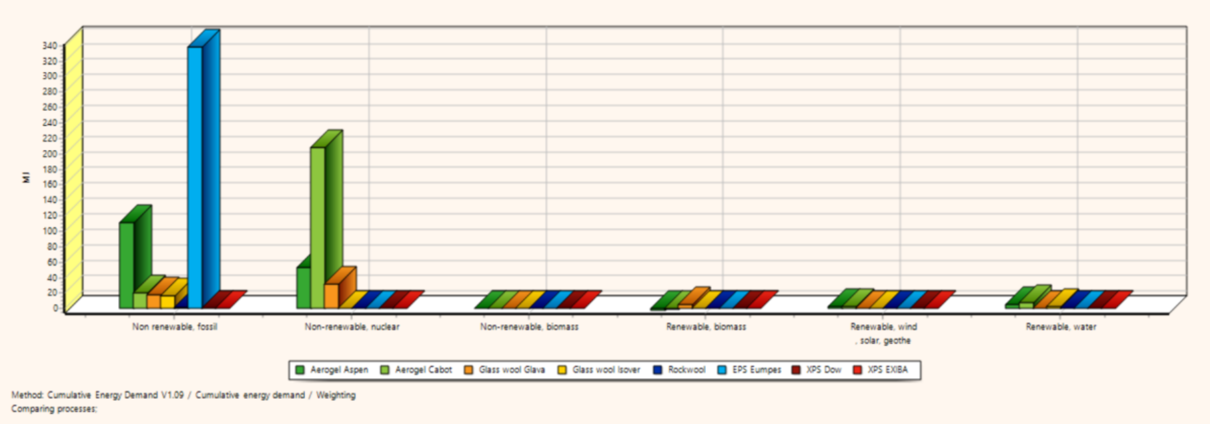


Figure 8 comparison of aerogel and conventional insulation materials

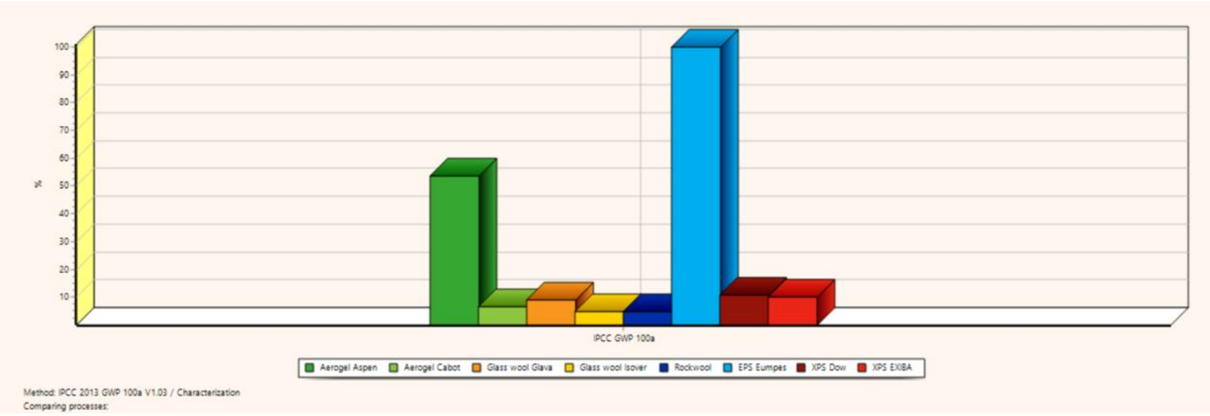


Figure 9 comparison of aerogel and conventional insulation materials

6.6 Incorporation of MKP

The mass of MgO and KH_2PO_4 in the MKP - FA – Aerogel composite is defined as cement mass in the concrete preparation. The main advantages of using MKP as alternative to cement is the low thermal conductivity. The low thermal conductivity will reduce the need for insulation in the building. The need for insulation in the building cause energy consumption of the climate condition regulation systems and building operation of insulation panels. The energy consumption and building operations release a lot of negative environmental impact as emissions or waste. The MKP will reduce this environmental impact. Consequently, improve the sustainable performance of the buildings. The figure 1 shows the comparison of the environmental impact between the mass of (MgO and KH_2PO_4) and Portland cement based on data from databases in Simapro.

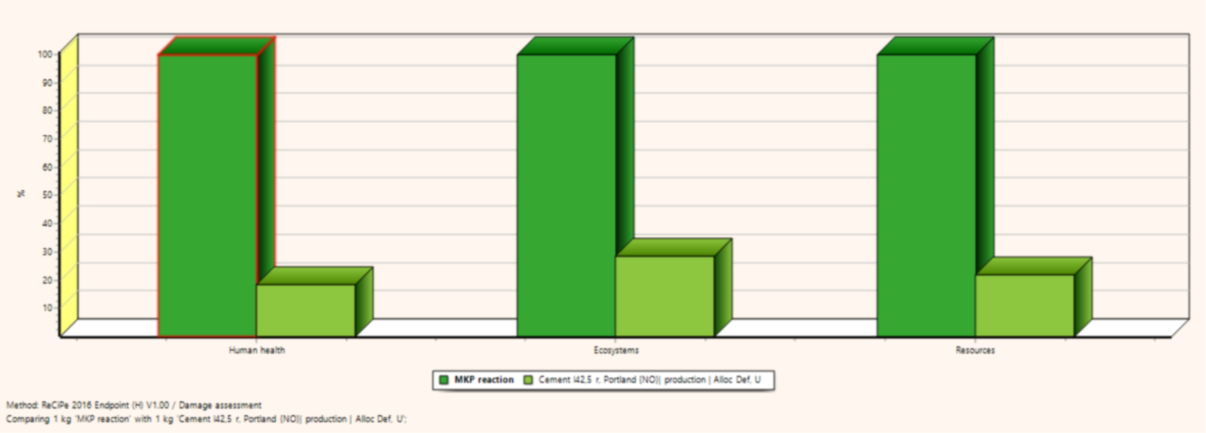


Figure 10 LCA of MKP & Cement

7 Conclusion

The MKP – FA - Aerogel composites have higher environmental impact than the most traditional insulation materials. The main cause for this difference of environmental impact is the low thermal conductivity of the MKP compared to the conventional insulation materials. Therefore, it needs larger amount of MKP to ensure the thermal conductivity of the conventional insulation materials. Although, the high energy consumption and CO_2 emissions of aerogel production is a challenge for MKP. The progress in developing environmental friendly production of aerogel is critical for commercial using of these composites as alternatives to insulation walls.

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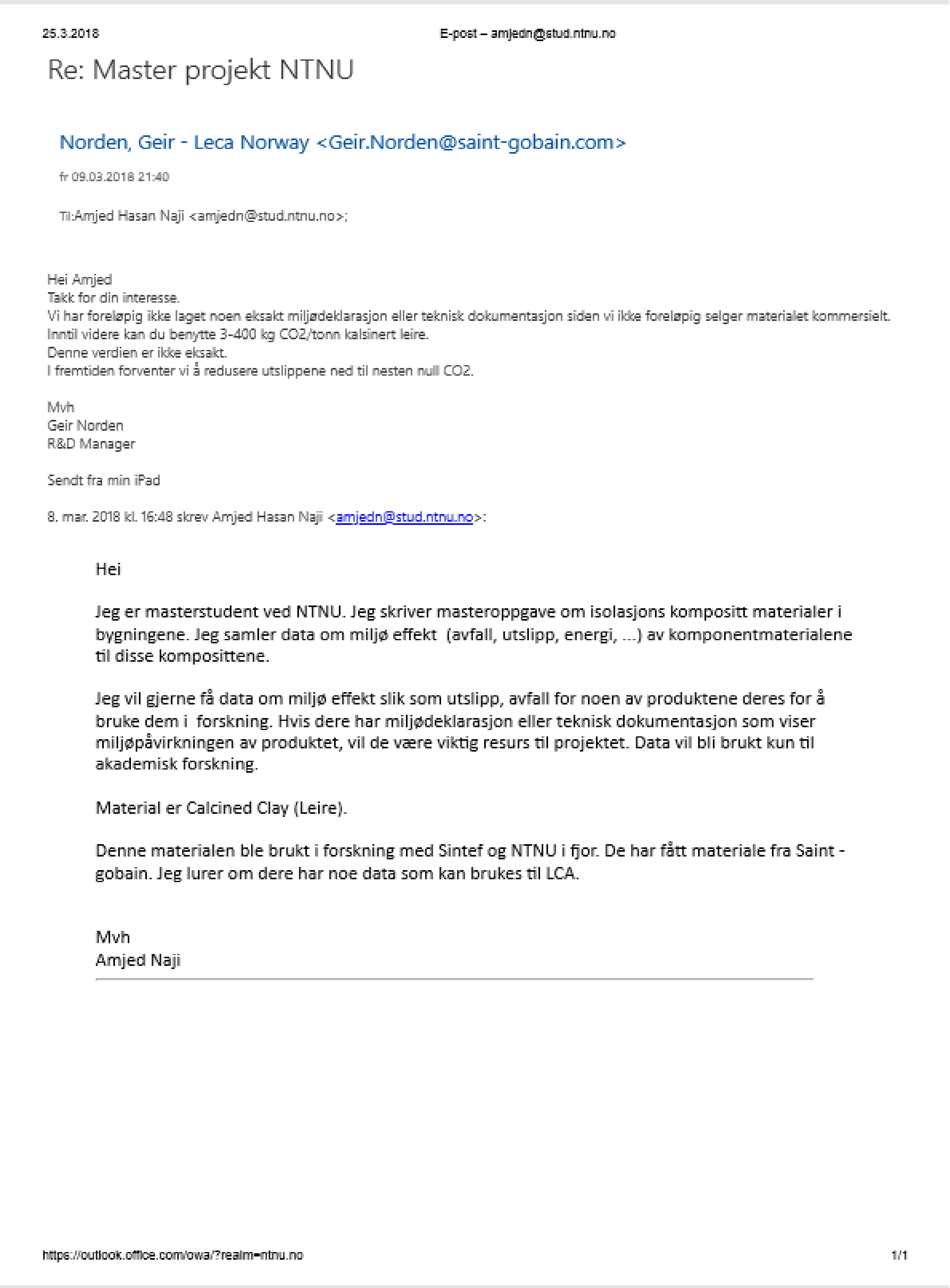
Appendix B Emails

Calcined clay

Email from sant gobain for calcined clay



25.3.2018 E-post – amjedn@stud.ntnu.no

Re: Master projekt NTNU

Norden, Geir - Leca Norway <Geir.Norden@saint-gobain.com>

fr 09.03.2018 21:40

Til:Amjed Hasan Naji <amjedn@stud.ntnu.no>;

Hei Amjed
Takk for din interesse.
Vi har foreløpig ikke laget noen eksakt miljødeklarasjon eller teknisk dokumentasjon siden vi ikke foreløpig selger materialet kommersielt.
Inntil videre kan du benytte 3-400 kg CO2/tonn kalsinert leire.
Denne verdien er ikke eksakt.
I fremtiden forventer vi å redusere utslippene ned til nesten null CO2.

Mvh
Geir Norden
R&D Manager

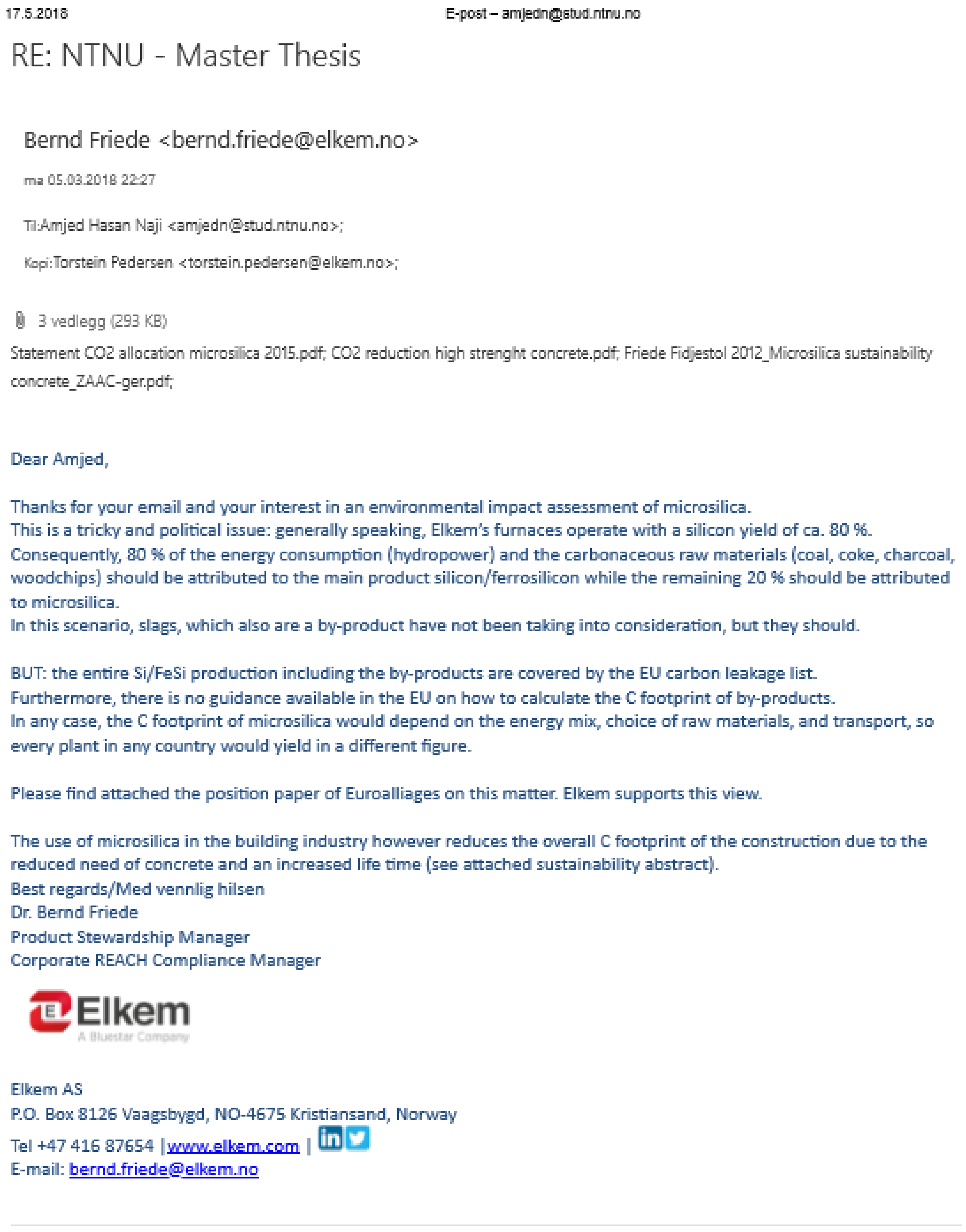
Sendt fra min iPad

8. mar. 2018 kl. 16:48 skrev Amjed Hasan Naji <amjedn@stud.ntnu.no>:

> Hei
>
> Jeg er masterstudent ved NTNU. Jeg skriver masteroppgave om isolasjons kompositt materialer i bygningene. Jeg samler data om miljø effekt (avfall, utslipp, energi, ...) av komponentmaterialene til disse komposittene.
>
> Jeg vil gjerne få data om miljø effekt slik som utslipp, avfall for noen av produktene deres for å bruke dem i forskning. Hvis dere har miljødeklarasjon eller teknisk dokumentasjon som viser miljøpåvirkningen av produktet, vil de være viktig resurs til projektet. Data vil bli brukt kun til akademisk forskning.
>
> Material er Calcined Clay (Leire).
>
> Denne materialen ble brukt i forskning med Sintef og NTNU i fjor. De har fått materiale fra Saint -gobain. Jeg lurer om dere har noe data som kan brukes til LCA.
>
> Mvh
> Amjed Naji

https://outlook.office.com/owa/?realm=ntnu.no 1/1

Elkrem email



17.5.2018 E-post – amjedn@stud.ntnu.no

RE: NTNU - Master Thesis

Bernd Friede <bernd.friede@elkem.no>

ma 05.03.2018 22:27

Til:Amjed Hasan Naji <amjedn@stud.ntnu.no>;

Kopi:Torstein Pedersen <torstein.pedersen@elkem.no>;

3 vedlegg (293 KB)

Statement CO2 allocation microsilica 2015.pdf; CO2 reduction high strenght concrete.pdf; Friede Fidjestol 2012_Microsilica sustainability concrete_ZAAC-ger.pdf;

Dear Amjed,

Thanks for your email and your interest in an environmental impact assessment of microsilica.
This is a tricky and political issue: generally speaking, Elkem's furnaces operate with a silicon yield of ca. 80 %.
Consequently, 80 % of the energy consumption (hydropower) and the carbonaceous raw materials (coal, coke, charcoal, woodchips) should be attributed to the main product silicon/ferrosilicon while the remaining 20 % should be attributed to microsilica.
In this scenario, slags, which also are a by-product have not been taking into consideration, but they should.

BUT: the entire Si/FeSi production including the by-products are covered by the EU carbon leakage list.
Furthermore, there is no guidance available in the EU on how to calculate the C footprint of by-products.
In any case, the C footprint of microsilica would depend on the energy mix, choice of raw materials, and transport, so every plant in any country would yield in a different figure.

Please find attached the position paper of Euroalliages on this matter. Elkem supports this view.

The use of microsilica in the building industry however reduces the overall C footprint of the construction due to the reduced need of concrete and an increased life time (see attached sustainability abstract).
Best regards/Med vennlig hilsen
Dr. Bernd Friede
Product Stewardship Manager
Corporate REACH Compliance Manager

Elkem
A Bluestar Company

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Aerogel

Jeg har EPD for det ferdige produktet Isokalk, eller Fixit 222.

Skriver du dette navnet og søker på youtube dukker det mye opp.

Isokalk er at av verdens best dokumenterte og gjennomtestede fasadesystem, tror jeg.

Jeg legger ved her et lite utvalg av det som finnes.

Det første er en presentasjon fra et prosjekt gjennomført i Berlin, på side 10 står det noe som interesser deg, vil jeg tro.

Dernest legger jeg ved et paper fra Journal av Building Engineering, som er en undersøkelse av det første huset på kommersielt grunnlag som ble behandlet med Isokalk i 2012, og har siden stått under kontinuerlig overvåkning, så finner du en del generelle tester som kan være av interesse, blant annet EPD.

Skal du finne EPD for bare aerogel tror jeg du vil slite, det er to fabrikker i verden som klarer å produsere aerogel i stort nok volum til å være kommersiellt drivverdige. Vårt aerogel, Lumira, kommer fra Cabot Corporations fabrikk i Frankfurt. Den andre er Aspen i USA. Begge holder nøye kontroll på å ikke fortelle om hvordan de klarer å produsere sitt aerogel.

Vil du ha hjelp til noe er det bare å si i fra.

Vennlig hilsen
Per Jæger
Markedssjef
Mob: (+47) 915 95 295
E-post: per@isokalk.no

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Appendix B Excel calculations

This appendix includes all excel calculations in this research

Conventional insulation materials

Conventional insulation material	Producer	Product	Country	Thermal conductivity W/(m)K	Density (kg/m^3)	Thickness with R = 1 (mm)	Chemical
Glass wool	Glava	Glassull 16,5 kg/m^3 , λD = 0,035 W/(m)K	Norway	0,035	16,5	35	Inorganic
	Saint-Gobain Isover	Glassull Isover UNI skiva 35	Sweden	0,035	17	35	
Rockwool	Rockwool	Rockwool 29 kg/m^3 , λD = 0,037 W/(m)K	Denmark / Norway	0,037	29	35	
XPS	Exiba	Exiba XPS snitt	Europa	0,0355	34,5	35,5	Organic
	Dow Deutschland	Dow XENERGY XPS foam insulation snitt	Europa	0,031	35	31	
EPS	EUMEPS	EUMEPS EPS u/ flammehemmer snitt	Scandinavian	0,034	25	34	

Functional unit (F.U) equant mass

F.U = $R.\lambda.p.A$ *(Kg)*

Where R represents the thermal resistance as 1 (m^2 K)/W, λ represents the thermal conductivity measured as W/(m*K), U represents the thermal transmittance as W/(m^2*K). A represents the defined area in the functional unit as 1 m^2, F.U corresponds to the used weight of the compared composite material, P represents the density of the insulation product in kg/m3, and V represents the volume of the compared composite in M^3.

Material	Thermal conductivity W/(m)K	Density	Thickness for R = 1 (m)	Volume (m3)	F.U (Kg)
Glass wool Glava	0,035	16,5	0,035	0,035	0,5775
Glass wool Saint-Gobain	0,035	17	0,035	0,035	0,595
Rockwool	0,037	29	0,037	0,037	1,073
XPS ExiBa	0,0355	34,5	0,0355	0,0355	1,22475
XPS Dow	0,031	35	0,031	0,031	1,085
EPS	0,034	25	0,034	0,034	0,85

AIC

Functional unit equant mass

$$F.U = R.\lambda.p.A\ (Kg)$$

Aerogel	Thermal conductivity	Density	Thickness	volume	F.U (Kg)	weight for each sample	nr samples
0 %	1,9	1980	1,9	1,9	3762	0,50688	1906,88256
10 %	2	2100	2	2	4200	0,5376	2257,92
20 %	1,5	1900	1,5	1,5	2850	0,4864	1386,24
30 %	1,1	1800	1,1	1,1	1980	0,4608	912,384
40 %	0,8	1600	0,8	0,8	1280	0,4096	524,288
50 %	0,4	1300	0,4	0,4	520	0,3328	173,056
60 %	0,3	1000	0,3	0,3	300	0,256	76,8

Mixing

Aerogel	F.U (Kg)	Density	Mixing	Mixing Energy
0 %	3762	1980	0,625	0,328947368
10 %	4200	2100	0,625	0,3125
20 %	2850	1900	0,625	0,416666667
30 %	1980	1800	0,625	0,568181818
40 %	1280	1600	0,625	0,78125
50 %	520	1300	0,625	1,5625
60 %	300	1000	0,625	2,083333333

AIM

Density

The density of AIM is estimated in Excel by the formula

V = Volume m = Mass D = Density

$V_{composite} = V_{cement} + V_{aerogel} + V_{water} + V_{admixtures} + ...$

$D=m/V \rightarrow V= m/D$

$(m/D)_{composite} = (m/D)_{cement} + (m/D)_{aerogel} + (m/D)_{water} + (m/D)_{admixtures} + ...$

$D_{composite} = m_{composite} / [(m/D)_{cement} + (m/D)_{aerogel} + (m/D)_{water} + (m/D)_{admixtures} + ...]$

AIM	cement density	cement amount	Silica fume density	silica fume amount	calcined clay density	calcined clay amount	aerogel density	aerogel amount	NRG 700 DENSITY	NRG amount	Density
Concrete 0%	3140	945	350	180	450	0	100	0	1600	0	1125
Concrete 20%	3140	765	350	144	450	0	100	18,9	1600	10	937,9
Concrete 40%	3140	567	350	108	450	0	100	37,8	1600	7,5	720,3
Concrete 50%	3140	504	350	96	450	0	100	50,4	1600	6,7	657,1
Concrete 60%	3140	378	350	72	450	0	100	56,7	1600	5	511,7
Concrete 70%	3140	302,4	350	57,6	450	0	100	70,5	1600	4	434,5
Concrete 80%	3140	226,8	350	43,2	450	0	100	90,7	1600	3	363,7
CS 35 40%	3140	368,6	350	70,2	450	208,1	100	37,8	1600	9,4	694,1
CS 35 50%	3140	327,6	350	62,4	450	185	100	50,4	1600	8,4	633,8
CS 35 60%	3140	245,7	350	46,8	450	138,7	100	56,7	1600	6,3	494,2
CS 35 70%	3140	196,6	350	37,4	450	111	100	70,5	1600	5	420,5
CS 35 80%	3140	147,4	350	28,1	450	83,2	100	90,7	1600	3,8	353,2
CS 65 40%	3140	198,5	350	37,8	450	386,4	100	37,8	1600	13,1	673,6
CS 65 50%	3140	176,4	350	33,6	450	343,5	100	50,4	1600	11,6	615,5
CS 65 60%	3140	132,3	350	25,2	450	257,6	100	56,7	1600	8,7	480,5
CS 65 70%	3140	105,8	350	20,2	450	206,1	100	70,5	1600	7	409,6
CS 65 80%	3140	79,4	350	15,1	450	154,6	100	90,7	1600	5,2	345
CK 35 40%	3140	368,6	350	70,2	450	208,1	100	37,8	1600	9,4	694,1
Ck 35 50%	3140	327,6	350	62,4	450	185	100	50,4	1600	8,4	633,8
Ck 35 60%	3140	245,7	350	46,8	450	138,7	100	56,7	1600	6,3	494,2
Ck 35 70%	3140	196,6	350	37,4	450	111	100	70,5	1600	5	420,5
Ck 35 80%	3140	147,4	350	28,1	450	83,2	100	90,7	1600	3,8	353,2
Ck 65 40%	3140	198,5	350	37,8	450	386,4	100	37,8	1600	13,1	673,6
Ck 65 50%	3140	176,4	350	33,6	450	343,5	100	50,4	1600	11,6	615,5
Ck 65 60%	3140	132,3	350	25,2	450	257,6	100	56,7	1600	8,7	480,5
Ck 65 70%	3140	105,8	350	20,2	450	206,1	100	70,5	1600	7	409,6
Ck 65 80%	3140	79,4	350	15,1	450	154,6	100	90,7	1600	5,2	345

F.U equant mass

F.U = R.$\lambda.p.A$ *(Kg)*

AIM	Density	Thermal conductivity	F.U	weight each sample	number of samples
Concrete 0%	1379,96	1	1379,959819	1125	1,22663095
Concrete 20%	1103,01	0,9	992,7095402	909	1,092089703
Concrete 40%	826,19	0,47	388,3098249	675	0,575273815
Concrete 50%	696,83	0,4	278,7325589	600	0,464554265
Concrete 60%	570,95	0,3	171,2857908	450	0,380635091
Concrete 70%	448,69	0,25	112,1722035	360	0,311589454
Concrete 80%	329,28	0,18	59,27030488	270	0,219519648
CS 35 40%	596,16	0,41	244,4267227	646,9	0,377843133
CS 35 50%	526,86	0,32	168,5949319	575	0,293208577
CS 35 60%	452,93	0,26	117,7613054	431,2	0,273101358
CS 35 70%	374,02	0,15	56,10355665	345	0,162619005
CS 35 80%	289,15	0,12	34,69854108	258,7	0,13412656
CS 65 40%	475,68	0,36	171,2456838	622,7	0,275005113
CS 65 50%	431,40	0,31	133,7329163	553,5	0,241613218
CS 65 60%	381,65	0,23	87,77888933	415,1	0,211464441
CS 65 70%	325,39	0,15	48,80902665	332,1	0,146970872
CS 65 80%	260,92	0,12	31,31062091	249,1	0,125694986
CK 35 40%	596,16	0,38	226,5418405	646,9	0,350196074
Ck 35 50%	526,86	0,32	168,5949319	575	0,293208577
Ck 35 60%	452,93	0,26	117,7613054	431,2	0,273101358
Ck 35 70%	374,02	0,19	71,06450509	345	0,205984073
Ck 35 80%	289,15	0,07	20,24081563	258,7	0,078240493
Ck 65 40%	475,68	0,39	185,5161575	622,7	0,297922206
Ck 65 50%	431,40	0,33	142,3608464	553,5	0,257201168
Ck 65 60%	381,65	0,25	95,41183622	415,1	0,229852653
Ck 65 70%	325,39	0,19	61,82476709	332,1	0,186163105
Ck 65 80%	260,92	0,07	18,26452887	249,1	0,073322075

Mixing

AIM	f.U (Kg)	Density	Mixing	Mixing energy
Concrete 0%	1379,959819	1379,959819	0,625	0,625
Concrete 20%	992,7095402	1103,0106	0,625	0,5625
Concrete 40%	388,3098249	826,1911168	0,625	0,29375
Concrete 50%	278,7325589	696,8313971	0,625	0,25
Concrete 60%	171,2857908	570,9526359	0,625	0,1875
Concrete 70%	112,1722035	448,6888141	0,625	0,15625
Concrete 80%	59,27030488	329,2794715	0,625	0,1125
CS 35 40%	244,4267227	596,1627383	0,625	0,25625
CS 35 50%	168,5949319	526,8591622	0,625	0,2
CS 35 60%	117,7613054	452,9280977	0,625	0,1625
CS 35 70%	56,10355665	374,023711	0,625	0,09375
CS 35 80%	34,69854108	289,154509	0,625	0,075
CS 65 40%	171,2456838	475,682455	0,625	0,225
CS 65 50%	133,7329163	431,3965043	0,625	0,19375
CS 65 60%	87,77888933	381,6473449	0,625	0,14375
CS 65 70%	48,80902665	325,393511	0,625	0,09375
CS 65 80%	31,31062091	260,921841	0,625	0,075
CK 35 40%	226,5418405	596,1627383	0,625	0,2375
Ck 35 50%	168,5949319	526,8591622	0,625	0,2
Ck 35 60%	117,7613054	452,9280977	0,625	0,1625
Ck 35 70%	71,06450509	374,023711	0,625	0,11875
Ck 35 80%	20,24081563	289,154509	0,625	0,04375
Ck 65 40%	185,5161575	475,682455	0,625	0,24375
Ck 65 50%	142,3608464	431,3965043	0,625	0,20625
Ck 65 60%	95,41183622	381,6473449	0,625	0,15625
Ck 65 70%	61,82476709	325,393511	0,625	0,11875
Ck 65 80%	18,26452887	260,921841	0,625	0,04375

MKP – FA

F.U equant mass

F.U = R.$\lambda . p . A$ *(Kg)*

MKP	Density	Thermal conductivity	F.U
M0	1031	0,345	355,695
M1	568	0,117	66,456
M2	340	0,056	19,04

Molar mass

	k	H	P	O	C	total
K_2CO_3	78,2	0	0	48	12	138,2
$2H_3PO_4$	0	6	61,8	128	0	195,8
TOTAL						334
$2KH_2PO_4$	78,2	4	61,8	128	0	272
H_2O	0	2	0	16	0	18
CO_2	0	0	0	32	12	44
Total						334

Component	mass
C	12
O	16
k	39,1
H	1
P	30,9

Mixing

MKP	Density	Thermal conductivty	F.U	Mixing	Mixing energy
M0	1031	0,345	355,695	1,25	0,43125
M1	568	0,117	66,456	1,25	0,14625
M2	340	0,056	19,04	1,25	0,07

Environmental Product Declaration ISO 14025, EN 15804

Glava glass wool

NEPD nr.: 221E ver 3

Approved according to ISO 14025:2006, 8.1.4 and NS-EN15804:2012
Approved: 11.01.2012
Valid until: 11.01.2018
(Exctended validity: 11.07.18)

Verification Internal External X

Independent verification of data has been carried out by Marte Reenaas, Rambøll, in accordance with EN ISO 14025:2010, 8.1.3 and NS-EN 15804:2012.

Marte Reenaas

The declaration has been prepared by
Thale Plesser, SINTEF Building and Infrastructure

Thale Plesser

Manufacturer
Glava AS, www.glava.no
Addr.: Nybråtveien 2, 1801 Askim, Norway
Phone: +47 69 81 84 00 E-mail: post@glava.no
Org.nr.: NO-912 008 754
ISO 14001-certified: Yes
Contact person: John A. Bakke, +47 951 47 820

About EPD

EPD from other program operators than the Norwegian EPD Foundation may not be comparable.

PCR
PCR for insulation material, NPCR 012:2012

Environmental indicato	*Cradle to gate*		*Cradle to grave*	
Global warming	0,74	CO_2-eq./DU	0,76	CO_2-eq./FU
Energy consumption	18,9	MJ/DU	19,5	MJ/FU
Amount of renew. energy	24,3	%	23,6	%

Indoor air: TVOC < 0,8 μg/(m^2 h)

Chemicals: The finsihed product contains no chemicals on the REACH candidate list or the Norwegian priority list.

Scope and expected marked area

Declared unit (DU):	1m^2 glass wool insulation insulation material with a thickness that gives a declared thermal resistance of R = 1 m^2 K/W. This is achieved by using a product with a thickness of 35 mm, a λ_D of 0,0035 W/mK and a density of 16,5 kg/m^3.
Expected service life:	Set equal to the reference service life of the building, i.e. 60 years. The service life of the product is >> 60 years.
Scope:	The declaration is cradle to grave.
Year of study:	2012.
Year of data:	Production and emission data for Glava AS at Askim in 2011.
Expected market area:	Norway.

Product description

The insulation is mainly manufactured from recycled glass (75%). The product is used to insulate against cold, heat, fire and sound. They can be used in buildings, industrial installations, road, rail and marine constructions. The glass wool is elastic and can be compressed to 1/5 of the volume in use.

Product specification

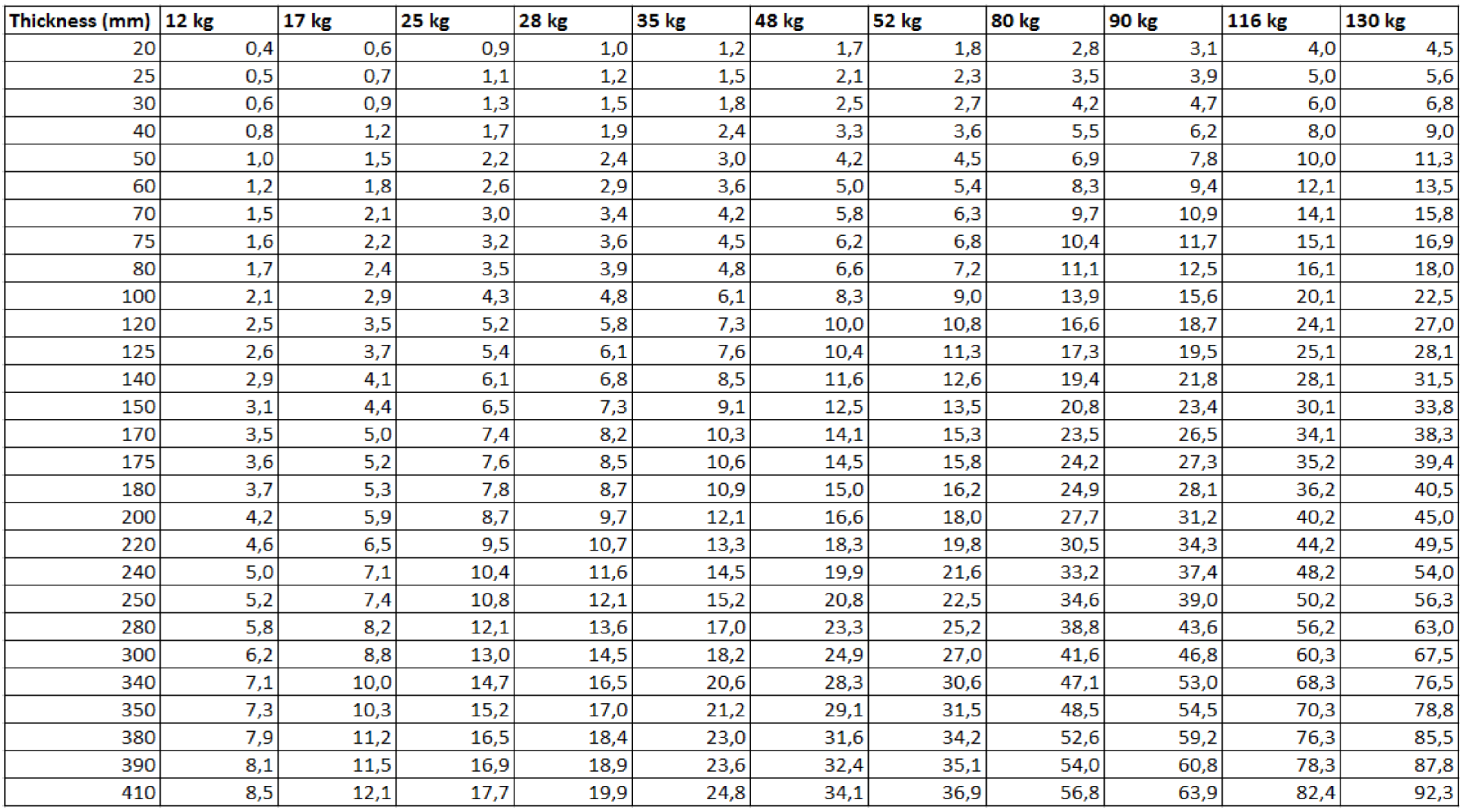
Composition of the final product Table 1

Material	Part [weight]	Per DU
Silicate glass	95,0 %	0,589 kg
Hardened, urea modified phenol formaldehyde resin	4,4 %	0,027 kg
Dust binding oil	0,6 %	0,004 kg
SUM	100 %	0,62 kg

Calculation of environmental impacts for other Glava glass wool products

Glava glass wool is produced in different thicknesses and densities. The environmental impact of each product can be estimated by multiplying with the factors in table 2. Some products are coated or covered with paper. The environmental impact of the coating or paper is not included in the estimates

Table 2. Factors that are used to estimate the environmental impact for each glass wool product.



Thickness (mm)	12 kg	17 kg	25 kg	28 kg	35 kg	48 kg	52 kg	80 kg	90 kg	116 kg	130 kg
20	0,4	0,6	0,9	1,0	1,2	1,7	1,8	2,8	3,1	4,0	4,5
25	0,5	0,7	1,1	1,2	1,5	2,1	2,3	3,5	3,9	5,0	5,6
30	0,6	0,9	1,3	1,5	1,8	2,5	2,7	4,2	4,7	6,0	6,8
40	0,8	1,2	1,7	1,9	2,4	3,3	3,6	5,5	6,2	8,0	9,0
50	1,0	1,5	2,2	2,4	3,0	4,2	4,5	6,9	7,8	10,0	11,3
60	1,2	1,8	2,6	2,9	3,6	5,0	5,4	8,3	9,4	12,1	13,5
70	1,5	2,1	3,0	3,4	4,2	5,8	6,3	9,7	10,9	14,1	15,8
75	1,6	2,2	3,2	3,6	4,5	6,2	6,8	10,4	11,7	15,1	16,9
80	1,7	2,4	3,5	3,9	4,8	6,6	7,2	11,1	12,5	16,1	18,0
100	2,1	2,9	4,3	4,8	6,1	8,3	9,0	13,9	15,6	20,1	22,5
120	2,5	3,5	5,2	5,8	7,3	10,0	10,8	16,6	18,7	24,1	27,0
125	2,6	3,7	5,4	6,1	7,6	10,4	11,3	17,3	19,5	25,1	28,1
140	2,9	4,1	6,1	6,8	8,5	11,6	12,6	19,4	21,8	28,1	31,5
150	3,1	4,4	6,5	7,3	9,1	12,5	13,5	20,8	23,4	30,1	33,8
170	3,5	5,0	7,4	8,2	10,3	14,1	15,3	23,5	26,5	34,1	38,3
175	3,6	5,2	7,6	8,5	10,6	14,5	15,8	24,2	27,3	35,2	39,4
180	3,7	5,3	7,8	8,7	10,9	15,0	16,2	24,9	28,1	36,2	40,5
200	4,2	5,9	8,7	9,7	12,1	16,6	18,0	27,7	31,2	40,2	45,0
220	4,6	6,5	9,5	10,7	13,3	18,3	19,8	30,5	34,3	44,2	49,5
240	5,0	7,1	10,4	11,6	14,5	19,9	21,6	33,2	37,4	48,2	54,0
250	5,2	7,4	10,8	12,1	15,2	20,8	22,5	34,6	39,0	50,2	56,3
280	5,8	8,2	12,1	13,6	17,0	23,3	25,2	38,8	43,6	56,2	63,0
300	6,2	8,8	13,0	14,5	18,2	24,9	27,0	41,6	46,8	60,3	67,5
340	7,1	10,0	14,7	16,5	20,6	28,3	30,6	47,1	53,0	68,3	76,5
350	7,3	10,3	15,2	17,0	21,2	29,1	31,5	48,5	54,5	70,3	78,8
380	7,9	11,2	16,5	18,4	23,0	31,6	34,2	52,6	59,2	76,3	85,5
390	8,1	11,5	16,9	18,9	23,6	32,4	35,1	54,0	60,8	78,3	87,8
410	8,5	12,1	17,7	19,9	24,8	34,1	36,9	56,8	63,9	82,4	92,3

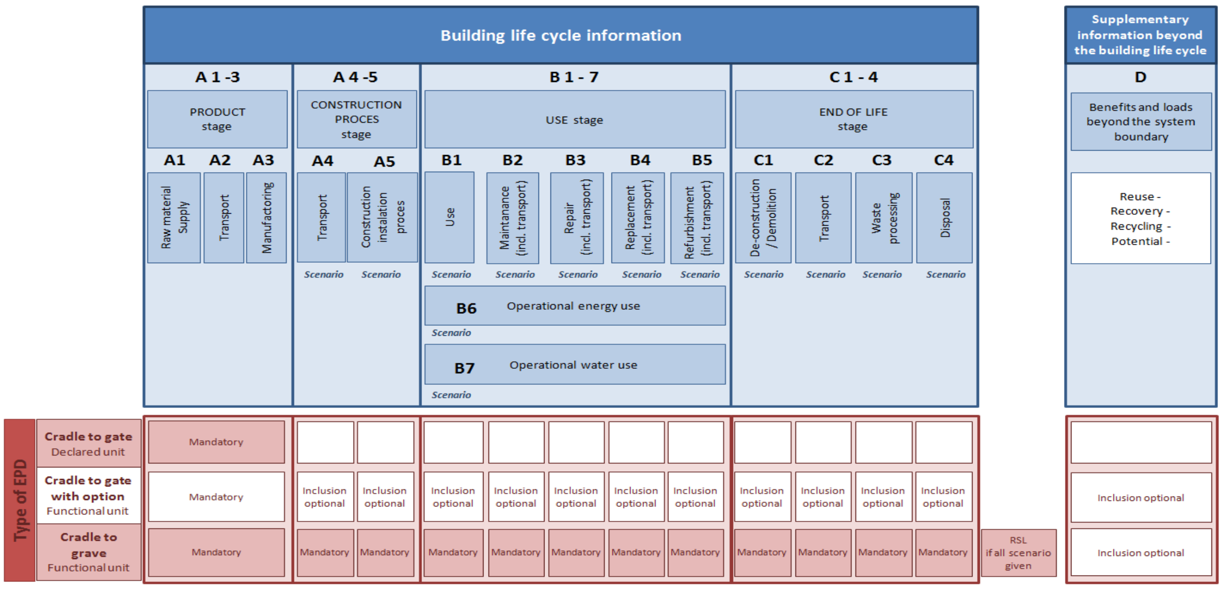
Category 12 kg:	Glava 38 products
Category 17 kg:	Proff 34 products, Marine mat, Vintermatte, Dyttestrimmel and Sydd matte
Category 25 kg:	Extrem 32 produkter, Laftestrimmel, Glava Blåseull (loft insulation)
Category 28 kg:	Murplate 32 and Lamellmatte
Category 35 kg:	Ventilasjonsplate and Lydfelleplate 2000
Category 48 kg:	Veggtopp plate, Veggplate 31, Glava Blåseull (cavity wall) and GLAVA® Akuduk products
Category 52 kg:	Glava Robust Lamell
Category 80 kg:	Glava Venus A and Glava Super Nova
Category 90 kg:	Robust Topplate (excluding 20 and 30 mm)
Category 116 kg:	Trinnlydplate and Glava Venus E
Category 130 kg:	Robust Topplate (20 and 30 mm)

Methodology

System boundaries

This EPD is cradle to grave, with system boundaries covering information modules A1-C4, see figure 1.

Information modules according to NS-EN 15804:2012 Figure 1



Scenarios and Technical information

Method:	The calculations on emissions are based on the method CML 2 Baseline 2000. The primary energy calculations are done using the method of Cumulative Energy Demand (CED). Background data is gathered from the database Ecoinvent v2.2 hosted by the Ecoinvent Centre.
Transport to construction site (A4) and transport to waste processing (C2):	Lorries used for transportation are assumed to be in the EURO 3 class (diesel consumption 0,25 l/km). The transport distance to the building site is assumed to be 400 km. The transport distance to waste processing is assumed to be 25 km. Volume utilisation of the truck is not included in the calculations.
Installation (A5):	Energy usage and loss of material at installation is assumed to be negligible. The insulation product is installed in a building envelope. The conditions during usage are dry.
Use (B1-B7)	Replacement of the insulation during the service life of the building is not needed. No operational water or energy usage is necessary.
End of life (C1, C3, C4):	At end-of-life the insulation material is disposed at landfill (non-hazardous waste).

Energy and resources

Primary energy

Table 3. Energy consumption specified for the different energy carrier and life cycle stages

	Unit	Raw materials A1	Transport A2	Production A3	Total A1-A3	Transport A4	Installation A5
Non-renewable primary energy							
Fossil	MJ	5,11	0,526	3,73	9,37	0,328	0
Nuclear	MJ	0,568	0,032	4,35	4,95	1,90E-02	0
Non-renewable, biomass	MJ	2,87E-06	1,48E-06	4,21E-06	0,00	9,80E-07	0
Renewable primary energy							
Renewable, biomass	MJ	0,037	1,04E-03	1,96	2,00	6,07E-04	0
Wind, solar, geothermal	MJ	0,010	3,04E-04	0,106	0,12	1,51E-04	0
Water	MJ	0,084	5,46E-03	2,40	2,49	3,39E-03	0

CO_2 factor for the production in Norway is 189 g CO_2 equivalents per kWh (NORDEL for 2007)

Table 4. Energy consumption specified for the different energy carrier and life cycle stages

	Unit	Use stage B1-B7	Demolition C1	Transport C2	Waste processing C3	Disposal C4
Non-renewable primary energy						
Fossil	MJ	0	0	0,041	0	0,190
Nuclear	MJ	0	0	2,36E-03	0	7,02E-03
Non-renewable, biomass	MJ	0	0	1,22E-07	0	3,09E-07
Renewable primary energy						
Renewable, biomass	MJ	0	0	7,59E-05	0	2,42E-04
Wind, solar, geothermal	MJ	0	0	1,89E-05	0	5,86E-05
Water	MJ	0	0	4,24E-04	0	1,16E-03

Table 5. Energy used as raw materials. Product stage and construction process stage.

Parameter	Unit	Raw materials A1	Transport A2	Production A3	Total A1-A3	Transport A4	Installation A5
Use of renewable primary energy excluding renewable primary energy resources used as raw materials	MJ	0,100	5,93E-03	3,24	3,35	3,92E-03	0
Use of renewable primary energy resources used as raw materials	MJ	0,031	8,76E-04	1,23	1,26	2,28E-04	0
Total use of renewable primary energy resources	MJ	0,131	6,80E-03	4,47	4,61	4,15E-03	0
Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials*	MJ	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated
Use of non renewable primary energy resources used as raw materials*	MJ	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated
Total use of non-renewable primary energy resources	MJ	5,68	0,558	8,08	14,32	0,347	0

*non renewable primary energy used as raw material is not calculated because it cannot be separated from non renewable primary energy used as energy.

Table 6. Energy used as raw materials. Use stage and end of life stage.

Parameter	Unit	Use stage B1-B7	Demolition C1	Transport C2	Waste processing C3	Disposal C4
Use of renewable primary energy excluding renewable primary energy resources used as raw materials	MJ	0	0	5,19E-04	0	1,28E-03
Use of renewable primary energy resources used as raw materials	MJ	0	0	0	0	1,82E-02
Total use of renewable primary energy resources	MJ	0	0	5,19E-04	0	1,46E-03
Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials*	MJ	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated
Use of non renewable primary energy resources used as raw materials*	MJ	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated
Total use of non-renewable primary energy resources	MJ	0	0	0,043	0	0,197

*non renewable primary energy used as raw material is not calculated because it cannot be separated from non renewable primary energy used as energy.

Table 7. Resources - secondary materials, fuels and fresh water

Parameter	Unit	Raw materials A1	Transport A2	Production A3	Total A1-A3	Transport A4	Installation A5
Use of secondary material	kg	0,377*	0	0	0,377	0	0
Use of renewable secondary fuels	MJ	0	0	0	0	0	0
Use of non renewable secondary fuels	MJ	0	0	0	0	0	0
Use of fresh water	m^3	0,60	0,039	9,02	9,659	0,024	0

*Recycled glass.

Table 8. Resources - secondary materials, fuels and fresh water

Parameter	Unit	Use stage B1-B7	Demolition C1	Transport C2	Waste processing C3	Disposal C4
Use of secondary material	kg	0	0	0	0	0
Use of renewable secondary fuels	MJ	0	0	0	0	0
Use of non renewable secondary fuels	MJ	0	0	0	0	0
Use of fresh water	m^3	0	0	8,23E-03	0	7,79E-03

Emissions and environmental impacts

Table 9. Environmental impacts.

Indicator	Unit	Raw materials A1	Transport A2	Production A3	Total A1-A3	Transport A4	Installation A5
Global warming potential	kg CO_2 eq.	0,236	0,034	0,467	0,737	0,021	0
Ozone layer depletion potential	kg CFC-11 eq.	2,01E-08	7,05E-06	1,52E-08	7,09E-06	3,35E-09	0
Acidification potential for soil and water	kg SO_2 eq.	7,49E-04	2,24E-04	2,97E-03	3,94E-03	1,03E-04	0
Eutrophication potential	kg $(PO_4)^{3-}$ eq.	3,84E-04	4,70E-05	8,04E-04	1,24E-03	2,68E-05	0
Photochemical ozone creation potential	kg C_2H_4 eq.	8,13E-05	7,05E-06	1,05E-04	1,93E-04	3,22E-06	0
Abiotic depletion potential for non fossil resources	kg Sb eq.	9,12E-05	1,47E-07	1,73E-06	9,31E-05	1,00E-07	0
Abiotic depletion potential for fossil resources	MJ	5,11	0,526	3,73	9,37	0,328	0

Table 10. Environmental impacts.

Indicator	Unit	Use stage B1-B7	Demolition C1	Transport C2	Waste processing C3	Disposal C4
Global warming potential	kg CO_2 eq.	0	0	2,67E-03	0	4,10E-03
Ozone layer depletion potential	kg CFC-11 eq.	0	0	4,18E-10	0	1,23E-09
Acidification potential for soil and water	kg SO_2 eq.	0	0	1,29E-05	0	2,44E-05
Eutrophication potential	kg $(PO_4)^{3-}$ eq.	0	0	3,35E-06	0	5,95E-06
Photochemical ozone creation potential	kg C_2H_4 eq.	0	0	4,03E-07	0	8,46E-09
Abiotic depletion potential for non fossil resources	kg Sb eq.	0	0	1,25E-08	0	2,11E-06
Abiotic depletion potential for fossil resources	MJ eq.	0	0	0,041	0	0,110

Output flows and waste

Table 11. Output flows through the life cycle

Parameter	Unit	Raw materials A1	Transport A2	Production A3	Total A1-A3	Transport A4	Installation A5
Hazardous waste disposed	kg	8,29E-06	0	3,69E-07	8,66E-06	0	0
Non hazardous waste disposed	kg	1,74E-02	0	3,02E-05	1,74E-02	0	0
Radioactive waste disposed	kg	0	0	0	0	0	0

Table 12. Output flows through the life cycle

Parameter	Unit	Use stage B1-B7	Demolition C1	Transport C2	Waste processing C3	Disposal C4
Hazardous waste disposed	kg	0	0	0	0	0
Non hazardous waste disposed	kg	0	0	0	0	0,578
Radioactive waste disposed	kg	0	0	0	0	0

Chemicals

The following substances have not been added to the product: substances on the Candidate list of substances of very high concern, substances recommended for inclusion into the Authorisation list, substances included into the Authorisation List (REACH Annex XIV), substances on the Norwegian Priority list and substances that lead to the product being classified as hazardous waste. The chemical content of the product complies with regulatory levels as given in REACH Annex XVII and the Norwegian Product Regulations.

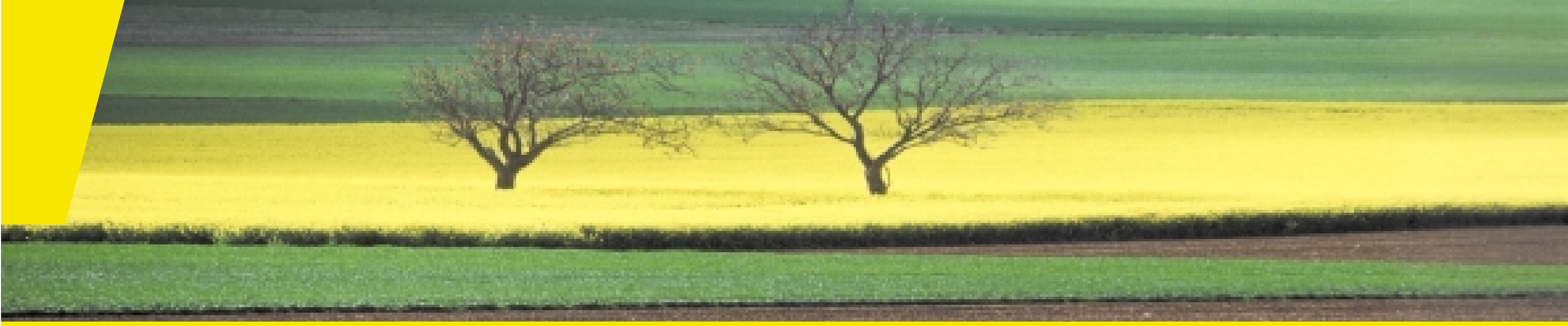
The product has been tested with regard to emissions and has passed the critereia for low emitting according to NS-EN 15251:2003.

References

NS-ISO 14025:2006, Environmental labels and declarations - Type III environmental declarations - Principles and procedures
PCR for preparing an environmental product declaration (EPD) for insulation products, NPCR 012 2012
NS-EN 15804:2012, Bærekraftige byggverk - Miljødeklarasjoner - Grunnleggende produktkategoriregler for byggevarer
CML 2 Baseline 2000. Versjon 2.05.
Jungbluth, N., Cumulative Energy Demand, in Implementation of Life Cycle Impact Assessment Methods, Data v2.2 (2010), R. Hischier and B. Weidema, Editors. 2007, ecoinvent centre: St. Gallen. p. 33-40.
Ecoinvent Centre is a competence Centre of ETH Zürich, EPF Lausanne, PSI, Empa, ART. Webpage: www.ecoinvent.org

Planet, people, prosperity
Our commitment to sustainable construction

ISOVER
Sustainable insulation



ISOVER is the world leader in sustainable insulation solutions. This position, based on our in-depth knowledge of the different market segments, the related applications and our strong focus on customers' needs and expectations, is bolstered by our leading edge in glass wool technology and our selective development of other insulation materials (expanded polystyrene, extruded polystyrene, stone wool, hemp wool). To meet current and even future demands, we are continuously striving to make efficient and high quality insulation possible for everyone, regardless of the climate of their country, the type of project and size of budget.

Foreword

Buildings: tackling the challenges of the 21st Century

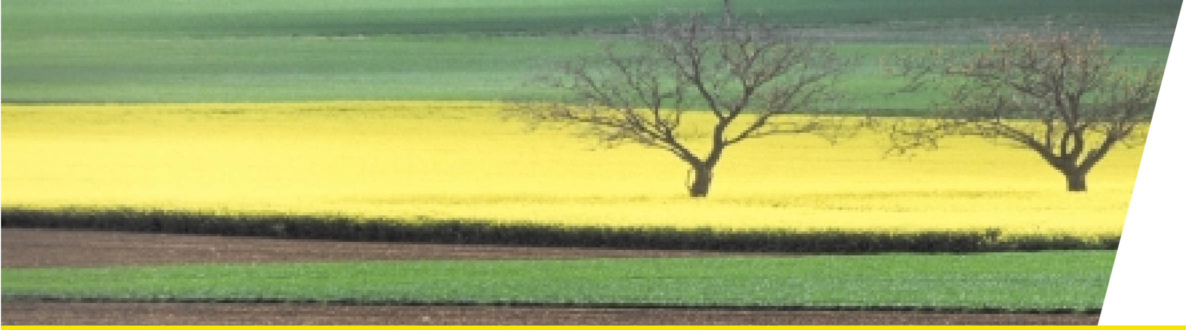
The world is changing at a faster rate than ever before. Whilst advances in science and technology have improved our quality of life, they have also highlighted how balanced is our environment. Global warming is no longer a remote concept, but a real threat to the future of mankind.

The building sector must recognise its impacts on global warming and preservation of our valuable and finite energy resources.

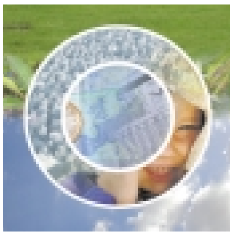
To address these issues we must change the way we design new buildings and renovate existing buildings so that we reduce their negative impacts on the environment. Through its support to sustainable construction, ISOVER wants to take up the challenge.

The construction process must preserve unique ecosystems, biodiversity and local landscapes, whilst ensuring a better quality of life and guaranteeing the health and safety of building occupants and users. Sustainable construction provides solutions that balance these sometimes contradictory issues and objectives. Working together with all of the partners in the building chain, ISOVER intends to be at the very front of this challenging new venture.

Benoit Carpentier
CEO
Saint-Gobain Insulation



Summary



Our vision: from sustainable development to sustainable construction

We aim to create efficient thermal and acoustic insulation solutions to support energy efficient construction, to provide safe comfort to users and to help protect the environment.

Sustainable development	5 global challenges to address	The key role of the building sector	
Planet 	**Energy supply security**	• 40% of Europe's total energy consumption comes from its 160 million buildings. • 2/3 of energy consumption in buildings is used for heating and cooling. • 3.3 million barrels of oil could be saved each day in Europe if buildings were made more energy efficient.(1)	P 6
	Climate change mitigation	• 460 million tons of CO_2 emissions could be saved each year in Europe through cost-effective energy-efficiency measures in buildings.(2) • Buildings are the single most significant contributor to greenhouse gas emissions and account for 39% of the CO_2 emissions in the US.(3)	P 8
	Waste management & resource preservation	• In OECD countries the built environment is responsible for 30 to 40% of solid waste generation, 30% of raw material use and 10% of land use.	P 10
People 	**Health and well being**	• In the US alone, $5.9 billion could be saved annually in health care and economic costs linked to air pollution simply by improved insulation.(4)	P 12
Prosperity 	**Economic growth / Availability of financial resources**	• Between 15 and 30% of european household incomes go on housing expenses. • Up to 530,000 jobs would be created in Europe through an ambitious strategy to improve energy efficiency in buildings.(5) • Aggressive increases in US building energy codes could result in an increase of $28.5 billion in income and 1.1 million jobs.(6)	P 13

The building sector has a significant impact on the global environment and has a positive role to play for the safety and comfort of its inhabitants.
It therefore offers a huge opportunity for action.

That's why building sector stakeholders, including ISOVER, have decided to take steps to enhance the environmental quality of buildings.
By adapting and translating the concept of sustainable development to the building sector, they have established a new approach to construction: sustainable construction.

Sustainable construction aims at reducing the environmental impact of a building over its entire lifetime, while optimizing its economic viability and the comfort and safety of its occupants.

New evaluation schemes, such as HQE®, LEED® and BREEAM®, are being increasingly developed to measure the results of this new approach.

P 14 - 25

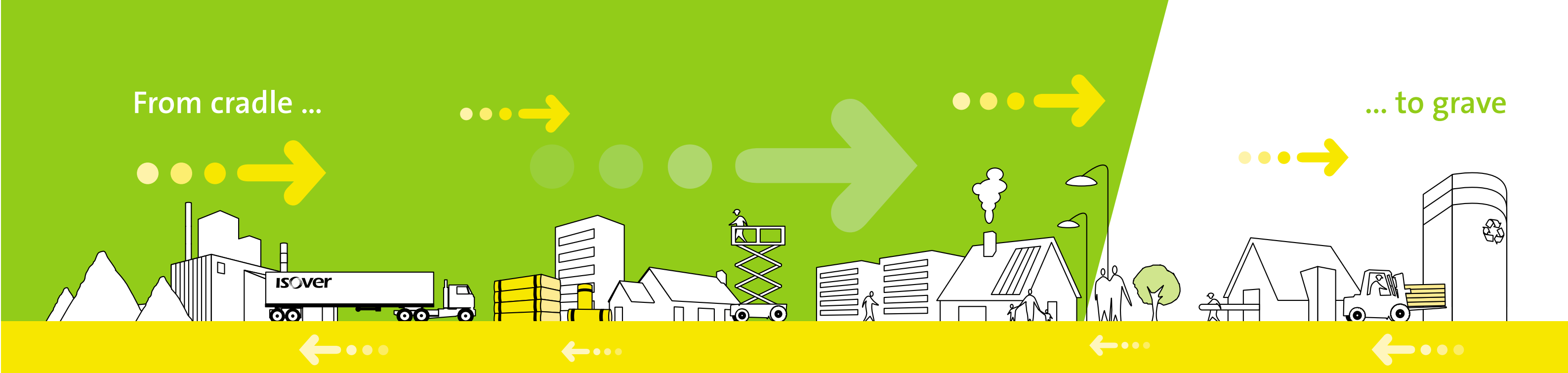
(1, 2) Source: Ecofys II, mitigation of CO_2 emissions from the building stock - Cologne 2004/Ecofys IV, cost effective climate protection in the EU building stock, Cologne 2005

(3) Source: PEW Center on Global Climate Change Intergovernmental Panel on Climate Change

(4) Source: Public Health Benefits of Insulation Retrofits in Existing Housing in the US, Levy et. al., Environmental Health, 2003

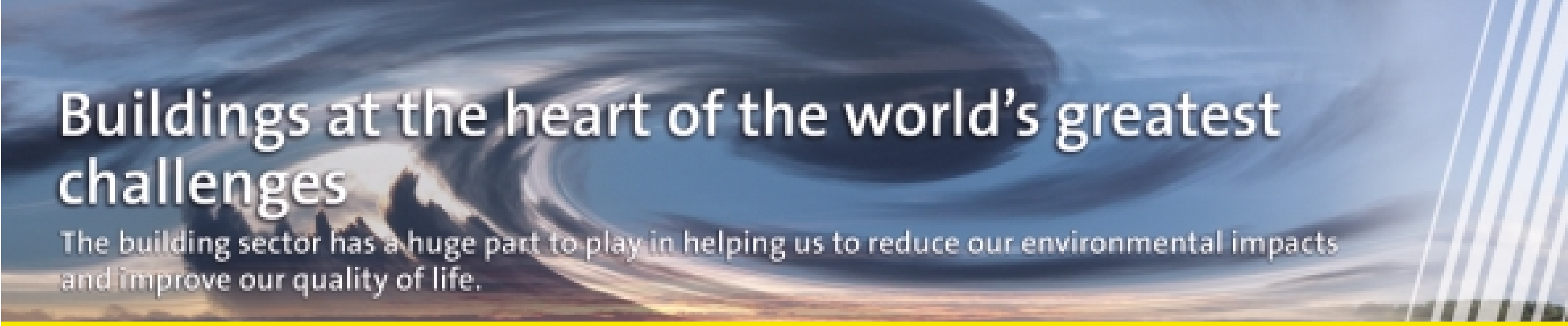
(5) EURIMA Estimates

(6) Source: American Council for an Energy Efficient Economy



The targets of sustainable construction and ISOVER's contribution

Material production and transportation	Design and construction	Use	End of life
Key indicators: • Raw material supply • Manufacturing of products: - Energy consumption - CO_2 emissions - Impact on air, soil, water - Production waste • Transport to jobsite	**Key indicators:** • Use of resources • Quality of the building (air tightness) • Waste generation	**Key indicators:** • Most important phase for environmental impacts: - Energy efficiency - Water use - CO_2 emissions • Maintenance and replacement • Impact on the built environment	**Key indicators:** • De-construction, demolition on site, recovery, disposal and transport • Impact of demolition waste • Building sustainability and ability to evolve over time
ISOVER's contribution: • Use of recycled materials (up to 80% for glass wool) • Reduced energy consumption per produced unit (Eg: 20% reduction between 1993 and 2007 for glass wool) • Reduced CO_2 specific emissions • More than 50% of major sites certified ISO 14001 • Limitation of production waste • Transport: optimised packaging and palletization	**ISOVER's contribution:** • Minimal waste creation on jobsite • Dry construction solutions (no water needed) • Special systems to improve airtighness and reduce thermal bridges • Wide range of solutions for all performance requirements and types of construction	**ISOVER's contribution:** • Insulation solutions to save up to 90% of the energy used by a building and relatively decrease CO_2 emissions • No maintenance needed • Glass wool to save more than 100 times the energy consumed and CO_2 emitted during manufacture and transport	**ISOVER's contribution:** • Products can be recycled if recycling facilities and processes are in place • Durability of products
Key indicators: • Impact of the plant on health and safety of workers • Nuisance of the plant for the neighbours	**Key indicators:** • Health and security of workers on jobsites • Nuisance for neighbours (noise, dust, congestion) • Installed performance vs design performance	**Key indicators:** • Solutions for thermal and acoustic comfort • Security: fire resistance • Health: indoor air quality	**Key indicators:** • Building sustainability and ability to evaluate over time
ISOVER's contribution: • Health and safety policy in plants • Noise, dust and water treatment	**ISOVER's contribution:** • Training and sensitizing for contractors, architects and installers • Easy and safe to install systems and solutions	**ISOVER's contribution:** • Efficient solutions for thermal and acoustical comfort • Solutions for passive fire protection • Safe products for the building occupants	**ISOVER's contribution:** • Non hazardous demolition waste
Key indicators: • Global economic impact	**Key indicators:** • Acquisition and construction costs	**Key indicators:** • Maintenance costs • External costs: heating, cooling, water, electricity ...	**Key indicators:** • End of life costs: de-construction, demolition and recovery/disposal
ISOVER's contribution: • Local production	**ISOVER's contribution:** • Affordable and easy to procure materials	**ISOVER's contribution:** • No maintenance needed • Insulation reduces heating costs by up to 90%!	**ISOVER's contribution:** • Easy to de-construct system
P 26	P 28	P 30	P 33



Buildings at the heart of the world's greatest challenges

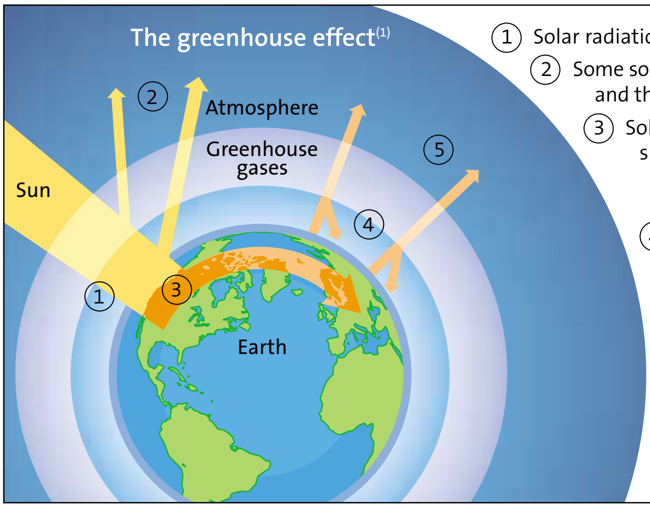
The building sector has a huge part to play in helping us to reduce our environmental impacts and improve our quality of life.

1 Building, a key sector to tackle climate change

The earth receives all of its energy from the sun. This energy is partly retained inside the earth's atmosphere by greenhouse gases that absorb infrared radiation and prevent it from dissipating back into space. Thus **the greenhouse effect is a natural phenomenon** and essential to maintain life on earth: it keeps the temperature of our atmosphere close to 15°C.

Human activities, however, have been producing increasing quantities of greenhouse gases, primarily from the burning of fossil fuels, such as oil, gas and coal. As the concentration of greenhouse gases increases, the more the atmosphere retains infrared radiation, which is what causes **global warming**.

Today, we emit twice the amount of greenhouse gas that can be absorbed naturally by the earth's oceans and ecosystems. **We have to reduce greenhouse gas emissions; we must therefore reduce our consumption of fossil fuels.**



The greenhouse effect[1]

① Solar radiation passes through the clear atmosphere.

② Some solar radiation is reflected by the atmosphere and the earth's surface.

③ Solar energy is absorbed by the earth's surface and warms it, and is converted into heat causing the emission of long wave (infrared) radiation back to the atmosphere.

④ Some of the infrared radiation is absorbed and reflected back to the earth by the greenhouse gas molecules, warming the atmosphere and the earth's surface. As the surface gains more heat, more infrared radiation is emitted, compounding the situation.

⑤ Some of the infrared radiation passes through the atmosphere and is lost in space.

Increasing awareness

- In Kyoto in 1997, the international community agreed a number of objectives to reduce greenhouse gas emissions. The Kyoto Protocol committed industrialized countries to reducing their greenhouse gas emissions by 5.2% from 1990 levels by the target period of 2008-2012. Developing countries were exempted from this commitment in order to preserve their growth. The Protocol came into force in early 2005.

- According to the Stern Report (2005), the cost of fighting climate change (1% of world GDP / year) is less than the cost of the damage it would generate (between 5 and 20% of world GDP / year).

- International Panel on Climate Change (IPCC) reports forecast that, by 2100, temperatures would rise by **between 1.8 and 4°C** above those at the end of the 20th century, if we fail to take action. The projected impacts of climate change would include: melting of the ice caps, hurricanes, drought, and decreases in agricultural production ... IPCC reports are comprehensive, objective and based on transparency, to give a strong basis to debates and to help decision makers.

- In 2006, the European Commission launched its famous 3 x 20% plan: 20% reduction in greenhouse gas emissions (30% in case of international agreement), 20% improvement in energy efficiency, and 20% renewables in energy supply by 2020 compared to 1990. Member States approved this European Energy Efficiency Action Plan in March 2007.

- Presently all countries are negotiating the second phase of the Kyoto agreement, covering the period from 2013-2017. In December 2007, participating countries agreed on a negotiating "mandate", known as the Bali Action Plan.
  The negotiations must be completed, with a final agreement on the second Kyoto commitment period in time for the next meeting, in Copenhagen, at the end of 2009.

Kyoto 1997 •••➜ Stern Report 2005 •••➜ IPCC 4th Report 2007 •••➜ European 3*20 Plan 2007 •••➜ Copenhagen 2009 •••➜

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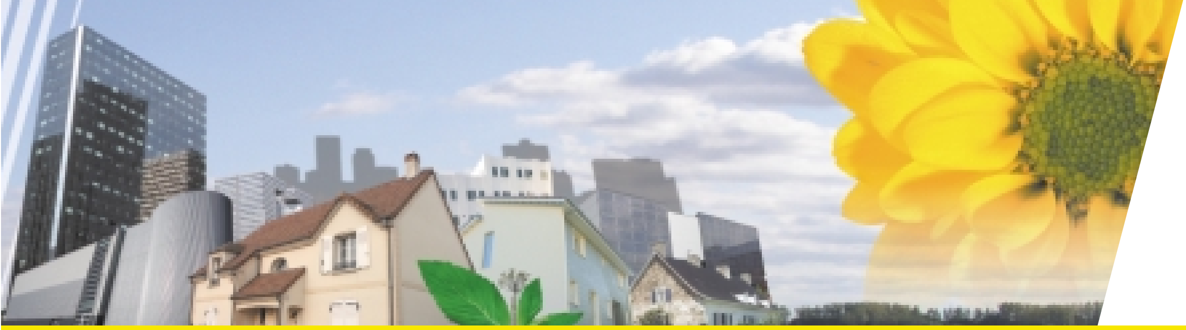
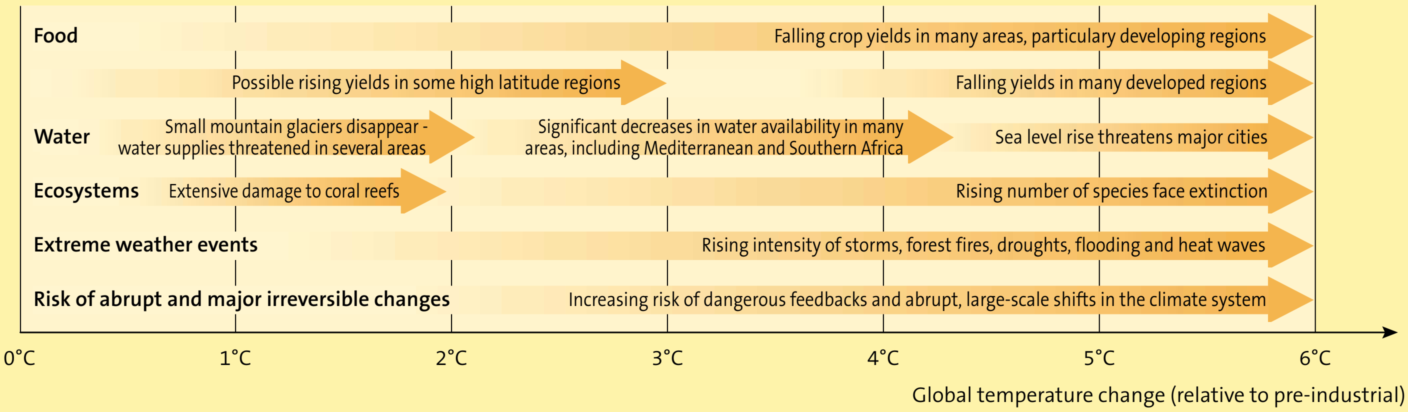
(1) Source: contribution of working group 1 to the second assessment report of the IPCC, UNEP and WMO, Cambridge university press, 1996



Projected impact of climate change



A global increase in temperature of more than 2°C could have catastrophic and irreversible impacts on the earth.(1) According to scientists, in order to stay below 2°C global warming compared to pre-industrial temperatures – the objective endorsed by the European Union – all developed nations need to achieve an overall greenhouse gas emissions reduction of 30% by 2020 and 80% by 2050, compared to 1990 levels.

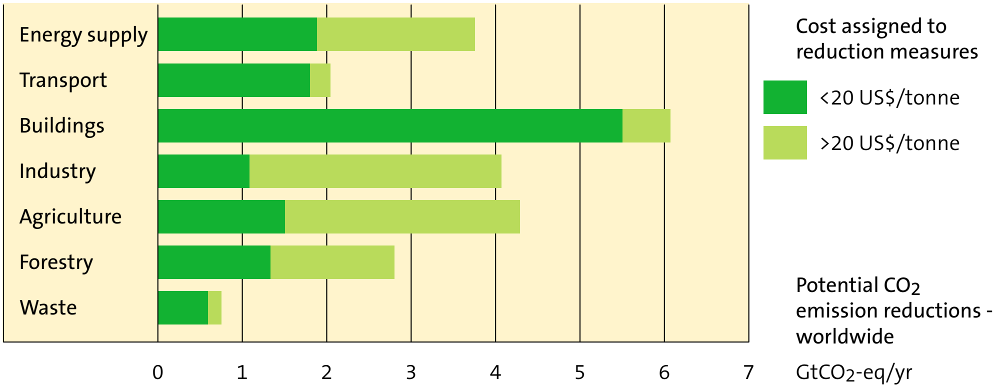
The building sector has a role to play

Heating and air conditioning are the major causes of greenhouse gas emissions from buildings. In Europe, buildings alone are responsible for 30% of all emissions, equating to some 842 million tonnes of CO_2 each year – almost twice the Kyoto target.
But **the building sector has a substantial potential**. According to EURIMA (European Mineral Wool Manufacturers Association)(2), by using advanced techniques and insulation systems to renovate or build better buildings, Europe could decrease its greenhouse gas emissions by 460 million tonnes – more than the total decrease commitment agreed in Kyoto!

To achieve this same level of saving by other means we would have to, for instance:

- Stop the 6 million cars currently running in London for 15 years, or
- Plant forests on a territory three times as large as France.

Insulation is the most cost effective solution for CO_2 savings(3)



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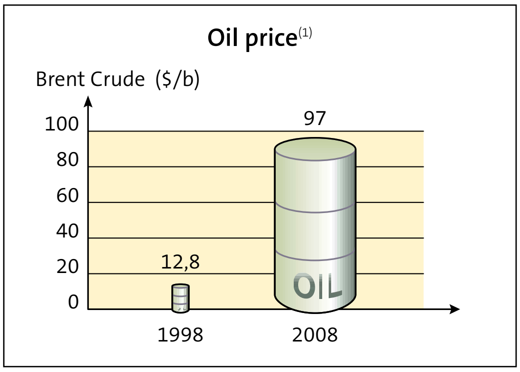
(1) Source: Stern Review
(2) Source: based on Ecofys II, 2004 / Ecofys IV, 2005
(3) Source: Terry Barker, IPCC Coordinating Lead Author and Chairman, Cambridge Econometrics

2 The most profitable energy is saved energy!

The EU consumption of energy has increased by 11% over the last 10 years. Yet stocks of **fossil fuels** such as oil, gas, and coal, which still account for **81% of world energy consumption**, are not unlimited. Scientists consider that at our current consumption rate, coal stocks will last for more than 2 centuries, but world stocks of gas would be used up in 63 years and oil stocks in less than 50 years.

The energy crisis is also a strategic and economic threat: according to EURIMA, European dependency on foreign energy sources should increase from 50% to 70% during the next 20 to 30 years. Spurred by last years large increases in the price of oil, the issue of security of supply is now at the top of the energy policy agenda.

> *"I think that easy oil and easy gas — that is, fuels that are relatively cheap to produce and very easy to get to the market — will peak somewhere in the coming ten years."*
>
> Jeroen van der Veer
> Chief Executive,
> Royal Dutch Shell pic



Oil price(1)

One reason for these price increases is the fact that supplies of all fossil fuels are becoming scarcer and more expensive to produce. The days of "cheap" oil and gas are coming to an end.

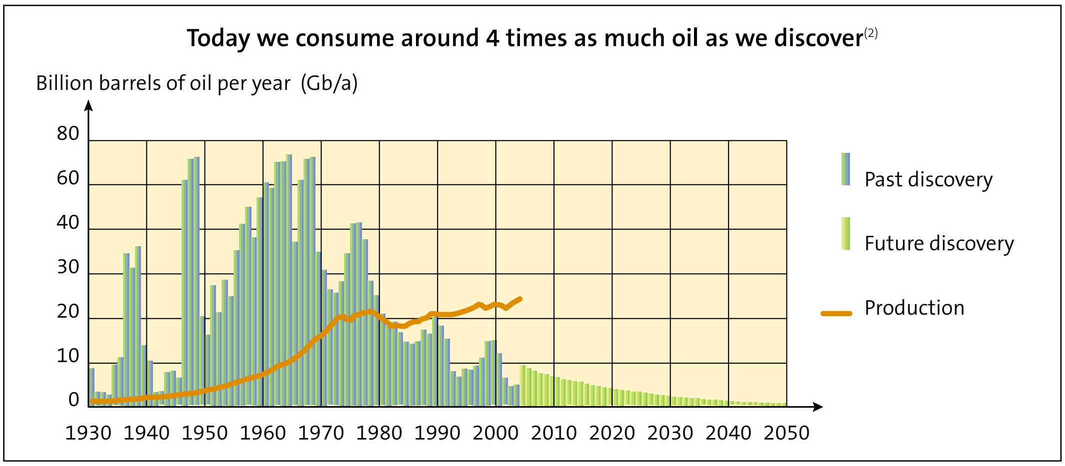
We must reduce our consumption and diversify our sources of production according to the Trias Energetica concept.

The Trias Energetica concept(3)

1
Reduce the demand for energy by avoiding waste and implementing energy-saving measures.

2
Use sustainable sources of energy instead of finite fossil fuels.

3
Produce and use fossil energy as efficiently as possible.

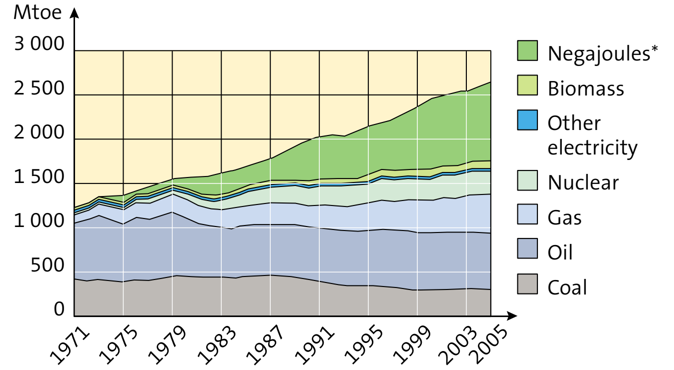


Today we consume around 4 times as much oil as we discover(2)

(1, 2) Source: ASPO newsletter #89 - May 2008

(3) Source: EURIMA

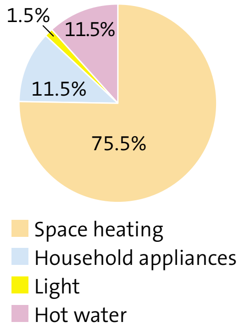
Development of primary energy demand and avoided energy use in the EU25, 1971 to 2005(1)



*Negajoules: energy savings calculated on the basis of 1971 energy intensity.

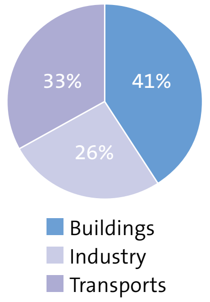
In the EU, energy efficiency (in the graph described as Negajoules) **is already the largest contributor to energy supply security.**

Final energy consumption of private households in Germany(2)



Space heating accounts for 75% of our energy demand.

Energy consumption by sector in Europe



In Europe, the building sector is the number one consumer of energy, followed by industry and transportation.

The building sector has real potential for energy savings

40% of Europe's total energy consumption results from its 160 million buildings.

For the rest of the world, the absolute figure is rising fast as construction booms, especially in countries such as China and India.
Heating and cooling are the main energy expenditures in buildings. Today in Europe, 2/3 of energy consumption in a building is for heating, and air conditioning is forecast to triple before 2030.

Insulation is the most cost effective way to reduce energy consumption in buildings and cut associated greenhouse gas emissions.
The huge potential of energy efficiency in buildings is already recognized. Progress can begin immediately because the knowledge and technology exist today to slash the energy buildings use, while at the same time improving levels of comfort. **By using well-proven energy efficiency techniques, 70 to 90% of a building's energy demand for heating or cooling can be cut.**

The potential savings are huge:

- In the U.S., it is estimated that up to 50% of the energy currently used in buildings could be saved with adequate insulation.(3)
- 3.3 million barrels of oil could be saved each day in Europe if buildings were made more energy efficient.(4)

> *"Buildings could be turned into climate savers rather than remaining energy wasters."*

Toward more restrictive regulations

Introduced in January 2006, the **Energy Performance of Buildings Directive** (EPBD) requires all 25 EU countries, plus Norway and Switzerland, to establish minimal requirements and certification systems for energy efficiency of buildings. Currently (2009), the EPBD is undergoing a revision.(5)

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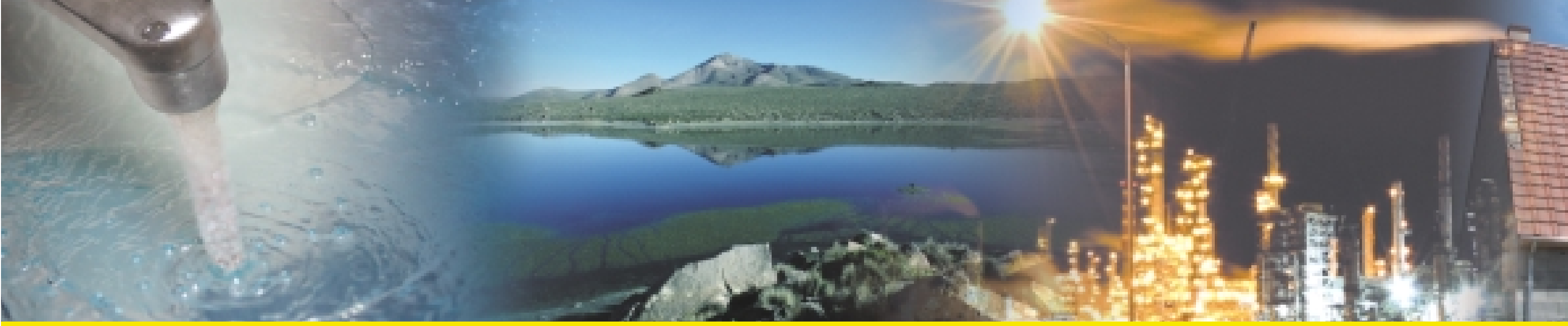
(1) Sources: COM(2006)545 and Enerdata 2006
(2) Source: VDEW, issued in 2002
(3) Source: International Energy Agency
(4) Source: Ecofys II, 2004/Ecofys IV, 2005
(5) For more information: www.buildingsplatform.org, www.europa.eu



3 Avoid forecasted shortages of raw materials, decrease waste

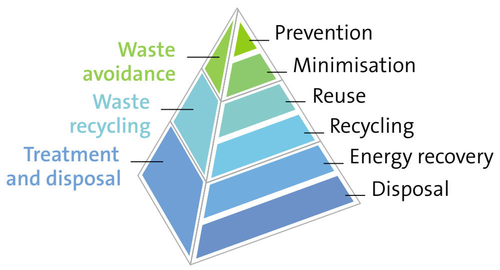
Since the industrial revolution, raw material demand has been increasing consistently. Today, the development of emerging countries, and the continuous increase of gross world product are adding to the situation.

Producing more also means that we create more waste. Waste from discarded products and packaging creates disposal problems and consumes valuable resources.

If every one in the world lived like an average North American, we would need five planets to live on; and if everyone lived like an average European, we would need three planets.

Waste management

(from most to least favorable option)(1)



Waste: toward more restrictive regulations

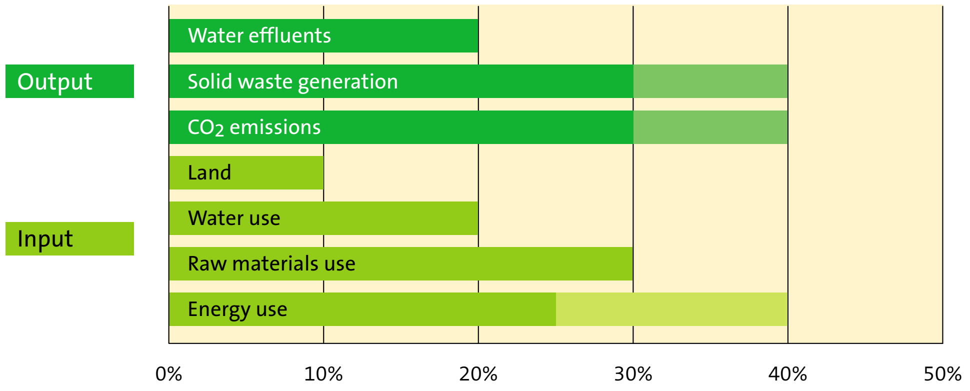
By 2020, all 27 European Union countries must have implemented national action plans for non-hazardous construction and demolition waste in order to achieve 70% reduction by weight of this waste put to landfill.

The building sector has a role to play

Building and construction works impact the environment in a number of ways. They are the largest single cause of global resource use and pollution emission.

In OECD countries, the built environment is responsible for around 25-40% of total energy use, 30% of raw material use, 30-40% of global greenhouse gas emissions and 30 to 40% of solid waste generation.

Share of built environment in pollution emission and resource use(2)



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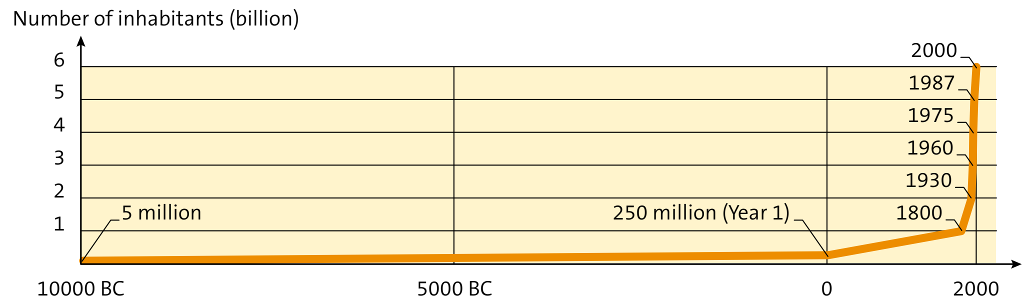
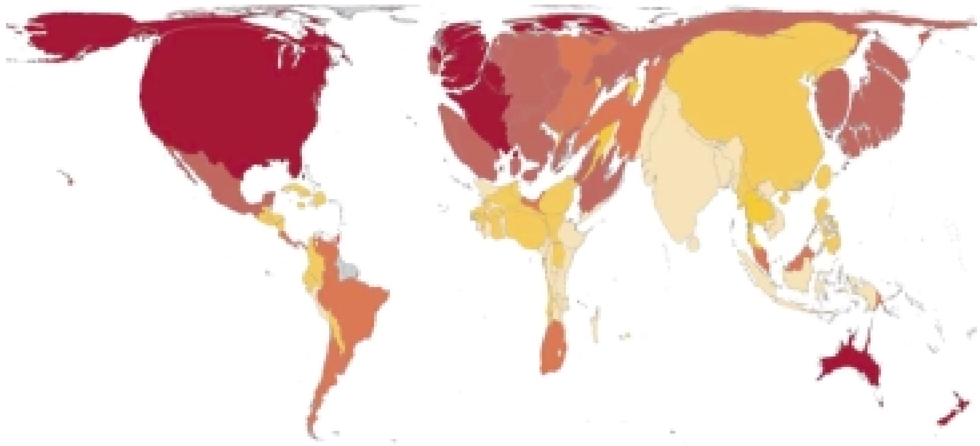
(1) Source: adapted from EU directive on waste management

(2) Source: Earth Trends, 2007 using data from UNEP SBCI, 2006


Demographic evolution from Neolithic times(1)

The rapid growth of world population causes scarcity of resources: with 6.7 billion inhabitants, the world population has doubled in 40 years, and is projected to increase to more than 9 billion by 2050.


Footprints across the world, 2003(2)

Total national footprints as a proportion of the global footprint are indicated by country size.
National per capita footprints are indicated by colour.

- ■ More than 5.4 global hectares per person
- ■ 3.6 - 5.4 global hectares per person
- ■ 1.8 - 3.6 global hectares per person
- ■ 0.9 - 1.8 global hectares per person
- ■ Less than 0.9 global hectares per person
- ■ Insufficient data

A country's Ecological Footprint is determined by its population, the amount consumed by its average resident, and the resource intensity used in providing the goods and services consumed. It includes the area required to meet people's consumption from cropland, grassland and pasture, fishing grounds and forest. It also estimates the area required to absorb the CO_2 released when fossil fuels are burned, less the amount taken up by the oceans. In the map, each country's size represents its share of the global Ecological Footprint. The colour of each country indicates the per capita footprint of its citizens.(2)

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(1) Source: Human Being museum (France)

(2) Source: WWF Living planet report 2006

4 Preserve our health

Each year in Europe, pollution is responsible for 370,000 deaths and high healthcare costs: it is estimated that we could save €27 billion per year by 2020, just by decreasing CO_2 emissions by 10%.(1)

Noise pollution, although less publicised, is still a major problem. Noise decreases our ability to rest, to concentrate, to learn and to solve problems. It disturbs communication between people, and can put us under stress and make us violent. At high levels, it becomes a threat to our health, causing general psychological stress and sometimes inducing very serious bodily harm, ranging from elevated blood pressure and hearing defects to heart attacks.

The noise factor(2)

- 80 million EU citizens are exposed to noise.
- Further 170 million live in acoustic grey zones that seriously affect people's well-being.
- Result of this negative health impact: the EU's GDP is cut by an estimated 0.2 to 2%.
- Annual follow-up costs: well over 12 billion euros.

The building sector has a role to play

In OECD countries, people spend almost 90% of their life inside buildings, either at home or in schools and offices. Keeping the indoor air clean is therefore important, particularly for children, pregnant women and the elderly.

Some sources, such as furniture, building materials and household products, may release pollutants more or less continuously. Other sources, related to activities carried out in the home (like smoking or cooking), release pollutants intermittently. Many different indoor contaminants exist (mould, bacteria, dust mites, gases, vapours, particles ...) that may have wide ranging effects on human health, depending on factors such as the concentration of the pollutant or the size of enclosed space. Source control and natural or mechanical ventilation will guarantee a good indoor air quality.

In the United States, the annual cost of **building-related sickness** is estimated at $58 billion. Healthy and comfortable indoor environments can therefore offer a major potential for reducing "external" costs to society through reducing disease. According to researchers, sustainable building has the potential to generate an additional $200 billion annually in the United States in **worker performance** by creating offices with improved indoor air quality.

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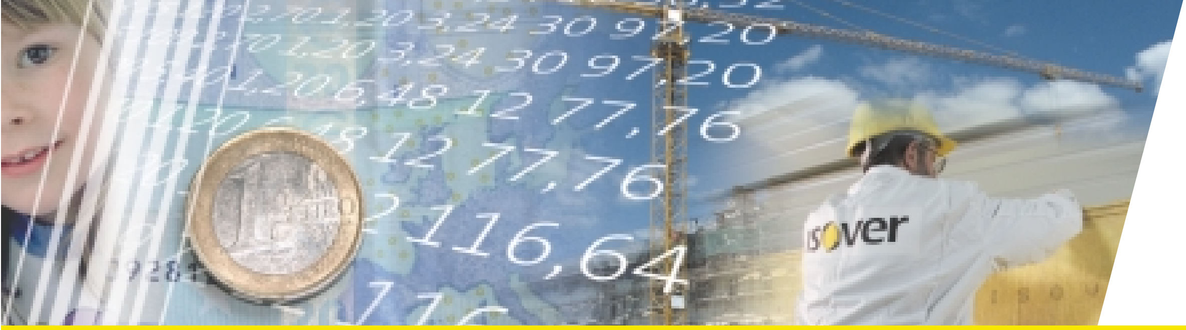
(1) Source: EU documentation on its energy policy (DG Research of the European Commission - July 2002).
(2) Data: European Noise Policy. Strategy Paper of the CALM Network European Union: Green Paper on Future Noise Policy (1996).



5 Protect our buying power

In a time of world economic crisis, it is essential to preserve quality of life.

Today, "housing" costs account for 15 to 30% of European household budgets. Building better, more sustainable buildings would reduce this expenditure through lower heating, cooling, ventilation, renovation and maintenance expenses. It is estimated that lack of energy efficiency in buildings is costing the European Union 270 billion euros every year.(1)

The construction sector accounts for 10% of world Gross Domestic Product, and employs over 100 million people, 28% of the world's total employed. It plays a major role in improving the quality of the built environment; buildings constitute one of the central features in society providing shelter, work spaces, and places for commerce and leisure.

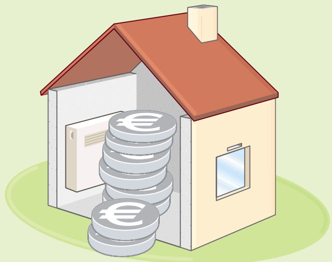
The building sector has a role to play

Globally, the building sector could have a very positive impact on the economic situation:

- From a micro economic viewpoint, people could decrease their heating expenses by up to 90% by enhancing the insulation of their house.
- From a macro economic viewpoint, up to 530,000 jobs could be created in Europe through an ambitious strategy to improve energy efficiency in buildings.(2)
- Aggressive increases in U.S. building energy codes could result in an increase of $28.5 billion in income and 1.1 million jobs.(3)

Significant numbers of people are still becoming ill and dying throughout the world in cold and damp homes, because of **fuel poverty**.

People are said to be living with fuel poverty when they can't afford to heat their homes adequately because the cost of the fuel needed represents more than 10% of their income, forcing them to cut back on food and other essentials.



270 billion euro is the amount of money that a lack of energy efficiency in buildings costs the European Union every year.(4)

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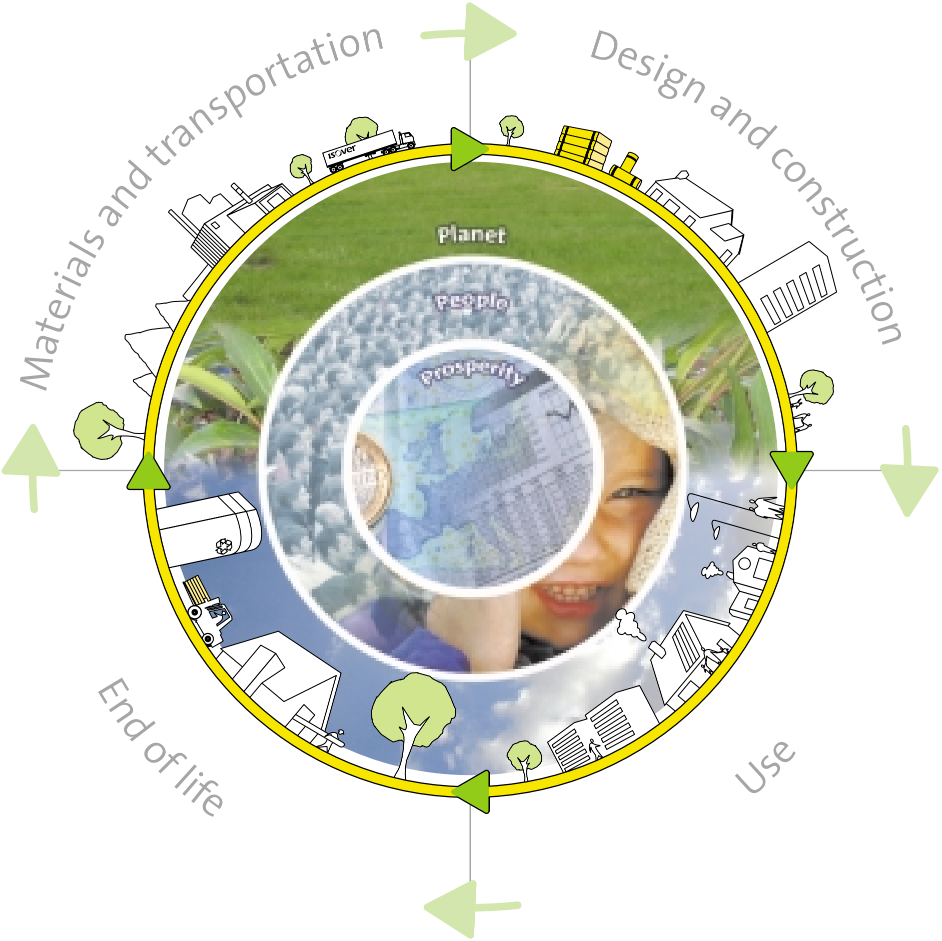
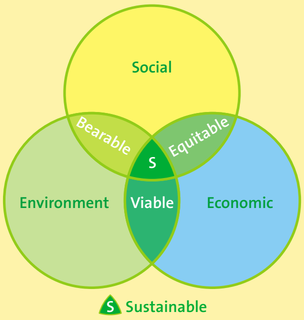
(1) Source: Ecofys VI, 2006
(2) EURIMA Estimates
(3) Source: American Council for an Energy Efficient Economy
(4) Source: Ecofys VI, 2006

Tackling the challenges with sustainable construction

Planet - People - Prosperity: a new and more global approach for the construction sector

While standard building practices are guided by short term economic considerations, sustainable construction is based on best practices which emphasize long term affordability, quality and efficiency. At each stage of the life cycle of the building, it increases comfort and quality of life, while decreasing negative environmental impacts and increasing the economic sustainability of the project.





The Brundtland report (1987) emphasizes the three main aspects of sustainable development:

- **environment** (we should preserve and enhance natural resources),
- **society** (human beings should be able to meet their needs in food, energy, housing, jobs ...),
- **economy** (we should boost economic growth, and developing countries should have the chance to reach the same quality of growth as developed countries).

Adapted from the concept of sustainable development, sustainable construction also targets these three objectives: societal, environmental and economic.

A balanced choice through a global view of the building life cycle

A building designed and constructed in a sustainable way minimizes the use of water, raw materials, energy, land ... over the whole life cycle of the building.

The following example, focused on the energy aspects, demonstrates why it is important to consider the whole life cycle.

Energy used by a building

=

Energy needed throughout its use

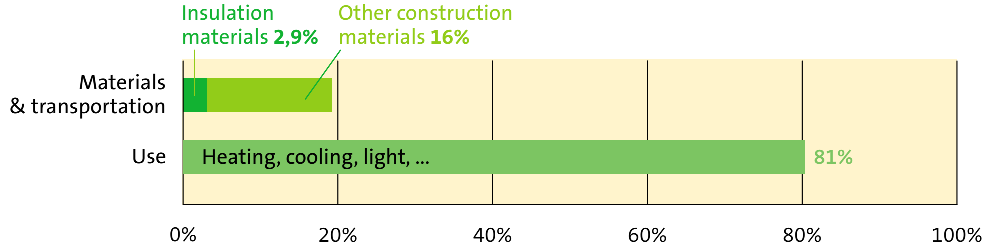
Today, energy is mainly used by buildings during their use (81%).

+

Energy needed for its construction and its deconstruction

The trend towards "very low" or "zero energy" buildings means that the energy consumed to produce and transport the materials used for construction and demolition becomes more significant. Therefore, we must also pay increased attention to those products that require less energy over their whole life cycle (from raw material extraction to end of life and disposal).

Total energy consumption of a typical french very low energy house over its entire life cycle(1)



The pay-back time and why we must consider the global cost of the building

A building generates various types of costs during its life cycle: the direct cost of building materials and construction, the running costs (repair and maintenance), demolition costs etc, but also indirect costs linked to the environment (pollution costs) and the costs for the users (occupancy costs such as water, gas and electricity).

Reducing short term costs does not always provide optimum savings in the longer term: for instance investment in efficient heat savings measures will recoup the initial investment over a period of 10 to 15 years (the pay-back time) and will continue to provide savings each year, for as long as the building is in use. In fact, **making a building sustainable is one of the best investments that you can make today.**

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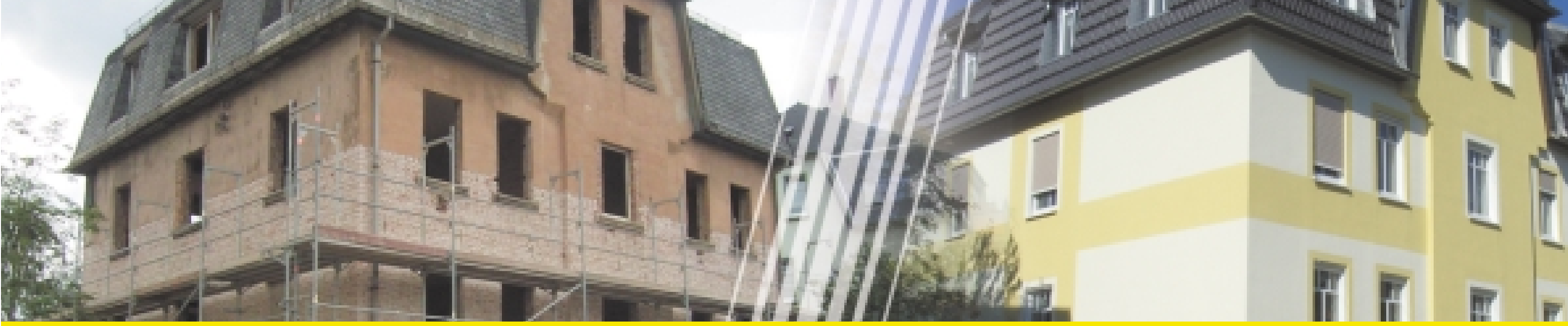
(1) Source: UStudy CSTB / ESE / ENV / 08-49 - consumption 50kWh/sq.m/y for heating, cooling, hot water, lighting and auxiliaries, life cycle of 100 years



Buildings evaluation schemes: towards international coordination

Because of the variety of challenges raised by sustainable construction, building evaluation can be highly complex. For this reason, tools have been developed to help measure the results and evaluate the success of these buildings.

Today, interest in sustainable "green" building is growing worldwide, as shown in the map.
There are a number of excellent and well proven environmental evaluation schemes already in existence, which are supported by ISOVER; these include LEED in the USA, BREEAM in the UK, HQE in France and CASBEE in Japan.

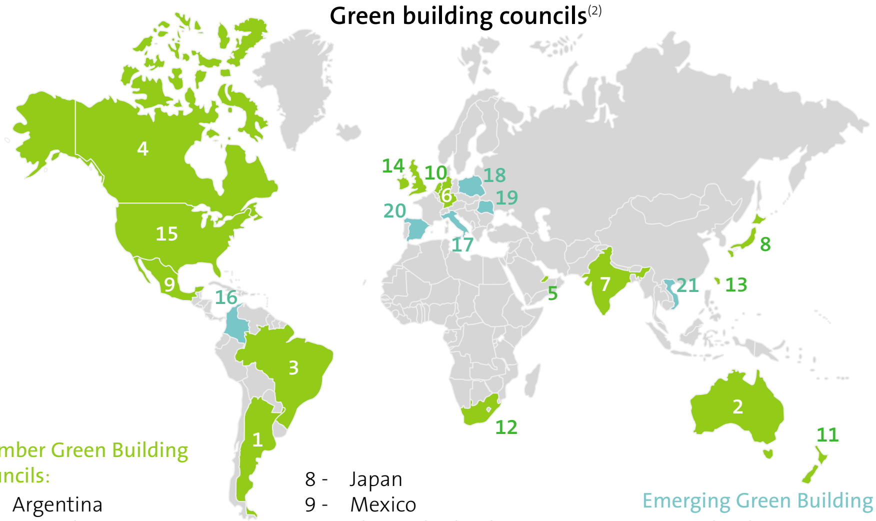
As different national evaluation schemes are developed, however, there is a clear need for coherence and consistency. Common definitions, evaluation criteria and metrics based on sound scientific grounds are essential.

That is why **ISOVER supports the on-going standardization work at European level** (CEN TC 350[1]), and why **Saint-Gobain, as an associate member of the SB Alliance project, is working to define common rules** which will **make national labels compatible and promote mutual recognition** of the different schemes.

Examples of schemes for sustainable buildings

	BREEAM	HQE	CASBEE	DGNB
USA	UK	France	Japan	Germany

Green building councils[2]



Member Green Building Councils:
1 - Argentina
2 - Australia
3 - Brasil
4 - Canada
5 - United Arab Emirates
6 - Germany
7 - India
8 - Japan
9 - Mexico
10 - The Netherlands
11 - New Zealand
12 - South Africa
13 - Taïwan
14 - United Kingdom
15 - United States of America

Emerging Green Building Councils:
16 - Colombia
17 - Italia
18 - Poland
19 - Romania
20 - Spain
21 - Vietnam

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(1) CEN TC 350: European Committee for Standardization - Technical Committee 350: Sustainability of construction works

(2) Source: World Green Business Council

Green buildings and urbanism: two related subjects

A building is always part of the wider environment with which it interacts and into which it must be integrated. All kinds of building are linked together through water and power supply networks and transportation schemes ...

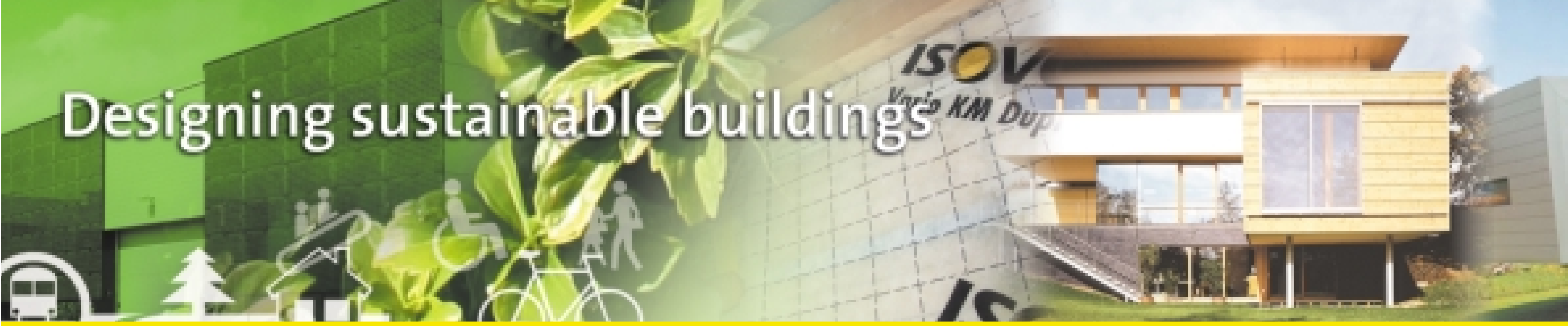
Yet this group of buildings, town or city, is also faced with a number of challenges:

- **Environmental**: consideration must be given to limiting urban spread, destruction of the landscape, water table depletion and making best use of space.
- **Societal**: the community should have a balanced mix of living, working, shopping and leisure space and adequate transportation links.

In designing more desirable, aesthetic, functional and energy efficient areas, urban planners must therefore make planning decisions, on both a local and regional basis, concerning issues of space organization, density and typology of residences, introduction of eco areas, urban tolls, trams and cycle tracks, ... all must be integrated during the design phase to produce a coherent and cohesive urban development plan.

© Osika GmbH

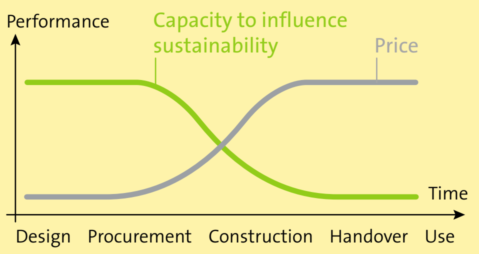
Eco areas are global urban zones created in such a way that they can be energy efficient and reduce their greenhouse gas emissions, to reduce as far as possible their impact on the environment. Various eco areas are developing in Europe, from London to Stockholm and Fribourg.



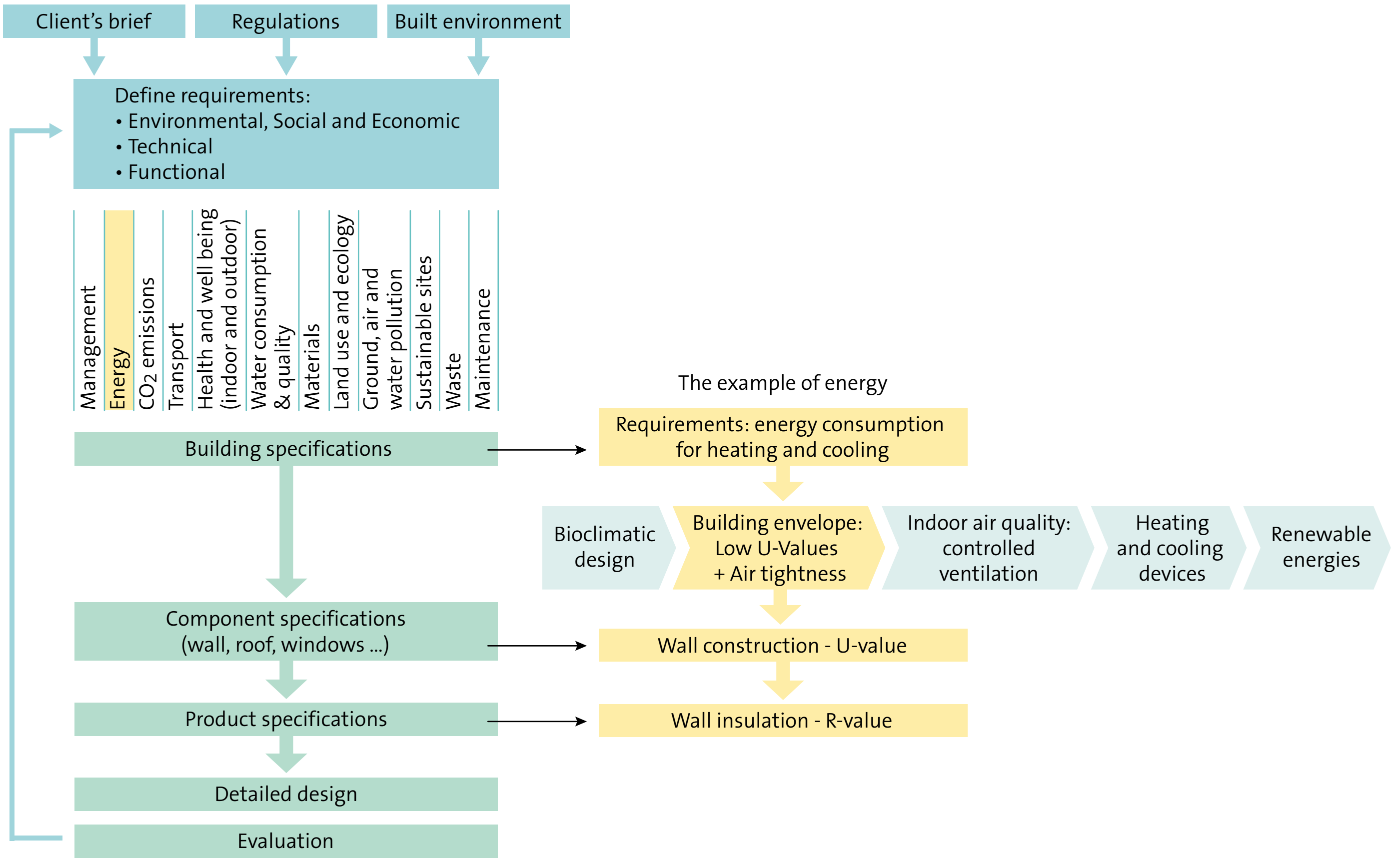
From building requirements to product specifications

Requirements for sustainability are very diverse and numerous. A sustainable building is at least energy efficient, and is much more than a choice of "green" materials. The final design is a compromise of a number of different choices – there is no one single solution.

The client must define his/her key sustainability targets, which may differ from one project to another. These targets must then be combined with technical and functional requirements from the different dimensions of the project (management, energy, transport etc) in order to arrive at the final building specifications. Product specification and choice is the last step in this process, integrating all the predefined requirements and criteria.



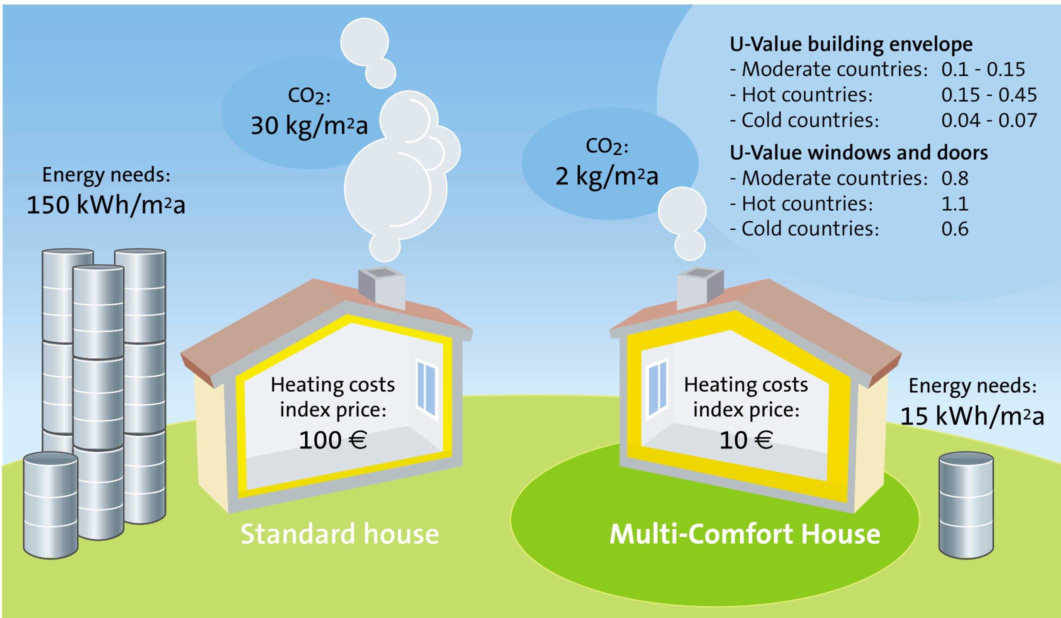
It is increasingly difficult as the project progresses to influence positively and cost efficiently the sustainability of the whole project. The involvement of all stakeholders at the design phase is therefore key to its success.



The ISOVER Multi-Comfort House: a practical starting point for sustainable construction

The ISOVER Multi-Comfort House is a development of the passive house concept.
Thanks to the excellent thermal performance of the building envelope (walls, windows, and doors), use of the internal heat sources in place of normal domestic heating systems, and minimization of ventilation losses using a controlled ventilation system – the passive house doesn't need conventional heating or cooling systems. At less than 15 kWh/m²a, the heating demand is 90% lower than that of a normal house.

Download "**The Multi-Comfort House**" brochures for moderate climate or hot climate on **isover.com**



The Multi-Comfort House offers a wealth of advantages, among them:

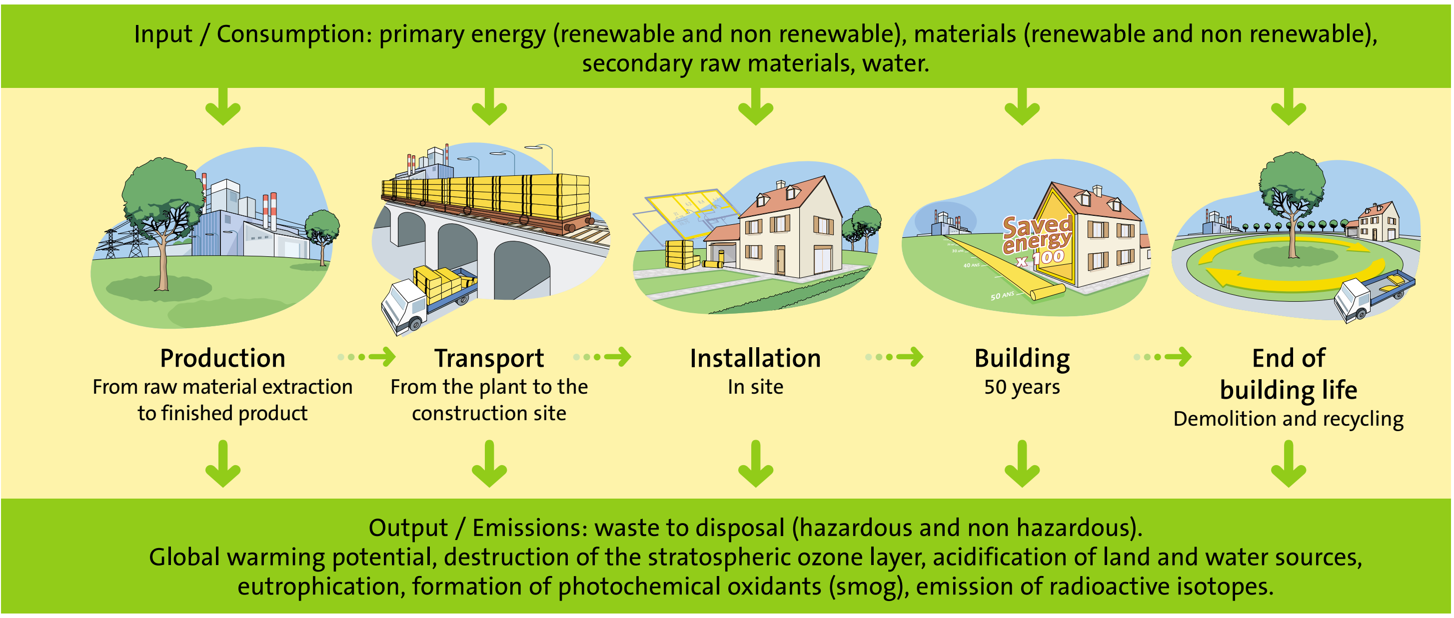
- Optimum **thermal comfort**: all internal room surfaces are maintained at a similar temperature and there is no air convection.
- **Energy savings**: the heat energy demand is reduced by a factor of 10 (typical European houses have a heat energy demand of about 150 kWh/m²a while the ISOVER Multi-Comfort House uses just 15 kWh/m²a).
- Related **CO_2 decrease**: also reduced by a factor of 10.
- Excellent **acoustic comfort** (utilizing ISOVER acoustic comfort classes), visual comfort, fire protection and safety.
- Excellent **indoor air quality**: thanks to a controlled ventilation system with heat recovery, providing permanent fresh air.
- **Flexibility** of building design – both externally and internally.

The ISOVER Multi-Comfort House can be built in any climate and has already been adapted to **moderate, hot and cold climates**.
Various pilot projects have been carried out in different countries.

Insulation materials and LCA's

LCA, the only way to make a scientific assessment of the environmental impact of products

A life cycle analysis (LCA) is an inventory of all of the positive and negative impacts of a product on its environment. These impacts are measured at each stage of the product life "from cradle to grave" (i.e. from the extraction of raw materials to the product's end of life following demolition of the building), with indicators linked to waste, emissions and consumption of resources. ISOVER supports the development of LCAs for insulation products according to the ISO standards: we believe this is the only scientifically sound way to calculate and compare the impacts of any products.
An assessment based only on a section of the life cycle would be biased. For instance, manufacturing hemp wool uses little energy during the production process but the polyester fibres used to bind the hemp fibres have a very high energy content.



Input / Consumption: primary energy (renewable and non renewable), materials (renewable and non renewable), secondary raw materials, water.

Production
From raw material extraction to finished product

Transport
From the plant to the construction site

Installation
In site

Building
50 years

End of building life
Demolition and recycling

Output / Emissions: waste to disposal (hazardous and non hazardous).
Global warming potential, destruction of the stratospheric ozone layer, acidification of land and water sources, eutrophication, formation of photochemical oxidants (smog), emission of radioactive isotopes.

There are no materials which can claim to be more "natural" than others.
All construction products are based on mineral, organic, vegetable or animal raw materials.

What is the best insulation material from an environmental perspective?

It is difficult to compare different insulation materials, as direct comparisons can only be made using two identical units of insulation products (e.g. 1 m^2), with the same thermal resistance (R) value, installed in the same way, in the same application, regardless of the material they are made of. These two products will save the same amount of energy for heating and cooling over their lifetime. They will also produce identical reductions in associated CO_2 emissions. But their environmental impacts will be different as they have been produced with different specifications in different sites using a different mix of resources. There is no best product as such: only individual comparison of LCAs can provide an objective basis for comparison. One product may be good on one impact criteria and not as good on another. Only factual data, quantified, argued and demonstrated can provide a credible comparison.

Per m^2 over the full life cycle	Unit	Glass wool	Hemp wool Flora
Primary energy	MJ	35,6	82,3
Water	L	16,7	11,7
Global warming	kg eq CO_2	1,14	4,39

*Source: LCA's according to NF P01-010 of two ISOVER products - 80 mm and R = 2 m^2.K/W

Understanding an environmental product declaration (EPD)

The tables presented in this brochure are environmental product declarations (EPDs) that provide verifiable, consistent and comparable data based on LCAs, relevant environmental aspects of the product throughout its life cycle are part of the declarations. The EPDs and the LCAs have been made according to the French standard NF P01-010 and have undergone third party verification (ECOBILAN, a division of Price Water House Coopers).

The data in the table are only valid for this specific product (production plant, technical performances) in the described application over a reference service life of 50 years.

10 **impacts** have been selected for the standardised French EPD. To avoid long tables, in this brochure only half of them have been listed for stone wool, EPS and hemp wool, but they are all available on demand.

One m^2 of a 190 mm ISOVER glass wool product* over 50 years use in a typical French building

Environmental impacts	Unit	Used in life cycle (a)	Saved in life cycle (b)	ISOVER eco-balance (b)/(a)
Climate change	kg eq.CO_2	3.91	593	152
Primary energy consumption	MJ	121	27302	226
Atmospheric acidification	kg eq.SO_2	0.0245	1.2	49
Photochemical ozone	kg eq.C_2H_4	0.0171	0.159	93
Water consumption	L	60.7	3857	64
Depletion of non renewable resources	kg eq.Sb	0.0271	4.17	154

*Wall insulation - Lambda = 0.035 W/m.K - R = 5.40 m^2.K/W
Produced and installed in France - LCA according to the French standard NF P01-010

Used in life cycle (a)

Negative environmental impacts of the insulation product over the complete life cycle of the product (from cradle to grave**). The lower, the better.

Saved in life cycle (b)

Positive environmental impacts of the insulation product over the 50 year use phase. The higher, the better.

ISOVER eco-balance (b)/(a)

Balance between the negative impacts over the full life cycle of the products and the positive impacts over the 50 year use phase. The higher, the better.

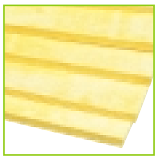
** End of life demolition waste has been considered to be disposed and not recycled.

How to read the table? Example:
190 mm ISOVER wall insulation product (lambda 0.035) will, over 50 year use in a French building, save 152 times more CO_2 than was emitted during its production, transport and disposal (Climate change impact) and save 226 times more primary energy than was consumed during its production, transport and disposal.

ISOVER insulation products: a very positive balance in terms of environmental impacts

ISOVER insulation products have a very positive eco-balance. When used in buildings they provide environmental benefits that far exceed the negative environmental impacts resulting from their production, transport and disposal, as the examples on the following pages clearly demonstrate.

To support our claims, we are undertaking Life Cycle Analyses (LCA's) at most of our European production facilities **according to ISO 14040 standards** and, if they exist, **national standards when developed in compliance with the ISO standards** (for instance the NF P01-010 standard in France).



ISOVER glass wool: good for the environment

Used for more than 70 years, ISOVER glass wool products have proven themselves as popular, ecological and safe to use insulation materials as they are probably the most well-documented and tested building materials in the world.

ISOVER glass wool insulation is manufactured from a combination of **sand** and up to 80% **recycled post-consumer glass** that would otherwise go to landfill. On average, our glass wool contains 50% recycled glass.

Process waste is reduced by incorporating production scrap back into the primary production process, or reprocessing it into other products.

Thanks to their resilient properties, glass wool products can be **compressed by a factor of up to ten** at the time of packaging and palletizing. This patented process lowers transport environmental impacts, improves handling and reduces the need for packaging materials.

With constant improvements to their quality and performance, today's technically advanced ISOVER products bear little resemblance to the early glass wools of the 1970's.

A very positive eco-balance

Over its installed life (usually 50 years), **a typical ISOVER glass wool insulation product saves more than 100 times the energy consumed and the CO_2 emitted in its manufacture, transport and disposal**. The CO_2 and energy balance switches to positive only a few months after installation.

One m^2 of a 190 mm ISOVER glass wool product*
over 50 years use in a typical French building

Environmental impacts	Unit	Used in life cycle (a)	Saved in life cycle (b)	ISOVER eco-balance (b)/(a)
Climate change	kg eq.CO_2	3.91	593	152
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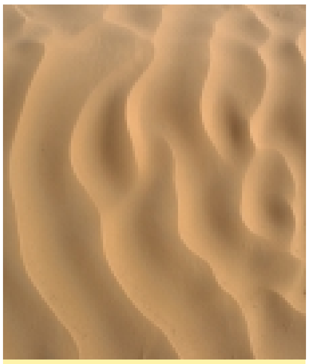
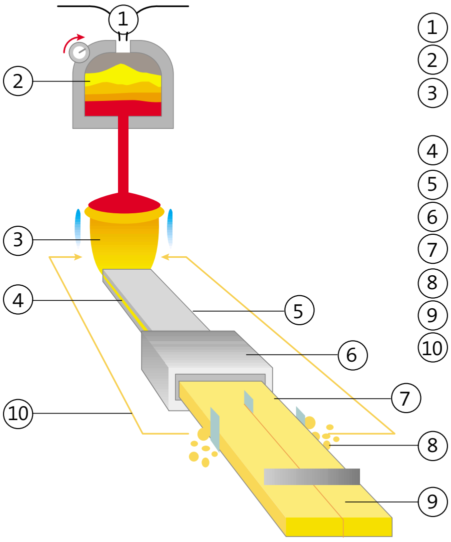
Water consumption	L	60.7	3857	64
Depletion of non renewable resources	kg eq.Sb	0.0271	4.17	154
Solid waste - recycled (total) - disposed (total)	 kg kg	 0.297 3.770	 15.1 31.928	 51 8
Air pollution (Eutrophication)	m^3	603	18.596	31
Water pollution	m^3	0.854	178.9	210
Destruction of the stratospheric ozone layer	kg CFC eq. R11	0	0	-

*Wall insulation - Lambda = 0.035 W/m.K - R = 5.40 m^2.K/W
Produced and installed in France - LCA according to the French standard NF P01-010



Sand is the final product of rock weathering. Much more raw sand is generated annually than is used by man, and therefore sand can be considered as rapidly renewable.

Glass wool production process

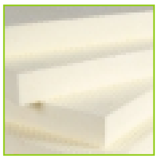


① Sand and cullet
② Melting 1,450°C
③ Fibre forming and binder injection
④ Forming section
⑤ “White” glass wool
⑥ Curing oven
⑦ Binder becomes yellow
⑧ Edge trim cutting
⑨ Cross cutting
⑩ Recycled waste

Safe products

- According to the International Agency for Research on Cancer (IARC) - part of the World Health Organisation - mineral wool insulation is “not classifiable as to its carcinogenicity to humans”. At European level also, ISOVER mineral wool fibres are not classified as carcinogenic, based on the Regulation (CE)1272/2008. This exoneration is regularly checked and certified by the European Certification Board for mineral wool: all ISOVER mineral wool products are euceb certified and RAL certified for the German market.
- Tested according to ISO 16000 standards, ISOVER glass wool products release a very low amount of formaldehyde. In several countries ISOVER glass wool products are certified by independent institutes such as Greenguard (USA), Blue Angel (Germany) or RTS M1 (Finland). Whilst a large number of tests conducted by independent expert laboratories in many countries have shown that glass wool products are an insignificant source of formaldehyde within buildings, we are nevertheless continuously improving our products to reduce formaldehyde emissions to the lowest possible levels.
- ISOVER encourages installers to follow the manufacturers’ recommendations printed on their packaging during handling of these products.

ISOVER glass wool products in Germany have been awarded the Blue Angel eco-label.



ISOVER EPS: organic insulation that demonstrates a positive eco-balance

Expanded Polystyrene, or EPS, is a lightweight, rigid plastic foam insulation material produced from solid beads of polystyrene, with a diameter of 0.2 to 0.3 mm.

Expansion is achieved by virtue of small amounts of pentane gas dissolved in the polystyrene base. When exposed to steam, the gas expands forming perfectly closed cells of EPS, with a volume up to 50 times that of the original polystyrene bead. The manufacturing process does not, and has never, involved the use of Chlorofluorocarbons (CFCs) or Hydrofluorocarbons (HCFCs). Therefore it does not damage the ozone layer.

Clean EPS waste is re-used by grinding and adding to virgin material during the production process, reducing the amount of virgin raw material used.

Expanded polystyrene foam (EPS) is usually white. Some innovative new EPS products sold by ISOVER, however, are grey due to the inclusion of graphite, which substantially increases insulation thermal performance.

EPS is a valuable valorisation of an oil derivate: naphta.

Of the total oil production in the world only 0,1% is used for the production of EPS foams.

The eco-balance of ISOVER EPS insulation product is positive

In its lifetime, **a typical ISOVER EPS product saves more than 50 times the energy consumed during its manufacture, transport and disposal.**

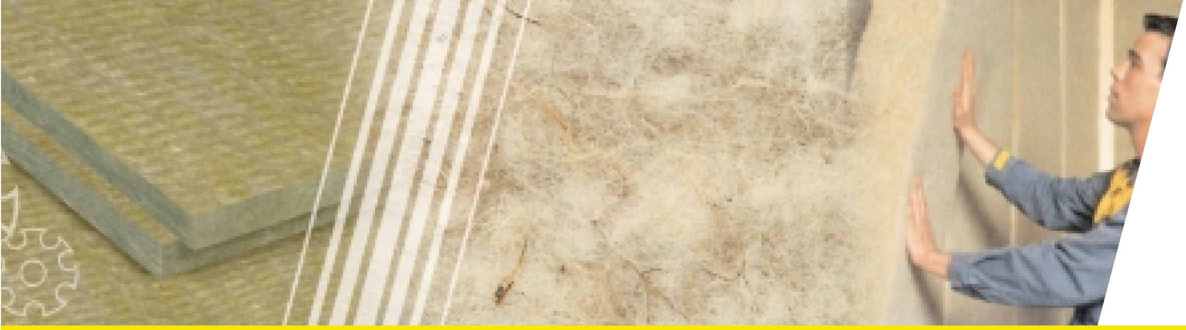
One m^2 of a 100 mm ISOVER EPS product*
over 50 years use in a typical French building

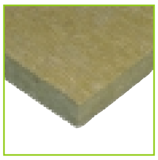
Environmental impacts	Unit	Used in life cycle (a)	Saved in life cycle (b)	ISOVER eco-balance (b)/(a)
Climate change	kg eq.CO_2	13.62	380.5	28
Primary energy consumption	MJ	319.21	17252	54
Atmospheric acidification	kg eq.SO_2	0.07	0.71	10
Photochemical ozone	kg eq.C_2H_4	0.05	0.05	1
Water consumption	L	38.08	2432.85	63
Depletion of non renewable resources	kg eq.Sb	0.13	2.63	20

*Flat roof insulation - Lambda = 0.035 W/m.K - R = 2.85 m^2.K/W - Produced and installed in France - LCA according to the French standard NF P01-010

What about fire safety with EPS insulation?

As with virtually all organic building materials, polystyrene foam is combustible. However, in practice its burning behaviour depends on the conditions under which it is used, as well as the inherent properties of the material. These inherent properties differ depending on whether the cellular material is made from EPS with or without a fire retardant additive. The bonding of other materials to cellular polystyrene also considerably affects its burning behaviour. It is strongly recommended that expanded polystyrene should always be protected by a facing material.





ISOVER stone wool: from molten volcanic rock

The principal raw materials used in the manufacture of stone wool are basalt, diabase and similar igneous rocks and blast furnace slag. Coke is used to fuel the furnace and dolomite is used as a fluxing agent. Our own waste stone wool is also recycled on site by transforming it into briquettes and returning it into the cupola furnace. This benefits the environment by substituting virgin raw materials, such as rock and fuel, with waste materials of a similar chemical composition.

During its lifetime a typical ISOVER insulation product saves nearly 100 times the energy invested in its manufacture, transport and disposal.

One m² of a 90 mm ISOVER stone wool product* over 50 years use in a typical French building

Environmental impacts	Unit	Used in life cycle (a)	Saved in life cycle (b)	ISOVER eco-balance (b)/(a)
Climate change	kg eq.CO_2	8.59	274	32
Primary energy consumption	MJ	134	12815	95
Atmospheric acidification	kg eq.SO_2	0.0833	0.497	6
Photochemical ozone	kg eq.C_2H_4	0.00289	0.0732	25
Water consumption	L	22.9	1827	80
Depletion of non renewable resources	kg eq.Sb	0.0636	1.92	30

*Ventilated facade insulation - Lambda = 0.035 W/m.K - R = 2.55 m².K/W - Produced and installed in France - LCA according to the French standard NF P01-010

The **volcanic Diabase rock** used to make ISOVER stone wool is present in large quantities throughout the earth, and is not a scarce resource.

Every year the earth's volcanoes and plate tectonics produce much more of this rock material than we use in our manufacturing process.

ISOVER hemp wool: the vegetal option

Hemp fibres lock up CO_2 during growth and therefore the hemp wool products sold by ISOVER have a positive role to play in combating global warming. Hemp is grown without the use of herbicides and pesticides.

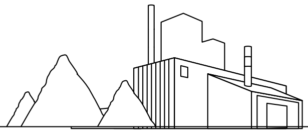
ISOVER hemp wool products are made from hemp and up to 40% recycled cotton. The hemp fibre is extracted by purely mechanical process, which is entirely free of chemicals and waste. The woody by-product from the hemp plant is used as high quality horse bedding. The recycled cotton fibres are a waste product of the cotton processing industry, and would otherwise go to landfill.

The natural fibres are bound together using a synthetic polyester binder. Fire safety is improved by an additional fire retardant.

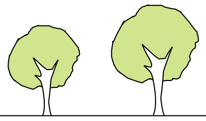
One m² of a 100 mm ISOVER hemp wool product* over 50 years use in a typical French building

Environmental impacts	Unit	Used in life cycle (a)	Saved in life cycle (b)	ISOVER eco-balance (b)/(a)
Climate change	kg eq.CO_2	5,43	113	21
Primary energy consumption	MJ	100	5350	53.5
Atmospheric acidification	kg eq.SO_2	0.0432	0.201	4.6
Photochemical ozone	kg eq.C_2H_4	0.00675	0.0253	4
Water consumption	L	14.4	764	53
Depletion of non renewable resources	kg eq.Sb	0.0366	0.80	22

*Pitched roof insulation - Lambda = 0.042 W/m.K - R = 2.4 m².K/W - Produced and installed in France - LCA according to the French standard NF P01-010



1 Material production and transportation



Decreasing the impact of our production process

More than 50% of all ISOVER factories in the world (71% for glass wool and stone wool only) are ISO 14001 certified, and we are continuously improving and controlling all environmental aspects of our production sites.

Our environmental policy is aimed at:

- **Decreasing energy use, air pollutants and, in particular, greenhouse gases**

ISOVER uses the most efficient techniques available for its furnaces and equipment, in terms of output and power consumption, in order to save energy, decrease CO_2 emissions, optimize combustion and thus reduce nitrogen oxide emissions.

In 2007, our energy consumption and CO_2 emissions per ton of produced glasswool were both 20% lower than in 2000.

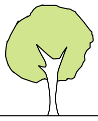
In order to minimise the amount of dust released into the environment, we also clean the gases from our production processes through filters.

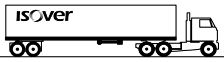
- **Managing natural resources**

Preserving biodiversity is a genuine concern for us, as natural raw materials are present in almost all of our products. Whilst water is used in our manufacturing processes for cleaning the fumes and for cooling high-temperature facilities, we aim to minimize groundwater extraction as much as possible. Between 1999 and 2007, by increased use of closed circuit systems and investing in new equipment that consumes less water, we decreased water consumption per ton of produced mineral wool by 30%.

The **International Organization for Standardization**, or **ISO**, aims at creating international norms in industrial and commercial fields called “ISO norms”. The **ISO 14000 family is about “environmental management” at plant level**, i.e. how the company:

- identifies and controls the environmental impact of its activities, products, and services,
- constantly increases its environmental performance,
- applies a systematic approach to define environmental targets, reaches them and proves they have been reached.





Managing waste and recycling

Our focus on recycling is enabling us to minimize waste and reduce our consumption of primary raw materials.

- We are increasing the use of “secondary” raw materials created from recycled primary raw materials, such as cullet for glass wool.
- We are increasingly recycling our production waste in the production process (75% of glass wool, 66% of stone wool and 100% of EPS production waste are recycled). As a result, waste levels have been reduced considerably.

Ensuring health and safety

Health and safety is a top priority for ISOVER plants worldwide, and workers receive constant advice and training. Our target is zero accidents and zero work-related injuries. Users also receive safety advice through clear and simple pictograms on product packaging.

Reducing transport

The compression of ISOVER glass wool products means transport requirements are reduced – in the case of non-compressible products, we achieve this by having production plants and storage close to customers, which limits transport impacts.
Our wide range of insulation types means we are also able to maximise transport by delivering full loads to customers.

ISOVER has developed a patented process for compressing glass wool: in the picture there is the same amount of glass wool in both trucks, but it is compressed on the right. Thanks to their elastic properties, products can be compressed by a factor up to ten at the time of packaging (in rolls) and palletizing. This process offers numerous advantages in terms of:

- simpler logistics and lower transportation,
- ease and safety of handling on construction sites when laying glass wool,
- streamlined waste management, due to the reduction in packaging materials.

2 Design and construction

Leading Information campaigns

In 2004, ISOVER France and 9 other groups from the building sector created the "**Isolons la Terre contre le CO2**" association to spread awareness on the dangers of CO2 emissions from buildings and support the development of effective anti-pollution policies to promote energy efficient constructions.

The association leads information campaigns, organises common actions with environmental NGOs, and prepares technical studies ...
Based on the success of "Isolons la Terre contre le CO2" other groups have used it as a template in their own countries: "**Isoterra**" in Belgium and "**Spaar het klimaat**" in the Netherlands in 2005, "**Isolando**" in Italy in 2007. In Germany, ISOVER G+H launched an action called "**CO2NTRA**".

Supporting effective sustainable buildings rating systems

ISOVER supports the projects of national sustainable building councils in various countries to define and promote environmental evaluation schemes for buildings. For instance, ISOVER is a founding member of the German and South African sustainable building councils.

Towards very low energy buildings

Very low energy buildings are designed to provide a significantly higher standard of energy efficiency than the minimum required by national Building Regulations. They are very often designed without traditional heating systems and without active cooling and result in energy consumption savings of 70 to 90% compared to the existing building stock.

ISOVER supports national initiatives to develop voluntary certification and labelling schemes for very low energy constructions: **Passiv Haus** (Germany), **BBC - Bâtiment Basse Consommation - Effinergie** (France), **"zero" carbon house** (UK), **Minergie** (Switzerland) ...

Informing architects

ISOVER organises contests to promote innovation and measurable energy efficiency to both students in architecture and established architects: more on www.isover-eea.com and www.isover-students.com.

ISOVER ENERGY EFFICIENCY
The Best of Awards

Our brochure "Multi Comfort House" is also a complete and detailed reference for architects, available to download from www.isover.com.

Training the building sector professionals

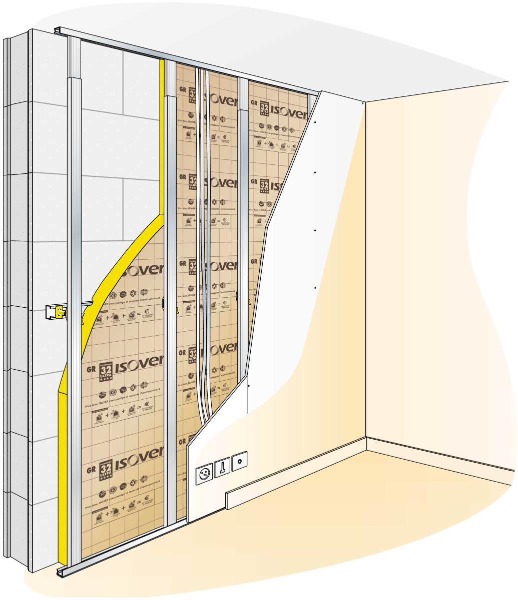
Backed by more than 30 years' experience in training, ISOVER is designing and setting up programs for building sector professionals to raise awareness of energy efficiency and help them to specify, sell and install insulation solutions. Training facilities are available in most of the countries in which ISOVER is active.

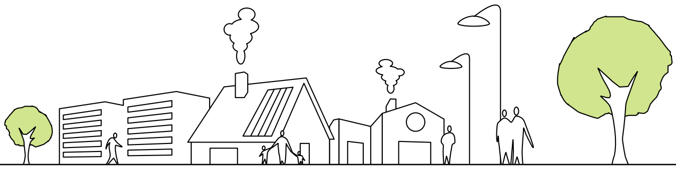
Training center in Chambéry, France

Developing innovative systems

We develop complete integrated systems to simplify installation of our products and guarantee their performance in a building.

For instance, the ISOVER OPTIMA System is an innovative solution for internal thermal-acoustic insulation of walls in new build and renovation. Unlike traditional linings, the OPTIMA wall lining system is simple and quick to install, without glue, allowing a thermal-acoustic jacket to be created quickly for optimum comfort.





Thermal comfort: enhancing the performance of our insulation solutions

Thermal comfort is mainly associated with the maintenance and even distribution of interior room temperature and air quality.

It can be achieved by applying very high resistance thermal insulation to all room surfaces (including windows), combined with ventilation adapted to the season, doors and shutters, perfect air tightness to avoid unwanted air input and the building's good thermal inertia.

ISOVER's range of high performance insulation solutions is constantly being developed with new and innovative products and systems which take the science of insulation to a new level.

ISOVER's glass wool is the most efficient on the market with **lambda 30** performance, and our global range of products includes lambda 32 products for glass wool and lambda 30 for polystyrene. In the last few months we have added a number of new products with very low lambda, including **Isoconfort 32** and **Multimax 30** in Belgium and, in Germany, a complete range of lambda 32 products.

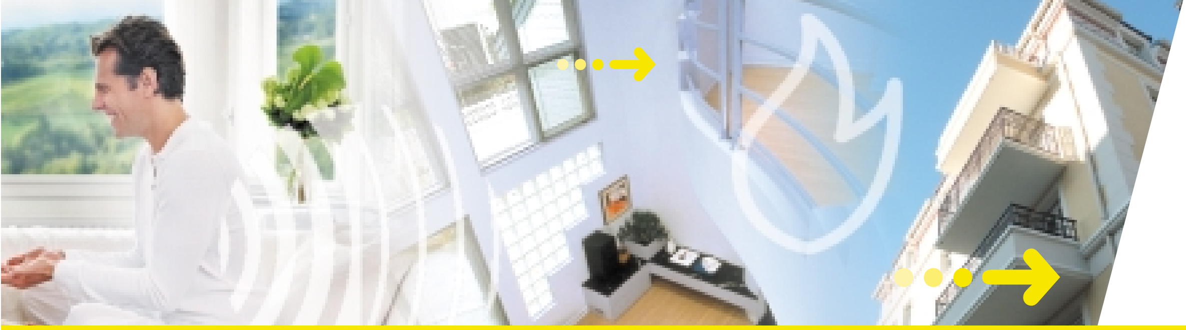
Acoustic comfort: enjoy the «comfort» class

Based on extensive studies of the very diverse types of noise, ISOVER has set a new insulation benchmark.

The new "ISOVER Acoustic Comfort Classes" define reliable acoustic comfort, going beyond the requirements set by the current European standards.

ISOVER Acoustic Comfort Classes help in selecting the most appropriate airborne and impact sound insulation, which is becoming increasingly important, especially in multi-occupancy buildings. ISOVER also offers various solutions for achieving these classes.

TECHNOSTAR is a complete commercial partition wall system for extended height applications requiring high levels of sound insulation performance as well as fire, thermal and structural performance. It is commonly used in cinemas to provide sound insulation between adjacent auditoria.



Exceptional energy savings

the ISOVER range of products and systems allows very high levels of energy efficiency to be achieved in buildings. Energy savings of up to 90% can be achieved over an equivalent uninsulated house.

© Planungs und konstruktionsbüro Taube

In 2006, the renovation of this german building improved the thermal comfort for all residents of the building and enabled a 90% drop in the consumption of primary energy. The building's thermal envelope was significantly upgraded and the new total energy consumption of the building is now 14 kWh/m²/year.

ISOVER, a fire security specialist

Insulation plays a dual role in terms of fire protection through:

- its own inherent fire safety properties,
- its effect on the fire performance and stability of the structure in the case of fire.

Mineral wool insulation will not support combustion and has the highest possible Euroclass A classification (A1 & A2 s1d0); neither will it produce toxic fumes in a fire situation.

The exceptional insulating properties of mineral wool means that it contributes to the fire resistance of walls and thus the overall stability of buildings, helping to provide valuable extra time for evacuation.

EPS also meets fire safety requirements. In almost all building applications, however, EPS is used in combination with another material, such as plasterboard or concrete, which provides additional protection. In specific applications where the EPS is exposed, fireproofed EPS is often recommended.

ULTIMATE has been specifically designed for improved safety. It is resistant to high temperatures (up to 650°C) and can serve as a fireproof barrier. It can also be used to make ducts airtight and watertight in air conditioning systems and industrial or domestic hot water piping systems.

Insulation solutions for an improved indoor environment

We want to help reduce the sources of pollution by selling solutions that comply with all existing requirements for indoor air quality. Our insulation solutions do not contribute to indoor air pollution, and are safe to handle and install in the home or office. None of the products sold by ISOVER is classified as a dangerous substance by the European Union(1), and based on available data(2), exposure to ISOVER insulation products will not cause any significant adverse health effects.

Mineral wool is generally installed in such a way that no release of dust and fibres occurs after application, and tests to determine possible exposure of building occupants have shown no significant generation of airborne mineral wool fibres.

ISOVER mineral wool and polystyrene products do not provide a medium for the growth of micro organisms. They do not rot, decay or sustain mould. ISOVER hemp wool products are treated with biocides and fungicides to prevent development of micro organisms.

Since moisture promotes mould growth, controlling the level of moisture is one of the best and easiest ways to improve indoor air and protect your health: that is why we have developed the ISOVER VARIO membrane.

Indoor air quality is closely related to ventilation. Fresh outdoor air replaces indoor air through ventilation, thus removing and diluting contaminants generated indoors. ISOVER encourages the development of high performance controlled ventilation to maintain adequate air quality while reducing energy consumption.

The **VARIO** system allows timber roof and wall structures to breathe and dry naturally. In winter, when the inside air is warmer than the outside, water vapour is pushed into the structure where it remains with potentially long term damaging affects on timber. The VARIO system impedes the ingress of this water vapour by automatically reacting to the climatic conditions and closing its pores. In summer however, when the ambient temperature is increased, the VARIO system has the reverse effect by opening its pores to allow trapped water vapour to escape inwards, thus ensuring that the structure can dry naturally.

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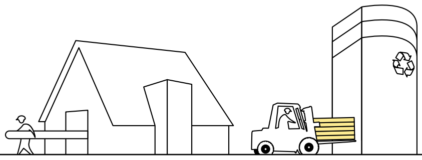
(1) Regulation (EC) N°: 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures

(2) Livre blanc: laines minérales et santé. 2008. FILMM (Syndicat National des Fabricants d'Isolants en Laine Minérale Manufacturée)

4 End of life



Waste management

ISOVER systems can be easily deconstructed at the end of the building's life, and all components sorted and recycled if the infrastructure exists.

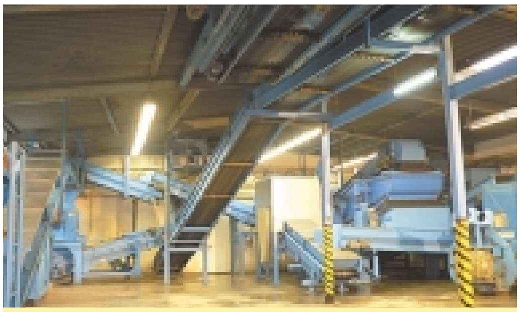
Clean EPS can be ground and used for new EPS production or to create other products (concrete, seat padding, etc). It can also be melted, extruded and cut into granules, then mixed with other polymers to use in the manufacture of rigid plastic products, such as CD cases or clothes hangers.
Mineral wool can be used to create new synthetic wool, raw materials for briquette plants, green roofs, etc.

ISOVER supports the development of recycling companies, and works with them whenever it's possible. ISOVER is also testing various internal initiatives to develop the recycling of its products.

Nevertheless, in the countries where recycling facilities and/or processes have not been developed, our products are deposited in ordinary landfills. Analyses confirm that mineral wool waste, EPS and hemp wool can be deposited without problems at ordinary landfill sites.
Additionally, hemp wool can be burnt to recover energy.

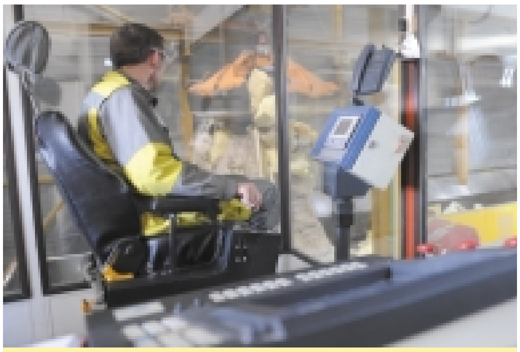
Jobsite waste collection in Switzerland

In 1993, in Switzerland, ISOVER introduced a system to collect and recycle ISOVER glass wool scrap from building sites. Contractors are able to return their waste in specially designed bags, free of charge, via building material retailers. The bags are then taken back to the ISOVER factory in Lucens on returning empty delivery trucks.



WOOL.rec. in Germany

WOOL.rec. GmbH is an independent enterprise that converts mineral fibres into a patented product, WOOLIT®, mainly used as aggregate in the brick industry. Thanks to this aggregate, bricks have a higher robustness and an improved thermal resistance.



Oxymelt plant in France

Since 1997 the OXYMELT process has been in place on the site of the ISOVER plant in Orange. Wastes are melted by the input of oxygen-enriched air to obtain a mineral material useable as a vitreous raw material in a glass melting process.
Some OEM customers use this installation to recycle their ISOVER glass wool waste.

ISOVER - upholding the values of the Saint-Gobain group

THE GLOBAL COMPACT

The Global Compact is a framework for businesses that are committed to aligning their operations and strategies with ten universally accepted principles in the areas of human rights, labour, the environment and anti-corruption. As the world's largest, global corporate citizenship initiative, **the Global Compact** is first and foremost concerned with exhibiting and building the social legitimacy of business and markets.

Saint-Gobain is proud to belong to a global community of corporate citizens who uphold the key values of respect for human rights, environmental protection and anti-corruption. It joined **the Global Compact** in July 2003.

www.unglobalcompact.org

FONDATION
SAINT-GOBAIN
INITIATIVES

Saint-Gobain believes it has the responsibility to undertake non-profit actions in domains consistent with its strategy.
The international corporate **Foundation "Saint-Gobain Initiatives"** supports projects proposed by employees in three fields:

- Integration of youth through work in the housing sector,
- construction, refurbishment or renovation of social housing for general interest purposes,
- reduction of energy consumption and environmental protection in social housing.

Global 100
Most Sustainable Corporations in the World

Saint-Gobain is included in the **Global 100** most sustainable corporations in the world. **Global 100** is a list of companies included in MSCI World - a global stock market index maintained by Morgan Stanley Capital International - that are evaluated according to how effectively they manage environmental, social and governance risks and opportunities, relative to their industry peers. The list is published each year during the Davos World Economic Forum.

www.global100.org

CARBON DISCLOSURE PROJECT

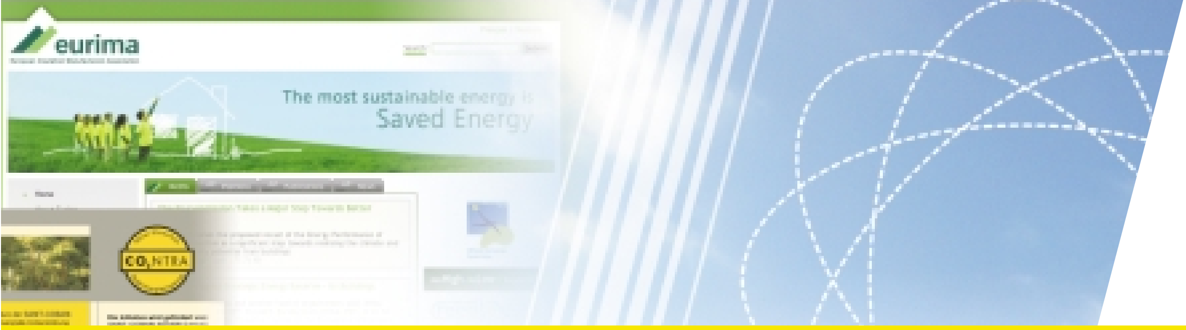
The **Carbon Disclosure Project** is an independent not-for-profit organisation. Since its formation in 2000, CDP has become the gold standard for carbon disclosure methodology and process, providing primary climate change data to the global market place. By joining the project in 2003, Saint-Gobain has committed to provide annual reports on the company's CO_2 emissions and climate strategy.

www.cdproject.net

The SB Alliance

Saint-Gobain is an associate member of the **SB Alliance** project, whose goal is to define common rules to make national labels compatibles and to promote mutual recognition.

www.sballiance.org



Sources & usefull links

- www.isover.com
- www.isover-eea.com
- www.isover-students.com

Mineral wool:

www.eurima.org	European Insulation Manufacturers Association
www.euceb.org	European Certification Board for Mineral Wool Products
www.naima.org	North American Insulation Manufacturers Association

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Polystyrene:

www.eumeps.org	European Manufacturers of Expanded Polystyrene
www.exiba.org	European extruded polystyrene insulation board association

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Energy efficiency promotion:

- www.isolonslaterre.org
- www.isolando.com
- www.isoterra.be
- www.contraco2.com
- www.spaarhetklimaat.nl
- www.euroace.org
- www.effinergie.org
- www.minergie.ch
- www.passiv.de

International institutions:

www.iea.org	International Energy Agency
www.www.ipcc.ch	International Panel on Climate Change
www.unep.org	United Nations Environment Programme
www.reeep.org	Renewable Energy & Energy Efficiency Partnership
www.wbcsd.org	World business council for sustainable development
www.oneplanetliving.com	A program from BioRegional and WWF International
www.worldgbc.org	World Green Building Council
www.sballiance.org	Sustainable Buildings Alliance

“Will we look into the eyes of our children
and confess that we had the opportunity,
but lacked the courage?
That we had the technology,
but lacked the vision?”

(International environmental NGO)

SAINT-GOBAIN ISOVER - SA au capital de 45 750 000 € - 312 379 076 RCS NANTERRE

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This brochure is meant as a quick guide to help you find useful information on sustainable construction. The information given in the brochure is based on the current state of our knowledge and experience and was carefully compiled. Should any incorrect information be provided, a deliberate or grossly negligent fault from our side can be excluded. Nevertheless, we do not accept any liability for the topicality, correctness and completeness of this information since unintentional faults cannot be excluded and continuous updates not ensured. The brochure contains the Internet addresses of other companies and third parties. These have been included to help you get a complete overview of the spectrum of information and services available. As the contents of these websites do not necessarily reflect our views or position, we must therefore exclude any liability.

SAINT-GOBAIN

ENVIRONMENTAL PRODUCT DECLARATION

ISO 14025 ISO 21930 EN 15804

Owner of the declaration	AS ROCKWOOL
Program holder	The Norwegian EPD Foundation
Publisher	The Norwegian EPD Foundation
Declaration number	00131E rev1
Issue date	25.10.2013
Valid to	25.10.2018

ROCKWOOL® isolering

Product

AS ROCKWOOL

Manufacturer

General information

ROCKWOOL® isolering
Product

AS ROCKWOOL
Manufacturer

Program holder:
The Norwegian EPD Foundation
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Phone: +4723088000
e-mail: post@epd-norge.no

Owner of the declaration:
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Declaration number:
00131E rev1

Place of production:
Vamdrup and Doense, Danmark
Trondheim and Moss, Norway

This declaration is based on Product Category Rules:
CEN Standard EN 15804 serve as core PCR
Product Group Insulation materials, NPCR 012rev,

Management system:
ISO 9001, ISO14001, EN13.162, EN13.172, EN14303

Declared unit:
1 m^2 of 37mm thick stone wool insulation product with a density of 29 kg/m^3 and a thermal resistance of R=1 m^2 K/W.

Org. No:
923828583

Declared unit with option:

Issue date:
25.10.2013

Functional unit:

Valid to:
25.10.2018

The environmental product declaration has been worked out by:
Rasmus Nielsen and
Anders Schmidt, Ph.D.,
FORCE Technology,
Lyngby, Danmark

Comparability:
EPD of construction products may not be comparable if they not comply with EN 15804

Year of study:
2013

Verification:
Independent verification of data and other environmental information has been carried out in accordance with ISO14025, 8.1.3.

externally ☑ internally ☐

President Joep Meijer
(Independent verifier approved by EPD Norway)

Approved according to ISO14025, 8.1.4

Sverre Fossdal
Dr. ing. Sverre Fossdal
(Chairman of the Verification Group of EPD-Norway)

Declared unit:
1 m^2 of 37 mm thick stone wool insulation product with a density of 29 kg/m^3 and a thermal resistance of R=1 m^2 K/W.

Key environmental indicators	Unit	Cradle to gate A1 - A3	Transport Production site - central warehouse Norway
Global warming	kg CO_2 -eqv	1,27	1,19*10^{-2}
Energy use	MJ	13,8	0,17
Dangerous substances	*		

* The product contains no substanses from the REACH Candidate list or the Norwegian priority list

Product

Product description:

Stone wool insulation from ROCKWOOL is a firesafe* material for insulation against heat, cold, fire, vibrations and noise. The product is wrapped with PE-foil and placed on wooden pallets for further distribution.

Stone wool insulation from ROCKWOOL for the Scandinavian market is supplied by two production sites in Norway (Moss and Trondheim) as well as two sites in Denmark (Doense and Vamdrup), each with two lines. The properties of the ROCKWOOL products from the different production sites are identical. The reference flow is a weighted average and is calculated using the following distribution of production capacity (2011) on the four production sites: Vamdrup 30,6%, Doense 35,7%, Trondheim 11,9%, Moss 21,7%.

* A1 when tested according to EN 13501-1 (Euroclasses)

Description of manufacturing processes:

The furnace used in all four production sites is an oven with coke as the main energy source. The virgin stone raw materials used at all sites are mainly basalt, diabase and dolomite. The Danish sites also use various secondary materials, including internal wool waste, which is mixed with cement into briquettes. The mineral raw materials are melted and spun into fibers at a temperature of about 1500^{0}C. A synthetic binder and a water-repellant agent are added, whereafter the final curing (polymerisation) and forming takes place at a temperature of about 230^{0}C. Finally the product is cut into the desired dimensions and packed in PE foil.

Technical data:

Scaling factors for ROCKWOOL Insulation materials in this EPD can be seen in the table below. The scaling factors show how much to multiply the environmental burdens by in order to obtain a thermal resistance of R=1 m^2 K/W with other ROCKWOOL products.The R-values used for scaling gives a very good indication of the amount of materials needed to achieve the desired insulation effect of other product types, but is not an exact measure. Stone wool insulation products marked with an asterix (*) in the table are sold with extra features for special applications e.g. with wire netting, a bitumen membrane or aluminium foil. The extra features are not covered by this LCA.

The products covered by the EPD are produced at all production lines in a full year. The variation between production lines has not been determined.

Market:

Scandinavia

Product specification

Material input per functional unit

Material	kg	% of total
Stones	0,902	67,1
Secondary resources mostly slag	0,251	18,7
Cement	0,087	6,46
Formaldehyde (37%)	0,052	3,89
Urea (46%)	0,021	1,57
Phenol	0,016	1,21

Products	Scaling Factor
B-plate	1.0
Bjälklagsskiva med vindskydd*	
Byggrulle med vindskydd*	
A-Murbatts	
Isolerasjälv	
Stålregelskiva 40	1.1
Flexibatts 35	
Flexibatts	1.2
Flexi A-plate	
Takstolplate	
Takstolsskiva med vindskydd*	
I-plate A	
Stålstenderplate	
Roxremsa	
A-Rullebatts	
BD-60 FlexiBatts	
Lamelmatte*	1.3
Murplate	1.4
Brannplate 50	
Skalmursskiva	
SuperFlexiBatts	
Super A-Murbatts	
Stålregelskiva 37	1.6
Lydplate	1.7
Rockvegg	
Rockorbit	
RockOrbit	
Flex Systemplate	2.0
FlexExtrem 33	
REDAirFLEXsystem	

Products	Scaling Factor
Super VentiBatts	2.1
Hardrock Elementbatts	
RockProfil skiva	
A-Pladebatts 10	2.3
Plåtunderlagsskiva 80	2.6
Betonelementbatts 35	
Västkustskiva	
Trådvævsmåtte 80 *	
Betonelementplate	2.8
Conlit Brannmatte*	
Alu Brandmatte 80*	
Toprock Lamell	2.9
Underlag Energy	3.4
Trådvævsmåtte 105*	
Brandbatts	3.5
Hardrock Energy	
Stålunderlag Energy	
Drensplate	3.6
RockTorv	
Støpeplate Pluss	
Hardrock Fasadeplate	
Fallunderlagsplate	
Lydunderlagsplate	
Ljudunderlagsskiva	
Underlagsskiva stål & betong	
Facadebatts	
Gulvrenoveringsplade	3.7
Terrænbatts Erhverv	
Universal rørskål *	3.8
Hardrock Energy	4.5

Products	Scaling Factor
Markplate	4.7
Tungplate 150	
Marksskiva Industri	
Stegljudsskiva	
Väggboard	
Conlit 150	5.7
Trinnlytplate	6.0
Renoveringsboard	
TF-plate	6.2
TF-Takkile	
Hardrock Energy Takfall	
TF Renneplate	
Fallränna TF	
Hardrock Takfall 1:40/60	
Hardrock kilskiva 1:40/60	
Ränndalskil 180	
Takboard	
Takkil	
TopRock Takboard	
TF-Plade	
Conlit 300	11.2

*: Products marked with an * are specialty products with extra features like wire netting and aluminium foil.
The extra features are not included in the EPD-calculations

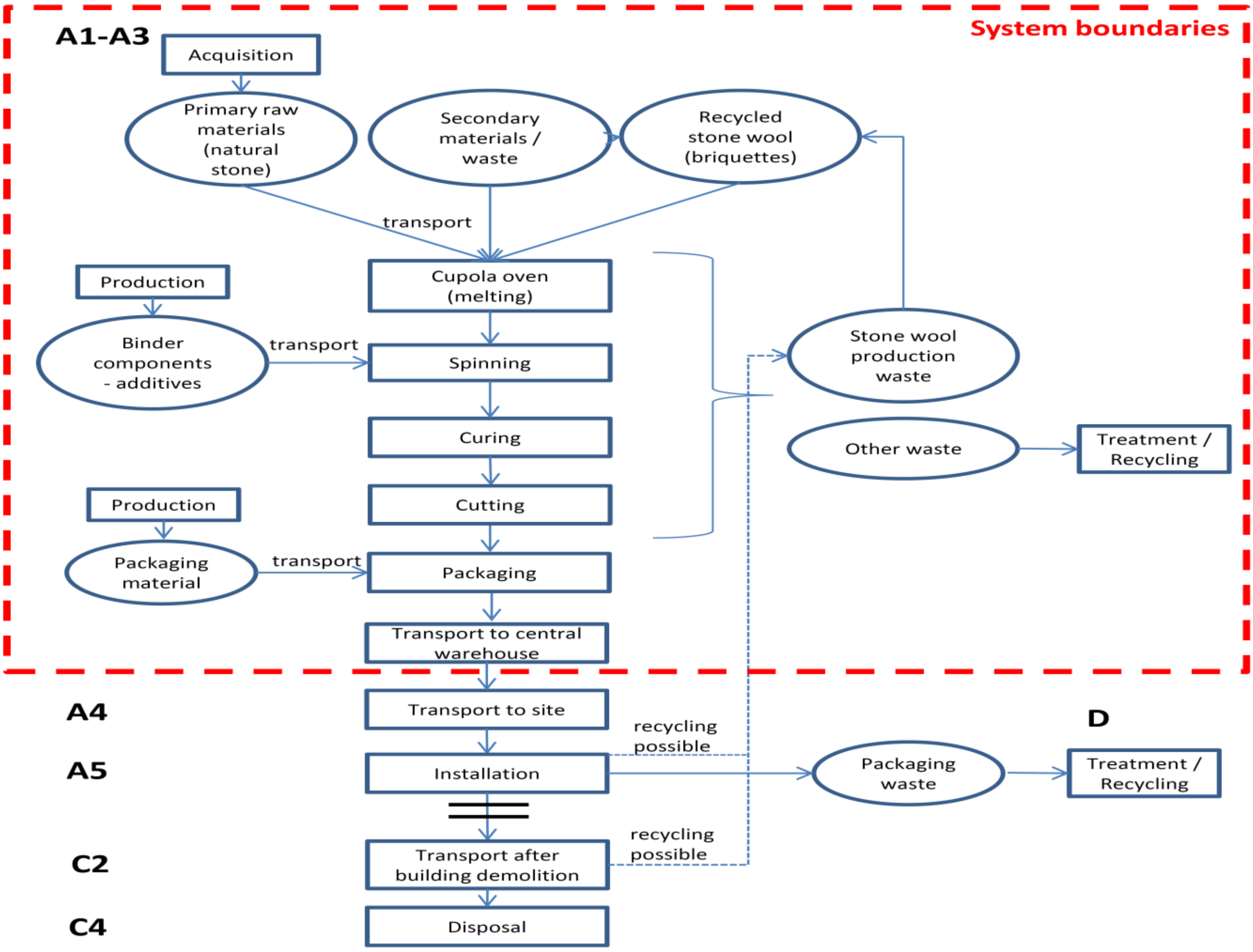
LCA: Calculation rules

Declared unit:

1 m^2 of 37 mm thick stone wool insulation product with a density of 29 kg/m^3 and a thermal resistance of R=1 m^2 K/W.

System boundary:

The overall system boundaries include extraction and transportation of raw materials as well as all manufacturing processes (cradle-to-gate). Transport from all factories to a central storage in Norway has been included.
See Figure below for details



Data quality:

High quality data from GaBi 6 and ecoinvent have been used for acquisition of raw materials and transportation. Legally required information has been used for manufacturing processes at ROCKWOOL. The age of the oldest dataset in the database is 13 years and the vast majority of datasets are under 5 years old. The data collected from the sites are from 2011. Accordingly, the overall quality is judged to be good to very good.

Cut-off criteria:

All inputs of raw materials and energy have been included. Please note that products with special features e.g. wirenetting, bitumen membrane or alufoil are not included in the EPD. Please consult ROCKWOOL AS for more information.

Allocation:

Allocation has been made according to the provisions in EN 15804. Impacts from recycled material have been allocated to the primary product, except transportation. ROCKWOOL supply district heating in Denmark. Respectively 7,3% and 9,4% of the energy consumed in the two production sites in Denmark have been allocated to district heating, using the energy content as the allocation key. The emissions associated with energy production have been allocated in the same way. A sensitivity analysis of the results using a different allocation key, such as the economic value, or substitution approach has not been performed.

LCA: Scenarios and additional technical information

The following information describe the scenaries in the different modules of the EPD.

Transport from production site to sentral warehouse in Norway

Type	Capacity utilisation	Gross density of products	Type of vehicle	Distance km	Fuel/Energy consumption	Value (l/t)
Truck*	30		****	127	$1{,}7 \cdot 10^{-2}$ l/tkm	2,16
Truck**	30		****	50	$1{,}7 \cdot 10^{-2}$ l/tkm	0,860
Boat***	48		*****	149	$4{,}6 \cdot 10^{-3}$ l/tkm	0,685

* Transport byTruck (weighted average). From Danish production sites to Moss in Norway
** Transport byTruck. From Moss and Trondheim to central warehouse in Norway
*** Transport by Boat (weighted average). From Denmark to Norway (Frederikshavn terminal to Oslo)
**** Dataset from GaBi with a Euroclass 3 truck-trailer with a payload of 22 tons.
***** Dataset from GaBi with a Bulk commodity carrier with 1,500-20,000 dwt. payload capacity and light fuel oil driven.

Additional information: Transport from production site to central warehouse in Norway 326 km

LCA: Results

System boudaries (X=included, MND=modul not declared, MNR=modul not relevant)

Product stage			Construction installation stage		Use stage							End of life stage				Beyond the system boundaries
Raw materials	Transport	Manufacturing	Transport	Construction installation stage	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND

Environmental impact

Parameter	A1 - A3								
GWP	1,27								
ODP	$1{,}48 \cdot 10^{-9}$								
POCP	$6{,}92 \cdot 10^{-4}$								
AP	$8{,}96 \cdot 10^{-3}$								
EP	$8.87 \cdot 10^{-4}$								
ADPM	$2{,}52 \cdot 10^{-7}$								
ADPE	12,5								

GWP Global warming potential (kg CO_2-eqv.); **ODP** Depletion potential of the stratospheric ozone layer (kg CFC11-eqv.); **POCP** Formation potential of tropospheric photochemical oxidants (kg C_2H_4-eqv.); **AP** Acidification potential of land and water (kg SO_2-eqv.); **EP** Eutrophication potential (kg PO_4^{-3}-eqv.); **ADPM** Abiotic depletion potential for non fossil resources (kg Sb -eqv.); **ADPE** Abiotic depletion potential for fossil resources (MJ)

Reading example: $9{,}0 \cdot 10^{-3} = 0{,}009$

Resource use

Parameter	A1 - A3								
RPEE	0,543								
RPEM	0,906								
TPE	1,45								
NRPE	12,97								
NRPM	0,00								
TRPE	12,97								
SM	0,281								
RSF	$3,89*10^{-2}$								
NRSF	0,202								
W	$3,39*10^{-3}$								

RPEE Renewable primary energy resources used as energy carrier (MJ); **RPEM** Renwable primary energi resources used as raw materials (MJ); **TPE** Total use of renewable primary energy resources (MJ); **NRPE** Non renewable primary energy resources used as energy carrier (MJ); **NRPM** Non renewable primary energy resources used as materials (MJ); **TRPE** Total use of non renewable primary energy resources (MJ); **SM** Use of sekundary materials (kg); **RSF** Use of renewable sekundary fuels (MJ); **NRSF** Use of non renewable sekundary fuels (MJ); **W** Use of net fresh water (m^3)

End of life - Waste

Parameter	A1 - A3								
HW	$7,22*10^{-3}$								
NHW	0,226								
RW	n/a								

HW Hazardous waste disposed (kg); **NHW** Non hazaedous waste disposed (kg), **RW** Radioactive waste disposed (kg)

End of life - Output flow

Parameter	A1 - A3								
CR	0								
MR	$2,63*10^{-2}$								
MER	$8,29*10^{-4}$								
EEE	0								
ETE	0								

CR Components for reuse (kg); **MR** Materials for recycling (kg); **MER** Materials for energy recovery (kg); **EEE** Exported electric energy (MJ); **ETE** Exported thermal energy (MJ)

Reading example: $9,0*10^{-3} = 0,009$

Specific Norwegian requirements

Electricity

Electricity used in the manufacturing processes has been accounted for using the process Danish Electricity grid mix (1kV-60kV) from GaBi6 (reference year 2009).

Electricity mix 0,139 kg CO_2 eqv/MJ

and the process Norwegian Electricity grid mix (1kV-60kV) from GaBi6 (reference year 2009).
Electricity mix 0,011 kg CO_2 eqv/MJ

Dangerous substances

None of the following substances have been added to the product: Substances on the REACH Candidate list of substances of very high concern (of 25.10.2013) substances on the Norwegian Priority list (pr.25.10.2013) and substances that lead to the product being classified as hazardous waste. The chemical content of the product complies with regulatory levels as given in the Norwegian Product Regulations.

Transport

Transport from production site to central warehouse in Norway is 326 km

Indoor environment

In general, ROCKWOOL products have been assessed using the Finnish M1 emission classes for building material. In total 32 specific ROCKWOOL products have been tested representing a wide range of products. To be granted the M1 quality label, an emission test (incl. ammonia, formaldehyde, and carcinogens) and an odour test has to be performed. The time period of testing is 28 days. Criteria: TVOC (Minimum of 70% of the compounds shall be identified): <0,2 mg/m2h, Formaldehyde (HCOH): < 0,05 mg/m2h, Ammonia (NH3): <0,03 mg/m2h, Carcinogenic compounds (belonging to category 1 of IARC monographs): <0,005 m,/m2h, Odour (dissatisfaction with odour shall be below 15%): No Odour. The M1 is the highest achievable best rank in the classification system.
(https www.rakennustieto.fi/index/english/emissionclassificationofbuildingmaterials.html)

Carbon footprint

Carbon footprint has not been worked out for the product.

Bibliography

ISO 14025:2006	*Environmental labels and declarations - Type III environmental declarations - Principles and procedures*
ISO 14044:2006	Environmental management - Life cycle assessment - Requirements and guidelines
EN 15804:2012	*Sustainability of construction works - Environmental product declaration - Core rules for the product category of construction products*
ISO 21930:2007	*Sustainability in building construction - Environmental declaration of building products*
Schmidt A, Nielsen. R, (2013).	*LCA of stone wool insulation on the Scandinavian market from ROCKWOOL, Project report, FORCE Technology, 2013*
PCR 2012	*Product-Category Rules. NPCR 12 rev. Insulation materials, epd-norge.no, 2012*

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ENVIRONMENTAL PRODUCT DECLARATION

as per ISO 14025 and EN 15804

Owner of the Declaration	**EXIBA - European Extruded Polystyrene Insulation Board Association**
Programme holder	Institut Bauen und Umwelt e.V. (IBU)
Publisher	Institut Bauen und Umwelt e.V. (IBU)
Declaration number	EPD-EXI-20140155-IBE1-EN
Issue date	12.11.2014
Valid to	11.11.2019

Extruded Polystyrene (XPS) Foam Insulation
with alternative flame retardant

EXIBA - European Extruded Polystyrene Insulation Board Association

www.bau-umwelt.com / https://epd-online.com

1. General Information

EXIBA - European Extruded Polystyrene Insulation Board Association

Programme holder

IBU - Institut Bauen und Umwelt e.V.
Panoramastr. 1
10178 Berlin
Germany

Declaration number

EPD-EXI-20140155-IBE1-EN

This Declaration is based on the Product Category Rules:

Insulating materials made of foam plastics, 07.2014
(PCR tested and approved by the independent expert committee)

Issue date

12.11.2014

Valid to

11.11.2019

Prof. Dr.-Ing. Horst J. Bossenmayer
(President of Institut Bauen und Umwelt e.V.)

Dr. Burkhart Lehmann
(Managing Director IBU)

Extruded Polystyrene (XPS) Foam Insulation

Owner of the Declaration

EXIBA - European Extruded Polystyrene Insulation Board Association
Avenue E. van Nieuwenhuyse, 4
1160 Brussels
Belgium

Declared product / Declared unit

XPS (extruded polystyrene foam) boards produced by the EXIBA members. The EPD applies to 1 m^2 of 100 mm thick XPS board, i.e. 0.1 m^3, with an average density of 33.7 kg/m^3.

Scope:

The companies contributing to the data collection produce more than 90% of the extruded polystyrene foam boards containing alternative flame retardant sold by the members of the EXIBA association in Europe. The data have been provided by 19 factories out of six companies (BASF, Dow Building Solutions, Fibran, Jackon Insulation, Knauf Insulation and Ursa) for the year 2012.

The owner of the declaration shall be liable for the underlying information and evidence; the IBU shall not be liable with respect to manufacturer information, life cycle assessment data and evidences.

Verification

The CEN Norm EN 15804 serves as the core PCR

Independent verification of the declaration according to ISO 14025

☐ internally ☒ externally

Prof. Dr. Birgit Grahl
(Independent tester appointed by SVA)

2. Product

2.1 Product description

Extruded polystyrene foam (XPS) is a thermoplastic insulation foam produced according to /EN 13164/ and available in board shape with a density range from 20 to 50 kg/m^3. The boards can be delivered in various compressive strength values from 150 to 700 kPa. To meet the need of various applications the boards are produced with different surfaces: with the extrusion skin, planed, grooved or with thermal embossing. XPS boards are supplied with different edge treatments such as butt edge, ship lap and tongue and groove.
The EPD is related to unlaminated XPS products only; lamination and additional product treatment are not considered.
The declared product reflects the European average of the association members.

2.2 Application

The variety of the performance properties of XPS thermal insulation foams make them suitable for use in a large number of applications such as: perimeter insulation, inverted insulation for terrace roofs, insulation of pitched roofs, floor insulation including insulation of highly loaded industrial floors, insulation of thermal bridges for exterior walls, ETICS, insulation of cavity walls, agricultural building ceiling insulation, prefabricated elements e.g. building sandwich panels, insulation for building equipment and industrial installations (pipe sections, …).

2.3 Technical Data

Acoustic properties are not relevant for XPS. For fire performance these products except in Scandinavia achieve the fire classification Euroclass E according to /EN 13501-1/.

Constructional data

Name	Value	Unit
Gross density	20 - 50	kg/m^3
Calculation value for thermal conductivity acc. to /EN 12667/ and /EN 13164/ Annex C	0.03 - 0.041	W/(mK)

Water vapour diffusion resistance factor acc. to /EN 12086/	50 - 250	-
Water absorption after diffusion acc. to /EN 12088/	3 - 5	Vol.-%
Deformation under compressive load and temperature acc. to /EN 1605/	≤ 5	%
Compressive stress or strength at 10% deflection acc. to /EN 826/	150 - 700	kPa
Compressive modulus of elasticity acc. to /EN 826/	10000 - 40000	kPa
Tensile strength perpendicular to faces acc. to /EN 826/	100 - 400	kPa
Compressive creep/long-term comppressive strength acc. to /EN 1606/	< 250	kPa
Freeze-thaw resistance acc. to /EN 12091/	≤ 2	Vol.-%
Dimensional stability acc. to /EN 1604/	≤ 5	%

2.4 Placing on the market / Application rules

XPS foams are labeled with the CE-mark according to EN 13164. These products are additionally approved for use in specific applications under mandatory or voluntary agreement or certification schemes at the national level. These products are controlled and certified by Notified Bodies. A large number of the manufacturing plants are certified according to ISO 9001 and/or ISO 14001.

2.5 Delivery status

Length: 1000-3000 mm; Width: 600-1200 mm;
Thickness: 20-200 mm (320 mm multilayer product)
For the LCA a thickness of 100 mm was considered.

2.6 Base materials / Ancillary materials

XPS foams are mostly made of Polystyrene (90 to 95% by weight – CAS 9003-53-6), blown with carbon dioxide (CAS 124-38-9) and halogen-free co-blowing agents altogether up to 8% by weight.

Basic material	Mass portion
Polystyrene	90 - 95 %
Blowing agents	5 - 8 %
Carbon Dioxide	40 - 80 %
Co-blowing Agents	20 - 60 %
Flame retardant	0.5 - 3 %
Additives (e.g. pigments)	Less than 1%

The alternative flame retardant is used to enable the foam to meet fire performance standards. The foam no longer contains HBCD nor any other /REACH/ SVHC. Other additives are used, e.g. color pigments and processing aids in minor quantity.
Polystyrene is produced from oil and gas therefore it is linked to the availability of these raw materials.
Polystyrene is mostly transported by road or sometimes produced on the same site.

2.7 Manufacture

XPS is produced by a continuous extrusion process using electricity as the main power source: polystyrene granules are melted in an extruder and a blowing agent is injected into the extruder under high pressure. The drop in pressure at the exit die causes the polystyrene to foam into a board with homogeneous and closed cell structure.
Then the boards' edges are trimmed, and the product is cut to dimensions. The smooth foam skin resulting from the extrusion process remains on the boards or is removed mechanically for particular board types to achieve better adhesive strength in combination with e.g. concrete, mortar, or construction adhesives. Some boards receive special surface patterns or grooves.
Most of XPS foams off-grade material or scrap from production is recycled in the production process of XPS.
A large number of the manufacturing plants are certified according to /ISO 9001/.

2.8 Environment and health during manufacturing

No further health protection measures beyond the regulated measures for manufacturing firms are necessary during all production steps. A large number of the manufacturing plants are certified according to /ISO 14001/.

2.9 Product processing/Installation

Handling recommendations for XPS foams can be found in product and application literature, brochures and data sheets provided directly by suppliers or available from the internet. There are no special required instructions regarding personal precautions and environmental protection during the product handling and installation.

2.10 Packaging

The polyethylene-based packaging film is recyclable and actually recycled in those countries having a return system.

2.11 Condition of use

Water pick-up by capillarity does generally not occur with XPS foams due to their closed cell structure. The thermal insulation performance of XPS is practically not affected by exposure to water or water vapour. Usually maintenance will not be required, if the XPS boards are installed according to handling installation requirements (see: Installation description).

2.12 Environment and health during use

XPS product is in most applications not in direct contact with the environment nor with the indoor air. There is no significant release of substances from the product as installed during its service life, as confirmed by the best possible ratings obtained in existing VOC emission schemes; e. g. /AgBB/.

2.13 Reference service life

The durability of XPS foam is normally at least as long as the lifetime of the building in which it is used. This is explained by the superior mechanical and water resistance properties of these products.

2.14 Extraordinary effects

Fire

XPS products except in Scandinavia achieve the fire classification Euroclass E according to EN 13501-1. If the contact with the external flame stops, neither further burning nor smouldering can be observed. Ignition of the foam can only be observed after longer small flame exposures.

Fire performance

Name	Value
Building material class	E
Burning droplets	-
Smoke gas development	-

Water

Water pick-up by capillarity does generally not occur with XPS foams due to their closed cell structure. The thermal insulation performance of XPS is practically not affected by exposure to water or water vapour.

Mechanical destruction

Not relevant for XPS products that have superior mechanical properties.

2.15 Re-use phase

In order to maximize the potential to re-use XPS boards, one must avoid that they are damaged or glued. Instead separation layers between the insulation and the concrete should be used or mechanical fixation should be applied.

In the inverted roof application XPS boards are installed loose laid and therefore can be easily removed and reused on another roof. For existing conventional flat-roofs the XPS boards can stay in place when for example the existing roof construction is thermally upgraded as a plus-roof. Recovered XPS boards from mechanically fixed applications can be reused for insulation of basement walls and foundations.

Due to the high calorific value of polystyrene, energy embedded in XPS boards can be recovered in municipal waste incinerators equipped with energy recovery units for steam and electricity generation and district heating.

2.16 Disposal

XPS boards that cannot be easily retrieved from the building are usually landfilled. The material is assigned to the waste category: 17 06 04 insulation materials other than those mentioned in 17 06 01 (insulation materials containing asbestos) and 17 06 03 (other insulation materials consisting of or containing dangerous substances).

2.17 Further information

Additional information can be found at the following Webpages:

www.exiba.org
www.austrotherm.com/en
www.styrodur.de
www.dowbuildingsolutions.eu
www.fibran.com
www.jackon-insulation.com/en
www.knaufinsulation.com
www.ediltec.com
www.sirapinsulation.com
www.ursa.es

3. LCA: Calculation rules

3.1 Declared Unit

The declared unit is 1 m^2 with a thickness of 100 mm, e.g. 0.1 m^3. The declared product reflects the European average of the association members weighted for market share.

Corresponding conversion factors are listed in the table below.

Declared unit

Name	Value	Unit
Declared unit with thickness 100 mm	1	m^2
Conversion factor to 1 kg	0.3	-
Gross density	33.7	kg/m^3
Declared unit	0.1	m^3

For XPS products with densities or thickness different from the reference density of 33.7 kg/m^3 the environmental impacts may be calculated using the following equation:

$$I_{adap} = I_{ref} \times \frac{\rho_{adap}}{\rho_{ref}} \times \frac{d_{adap}}{d_{ref}}$$

Iadap – adapted LCIA indicator or LCI parameter
Iref – LCIA indicator or LCI parameter for reference density of 33.7kg/m^3
ρadap – adapted density
ρref – reference density 33.7 kg/m^3
dadap – adapted board thickness
dref – thickness of reference board (100 mm)

Exceptions are categories, which are not mainly driven by raw material consumption respective mass. That applies to acidification potential and ozone depletion potential. These two categories do not correlate with the mass of the product and cannot be evaluated that way.

3.2 System boundary

Type of EPD: cradle-to-gate (A1 - A3) – with options

The following modules are considered in the Life Cycle Assessment:

- Raw material supply (A1),
- Transport to manufacturer (A2),
- Manufacturing (A3),
- Transport to construction site (A4)
- Transport to EoL (C2),
- Disposal (C4) with two scenarios (landfill (sc. 1) and thermal treatment (sc. 2)
- Reuse, recovery or recycling potential (D) - beyond system boundary.

3.3 Estimates and assumptions

The environmental profile of the flame retardant is based on valid estimations, based on literature data, basically /Ullmanns/.

3.4 Cut-off criteria

In the assessment, all available data from production process are considered, i.e. all raw materials used, utilised thermal energy, and electric power consumption using best available LCI datasets.

A few additives with low mass ratio were not addressed in the questionnaire. These filler materials and pigments underrun a ratio of 5 mass-% of total material input. Used fillers are e. g. talc and citric acid, which do not have relevant impacts in regard to the considered categories. Pigments, which are generally used in all XPS products are included in the declared mass of polystyrene already. The PS granulate is often already coloured. Only environmentally non-hazardous pigments are applied. The missing filler amount is calculative filled up by polystyrene; thus an under-counting is avoided.

3.5 Background data

Background data is taken from the GaBi software /GaBi 2013/, see www.gabi-software.com/databases.

3.6 Data quality

The foreground data, mainly the raw material and energy consumption during the production process is measured data.
Most of the necessary life cycle inventories are available in the GaBi database. The last update of the database was 2013.

3.7 Period under review

The foreground data collected by the manufacturers are based on yearly production amounts and extrapolations of measurements on specific machines and plants. The production data refer to an average of the year 2012.

3.8 Allocation

There are no co-products generated during the XPS-production. Allocations in the foreground system are done for waste respective recycling materials only.

Allocation for waste materials:
Post-industrial XPS waste from extrusion lines, which does not get reused in the process, is sent to a waste incineration plant.
All applied incineration processes are displayed via a partial stream consideration for the combustion process, according to the specific composition of the incinerated material. For the waste incineration plant an R1-value of 0.6 is assumed.
Resulting electrical and thermal energy is looped inside module A1-A3. The quality of the recovered energy is assumed to be the same as that of the input energy.
In the software model the environmental burdens of the supply chain are displayed via aggregated datasets. Due to this fact thermal energy resulting from incineration processes are credited with a GaBi-process of thermal energy from natural gas (EU-27), integrated in module A1-A3.
Environmental burden of the incineration the product in the EoL-scenario are assigned to the system (C4); resulting benefits for thermal and electrical energy are declared in module D.
Benefits are given according European average data for electrical and thermal energy generated from natural gas.

Allocation for upstream data
For all refinery products, allocation by mass and net calorific value has been applied. The manufacturing route of every refinery product is modelled and the product-specific effort associated with their production is calculated.
For other materials' inventory used in the production process calculation the most suitable allocation rules are applied. Information on single LCIs is documented on http://database-documentation.gabi-software.com/support/gabi/.

3.9 Comparability

Basically, a comparison or an evaluation of EPD data is only possible if all the data sets to be compared were created according to /EN 15804/ and the building context, respectively the product-specific characteristics of performance, are taken into account.

4. LCA: Scenarios and additional technical information

The following technical information is a basis for the declared modules or can be used for developing specific scenarios in the context of a building assessment if modules are not declared (MND).
The values refer to the declared unit of 1 m² XPS.

Transport to the building site (A4)

Name	Value	Unit
Payload of truck	5	t
Litres of fuel diesel with maximum load	0.018	l/100km
Transport distance (market-weighted average)	528	km
Capacity utilisation (including empty runs)	70	%
Gross density of products transported	33.7	kg/m^3
Capacity utilisation volume factor	1	-

End of life (C1-C4; C2 and C4)

For the End of Life stage two different scenarios are considered. One scenario with 100% landfill (sc. 1) and one scenario with 100% incineration (sc. 2) are calculated. The incineration of XPS results in benefits, beyond the system boundary, for thermal energy and electricity under European conditions.

Name	Value	Unit
Collected separately XPS	3.37	kg
Collected as mixed construction waste	0	kg
Reuse	0	kg
Recycling	0	kg
Landfilling Scenario 1	3.37	kg
Energy recovery Scenario 2	3.37	kg

Reuse, recovery and/or recycling potentials (D), relevant scenario information

Module D includes the credits of the incineration process C4 (incineration of XPS boards). A waste incineration plant with R1-value < 0.6 is assumed.

5. LCA: Results

The following tables display the environmental relevant results according to EN 15804 for 1 m² XPS board. The two EoL Scenarios are represented in modules C4 and D. C4/1 and D1 reflect the landfilling of XPS, C4/2 and D2 shows the environmental results in case of thermal treatment of XPS-boards.

DESCRIPTION OF THE SYSTEM BOUNDARY (X = INCLUDED IN LCA; MND = MODULE NOT DECLARED)

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARYS
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement$^{1)}$	Refurbishment$^{1)}$	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
X	X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	X	MND	X	X

RESULTS OF THE LCA - ENVIRONMENTAL IMPACT: 1 m² XPS board with thickness of 100 mm

Parameter	Unit	A1 - A3	A4	C2	C4/1	C4/2	D/1	D/2
GWP	[kg CO_2-Eq.]	9.444	0.283	0.026	0.241	11.190	0.000	-5.292
ODP	[kg CFC11-Eq.]	1.250E-9	1.350E-12	1.259E-13	9.398E-12	2.913E-11	0.000E+0	-1.678E-9
AP	[kg SO_2-Eq.]	2.661E-2	7.779E-4	7.235E-5	7.488E-4	6.857E-4	0.000E+0	-1.376E-2
EP	[kg $(PO_4)^{3-}$- Eq.]	2.068E-3	1.605E-4	1.493E-5	8.977E-4	1.358E-4	0.000E+0	-9.336E-4
POCP	[kg Ethen Eq.]	2.294E-2	-2.000E-4	-1.860E-5	9.332E-5	8.089E-5	0.000E+0	-1.109E-3
ADPE	[kg Sb Eq.]	4.290E-6	1.066E-8	9.913E-10	4.817E-8	1.502E-7	0.000E+0	-4.359E-7
ADPF	[MJ]	274.000	3.902	0.363	3.480	1.226	0.000	-74.120

Caption	GWP = Global warming potential; ODP = Depletion potential of the stratospheric ozone layer; AP = Acidification potential of land and water; EP = Eutrophication potential; POCP = Formation potential of tropospheric ozone photochemical oxidants; ADPE = Abiotic depletion potential for non fossil resources; ADPF = Abiotic depletion potential for fossil resources

RESULTS OF THE LCA - RESOURCE USE: 1 m² XPS board with thickness of 100 mm

Parameter	Unit	A1 - A3	A4	C2	C4/1	C4/2	D/1	D/2
PERE	[MJ]	7.218	-	-	-	-	-	-
PERM	[MJ]	0.000	-	-	-	-	-	-
PERT	[MJ]	7.218	0.154	0.014	0.182	0.141	0.000	-7.977
PENRE	[MJ]	152.200	-	-	-	-	-	-
PENRM	[MJ]	134.600	-	-	-	-	-	-
PENRT	[MJ]	286.800	3.915	0.364	3.643	1.427	0.000	-89.900
SM	[kg]	0.000	0.000	0.000	0.000	0.000	0.000	0.000
RSF	[MJ]	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NRSF	[MJ]	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FW	[m³]	4.395E-2	1.085E-4	1.009E-5	-3.226E-3	2.157E-2	0.000E+0	-1.980E-2

Caption	PERE = Use of renewable primary energy excluding renewable primary energy resources used as raw materials; PERM = Use of renewable primary energy resources used as raw materials; PERT = Total use of renewable primary energy resources; PENRE = Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials; PENRM = Use of non renewable primary energy resources used as raw materials; PENRT = Total use of non renewable primary energy resources; SM = Use of secondary material; RSF = Use of renewable secondary fuels; NRSF = Use of non renewable secondary fuels; FW = Use of net fresh water

RESULTS OF THE LCA – OUTPUT FLOWS AND WASTE CATEGORIES: 1 m² XPS board with thickness of 100 mm

Parameter	Unit	A1 - A3	A4	C2	C4/1	C4/2	D/1	D/2
HWD	[kg]	7.332E-3	8.918E-6	8.294E-7	1.209E-4	4.385E-6	0.000E+0	-6.047E-3
NHWD	[kg]	3.771E-2	4.923E-4	4.579E-5	3.357E+0	7.718E-2	0.000E+0	-1.982E-2
RWD	[kg]	5.062E-3	5.126E-6	4.767E-7	6.441E-5	8.320E-5	0.000E+0	-6.285E-3
CRU	[kg]	0.000	0.000	0.000	0.000	0.000	-	-
MFR	[kg]	0.000	0.000	0.000	0.000	0.000	-	-
MER	[kg]	0.000	0.000	0.000	0.000	0.000	-	-
EEE	[MJ]	0.000	0.000	0.000	0.000	0.000	-	-
EET	[MJ]	0.000	0.000	0.000	0.000	0.000	-	-

Caption	HWD = Hazardous waste disposed; NHWD = Non hazardous waste disposed; RWD = Radioactive waste disposed; CRU = Components for re-use; MFR = Materials for recycling; MER = Materials for energy recovery; EEE = Exported electrical energy; EEE = Exported thermal energy

6. LCA: Interpretation

Overall most of the impact categories and LCI parameters are dominated by the polystyrene (PS) production.

Another very important driver is the electricity consumption during XPS production with 25% contributing to the acidification potential (AP) and even more than 50% to the ozone depletion potential (ODP). Reasons for the acidification potential are the combustion of fossil fuels for power generation with emissions of nitrogen oxides and sulfur oxide. The

ozone depletion is determined by the used cooling agents during nuclear electricity generation.
Emissions of blowing agents during the manufacturing process are of relevant influence within the photochemical ozone creation potential with 85% share rate. In general the transports, the production of blowing agents and flame retardant have low relevance regarding the considered impact categories. The chosen EoL scenario has a high influence on the results.
Moreover the Eutrophication (EP) is driven to one third by the end of life in case of scenario landfill. But it must be stated that in total the nutrient contamination during XPS production is on a low level. That is one reason for the dominance of the landfill process, another one is rooted in limitations of the LCA landfill model. The deposit of plastics is a very extreme situation, due to the fact, that actually there is no release or depletion within a period of 100 years. This conflicts with background standard values, which consider leakage from a municipal waste landfill body.
The landfill process seems to “generate” fresh water; a negative fresh water use is detectable regarding the fresh water use (FW) in module C4/1 . This is a flow characterization issue due to the fact that the rain water input in contrast to river water output is not considered in regard to fresh water use.
There is a difference detectable regarding primary energy renewable between A1-A3 and the benefit in D/2 (plus 10%). In this study renewable energy is only consumed via the electricity grid mix. Due to the high heating value of XPS the benefit of electricity generated in the waste incineration plant is higher than the requested electricity during manufacturing.
Moreover the additional benefit is caused by the use of different electricity datasets on input and output side. In A1-A3 country-specific electricity data sets are used on base of the market share. In D the model refers to an average EU electricity dataset with higher renewable energy content.

The following figures reflect the global warming potential (GWP) and the primary energy consumption (PENRT) with its contribution to the life cycle stages.

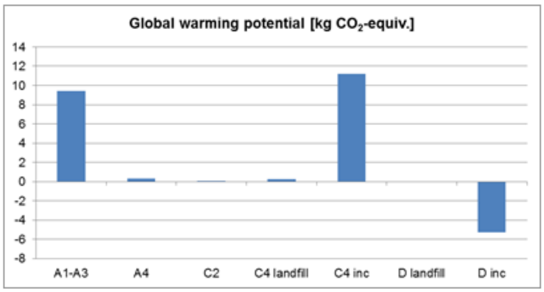

Figure 6-1

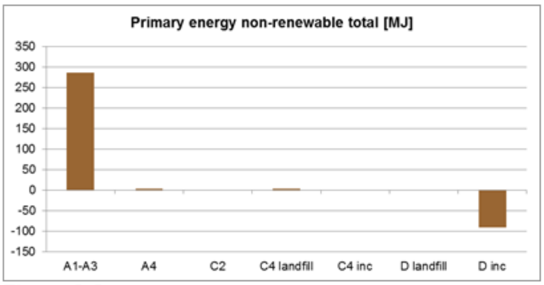

Figure 6-2

7. Requisite evidence

7.1 VOC Emissions

XPS products can be used indoor however they are generally not exposed to the indoor air but covered by a finishing element or system.
The emissions of 14 samples of XPS products from 9 different EXIBA members have been tested by Eurofins Product Testing A/S, Denmark in July 2011. The emission testing meets the requirements of the AgBB/DIBt method.
The tested products all comply with the requirements of DIBt (October 2008) and AgBB (May 2010) for the use in the indoor environment.

VOC Emissions

Name	Value	Unit
Overview of Results (28 days)	-	µg/m³
TVOC (C6 - C16)	0 - 1000	µg/m³
Sum SVOC (C16 - C22)	0 - 100	µg/m³
R (dimensionless)	0 - 1	-
VOC without NIK	0 - 100	µg/m³
Carcinogenic Substances	not detected	µg/m³

7.2 Leaching performance

Leaching behaviour is not relevant for extruded polystyrene foam products.

8. References

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DIBt
German Institute for Construction Technology, Berlin

www.dibt.de

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Web	**www.exiba.org**

ENVIRONMENTAL PRODUCT DECLARATION

as per ISO 14025 and EN 15804

Owner of the Declaration	**EUMEPS – Expanded Polystyrene (EPS) Foam Insulation**
Programme holder	Institut Bauen und Umwelt e.V. (IBU)
Publisher	Institut Bauen und Umwelt e.V. (IBU)
Declaration number	EPD-EPS-20130078-CBG1-EN
Issue date	28.05.2013
Valid to	27.05.2018

Expanded Polystyrene (EPS) Foam Insulation (without flame retardant, density 25 kg/m³), EPS 150

EUMEPS (region Scandinavia)

Institut Bauen
und Umwelt e.V.

www.bau-umwelt.com / https://epd-online.com

General Information

EUMEPS

Programme holder

IBU - Institut Bauen und Umwelt e.V.
Rheinufer 108
D-53639 Königswinter

Declaration number

EPD-EPS-20130078-CBG1-EN

This Declaration is based on the Product Category Rules:

Insulating materials made of foam plastics, 10-2012
(PCR tested and approved by the independent expert committee)

Issue date

28.05.2013

Valid to

27.05.2018

Prof. Dr.-Ing. Horst J. Bossenmayer
(President of Institut Bauen und Umwelt e.V.)

Prof. Dr.-Ing. Hans-Wolf Reinhardt
(Chairman of SVA)

EPS

Owner of the Declaration

EUMEPS – European Association of EPS
Weertersteenweg 158
B-3680 Maaseik (Belgium)

Declared product / Declared unit

Expanded Polystyrene (EPS) without flame retardant, with average density of 25 kg/m³ / 1 m³ and 1 m² with R-value 1

Scope:

The applicability of the document is restricted to EPS boards produced by manufacturing plants of EPS converters who are members of their national EPS association, which themselves are members of EUMEPS. The data have been provided by a representative mix of 4 converters from amongst the EUMEPS membership from Scandinavia, based upon production during 2011.

Verification

The CEN Norm EN 15804 serves as the core PCR

Independent verification of the declaration and data according to ISO 14025

☐ internally ☒ externally

Olivier Muller
(Independent tester appointed by SVA)

Product

Product description

This EPD describes Expanded Polystyrene foam (EPS) in accordance with EN 13163. The closed cell structure is filled with air (98% air; only 2% polystyrene) and results in a light weight, tough, strong and rigid thermoplastic insulation foam. The products are mainly used for thermal and acoustical insulation of buildings. The foam is available in various dimensions and shapes. Boards can be supplied with different edge treatments such as butt edge, ship lap, tongue and groove. Density range is from about 23 to 27 kg/m³ corresponding to a compressive strength value of about 150 kPa.
This EPD is applicable to homogeneous EPS products without material combinations or facings. Most important properties are the thermal conductivity and compressive strength.
The declared products are manufactured without use of flame retardant.

Application

The performance properties of EPS thermal insulation foams make them suitable for use in many applications. The range of products described in this document is used in applications such as wall insulation, pitched roof insulation, ETICS, cavity wall insulation, ceiling insulation, insulation for building equipment and industrial installations.

Technical Data

Constructional data

Name	Value	Unit
Gross density	23-27	kg/m^3
Thermal conductivity acc. to EN 12667	0.034	W/(mK)
Compressive strength acc. to EN 826	150	kPa
Bending strength acc. to EN 12089	200	kPa
Water vapour diffusion resistance factor acc. to EN 12086	30-70	-

Base materials / Ancillary materials

EPS foams are made of polystyrene (95 % by weight), blown with pentane up to 6 % by weight, which is released partly during or shortly after production.
This EPD refers to products, which are produced without the addition of a flame retardant.
Typically no other additives are used. Polystyrene and pentane are produced from oil and gas therefore linked to the availability of these raw materials.
The product dimensions can vary depending on, for example, the product, the manufacturer, the application and the applicable quality label.

Reference service life

Properly installed EPS boards (see: Installation) are durable with respect to their insulation, structural and dimensional properties. They are water resistant,

resistant against micro-organisms and against most chemical substances. EPS, however, should not be brought into contact with organic solvents.
If applied correctly the lifetime of EPS insulation is equal to the building life time, usually without requiring any maintenance. Durability studies on applied EPS show no loss of technical properties after 35 years. Additional tests with products under artificial aging show that “no deficiencies are to be expected from EPS fills placed in the ground over a normal life cycle of 100 years.”/Langzeitverhalten 2004/, /Long-term performance 2001/.

The application of insulation material has a positive impact on energy efficiency of buildings. Quantification is only possible in context with the construction system of the building.

Dependent on the specific material and the frame conditions of installation, residual pentane may diffuse. Quantified measurements and release profiles cannot be declared.

LCA: Calculation rules

Declared Unit

Reference value is 1 m³ of expanded polystyrene rigid foam. In addition, the results for the functional unit of a volume per square metre that leads to an R-value of 1 are considered.

Declared unit

Name	Value	Unit
Declared unit	1	m^3
Gross density	25	kg/m^3
Conversion factor to 1 kg	1/25	-
Declared unit	1	m^2
R-value	1	-
Thickness	3.4	cm
Volume per m²	0.034	m³
Conversion factor to 1 kg	1/0.85	-

System boundary

The analysis of the product life cycle includes production of the basic materials, transport of the basic materials, manufacture of the product and the packaging materials and is declared in module A1-A3. Transport of the product is declared in module A4, and disposal of the packaging materials in module A5.

Gained energy from packaging incineration is declared in module D.
The use stage is not taken into account in the LCA calculations. The positive impact on environment due to energy saving depends on the application system in the building. This needs to be considered on next level by the evaluation of buildings.
The end-of-life scenarios include the transport to end-of-life stage (C2)

<u>EoL-scenario “Incineration”:</u> 100% incineration: The effort and emissions of an incineration process is declared in module C3. Resulting energy is declared in module D.
<u>EoL-scenario “Landfilling”:</u> 100% landfilling: The effort and emissions of the landfilling is declared in module C4.

Comparability

Basically, a comparison or an evaluation of EPD data is only possible if all the data sets to be compared were created according to EN 15804 and the building context, respectively the product-specific characteristics of performance, are taken into account.

LCA: Scenarios and additional technical information

Transport to the building site (A4)

Name	Value	Unit
Litres of fuel (truck, per 1m³)	0,15	l/100km
Transport distance	200	km
Capacity utilisation (including empty runs)	60	%
Gross density of products transported	25	kg/m^3

Installation into the building (A5)

Product specific handling recommendations can be found in product and application literature, brochures and data sheets provided by the suppliers.

End of life (C1-C4)

The considered amount of product for the End-of-Life scenario “Incineration” and “Landfilling” refers to the respective declared unit.

LCA: Results

All impact categories, with the exception of POCP, are dominated by the influence of the basic material (polystyrene granules mix) production. The polystyrene deployed in the production process already contains a large part of the environmental burdens. The foaming process for the declared product polystyrene rigid foam also contributes significantly to the environmental impacts. The emission of pentane during that process makes a contribution to the Photochemical Ozone Creation Potential (POCP).
Transportation has a low influence on all impact categories compared to the contributions from other areas.
The primary energy demand is basically determined by the requirements for the basic material production (polystyrene granules with pentane).
Due to the high calorific value of the product, incineration during the end-of-life stage in scenario "Incineration" results in an energy gain.

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARYS
Raw material supply	Transport	Manufacturing	Transport	Construction-installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
X			X	X	MND	MND	MND	MND	MND	MND	MND	MND	X	X	X	X

RESULTS OF THE LCA - ENVIRONMENTAL IMPACT: density 25 kg/m³ (range: 23-27 kg/m³)

Results per declared unit of 1 m³

Para-meter	Unit	A1-A3	A4	A5	C2	C3/I[1]	C3/L[2]	C4/I	C4/L	D/I	D/L
GWP	[kg CO_2-Eq.]	5,9E+01	8,0E-01	1,4E+00	1,2E-01	8,6E+01	0	0	1,7E+00	-4,8E+01	-7,4E-01
ODP	[kg CFC11-Eq.]	1,3E-06	1,4E-09	2,3E-10	2,2E-10	9,0E-09	0	0	7,4E-08	-2,7E-06	-4,0E-08
AP	[kg SO_2-Eq.]	1,4E-01	3,6E-03	1,5E-04	5,4E-04	5,4E-03	0	0	5,9E-03	-1,1E-01	-1,6E-03
EP	[kg $(PO_4)^{3-}$- Eq.]	1,6E-02	8,1E-04	4,7E-05	1,2E-04	2,0E-03	0	0	6,6E-03	-8,5E-03	-1,3E-04
POCP	[kg Ethen Eq.]	2,9E-01	3,8E-04	2,5E-05	5,3E-05	8,2E-04	0	0	7,4E-04	-7,9E-03	-1,2E-04
ADPE	[kg Sb Eq.]	9,0E-06	2,7E-08	9,1E-09	4,1E-09	4,0E-07	0	0	2,6E-07	-2,9E-06	-4,5E-08
ADPF	[MJ]	1,9E+03	1,1E+01	4,9E-01	1,7E+00	2,5E+01	0	0	2,5E+01	-7,3E+02	-1,1E+01

Results per declared unit of 1 m² with R-value 1 (λ = 0.034 W/mK, thickness 3.4 cm)

Para-meter	Unit	A1-A3	A4	A5	C2	C3/I	C3/L	C4/I	C4/L	D/I	D/L
GWP	[kg CO_2-Eq.]	2,0E+00	2,7E-02	4,8E-02	4,2E-03	2,9E+00	0	0	5,8E-02	-1,6E+00	-2,5E-02
ODP	[kg CFC11-Eq.]	4,3E-08	4,8E-11	7,7E-12	7,4E-12	3,1E-10	0	0	2,5E-09	-9,2E-08	-1,4E-09
AP	[kg SO_2-Eq.]	4,8E-03	1,2E-04	5,2E-06	1,8E-05	1,9E-04	0	0	2,0E-04	-3,7E-03	-5,6E-05
EP	[kg $(PO_4)^{3-}$- Eq.]	5,3E-04	2,8E-05	1,6E-06	4,2E-06	6,8E-05	0	0	2,2E-04	-2,9E-04	-4,5E-06
POCP	[kg Ethen Eq.]	9,8E-03	1,3E-05	8,4E-07	1,8E-06	2,8E-05	0	0	2,5E-05	-2,7E-04	-4,1E-06
ADPE	[kg Sb Eq.]	3,0E-07	9,1E-10	3,1E-10	1,4E-10	1,4E-08	0	0	8,9E-09	-1,0E-07	-1,5E-09
ADPF	[MJ]	6,5E+01	3,8E-01	1,7E-02	5,8E-02	8,6E-01	0	0	8,6E-01	-2,5E+01	-3,8E-01

Caption	GWP = Global warming potential; ODP = Depletion potential of the stratospheric ozone layer; AP = Acidification potential of land and water; EP = Eutrophication potential; POCP = Formation potential of tropospheric ozone photochemical oxidants; ADPE = Abiotic depletion potential for non fossil resources; ADPF = Abiotic depletion potential for fossil resources

RESULTS OF THE LCA - RESOURCE USE: density 25 kg/m³ (range: 23-27 kg/m³)

Results per declared unit of 1 m³

Para-meter	Unit	A1-A3	A4	A5	C2	C3/I	C3/L	C4/I	C4/L	D/I	D/L
PERE	[MJ]	1,5E+01	1,2E-02	1,5E-03	1,9E-03	5,3E-02	0	0	7,9E-01	-1,6E+01	-2,4E-01
PERM	[MJ]	0	0	0	0	0	0	0	0	0	0
PERT	[MJ]	1,5E+01	1,2E-02	1,5E-03	1,9E-03	5,3E-02	0	0	7,9E-01	-1,6E+01	-2,4E-01
PENRE	[MJ]	9,7E+02	1,1E+01	5,0E-01	1,7E+00	2,6E+01	0	0	2,8E+01	-8,2E+02	-1,3E+01
PENRM	[MJ]	9,9E+02	0	0	0	0	0	0	0	0	0
PENRT	[MJ]	2,0E+03	1,1E+01	5,0E-01	1,7E+00	2,6E+01	0	0	2,8E+01	-8,2E+02	-1,3E+01
SM	[kg]	0	0	0	0	0	0	0	0	0	0
RSF	[MJ]	0	0	0	0	0	0	0	0	0	0
NRSF	[MJ]	0	0	0	0	0	0	0	0	0	0
FW	[kg]	2,1E+02	2,0E-01	1,7E+00	3,1E-02	9,2E+01	0	0	2,5E+00	-9,9E+01	-1,5E+00

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[1] Scenario "I" = 100% Incineration

[2] Scenario "L" = 100% Landfilling

Results per declared unit of 1 m² with R-value 1 (λ = 0.034 W/mK, thickness 3.4 cm)

Para-meter	Unit	A1-A3	A4	A5	C2	C3/I	C3/L	C4/I	C4/L	D/I	D/L
PERE	[MJ]	5,2E-01	4,1E-04	5,1E-05	6,4E-05	1,8E-03	0	0	2,7E-02	-5,4E-01	-8,1E-03
PERM	[MJ]	0	0	0	0	0	0	0	0	0	0
PERT	[MJ]	5,2E-01	4,1E-04	5,1E-05	6,4E-05	1,8E-03	0	0	2,7E-02	-5,4E-01	-8,1E-03
PENRE	[MJ]	3,3E+01	3,8E-01	1,7E-02	5,8E-02	8,7E-01	0	0	9,4E-01	-2,8E+01	-4,3E-01
PENRM	[MJ]	3,4E+01	0	0	0	0	0	0	0	0	0
PENRT	[MJ]	6,7E+01	3,8E-01	1,7E-02	5,8E-02	8,7E-01	0	0	9,4E-01	-2,8E+01	-4,3E-01
SM	[kg]	0	0	0	0	0	0	0	0	0	0
RSF	[MJ]	0	0	0	0	0	0	0	0	0	0
NRSF	[MJ]	0	0	0	0	0	0	0	0	0	0
FW	[kg]	7,0E+00	7,0E-03	5,8E-02	1,1E-03	3,1E+00	0	0	8,6E-02	-3,4E+00	-5,1E-02

Caption	PERE = Use of renewable primary energy excluding renewable primary energy resources used as raw materials; PERM = Use of renewable primary energy resources used as raw materials; PERT = Total use of renewable primary energy resources; PENRE = Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials; PENRM = Use of non renewable primary energy resources used as raw materials; PENRT = Total use of non renewable primary energy resources; SM = Use of secondary material; RSF = Use of renewable secondary fuels; NRSF = Use of non renewable secondary fuels; FW = Use of net fresh water

RESULTS OF THE LCA – OUTPUT FLOWS AND WASTE CATEGORIES: density 25 kg/m³ (range: 23-27 kg/m³)

Results per declared unit of 1 m³

Para-meter	Unit	A1-A3	A4	A5	C2	C3/I	C3/L	C4/I	C4/L	D/I	D/L
HWD	[kg]	1,4E-01	0	2,3E-03	0	0	0	0	0	0	0
NHWD	[kg]	3,4E+01	5,5E-02	7,3E-03	8,5E-03	3,2E-01	0	0	2,8E+01	-4,0E+01	-5,9E-01
RWD	[kg]	1,6E-02	1,8E-05	2,8E-06	2,7E-06	1,1E-04	0	0	9,2E-04	-3,4E-02	-5,1E-04
CRU	[kg]	-	-	-	-	-	-	-	-	0	0
MFR	[kg]	-	-	-	-	-	-	-	-	0	0
MER	[kg]	-	-	-	-	-	-	-	-	0	0
EEE	[MJ]	-	-	-	-	-	-	-	-	-6,6E+01	-9,9E-01
EET	[MJ]	-	-	-	-	-	-	-	-	-5,9E+02	-9,2E+00

Results per declared unit of 1 m² with R-value 1 (λ = 0.034 W/mK, thickness 3.4 cm)

Para-meter	Unit	A1-A3	A4	A5	C2	C3/I	C3/L	C4/I	C4/L	D/I	D/L
HWD	[kg]	4,7E-03	0	8,0E-05	0	0	0	0	0	0	0
NHWD	[kg]	1,2E+00	1,9E-03	2,5E-04	2,9E-04	1,1E-02	0	0	9,4E-01	-1,4E+00	-2,0E-02
RWD	[kg]	5,3E-04	6,0E-07	9,5E-08	9,2E-08	3,8E-06	0	0	3,1E-05	-1,2E-03	-1,7E-05
CRU	[kg]	-	-	-	-	-	-	-	-	0	0
MFR	[kg]	-	-	-	-	-	-	-	-	0	0
MER	[kg]	-	-	-	-	-	-	-	-	0	0
EEE	[MJ]	-	-	-	-	-	-	-	-	-2,3E+00	-3,4E-02
EET	[MJ]	-	-	-	-	-	-	-	-	-2,0E+01	-3,1E-01

Caption	HWD = Hazardous waste disposed; NHWD = Non hazardous waste disposed; RWD = Radioactive waste disposed; CRU = Components for re-use; MFR = Materials for recycling; MER = Materials for energy recovery; EEE = Exported electrical energy; EEE = Exported thermal energy

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Jackon AS, Norway
Styropack A/S, Denmark
ThermiSol A/S, Denmark
ThermiSol Oy, Finland

ENVIRONMENTAL PRODUCT DECLARATION

as per ISO 14025 and EN 15804

Owner of the Declaration	Dow Deutschland GmbH & Co.OHG
Publisher	Institut Bauen und Umwelt (IBU)
Programme holder	Institut Bauen und Umwelt (IBU)
Declaration number	EPD-DOW-2013111-E
Issue date	01/05/2013
Valid to	30/04/2018

XENERGY$^{\text{TM}}$ XPS extruded polystyrene foam insulation

Dow Deutschland GmbH & Co. OHG

www.bau-umwelt.com

Institut Bauen
und Umwelt e.V.

1 General Information

Dow Deutschland GmbH & Co.OHG
Dow Building Solutions

Programme holder

IBU - Institut Bauen und Umwelt e.V.
Rheinufer 108
D-53639 Königswinter

Declaration number

EPD-DOW-2013111-E

This declaration is based on the following product category rules:

Foam plastics, 12-2009

(PCR tested and approved by the independent expert committee)

Issue date

01/05/2013

Valid to

30/04/2018

Prof. Dr.-Ing. Horst J. Bossenmayer
(President of Institut Bauen und Umwelt e.V.)

Prof. Dr.-Ing. Hans-Wolf Reinhardt
(Chairman of SVA)

XENERGY™
Extruded polystyrene foam

Owner of the declaration

Dow Deutschland GmbH & Co. OHG
Dow Building Solutions
Am Kronberger Hang 4
D-65824 Schwalbach

Declared product/declared unit

XENERGY^{TM} XPS extruded polystyrene foam insulation

Scope:

XENERGY extruded polystyrene foam (XPS) is a thermoplastic insulation foam which complies with DIN EN 13164 and is manufactured in the form of boards within a density range from 30 to 50 kg/m^3. The boards are supplied in three different compressive strength levels from 100 to 700 kPa within a thickness range of 20 to 200 mm. The manufacturer is Dow with production facilities in Europe, particularly in Germany and Greece.

This declaration refers to 1 m^2 of extruded polystyrene foam board (XPS board) with a thickness of 100 mm, i.e. 0.1 m^3 with a density of 35 kg/m^3. This corresponds to the weighted average of the boards produced in both works in Greece and Germany.

The owner of the declaration is liable for the underlying information and verifications.

Verification

CEN standard DIN EN 15804 serves as the core PCR

Verification of the declaration and data EPD by an independent third party in compliance with ISO 14025

☐ internal ☒ external

Dr.-Ing. Ivo Mersiowsky
(Independent tester appointed by SVA)

2 Product

2.1 Product description

XENERGY extruded polystyrene foam (XPS) is a plastic foam insulating material which complies with DIN EN 13164and is produced in the form of boards within a density range of 30 to 50 kg/m^3. To meet the needs of various applications the boards are supplied in different compressive strength levels from 150 to 700 kPa within a thickness range of 20 to 200 mm. The boards may have different surfaces (with extrusion skin, planed, grooved or thermally embossed) for different application areas. Xenergy boards are supplied with butt edge, shiplap and tongue-and-groove profiles.

The main ingredient is polystyrene; carbon dioxide in combination with process aids is used as a blowing agent.

2.2 Application

According to DIN 4108–10, application areas are thermal insulation of roofs, ceilings, walls, floor and perimeters with requirements of the physical properties:

- Perimeter insulation for the basement/foundation
- Perimeter insulation of the exterior cellar walls
- Inverted insulation for terrace roofs
- Floor insulation of floors including insulation of highly loaded industrial floors
- Insulation of thermal bridges for exterior walls Insulation of cavity walls
- ETICS
- Thermal insulation of ceilings in agricultural buildings
- Interior insulation of walls
- Interior insulation of ceilings
- Thermal insulation of pitched roofs above and below the rafters
- Core material for sandwich elements
- Insulation for building equipment and industrial installations (e.g. pipe insulation)

2.3 Technical data

Declared thermal conductivity [W/(mK)] according to DIN EN 12667 & DIN EN 12939	**0.030 – 0.032**
Deformation according to DIN EN 1605 [%] Load 40 kPa; 70°C	**≤ 5**
Compressive strength or stress [kPa] at 10% deflection as per DIN EN 826	**100 – 700**
Elasticity module [kPa] as per DIN EN 826	**10,000 – 40,000**
Tensile strength [kPa] as per DIN EN 1607	**100 – 600**
Compressive creep (50 years, 2% deflection) and long term compressive strength [kPa] as per DIN EN 1606	**Up to 250**
Water absorption after diffusion [Vol.-%] as per DIN EN 12088	**≤ 3**
Water vapour transmission μ [-] as per DIN EN 12086	**50 – 250**
Freeze-thaw resistance (maximum water uptake) in [Vol.-%] as per DIN EN 12091	**≤ 1**
Dimensional stability 70°C, 90% r.F. as per DIN EN 1604 [%]	**≤ 5**
Fire performance as per DIN EN 13501-1	**Euro class E**
Acoustic property	**Not relevant for XPS**

2.4 Placing on the market /Application rules

Manufacture and CE marking as per product standard DIN EN 13164. Application following building inspection approval of the DIBt for Xenergy :

- Z-23.15-1476 (product approval)
- Z-23.33-1882 (approval for use as perimeter insulation against pressing water)
- Z-23.31-1881 (approval for the inverted roof thermal insulation system)

The production facilities involved in data collection for this EPD are certified to ISO 9001 and ISO 14001.

2.5 Delivery status

Length: 1000 – 3000 mm/ width: 600 mm/ thickness: 20 – 200 mm

2.6 Base materials/Ancillary materials

The main material used is general purpose polystyrene (GPPS) [CAS 9003-53-6] with 90 to 95 weight %. This is foamed with the help of a blowing agent with approx. 8 weight %. The foaming agent consists of carbon dioxide [CAS 124-38-9] and halogen-free Co-blowing agents.
The flame retardant hexabromcyclododecane (HBCD) [CAS 25637-99-4] is used as an additive. HBCD will be replaced by a polymeric flame retardant by August 2015 at the latest. Pigment (carbon particles) less than 6% and other additives (such as processing aids) less than 1% are also added to the XENERGY extrusion process. Polystyrene and the co-blowing agents are manufactured from oil and natural gas. GPPS is transported by road or via pipeline from the production site to the XPS manufacturing plants. CO_2 is produced as a by-product from various processes and is available in unlimited quantities.

2.7 Manufacture

XENERGY is manufactured in a continuous extrusion process with electricity as the main energy source. Polystyrene granules are melted together with the additives in the extruder under high pressure. The blowing agents are injected into the melted mass and dissolved in it. The melted mass is extruded through a flat die. The drop in pressure causes the polystyrene to foam and cool down to solidify. An endless board of homogenous closed-cell polystyrene foam is produced. This is cooled further and then cut to dimensions, trimmed, the surface modified if necessary and packed in 4- or 6-sided polyethylene film bags and piled up on pallets. Board thicknesses of 20 to 200 mm can be produced by using different extruding dies.
More than 99% of the XPS from production trimmings and production waste is recycled directly back into the production facilities to manufacture XPS. Polystyrene is a thermoplastic material and can therefore be recycled easily and economically by melting it.

2.8 Environment and health during manufacturing

No measures beyond those already specified in the national work protection regulations are necessary in any of the production steps to protect the health of staff during the manufacture of XPS.
Dow has engaged since 2006 in the SECURE (Self-Enforced Control of Use to Reduce Emissions) programme including a Code of Good Practice to commit to a safe use of HBCD.

2.9 Product processing/Installation

Handling recommendations are described in brochures, application literature and product data sheets. These can be obtained directly from Dow Deutschland GmbH & Co. OHG or via the Internet.
Work and environmental protection measures during product installation are described in the safety data sheets. No special personal protection is necessary for handling XENERGY. XPS construction waste which accumulates as cuttings on the construction site should be collected separately and disposed of professionally.

2.10 Packaging

The packaging consists of polyethylene film which should be collected separately and sent for professional disposal. Polyethylene can then be recycled.

2.11 Condition of use

The base material used is inert and water resistant when installed which means that the insulating performance and also the mechanical properties remain unchanged during the entire period of use.

2.12 Environment and health during use

During use, no effect is expected from the XPS on the environment or the user's health if XENERGY is used appropriately.
Environment: XENERGY is not in direct contact with the environment in the aforementioned applications (except in perimeter insulation). As a flame retardant it contains HBCD, a compound which is classified as "substance of very high concern" in the European Regulation REACH. The HBCD is integrated into the polymer matrix of XPS. HBCD will no longer be used as from August 2015 at the latest and will be replaced by a polymeric flame retardant.
Health: in most applications, XENERGY is not in direct contact with indoor air. There are no known detrimental effects for health when XENERGY is used for interior insulation.

2.13 Reference service life

The durability of XENERGY is as long as the lifetime of the building in which it is used. This is due to the superior mechanical and water resistance properties of this product.

2.14 Extraordinary effects

Fire

The fire behaviour of XENERGY is defined within the general building inspection approvals. XENERGY products fulfil the requirements of Class E as per standard DIN EN 13501-1 (corresponds to the building inspection denomination of “normal flammability”).

Water

When used appropriately, XENERGY is chemically neutral, not water-soluble and emits no water-soluble substances which could cause the pollution of ground water, rivers and oceans.

Mechanical destruction

2.15 Re-use phase

Re-use: if the full re-use potential of XPS insulation products is to be exploited the insulation boards should as far as possible be laid in such a way that they can be removed again with little or no damage: non-adhesive systems, separating layers between the insulation and concrete and mechanical fixings. On inverted roofs, extruded polystyrene foam boards are installed loose laid and can therefore be removed from the roof without damage and laid again on another roof. With an existing conventional flat roof, the XPS insulation boards can stay in place if a “plus roof” is to result from upgrading the insulation.

Further use: dismantled, re-usable XPS insulation boards recovered from mechanically fixed applications can, for example, be used for insulating cellar walls or as non-load bearing floor panels.

Recycling and recovery: Recycling of XPS foam – and therefore also XENERGY products – consisting of production trimmings and production waste – has worked for many years and is a standard practice. These manufacturing scraps are recycled directly in the production facilities for producing XPS.

Clean material from building site offcuts and breakages can be recycled. Under certain circumstances it is also possible to manufacture new insulation boards using recycled material.

2.16 Disposal

Waste code as per European waste catalogue / List of Waste Materials Directive (/AVV/):
17 06 04 insulation material with the exception of that which falls under 17 06 01 and 17 06 03.

2.17 Further information

See Chapter 7: Requisite evidence.

3 LCA: Calculation rules

3.1 Declared unit

This declaration refers to 1 m² of extruded polystyrene foam board (XPS board) 100 mm thick, i.e. 0.1 m^3 with a density of 35 kg/m^3.

The following conversion is to be used when calculating environmental indicators and inventory parameters for XPS products of a different gross density:

$$I_{adap} = I_{ref} * \frac{\rho_{adap}}{\rho_{ref}} * \frac{d_{adap}}{d_{ref}}$$

I_{adap} – Adapted environmental indicator or environmental inventory parameter

I_{ref} – Environmental indicator or environmental inventory parameter for a density of 35 kg/m^3

ρ_{adap} – Adapted density

ρ_{ref} – Reference density of 35 kg/m^3

d_{adap} – Adapted board thickness

d_{ref} – Reference board thickness (100mm)

3.2 System boundary

Type of the EPD: cradle to gate with options
The LCA examines the following points of the life cycle:

- Production of raw materials and energy (A1)
- Manufacture of polystyrene foam (A3)
- Manufacture of packaging (A3)
- Transports (raw materials to manufacturer, products to building site, waste to EoL) (A2, A4, C2)
- The emissions of the process aids and the Co foaming agents from the manufacturing process (A3) are examined.
- Thermal re-use or disposal of the product (C3 or C4)
- Emissions and pollution as a result of disposal of packaging are attributed to module A5.
- Credits as a result of disposal of packaging are attributed to module D.
- Energy savings which result from the application of XPS foam are specific to each application case and are not part of this LCA.

3.3 Estimates and assumptions

An estimate is used for the environmental profile of the manufacture of the flame retardant. The environmental contamination of the CO2 process aid originates exclusively from the electricity requirement for compression and transport on the assumption that CO2 occurs as a waste or co-product of other industrial processes and thus no environmental contamination occurs in the upstream chain.

3.4 Cut-off criteria

All data from operating data collection, i.e. all source materials used according to the formulation (inc. the additives), the thermal energy used, the internal fuel and electricity consumption, all direct production waste and also all available emission measurements are accounted for in the balance sheet. Assumptions as to transport expenses are made for the raw material polystyrene, all further pre-products and also the product XPS. Material and energy streams with a share of less than 1% are also accounted for. It can be assumed that the disregarded processes would each have contributed less than 5% to the impact categories included. The manufacture of the necessary machines and plant is disregarded.

3.5 Background data

Data on the use of material and energetic resources and also transport distances were provided by Dow. Background data has been taken from the GaBi 6 database.

3.6 Data quality

Modelling of the XENERGY products is based on company manufacturing data from 2010. The last audit of the relevant background data records in the GaBi 6 database took place less than 4 years ago. All data records used originate from the GaBi 6 databases and are therefore consistent.

3.7 Period under review

Manufacturing data from 2010 serves as a data basis.

3.8 Allocation

Electricity and heat consumption for the production of XENERGY in both plants in Greece and Germany was allocated by means of the production volume. No allocations were used for manufacturing. A multi-input allocation with a credit for electricity and thermal energy according to the simple credit method is deployed for the incineration of the packaging. The credits from the disposal of packaging are credited in module D.

3.9 Comparability

Basically, a comparison or an evaluation of EPD data is only possible if all the data sets to be compared were created according to DIN EN 15804 and the building context, respectively the product-specific performance characteristics, are taken into account.

4 LCA: Scenarios and further technical information

The following technical information forms the basis for the declared modules or can be used for the development of specific scenarios in the context of a building assessment.

Transport to the building site (A4)

Litres of fuel (diesel) Euro 4 truck:	25.2 l/100 km
Capacity utilisation (including empty runs):	10%
Gross density of products transported:	30-50 kg/m³
Capacity utilisation volume factor:	95%

Installation into the building (A5)

Transport to building site:	400 km (Greece); 500 km (Germany)
Material loss:	disregarded
VOC in the air:	none

Transport to EoL (C2):
Transport for thermal recycling or disposal: 100 km

Waste management (C3):
Since XENERGY collection and recycling quotas can vary greatly depending on the type of installation and the country, two scenarios are presented in the assessment which permits individual calculation of the actual waste management:

1.) 100 % thermal recycling including credit for electricity and heat
2.) 100 % disposal

5 LCA: Results

DESCRIPTION OF THE SYSTEM BOUNDARY (X = INCLUDED IN LCA; MND = MODULE NOT DECLARED)																
Product stage			Construction process stage		Use stage							End of life stage				Benefits and loads beyond the system boundaries
Raw material supply	Transport	Manufacturing	Transport to construction site	Installation in building	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/ Demolition	Transport	Waste processing	Disposal	Reuse, Recovery or Recycling potential
A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
X	X	X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	X	X	X	X

RESULTS OF THE LCA: ENVIRONMENTAL IMPACT: 0.1 m³ XENERGY^{TM}: Scenario 1 & 2

		Production	Transport to site	Installation	Transport to EoL	100% thermal recycling (Scenario1)		100% disposal (Scenario 2)	
	Unit	**A1-A3**	**A4**	**A5**	**C2**	**C3**	**D**	**C4**	**D**
GWP	[kg CO_2-Äq.]	1.02E+01	4.17E-01	2.25E-01	9.59E-02	1.18E+01	-8.19E+00	2.01E-01	-1.18E-01
ODP	[kg CFC11-Äq.]	1.63E-09	7.28E-12	9.18E-13	1.68E-12	4.82E-11	-8.06E-10	3.75E-11	-4.39E-09
AP	[kg SO_2-Äq.]	3.78E-02	2.01E-03	1.45E-05	4.63E-04	7.61E-04	-4.15E-02	2.98E-04	-2.80E-04
EP	[kg PO_4^{3-}-Äq.]	2.23E-03	4.68E-04	2.73E-06	1.08E-04	1.43E-04	-1.27E-03	4.57E-05	-1.92E-05
POCP	[kg Ethen Äq.]	7.93E-03	-6.74E-04	1.69E-06	-1.55E-04	8.84E-05	-2.36E-03	7.75E-05	-2.34E-05
ADPE	[kg Sb Äq.]	3.60E-06	1.55E-08	9.90E-10	3.58E-09	5.19E-08	-5.45E-07	1.75E-08	-9.21E-09
ADPF	[MJ]	2.86E+02	5.77E+00	2.67E-02	1.33E+00	1.40E+00	-1.08E+02	6.84E-01	-2.00E+00
Key	GWP = Global warming potential; ODP = Depletion potential of the stratospheric ozone layer; AP = Acidification potential of land and water; EP = Eutrophication potential; POCP = Formation potential of tropospheric ozone photochemical oxidants; ADPE = Abiotic depletion potential for non-fossil resources; ADPF = Abiotic depletion potential for fossil resources								

RESULTS OF THE LCA: RESOURCE USE: 0.1 m³ XENERGY^{TM}: Scenario 1 & 2

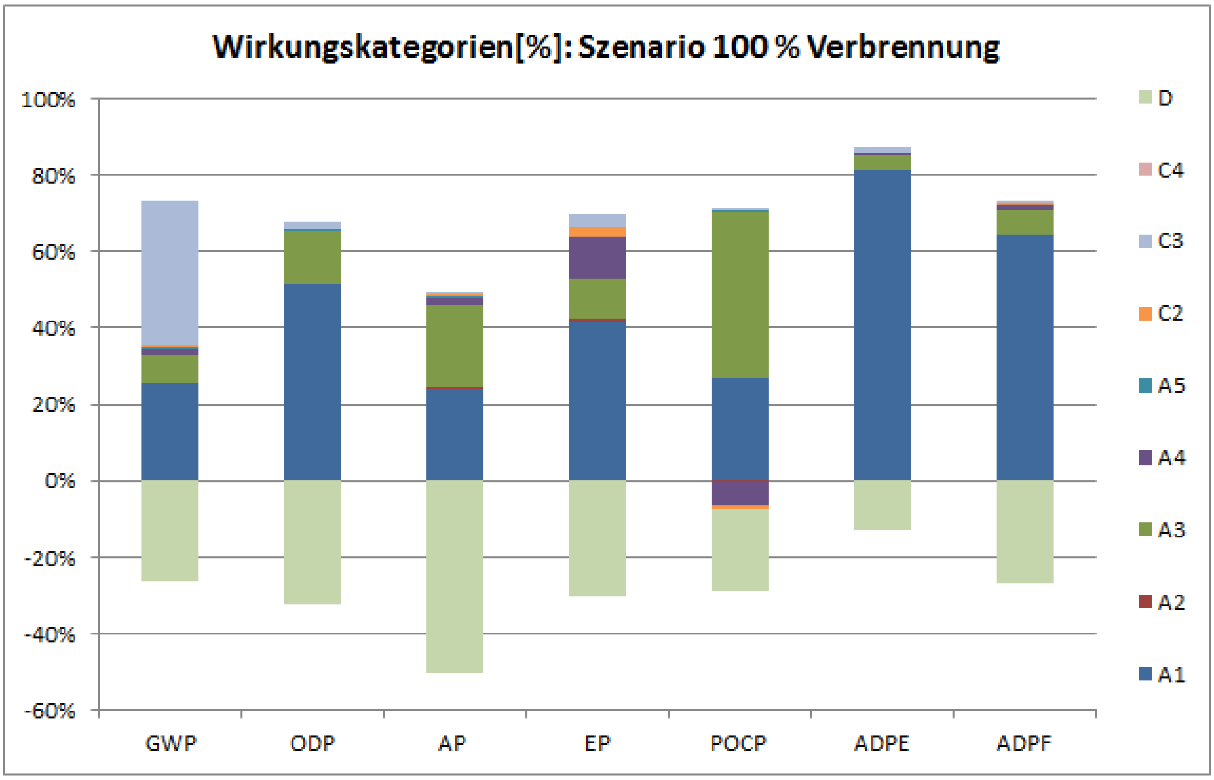
		Production	Transport to site	Installation	Transport to EoL	100% thermal recycling (Scenario1)		100% disposal (Scenario 2)	
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**C2**	**C3**	**D**	**C4**	**D**
PERE	[MJ]	5.07E+00	-	-	-	-	-	-	-
PERM	[MJ]	0	-	-	-	-	-	-	-
PERT	[MJ]	5.07E+00	2.26E-01	2.03E-03	5.21E-02	1.07E-01	-6.05E+00	5.07E-02	-1.43E-01
PENRE	[MJ]	1.46E+02	-	-	-	-	-	-	-
PENRM	[MJ]	1.40E+02	-	-	-	-	-	-	-
PENRT	[MJ]	2.86E+02	5.77E+00	2.67E-02	1.33E+00	1.40E+00	-1.08E+02	6.84E-01	-2.00E+00
SM	[kg]	-	-	-	-	-	-	-	-
RSF	[MJ]	2.77E-03	3.65E-05	1.05E-06	8.40E-06	5.5E-05	-1.47E-03	1.20E-03	-2.75E-05
NRSF	[MJ]	2.91E-02	3.82E-04	1.04E-05	8.79E-05	5.48E-04	-1.54E-02	2.84E-03	-2.88E-04
FW	[m³]	5.69E-02	2.51E-04	4.28E-04	5.78E-05	2.24E-02	-2.59E-02	-1.29E-03	-4.02E-04
Key	PERE = Use of renewable primary energy excluding renewable primary energy resources used as raw materials; PERM = Use of renewable primary energy resources used as raw materials; PERT = Total use of renewable primary energy resources; PENRE = Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials; PENRM = Use of non-renewable primary energy resources used as raw materials; PENRT = Total use of non-renewable primary energy resources ; SM = Use of secondary material; RSF = Use of renewable secondary fuels ; NRSF = Use of non-renewable secondary fuels ; FW = Use of net fresh water								

RESULTS OF THE LCA: OUTPUT FLOWS AND WASTE CATEGORIES: 0.1 m³ XENERGY: Scenario 1 & 2

		Production	Transport to site	Installation	Transport to EoL	100% thermal recycling (Scenario1)		100% disposal (Scenario 2)	
	Unit	**A1-A3**	**A4**	**A5**	**C2**	**C3**	**D**	**C4**	**D**
HWD	[kg]	3.29E-03	0	1.99E-04	0	1.04E-02	0	4.88E-04	0
NHWD	[kg]	4.46E-02	8.12E-03	7.49E-04	1.72E-04	1.09E-03	0	3.46E+00	0
RWD	[kg]	3.01E-03	8.03E-06	1.74E-06	1.85E-06	9.16E-05	-2.24E-03	1.22E-05	-1.26E-04
CRU	[kg]	-	-	-	-	-	-	-	-
MFR	[kg]	-	-	-	-	-	-	-	-
MER	[kg]	-	-	-	-	-	-	-	-
EE [Strom]	[MJ]	0	0	0	0	0	1.86E+01	0	3.49E-01
EE [Dampf]	[MJ]	0	0	0	0	0	5.09E+01	0	9.50E-01
Key	HWD = Hazardous waste disposed; NHWD = Non-hazardous waste disposed; RWD = Radioactive waste disposed; CRU = Components for re-use; MFR = Materials for recycling; MER = Materials for energy recovery; EE = Exported energy per energy source								

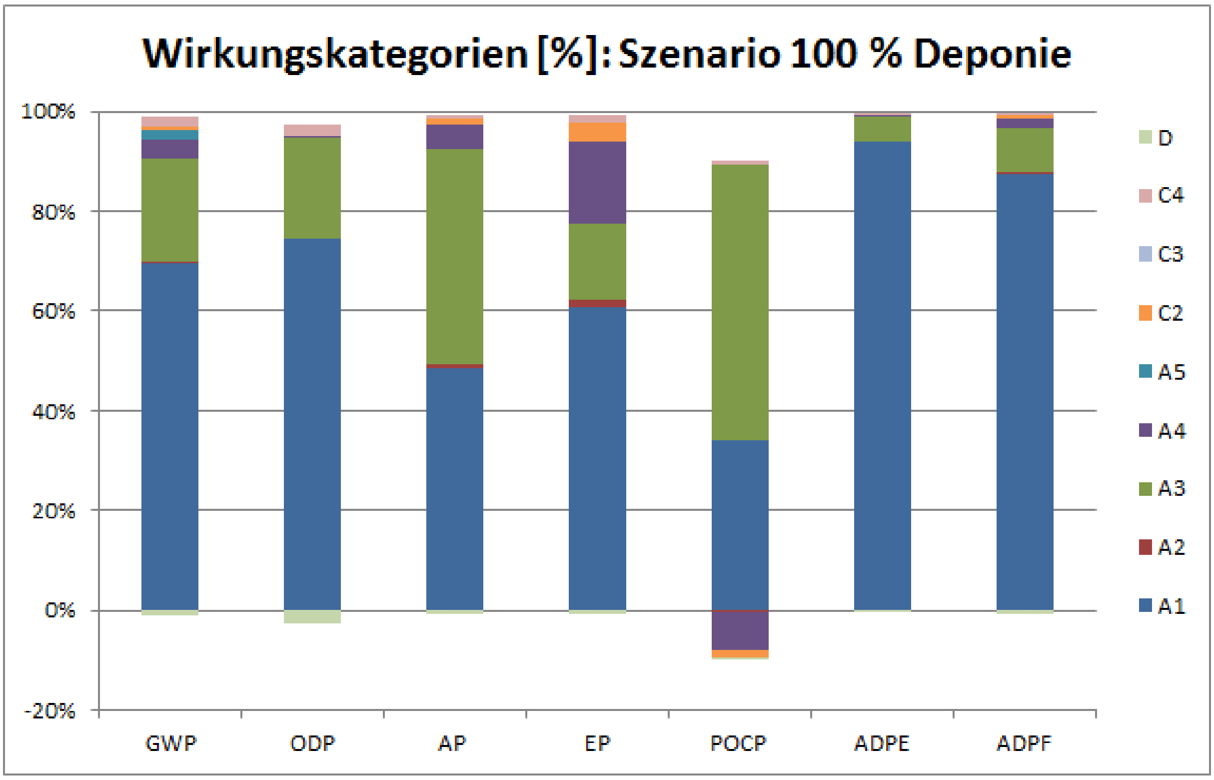
6 LCA: Interpretation

The following bar graphs show the most important influencing factors on important impact and material assessments.



The dominant influence of pre-product manufacturing (A1) is reflected in most impact categories with ratios between 24% for the acidification potential (AP) and 81% in relation to the potential for the abiotic depletion of non-fossil resources (ADP Elementary). The manufacture of the polystyrene granulate, which makes up over 90% of the XENERGY weight, contributes most to the environmental impacts (in relation to module A1: > 80% in all categories except ADP Elementary, where the manufacture of the HBCD flame retardant has a large influence). The extrusion process (A3) plays an important role in the photochemical ozone formation potential (POCP: 51%) and in the acidification potential (21%). The influence of the POCP can be attributed above all to emissions of the Co blowing agent isobutane. The electricity requirement of the extrusion process has a significant effect on the acidification potential as especially the Greek electricity mix has a high proportion of lignite. The transports to the building site have a clear effect on the eutrophication potential (11%) as well as the POCP (-7%). The nitrogen monoxide emissions which are emitted by combustion engines have a reducing effect on the POCP. The thermal treatment at end of life (C3) contributes greatly to the GWP (38%). In the case of the GWP, the waste incineration emissions exceed the credits which accrue from this thermal treatment by approximately 12 %. With the acidification potential (AP), the thermal treatment leads to high credits, as especially sulphur dioxide emissions from electricity produced from coal (lignite) are avoided.

The primary energy requirement consists almost exclusively of non-renewable primary energy (PENRT). The main portion of the non-renewable primary energy requirement is caused by the manufacture of the pre-products. This is explained by the fact that the pre-products are made almost exclusively of fossil raw materials (especially polystyrene), which are mostly energy-intensive to manufacture. The energy supplies mainly used are therefore natural gas and oil. The electricity requirement of the extrusion process (A3) contributes approximately 6-9% to the primary energy requirement depending on the scenario. The influence of lignite becomes apparent due to its high share of the Greek electricity mix. The primary energy requirement of the 100% recycling disposal scenario is reduced by approximately 30% due to the thermal recycling at end of life.



In contrast to the thermal treatment, no credits are generated by disposal at end of life as XENERGY is taken to waste sites for inert materials together with construction waste. In return, disposal also causes no emissions.

The absolute values of modules A1-C2 do not differ from the first scenario; however, the percental shares are different due to the missing combustion emissions and credits.

7 Requisite evidence

7.1 VOC emissions

(Test of product emissions as per the AgBB/DIBt-method XENERGY™ extruded polystyrene foam (May 2012, Eurofins Product Testing, Denmark)

Name and suffix	Value	Unit
AgBB results overview (28 days)		
TVOC (C6 - C16)	< 50	µg/m^3
Total SVOC (C16 - C22)	< 5	µg/m^3
R (dimensionless)	<0.05	-
VOC without NIK	< 5	µg/m^3
Carcinogens	No traces	µg/m^3

7.2 Leaching performance

Leaching behaviour is not relevant for Xenergy.

8 References

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DIN EN 1604

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DIN EN 1605

DIN EN 1605:2013-05: Thermal insulating products for building applications – Determination of deformation under specified compressive load and temperature conditions; German version EN 1605:2013

DIN EN 1606

2013-05: Thermal insulating products for building applications – Determination of compressive creep; German version 1606:2013

DIN EN 1607

2013-05 Thermal insulating products for building applications – Determination of tensile strength perpendicular to face; German version EN 1607:2013

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2013-06: Thermal insulation products for building applications – Determination of water vapour transmission properties; German version EN 12086:2013

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DIN EN 15804

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DIN EN 12667

2001-05: Thermal performance of buildings materials and products – Determination of thermal resistance by means of guarded hot plate and heat flow meter methods - Products of high and medium thermal resistance; German version EN 12667:2001

DIN EN 12939

2001-02: Thermal performance of building materials and products- Determination of thermal resistance by means of guarded hot plate and heat flow meter methods- Thick products of high and medium thermal resistance; German version EN 12939:2000

DIN EN 13164

2013-03, Thermal insulation products for buildings – Factory-made extruded polystyrene foam (XPS) products – Specification; German version EN 13164:2012

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Approvals

Z-23.15-1476 (product approval)

Z-23.33-1882 (Approval for the application as perimeter insulation against pressing water)

Z-23.31-1881 (Approval for the inverted roof thermal insulation system)

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MAKING A DIFFERENCE

CABOT CORPORATION

2016 SUSTAINABILITY REPORT

CABOT

MAKING A DIFFERENCE

Specialty fluids laboratory in Aberdeen, United Kingdom.

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A MESSAGE FROM THE CEO

SEAN D. KEOHANE
President and
Chief Executive Officer

I am pleased to share Cabot Corporation's 2016 Sustainability Report with you.

2016 marked not only the launch of a new vision and strategy for our company, but we also enhanced our approach to sustainability. We conducted an extensive materiality assessment that enabled the reevaluation of those areas of sustainability that are most important to Cabot. This effort, which included outreach to customers, investors and our employees around the globe, helped us confirm our priorities and sharpen our focus. It also pushed us to look beyond our operational footprint into the value chain, where we believe there are many opportunities to partner with our customers and suppliers in order to make a difference.

Society is demanding more from companies in this area and, in turn, we are demanding more of ourselves. We have a unique opportunity to demonstrate our leadership, improve our connection with our customers and, ultimately, outperform our competition by developing products that are needed to enhance the performance and efficiency of our customers' applications. These products and our application innovation address complex global sustainability challenges such as improved battery performance, lighter automotive materials, superior tire durability, and clean air and water. This is an exciting time for us as we find new ways to improve our own performance while delivering game-changing solutions to our customers for a more sustainable future.

We believe that integrating sustainability into our business agenda will greatly enhance our ability to deliver superior solutions. As we move forward, we are working to enhance our level of collaboration with our suppliers in an effort to address shared sustainability challenges. Our sustainability efforts are guided by our core values of integrity, respect, excellence and responsibility and we depend on our team of highly skilled and dedicated employees to help us focus on those aspects of sustainability that are most material to our business. As a responsible corporate citizen, we strive to continuously improve our performance in the areas of environmental, social and economic commitments through the delivery of superior products, flawless operations and active engagement with our stakeholders.

I invite you to review the following pages to discover the many examples of our sustainability progress over the past year and to learn more about our goals for the coming years. Our sustainability program is a source of pride for me and all of my Cabot colleagues. It underscores our core values and our ambitions to positively impact the markets we serve, the communities where we operate and the lives of all of our employees. The report also reaffirms our commitment to the Ten Principles of the United Nations Global Compact in the areas of human rights, environment, labor and anti-corruption. I'm thrilled to share our story of how together, we are taking the next step on our sustainability journey and collectively, making a difference.

Thank you,

Carbon black manufacturing in Valmez, Czech Republic.

Carbon black manufacturing in Ravenna, Italy.

Our sustainability efforts are guided by our core values of integrity, respect, excellence and responsibility.

ABOUT THIS REPORT

Cabot publishes sustainability reports conforming to the Global Reporting Initiative (GRI) sustainability reporting framework on a biennial cycle, with update reports in the alternating years. Our last sustainability update report was published in June of 2016.

This report has been prepared in accordance with the GRI Standards: Core option. Additionally, this report serves as our annual Communication on Progress in support of our commitment to the United Nations Global Compact.

Data and information covered in this report represent our performance across all significant Cabot locations for which the Company has operational control and majority ownership during the 2016 calendar year, with the exception of financial data which reflects the Company's 2016 fiscal year (October 1, 2015 through September 30, 2016). To ensure the highest level of data integrity, we maintain databases for safety and environmental incident tracking, greenhouse gas emissions, finance and human resources. This data is collected, analyzed and reviewed by subject-matter experts within the organization and in the case of our greenhouse gas emissions, this data undergoes biennial verification by an independent third-party. Most recently, this data was verified according to the ISO-14064-3:2006(E) Specifications with Guidance for the Validation and Verification of Greenhouse Gas Assertions in June 2017 for our 2015 and 2016 data.

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GRI 102-12
GRI 102-46
GRI 102-50
GRI 102-51
GRI 102-52
GRI 102-54
GRI 102-56

** Throughout this report, sidebar navigation showcases how Cabot has implemented the GRI Standards. Each marker is numbered according to the relevant GRI General Disclosure or Topic-Specific Disclosure. The GRI Content Index (p. 42) provides a comprehensive list of all GRI disclosures deemed material to Cabot.*

DETERMINING WHAT IS MATERIAL

In keeping with the reporting framework of the new GRI Standards including its Reporting Principles, we took a closer look at what sustainability topics are most important to our business and stakeholders' interests. This was done through a comprehensive materiality assessment in which a broad range of sustainability-related topics were evaluated for their relative significance and our ability to positively influence our value chain. The assessment involved nearly 300 individuals from internal and external stakeholder groups who shared their perspectives. The groups represented diverse experiences across a wide variety of functions, all our business segments and each region where we operate.

GRI 102-46

This process not only aided us in keeping the content of this report focused on our readers' interests, but it has also granted valuable insight into how we can refocus the vision for our sustainability program. In the majority of instances, the results of the materiality assessment did not differ significantly from the sustainability topics that were already being addressed; however, we can now move forward with confidence that we are focusing our efforts in the right areas. This will aid in the development of strategic plans to improve our management practices and performance.

One notable topic that was recognized through the materiality assessment as highly material was our suppliers' sustainability impact. As a resource-intensive manufacturing company, we recognize that environmental and social impacts may also result from the activities and products of our suppliers in addition to our own. As a result, we are in the initial stages of developing a management approach to our suppliers' sustainability. We expect this effort to build on recent measures to improve the tracking of our top-tier suppliers' commitment to our Supplier Code of Conduct and in the coming year, we will review relevant benchmarks and best practices to help guide our next steps. We see this as an opportunity to expand our influence and engage suppliers to improve their environmental and social performance.

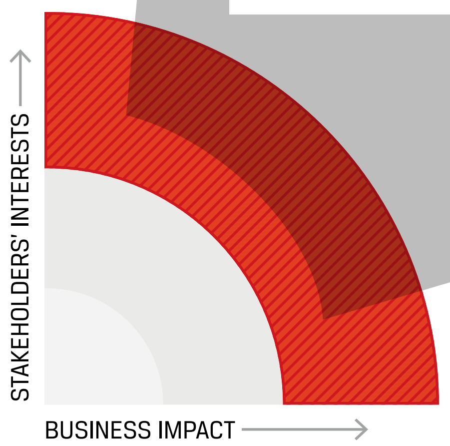
GRI 102-9
GRI 102-49
GRI 103-1
GRI 103-2
GRI 308-1
GRI 414-1

Linking Material Topics

The topics that were deemed most material in the assessment are important beyond the scope of our value chain, which is easily seen when mapping these topics to the United Nations' Sustainable Development Goals (SDGs). The SDGs set forth 17 targets for all organizations and governments to work toward. We believe our renewed sustainability strategy, based on our recent materiality assessment, will help us make valuable contributions to many of these important collective goals.

GRI 102-47

HIGHLY MATERIAL TOPICS	Mapping to United Nations Sustainable Development Goals
Occupational Health & Safety	3, 8
Environmental Compliance	11, 13
Economic Value Generated & Distributed	8
Emissions	11
Energy	7, 9, 11, 13
Product Sustainability	6, 7, 9, 11, 12, 13
Employee Retention, Diversity & Development	8, 10
Waste & Spills	12
Community Engagement	4, 11
Suppliers' Sustainability	10, 13, 17
Water	6



Making progress in the areas of these material sustainability topics will also help us in our commitment as a signatory to the United Nations Global Compact.

GRI 102-12

THE GLOBAL COMPACT
WE SUPPORT

ENVIRONMENT

LABOR

HUMAN RIGHTS

ANTI-CORRUPTION

ENVIRONMENT We are regularly looking for opportunities to reduce our environmental impact through efficiency and optimization initiatives. Many of our efforts are guided by our environmental goals for the reduction of energy use, greenhouse gas emissions, nitrogen oxide (NO_x) emissions, sulfur dioxide (SO_2) emissions and waste disposal. These goals have a target year of 2025 and we are making progress compared to our baseline years. All facilities monitor these metrics and are expected to support these corporate goals. Moving forward, we will look for additional opportunities based on the results of the recently completed materiality assessment.

LABOR Keeping employees safe and treated fairly is of the utmost importance to Cabot as we drive to reach zero injuries. We have no tolerance for discrimination and strive to foster a culture of respect for each other and our individual differences. We recognize the value of a workforce rich in diversity as it provides a broad spectrum of backgrounds and experiences that drive more productive collaboration. We constantly look for ways to make Cabot an even better place to work and in 2016 we piloted a company-wide employee engagement survey that will be rolled out globally in 2017.

HUMAN RIGHTS Our employees are our most valuable asset, so meeting their most basic needs and respecting their human rights is a standard across all of our operations and regions. We strive to go far beyond meeting these civic rights by offering our employees a fulfilling place to work. Still, we felt it was important to document our position on human rights in a policy which was introduced in the spring of 2016. This Human Rights Policy captures the practices that we have been adhering to for many years, and helps our employees and partners clearly understand our expectations of them. As we look to gain more insight into our supply chain, we also plan to implement the use of our new Human Rights Policy through our engagements with suppliers.

ANTI-CORRUPTION Upholding a strong sense of responsibility and ethics is deeply embedded in how we do business. All forms of corruption including bribes, kickbacks and improper payments are explicitly prohibited. All employees are required to undergo training annually to ensure that they understand and adhere to our Code of Business Ethics and are able to identify circumstances that could pose a compliance risk. We also conduct additional focused trainings on anti-corruption for employees with certain roles and responsibilities. Our International Anti-Corruption Compliance Manual provides further guidance on how to comply with our high ethical standards and what due diligence measures are required prior to engaging third parties who will act on Cabot's behalf. Our Office of Compliance oversees Cabot's compliance with laws and regulations, the Code of Business Ethics and other Cabot policies. The Office also reviews matters of potential noncompliance and recommends management actions to address any misconduct or noncompliance.

We will also continue to engage with our key stakeholder groups on our material topics. We understand our success depends on meaningful engagements with each of these groups and we diligently work to ensure their respective needs are being met to the best extent possible.

GRI 102-40
GRI 102-42
GRI 102-43
GRI 102-44

Stakeholders	Types of Engagement	Key Topics
Customers	Surveys, technical information, exchanges, plant visits, complaint resolution	Performance, sustainability, satisfaction surveys, technical solutions, production plans, safety data sheets
Investors	Annual report, quarterly disclosures, sustainability report, annual meeting	Performance, strategy, execution, material disclosures, sustainability
Employees	Meetings, executive briefings, training sessions, surveys, regular intranet communication	Performance, strategic initiatives and vision, policy and structure, benefits and compensation, safety data sheets, sustainability
Regulators	Plant visits, training sessions, technical information, exchanges, inspections	Compliance reporting, problem solving, technical information
Communities	Plant visits, open house events, community events, sponsorships, engagement programs	Plant operations, emergency response planning, compliance programs, emissions, community sponsorships, local engagement

Activated carbon shared service center in Amersfoort, the Netherlands.

HIGHLIGHTING OUR PROGRESS

MARTIN J. O'NEILL
Senior Vice President
Safety, Health and Environment

Thank you for your interest in our 2016 Sustainability Report. This year, we reexamined our sustainability program to ensure we focus our efforts in areas that are most relevant to our business and allow us to make a difference in our communities and the environment. With the support of many of our key stakeholders, we conducted an extensive materiality assessment, which affirmed that our sustainability efforts to date are valued. It also shed light on areas that we must develop further. I look forward to utilizing the learnings from the materiality assessment to accelerate our progress in sustainability and uncover more opportunities to integrate sustainability initiatives into our business.

The business climate was filled with optimism and opportunities in 2016. We continued to focus on keeping our people safe, working with our customers to develop solutions for a more sustainable future, reducing our environmental footprint and giving back to our communities.

We diligently work to maintain some of the best safety standards in the industry. To that end, we have taken positive steps to improve the training of our frontline supervisors that help them execute their work safely each and every day. As a result, the total number of recordable safety incidents decreased by 17% while our total recordable incident rate decreased by 10% since 2015 and remains well below the industry average. We also had a 50% drop in process safety events as a result of our efforts aimed at improving plant and equipment reliability.

In executing our new corporate strategy, we are specifically focused on finding opportunities to meet our environmental goals while optimizing our operations and enhancing efficiency. In some respects, the challenges we faced from increased production in 2016 affected our ability to make progress on some of our environmental metrics on a year-over-year basis. However, we continue to make progress against our long-term objectives and I remain encouraged that we will be able to achieve our 2025 goals. We continue to invest in our operations to increase efficiency and reduce our overall impact. I expect that we will continue to realize positive results from these investments. We also look forward to making more important contributions in a number of our customers' products that are propelling us all into a more sustainable future.

Finally, an element of our sustainability program that runs deep in our culture is engagement with the communities where we operate. At every one of our facilities, we strive to be a good neighbor and find ways to make a positive impact in our communities. Through our collective philanthropy efforts, Cabot has contributed over $1.6 million in charitable donations that make a difference.

I hope you find this report helpful in better understanding our commitments, accomplishments and plans for continually improving our sustainability performance. I would like to invite you to share your feedback after reading our report and thank you for your interest in Cabot.

Best regards,

TOTAL RECORDABLE SAFETY INCIDENTS

17%

PROCESS SAFETY INCIDENTS

50%

1.6 MILLION

IN CHARITABLE DONATIONS

> We are specifically focused on finding opportunities to meet our environmental goals while optimizing our operations and enhancing efficiency.

Cabot team runs for charity on Thompson Island, Boston, MA, USA.

Activated carbon laboratory in Marshall, Texas, USA.

Specialty fluids facility in Aberdeen, United Kingdom.

OUR COMPANY

As a global specialty chemicals and performance materials company, we build on our market leadership by collaborating with customers across a broad range of industries such as transportation, infrastructure, environment and consumer goods to address important needs in key applications. We are committed to improving product performance, conducting our operations responsibly, focusing on our customers and innovating for the future. Our commitment to innovation is driven by a passion to advance our customers' businesses through our deep understanding of their industries and the global trends that impact their operations.

GRI 102-7
GRI 102-10

Our global network consists of approximately 4,300 employees and 44 manufacturing facilities across 21 countries. All are joined by our commitment and continued dedication to safety, health and environmental leadership and progress. Since our last sustainability report, the scope of our operations was impacted by the closure of our carbon black facility in Merak, Indonesia in January 2016. This difficult decision was driven by a need to consolidate production in Asia to remain competitive and meet market demands. Spurred by similar market demands, we announced a joint venture agreement with Hengyecheng Silicone Co. (HYC) in September 2016[1], and will break ground on a state-of-the-art fumed silica manufacturing facility in Wuhai, China in June 2017. Through this partnership, we will be better positioned to meet increased demands for our high-quality, high-performance fumed silica for use in growth markets such as automotive, construction and renewable energy.

OUR INDUSTRIES

GRI 102-2
GRI 102-6

Consumer

Our performance solutions are an essential part of modern-day life.

Environment

We believe that a sustainable future is possible.

Transportation

We help manufacturers improve the performance, safety and lifespan of vehicles and their components.

Infrastructure

We provide eco-friendly products that address tomorrow's challenges today.

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[1] *Although the agreement was confirmed in 2016, production is not slated to begin until 2019 so performance data associated with this facility has not been included in the data presented in this report.*

OUR BUSINESS SEGMENTS

GRI 102-2

Performance Chemicals

Specialty Carbons and Formulations; Metal Oxides

Specialty additives that enable performance in: plastics, wire and cable, toners, coatings, adhesives and sealants, electronics, batteries, inks, inkjet printing, composites, silicones, building construction materials, industrial insulation

Reinforcement Materials

Rubber Blacks; Elastomer Composites

Carbon black to reinforce and optimize the performance of rubber products including: tires, hoses, belts, molded goods

Specialty Fluids

Cesium Formate Brines; Fine Cesium Chemicals

Advanced cesium products for use in: oil and gas well drilling and completion fluids, catalysts, titanium dioxide, glass, brazing fluxes

Purification Solutions

Activated Carbon

Activated carbon for purification in various applications including: air and water, food and beverages, pharmaceuticals, catalysts

OUR LOCATIONS

GRI 102-4

NORTH AMERICA
- Canada
- Mexico
- United States

SOUTH AMERICA
- Argentina
- Brazil
- Colombia

EUROPE, MIDDLE EAST & AFRICA (EMEA)
- Belgium
- Czech Republic
- France
- Germany
- Italy
- Latvia
- Norway
- Switzerland
- the Netherlands
- United Arab Emirates
- United Kingdom

ASIA PACIFIC (APAC)
- China
- India
- Indonesia
- Japan
- Malaysia
- Singapore

REFRESHED CORPORATE VISION AND STRATEGY

Recently, we reviewed our vision and corporate strategy to ensure that we are focused on the right things and have a clear direction for the future. We set out to define a new vision and strategy that would make Cabot a more successful and sustainable company grounded in our shared values of excellence, integrity, respect and responsibility. The outcome of this effort was the introduction of a new corporate vision and strategy designed to guide our strategic decisions. Our vision is to be the most innovative, respected and responsible leader in our markets—delivering performance that makes a difference. This vision lays out our destination that guides our strategy to extend our leadership in performance materials by investing for growth in our core businesses, driving application innovation with our customers and generating strong cash flows through efficiency and optimization. This strategy drives our choices, enables us to prioritize our efforts, differentiates us from our peers and will help us build lasting value for our stakeholders.

CONDUCTING BUSINESS ETHICALLY

We maintain a steady focus on conducting our business ethically. This is rooted in our core company values of respect, responsibility, excellence and integrity. Our Code of Business Ethics provides guidance to all employees on how these values should be upheld in their respective roles. The Code describes the responsibility every employee has to treat each other with mutual respect, engage with customers and other stakeholders ethically, protect our assets and serve as responsible members of our community. It is translated into 13 languages and all employees are required to undergo annual training on its content. Overseeing the Code, along with other policies and compliance with laws and regulations, is the Office of Compliance that reports to the Audit Committee of the Board of Directors.

GRI 102-16

ECONOMIC PERFORMANCE

As a publicly traded company, one of our core objectives is to deliver sustained and attractive total shareholder return through our product sales across the globe. During our 2016 fiscal year, we generated $2.4 billion in revenue. This strong performance allows us to not only contribute to a healthy economy, but also cascade our value by providing fair wages to employees and offering charitable contributions to the communities in which we operate.

As we look for ways to generate increased financial growth, consideration of sustainability-related issues helps to ensure that we consider relevant risks and opportunities in our markets. For instance, as part of our Enterprise Risk Management program, we have identified risks including more stringent greenhouse gas (GHG) regulations in certain regions where we operate and potential physical risks to some of our facilities due to extreme weather events that may be brought on by climate change. We have also identified opportunities with regard to climate change including an increased demand for our products and services that support our customers' needs to meet energy and GHG regulations and improve energy efficiency. How such risks and opportunities are managed depends on a prioritization approach that takes into account timeframe, magnitude of impact, likelihood and financial implications.

GRI 102-7
GRI 103-1
GRI 201-1
GRI 201-2

CUSTOMERS

It is widely recognized that the environmental and potential health impacts of our products extend beyond the boundaries of manufacturing into how our customers and their customers use these products. Our vision of delivering performance that makes a difference is exemplified by products that provide health, safety, environmental and other sustainable benefits for our customers.

SUSTAINABLE PRODUCTS

When it comes to developing new products, we implement a stage gate process that aligns with Responsible Care® and our own Safety, Health and Environment (SH&E) Policy by considering the entire life-cycle of the product. Early in development, safety and hazard assessments are conducted to identify potential risks. If risks are identified, mitigation measures are evaluated to determine if development should proceed or cease. For all our products, we are diligent in conducting thorough hazard and regulatory assessments and developing comprehensive Safety Data Sheets, which include details on safe storage and handling.

GRI 103-1
GRI 103-2
GRI 103-3
GRI 416-1

Going beyond the stage gate process, we also work closely with customers to identify how we can support them in developing sustainable products and solutions beyond what complies with environmental and public health regulations. Often, this means producing solutions that improve energy efficiency or adhere to strict end-user requirements. For example, our conductive carbon blacks and treated silicas have been selected for their ability to improve wind turbine performance and our LP series of carbon black helps our customers adhere to the European Union Commission's limits on polycyclic aromatic hydrocarbons (PAH) for certain applications. We welcome opportunities to collaborate with customers on these types of projects and we are proud of our ability to introduce more innovative solutions to the market.

Effective method for biogas purification

Biogas that is generated by the breakdown of organic matter at landfills and digesters plays an important role as a sustainable source of energy. Our activated carbon products purify biogas by removing undesirable impurities such as hydrogen sulfide and siloxanes from the raw gas. These and other impurities must be removed from the biogas before it can be used to generate electricity or sold as an alternative to natural gas. Our activated carbon products help reduce equipment damage and downtime, ensure emission targets are met and meet gas purity specifications, and they have become a key component in the production of this renewable energy source. With increasing needs for improved, clean biogas for automotive fuel and other applications, we more than quadrupled our sales in the biogas market in 2016 compared to 2015. Our uniquely designed purification technology is poised to become an even more important part of biogas energy production in the future.

Unlocking cesium from filter waste

Due to a limited global supply of cesium ore and to minimize our environmental impact through mining, we supply cesium to customers through a unique fluid rental model. This model enables customers to return used cesium formate brine to Cabot. When fluid is returned to us it often contains contaminants and additives that need to be removed before the fluid can be utilized again. A number of steps are taken to return the fluid to its original condition, including precipitation reactions and filtration. We recognized that cesium was being lost during this reclamation process and conducted an experimental study to quantify the amount lost and identify the source of the losses to optimize the process. It was determined that significant losses of cesium occurred during filtration. We made a number of changes to the filtration process, including upgrades to our existing equipment and changes in operating procedures. As a result of the changes made, we significantly reduced losses. These savings reduce the volume of raw materials required for production and move us closer to a "closed loop" model.

Enabling truckless mining through reinforcement materials

Our carbon black business in South America is playing an integral part in an innovative project to replace the use of heavy duty trucks with rubber conveyer belts—also known as truckless technology. We provide specialty grade carbon black to two conveyor belt producers for Vale Mining Company to reinforce the rubber compound used to strengthen the conveyor belts against abrasion, cuts and other damages that the ore may cause. Utilizing a 30 kilometer-long conveyor belt, Vale will replace trucks with conveyor belts. In doing so, the consumption of diesel is reduced by about 70% and the annual GHG is reduced by at least 50%, which means approximately 130,000 tons less carbon dioxide equivalents emitted each year.

Aerogel insulating plasters enable increased energy savings in buildings

Aerogel insulating plasters are a new class of insulation materials that allow high-performance energy renovation of existing buildings. Due to the initial high cost of the product, the spectrum of uses seemed limited at first. Through a joint effort with our partner, Fixit AG, we enabled the next step toward market adoption by lowering the price of the aerogel plaster, thereby making it more accessible to a broader group of users. This change enabled a significant increase in application uses. Specifically, PROCERAM GmbH & Co. KG utilized Fixit aerogel insulating plaster in the renovation of an entire 8-story apartment complex near Berlin, Germany. By applying a 60 millimeter thick layer of the aerogel plaster, the building was able to achieve significant energy savings. Existing facades can now be insulated without changing the appearance of the building while also achieving significant energy savings of up to 70%.

Battery additives improve performance of energy storage systems

Despite a growing focus on delivering more efficient energy storage systems, India continues to depend heavily on lead-acid batteries for domestic, automotive and industrial energy storage. As such, it is vitally important to make the existing lead-acid batteries more efficient, able to accept a fast re-charge, offer a wide operating temperature range, and have an increased cycle life and stable voltage plateau. Our PBX® carbon additives enable battery developers to improve the durability and performance of batteries. In 2016, we made our first breakthrough in India by offering commercial quantities of our PBX carbon additive for use in batteries that offer improved dynamic charge acceptance and increased cycle life. Our PBX products are now supporting India's quest for sustainable, reliable energy storage systems.

RECOGNIZED FOR OUR LEADERSHIP

Our ability to partner with customers and deliver valuable contributions to their business does not go unnoticed. We are honored to have been recognized by numerous customers for our commitment to excellence and the superior service we provide.

Cabot Brazil awarded "Best Carbon Black Supplier"

In May 2016, our carbon black team in Brazil received the "Best Carbon Black Supplier" award from *Paint & Pintura*. This is the twelfth consecutive year that we have received this well-respected award in the coatings and inks industries in Brazil. We received first place with approximately 60% of the total votes. For the silica category, we received fourth place and were noted as one of the "Master Companies."

Cabot awarded "Core Strategic Supplier" by Linglong Tire

In March, we were the only reinforcement material manufacturer to be awarded "Core Strategic Supplier" by Linglong Tire. In addition to the award, we signed a core strategic supplier agreement to jointly build a global high-end purchasing and supply platform. Both companies will further their cooperation together in standard enhancements, quality improvements, and research and development.

Kraiburg names Cabot a "Top Supplier"

Kraiburg, a leading European compounder, recently conducted its annual supplier evaluation and graded us with an "A" as one of their best suppliers. This is a great achievement for our commercial supply chain production and customer care teams, recognizing their continuous efforts to focus on customer needs and leverage our expertise in plastics with this innovative player. Future projects with Kraiburg will provide ample opportunity to expand our successful collaboration.

ENVIRONMENT

Environmental laws and regulations establish standards for protecting the environment according to local, national and international norms. We are committed to operating in a responsible manner and adhering to these strict standards. At the same time, we continue to work toward our environmental goals and enhance our data collection processes to track our performance with a high level of accuracy. We regularly examine our site-specific data and engineering estimates to ensure we have the most accurate data possible for monitoring and reporting our performance. A recent reexamination of this data, improvements in our engineering estimates and updates to our facility-specific information resulted in restatements of some of our environmental data. For instance, our 2012 baseline emissions for nitrogen oxide (NO_x) and sulfur dioxide (SO_2), as well as our previously reported 2015 emissions data, have been restated as a result of this review. We have not altered our stated goals for SO_2 and NO_x emissions intensity reduction, which remain at 40% and 20% by 2025, respectively. We will continue to gather and analyze data with the highest level of accuracy to further enhance the integrity of data wherever possible. In support of this objective, we intend to commission a third party environmental data verification process for future data sets.

GRI 102-48
GRI 103-1
GRI 103-2
GRI 103-3

Land remediation leads to redevelopment

Over the years, we have been dedicated to the remediation of our former industrial properties to allow for their reuse. It is shown that redevelopment of these "brownfield" sites prevents sprawl into open space, forests and agricultural land, thereby preserving acres of undeveloped land. When we cease operations, we decommission the facility and perform a comprehensive environmental assessment and conduct appropriate remediation to render the property safe for redevelopment and similar reuse. To date, approximately 12 properties have been returned to beneficial uses through this program and most recently, the redevelopment of our former operating site in Altona, Australia was completed for reuse as an office park in 2016.

Carbon black industry entry conditions

With growing pressure for further environmental protection, the Chinese government has engaged with the China Carbon Black Industry Association to develop an environmental standard for companies wishing to begin carbon black manufacturing. Initially, only seven board member companies of the Association were eligible to draft the standard. Due to our global presence in the carbon black industry and strong commitment to safety, health and the environment, we were asked to contribute to the effort. As the only foreign-owned carbon black manufacturer to participate on the team, we worked closely with the Association to develop Carbon Black Industry Entry Conditions and contributed to the topic of emissions control for NO_x, SO_2, volatile organic compounds and solid waste. The new standard[2] promotes responsible manufacturing practices and will help drive sustainable development of the carbon black industry.

OUR ENVIRONMENTAL GOALS

In 2014, we introduced updated environmental goals that included new targets for cutting our nitrogen oxides (NO_x) and sulfur dioxide (SO_2) emissions and waste disposal goals in addition to revised energy and greenhouse gas (GHG) goals.

We continue to monitor our progress toward these targets and other environmental metrics. This is complemented by the projects underway at individual facilities to optimize our processes for efficiency and reduce our environmental impacts.

GRI 103-2

Energy Intensity	**GHG Intensity**	**Nitrogen Oxides Intensity**	**Sulfur Dioxide Intensity**	**Waste Disposal**
GJ / MT OF PRODUCTION	MT OF CO_2e / MT OF PRODUCTION	MT NO_x / KMT OF PRODUCTION	MT SO_2 / KMT OF PRODUCTION	MT OF WASTE DISPOSED / KMT OF PRODUCTION
10% ↓	20% ↓	20% ↓	40% ↓	15% ↓
REDUCTION	REDUCTION	REDUCTION	REDUCTION	REDUCTION
BASELINE YEAR 2005 TARGET YEAR 2025	BASELINE YEAR 2005 TARGET YEAR 2025	BASELINE YEAR 2012 TARGET YEAR 2025	BASELINE YEAR 2012 TARGET YEAR 2025	BASELINE YEAR 2012 TARGET YEAR 2025

Carbon black manufacturing facility in Tianjin, China.

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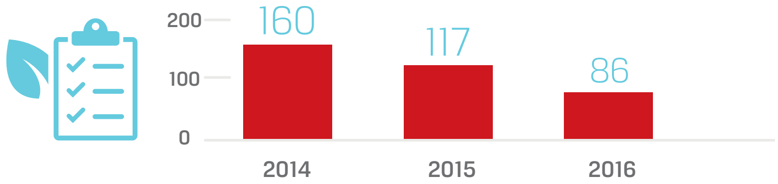
[2] *The standard, T/CRIA 20001-2016, was issued in January 2017.*

ENVIRONMENTAL COMPLIANCE

While we are continuously looking for ways to make our operations more efficient and reduce our environmental impacts, we also carefully manage our regulatory obligations to ensure we meet the requirements of the local governments where we operate. We monitor our performance in this area through our environmental non-conformance (ENC) metric, which we define as any event resulting in a reportable spill or release, a notice of violation, a public complaint or a regulatory permit deviation. In 2016, we continued our downward trend and realized a 26% reduction in the number of ENCs and a nearly 50% reduction in the fines paid from 2015 to approximately $70,000. As part of our "Drive to Zero" initiative, we maintain the philosophy that all ENCs are preventable. We learn from these events, share the results of root cause investigations throughout the organization and continue to reduce the number of ENCs by updating equipment, revising procedures, adopting best practices and training employees on important environmental compliance practices.

GRI 103-1
GRI 103-2
GRI 103-3
GRI 307-1

ENVIRONMENTAL NON-CONFORMANCES



ENERGY

The pursuit of energy efficiency helps us support our corporate strategy of operational optimization by generating cost savings from decreased energy consumption. We are constantly looking for opportunities to introduce energy savings at our facilities including capturing waste heat for production of electricity or producing steam to offset our demands. We deploy state-of-the-art variable speed drives that have reduced our energy demand.

GRI 103-1
GRI 103-2
GRI 103-3

While our long-term energy use and recovery trend continues to decrease, we saw a slight increase in our energy consumption and intensity in 2016 compared to 2015. This is primarily due to decreases in overall yield in our carbon black facilities. However, we were able to capture and utilize more waste energy from our carbon black facilities and saw the energy intensity decrease in our Purification Solutions segment by over 5%, reflecting improved yields in that business based on a greater use of more efficient production units.

ENERGY USE

ENERGY USE (MM GJ)		ENERGY INTENSITY (GJ / MT OF PRODUCTION)
126.1	2016	62.9
123.9	2015	62.3
123.9	2014	60.5

GRI 302-1
GRI 302-3

PROGRESS TOWARD GOAL

33%

Progress based on 2016 end-of-year data.

Energy centers recover 500 megawatts of thermal energy

Throughout our global network of carbon black plants, we have made significant investments to recover energy and reduce our environmental footprint. Currently, 12 of our 18 carbon black facilities recover approximately 500 megawatts (MW) of thermal energy annually in our energy centers from waste heat generated from our processes. In 2016, we developed a performance metric to measure the gap between the actual performance and the theoretically best available recovery performance with our existing assets and available waste energy. The gap was nearly 15% of the energy we could have recovered with existing assets. In order to reduce this gap, we are executing on a series of technical actions, primarily focused on efficiency improvements. This will enable us to further reduce the amount of energy that we and our partners need to purchase to operate our plants, and therefore reduce the associated greenhouse gas (GHG) emissions.

Franklin facility partners with Cleco Corporation for new clean energy center

In October 2016, crews broke ground on the St. Mary Clean Energy Center at our carbon black facility in Franklin, Louisiana, USA. In partnership with Cleco Corporation, the new center will be able to generate enough energy to power 17,000 homes and will do so without producing any additional emissions. The waste heat captured from our plant will produce steam that will drive a 50 MW turbine generator to produce the electricity, which will offset nearly 150,000 metric tons (MT) of GHG emissions. Together with Cleco, we will help to reduce air pollution while helping to provide reliable, renewable energy generation.

Botlek reduces tank energy consumption with aerogel coating

Our carbon black manufacturing site in Botlek, the Netherlands has significantly reduced the energy consumption of one of its feedstock storage tanks by applying an insulating coating material that utilizes our ENOVA® aerogel. The site has seven feedstock tanks that are heated by steam. None of the tanks were insulated which resulted in higher energy consumption due to thermal losses. The site coated one feedstock tank with 3 mm of Tnemec's AEROLON® thermal insulating coating. In comparison with the non-insulated tanks, this project resulted in a 55% reduction of energy consumption and achieved an internal rate of return of 28%. With this project, the site predicts a savings of €10,000 on energy per year.

AIR POLLUTANTS & GREENHOUSE GAS

Given the industrial nature of our operations, greenhouse gas (GHG) emissions and air pollutants including nitrogen oxide (NO_x) and sulfur dioxide (SO_2) are closely monitored. We understand the linkage these emissions have to climate change, we are continuously looking for ways to reduce these emissions.

GRI 103-1
GRI 103-2
GRI 103-3

In 2016, we saw a slight increase in our GHG emissions by 2.3% compared to 2015 and 1.1% on an intensity basis. This result can be attributed to the product mix from our Reinforcement Materials segment, which affects yield and therefore GHG emissions. While the year-over-year results are up, we have realized 32% of our goal to reduce our GHG emissions intensity from our base year emissions.

CO_2

GHG EMISSIONS			GHG INTENSITY		
SCOPE 1 (MM MT CO_2e)		SCOPE 2 (MM MT CO_2e)	SCOPE 1 (MT CO_2e / MT OF PRODUCTION)		SCOPE 2 (MT CO_2e / MT OF PRODUCTION)
4.5	2016	0.3	2.25	2016	0.17
4.4	2015	0.3	2.21	2015	0.17
4.6	2014	0.4	2.25	2014	0.20

GRI 305-1
GRI 305-2
GRI 305-4

PROGRESS TOWARD GOAL

32%

Progress based on 2016 end-of-year data.

Similarly, our SO_2 emissions intensity increased in 2016 by 4.9%, driven largely by a change in the feedstock mix in the Reinforcement Materials segment. While we are up year-over-year, we see an overall downward trend and have realized approximately 20.2% of our goal to achieve a 40% reduction of SO_2 emissions intensity by 2025. While the year-over-year variations are driven by feedstock mix, we continue our efforts to reduce our environmental footprint.

In 2016, our NO_x emissions intensity decreased by 3.3%, with an overall emissions reduction of 2.1%. We continue to make progress reducing our NO_x emissions and have reached 23.1% of our goal to achieve a 20% reduction of NO_x emissions intensity by 2025. These reductions were achieved by realizing the impact of the first full year of the NO_x control system implementation at our carbon black facility in Shanghai, China and the completion of the first phase of the implementation of the NO_x control system at our Tianjin, China carbon black facility. In 2016, we also completed the construction of the new NO_x control system at our Pampa, Texas, USA facility[3] and expect to significantly reduce emissions from that facility.

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[3] *The facility began the full operational shake-down period in March 2017.*

SO_2

SO_2 EMISSIONS

	SO_2 EMISSIONS (KMT)	SO_2 EMISSION INTENSITY (MT / KMT)
2012 BASELINE	43.2	22.6
2015	39.2	19.8
2016	41.6	20.8

PROGRESS TOWARD GOAL

20%

Progress based on 2016 end-of-year data. Baseline and targets were restated to reflect updated information.

NO_x

NO_x EMISSIONS

	NO_x EMISSIONS (KMT)	NO_x EMISSION INTENSITY (MT / KMT)
2012 BASELINE	14.9	7.8
2015	15.3	7.7
2016	14.9	7.5

PROGRESS TOWARD GOAL

23%

Progress based on 2016 end-of-year data. Baseline and targets were restated to reflect updated information.

GRI 305-7

WASTE & SPILLS

We acknowledge the potential impact that solid waste disposal or spills of hazardous materials could have on the environment in our local communities, therefore, we take a targeted approach to minimizing waste and working toward zero spills at our facilities. We also see that waste presents opportunities to contribute to a circular economy by finding alternative uses for certain waste types.

GRI 103-1
GRI 103-2
GRI 103-3

In 2016, our total waste generation intensity increased by 1.6%, which can be attributed entirely to a one-time event involving the generation of waste soil from a construction project at our Franklin, Louisiana, USA carbon black facility. Without this event, our total waste generation intensity would have been slightly lower than 2015. Our total waste disposed offsite per unit of production was also up year-over-year to 200.3 MT/KMT$_p$, but we still remain below our 2025 goal of 286 MT/KMT$_p$ of production.

Our focus continues to be on finding alternative beneficial uses for our waste materials to eliminate or minimize our total waste disposed. In the past year, we have been successful in identifying more opportunities to beneficially reuse both hazardous and non-hazardous waste for energy recovery or as substituted materials. In 2016, we increased our rates of reuse by 9.5% in absolute terms and 8.2% based on our production intensity. This was accomplished at a number of individual facilities that have identified improved recycling and reuse opportunities.

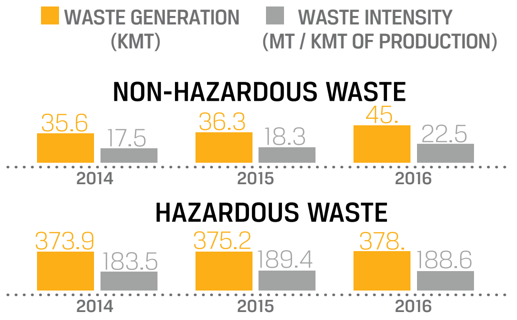
Haverhill reduces toxic chemical use

The City of Haverhill, Massachusetts, USA recently agreed to revise our inkjet facility's pH wastewater discharge limits from a range of 6.0 to 9.0 to a new range of 6.0 to 10.0. This change was actually beneficial to both Cabot and the City of Haverhill. Based on new industrial dischargers to the city's Publically Owned Treatment Works, Haverhill was looking to identify sources of high pH wastewater to offset lower pH wastewater expected from the new users. This revision to the upper pH limit enabled us to reduce the amount of sulfuric acid used to control the pH chemistry. Sulfuric acid is listed under the Massachusetts Toxic Use Reduction Act (TURA) program and requires the facility to report on its annual use and identify toxic use reduction opportunities whenever possible. The new pH range has enabled the site to reduce the volume of sulfuric acid used in 2016 by 10%, or 8,000 pounds.

GRI 306-2

TOTAL WASTE DISPOSED & INTENSITY

WASTE DISPOSED (KMT)		WASTE DISPOSED INTENSITY (MT / KMT OF PRODUCTION)
401.6	2016	200.3
391.9	2015	197.8
392.9	2014	192.9



BENEFICIAL WASTE

WASTE BENEFICIALLY USED (KMT)		WASTE BENEFICIALLY USED INTENSITY (MT / KMT OF PRODUCTION)
21.5	2016	10.7
19.6	2015	9.9
16.6	2014	8.2

PROGRESS TOWARD GOAL

100%

Progress based on 2016 end-of-year data. While this goal has been achieved, we anticipate more waste generation as part of pollution control measures so reduction efforts continue.

WATER

We are dependent on water for many of our manufacturing processes and at the same time, we deeply understand how critical this natural resource is to human life and ecosystems. We therefore strive to conserve water across our operations and ensure that wastewater is properly treated prior to discharge to avoid degradation to the surrounding environment.

GRI 103-1
GRI 103-2
GRI 103-3

In 2016, the volume of water supplied to our facilities was 51.7 million cubic meters (MM m^3), down 0.2% from 2015, which corresponds to a 1.4% reduction on an intensity basis. Our wastewater discharge totaled 39.9 MM m^3, up 7.6% from 2015 and an intensity increase of 6.3%. The most significant increase in water use was for once-through cooling at our Botlek, the Netherlands carbon black facility. We did see reductions at our specialty fluid facility in Lac Du Bonnet, Canada, as a result of a reduction in mining activities. We also have several carbon black facilities that capture and reuse wastewater, including Cartagena, Colombia; Maua, Brazil; and Xingtai, China that successfully capture and reuse 100% of their wastewater onsite. We are in the final design phase at our facility in Franklin, Louisiana, USA to implement a project for wastewater capture and reuse. We recognize the need for reducing our demand for water and will continue to track changing water supply conditions and regulatory programs.

GRI 303-3

Barry project reduces water and chemical use

Our Barry, United Kingdom fumed metal oxides facility implemented a project to upgrade the chemical treatment system within its cooling towers. The project involved the installation of a new analytical control system, providing more robust analysis of water quality and improved control of treatment chemicals. This ultimately reduced the amount of chemicals needed to maintain tower cleanliness, which both increased efficiency and reduced water consumption. The project is expected to yield both a reduction in chemical use by 20% and wastewater discharges by about 6,400 m^3 or approximately 25%.

GRI 303-1
GRI 306-1

WATER SUPPLY & INTENSITY

WATER SUPPLY (MILLION M^3)		WATER SUPPLY INTENSITY (M^3 / MT OF PRODUCTION)
51.7	2016	25.8
51.8	2015	26.1
57.3	2014	28.1

WASTEWATER DISCHARGE & INTENSITY

WASTEWATER DISCHARGE (MILLION M^3)		WASTEWATER DISCHARGE INTENSITY (M^3 / MT OF PRODUCTION)
39.9	2016	19.9
37.	2015	18.7
43.7	2014	21.4

TOTAL WATER USED & INTENSITY*

TOTAL WATER USED (MILLION M^3)		TOTAL WATER USED INTENSITY (M^3 / MT OF PRODUCTION)
11.8	2016	5.9
14.7	2015	7.4
13.6	2014	6.7

**Water used is the difference between water supplied and waste water discharged at a facility.*

PEOPLE

OCCUPATIONAL HEALTH AND SAFETY

Safe and healthy working conditions are a fundamental human right and maintaining strong occupational safety and health programs at our facilities is central to our culture. We are committed to industry leadership and excellence in safety, health and environmental (SH&E) performance which is underscored by our executive-endorsed SH&E Policy. Our goal is to be among the top 10% of our industry peers for safety performance. With this top-level management commitment and support, we strive to conduct our business in a manner that minimizes negative impacts on our employees, contractors, the public and the communities in which we operate. As such, all our employees and contractors receive safety training and all our facilities are required to have a safety program that meets all applicable health and safety laws as well as Cabot standards, which often exceed local regulations.

GRI 103-1
GRI 103-2
GRI 103-3

To reinforce the critical importance of safety, we host a company-wide Global Safety Day every year. This is an opportunity to celebrate achievements for excellent safety performance, discuss best practices and remind ourselves of our "Drive to Zero" program. This program challenges us to believe that all incidents are preventable, whether it is a personal safety, process safety or an environmental incident.

While we saw a decrease in the number of total injuries from 2015 to 2016, there was unfortunately an increase in the total number of lost work days due to severe incidents. We conduct a thorough evaluation of every incident, including "high potential near misses," to understand the root cause of such incidents and assess how we may implement measures to avoid similar safety risks in the future across our global operations. Throughout the years, these incident learnings and our strong safety culture have kept us an industry leader in safety performance and we will always focus on continuous improvement to achieve our goal of zero incidents.

GRI 102-12

Additionally, we remain an active member of the American Chemistry Council's Responsible Care® program. Three years after achieving initial certification in December 2013, all of our North American sites have been recertified according to the program's RC 14001 SH&E Management System requirements. This achievement reinforces our long-standing commitment to SH&E and our ability to maintain, improve and adapt related programs over time to suit the changing needs of the organization. In addition, recertification of the management system validates the successful implementation of our SH&E program not only for our North American facilities but also at the corporate level.

TOTAL RECORDABLE INCIDENT & LOST TIME RATE

TOTAL RECORDABLE INCIDENT RATE*		LOST TIME RATE
0.46	2016	0.27
0.51	2015	0.25
0.44	2014	0.28

*Total recordable incident and lost time rate are the number of incidents per 100 employees.

PROCESS SAFETY EVENTS

TIER	2016	2015	2014
1	0	2	1
2	2	2	1

The CCPS defines a process safety event as a release of material or energy from a process that resulted in injury, fire, explosion or release of flammable, combustible or toxic chemicals. Tier 1 events are the most severe process safety events.

PROCESS SAFETY MEASURES

Process safety is an intrinsic part of our SH&E policy. By designing and operating our facilities consistent with the fundamentals of a sound process safety management program, we keep our employees, our contractors and our communities safe and ensure we are a reliable supplier to our customers. Our program involves ongoing reviews of our existing facilities through process hazard analyses, management of change and prestart-up safety reviews. For significant facility changes, we conduct operations preparedness reviews using a team of subject matter experts to ensure the change has been fully evaluated and is ready to be placed into safe operation. Through these efforts, we continue to see improvement in our performance as measured by the reduction in our internal measure of significant process safety events, but also in the direct and indirect cost of these events. These events are also categorized using the criteria specified by the Center for Chemical Process Safety (CCPS). In 2016 we had no Tier 1 process safety events and remained flat year-over-year at two Tier 2 events. To ensure our global organization learns from these and other process safety events, our facilities initiate thorough root cause investigations, the outcomes of which are reviewed by the facility with Cabot senior management. These learnings are then broadly distributed to mitigate similar events globally.

GRI 403-2

Tianjin plant wins "Outstanding Pioneer in Safety Production"

In March, the Tianjin Economic-Technological Development Area (TEDA) held its 2016 Annual Meeting on safety production. The TEDA management committee recognized five "Elite Pioneers" selected from over 14,000 companies. Qiao Yanzhong, facility general manager of our Tianjin, China plant, was awarded this esteemed recognition on behalf of the facility. The TEDA management committee recommended that other TEDA-based companies learn skills such as excellent safety leadership, advanced experience and scientific and strict management from Cabot and the other four companies.

Managing safety performance training

We continue to invest in our employees through training in a variety of topics including safety. We recently conducted several two-day workshops to teach practical safety leadership skills to frontline supervisors, managers and other individuals. The sessions taught both "what to do" and "how to do it," while providing tools to best manage safety performance and increase employee engagement. Participants learned and were able to practice tangible tools that they can use every day to manage through words and actions, including management by walking around, leading by example, reinforcing positive behaviors, creating stump speeches and more. This training program was initiated in North America in 2016 with the participation of more than half of the frontline leaders and it will be expanded to our global facility leaders in the next two years.

Improving accessibility to personal protective equipment

Maintaining an adequate inventory of the required personal protective equipment (PPE) in various sizes, and having it readily available, is an important element of an effective injury prevention program. The easier it is for employees to obtain the necessary PPE, the more likely they will be to perform their tasks safely. Several of our facilities in Europe have taken steps to improve employee accessibility to various types of PPE by installing dedicated vending machines that distribute these supplies. Through this solution, PPE is available at any time of the day and night by swiping an employee badge or by entering a personal access code. In addition to safety-related benefits, the vending machines provide direct and controlled availability of proper PPE and industrial consumables at the point where they are needed, delivering savings on consumption and improvements in productivity.

EMPLOYEE RETENTION, DIVERSITY & DEVELOPMENT

GRI 103-1
GRI 103-2
GRI 103-3
GRI 401-2
GRI 404-2
GRI 405-1

Our employees are the most valuable asset we have for improving social, economic and environmental performance. One of the core principles of our corporate strategy is "talent matters." Our culture is one that emphasizes the full potential of our people, who are fundamental to our continued success. When it comes to hiring new employees, decisions are based on merit and qualifications, regardless of race, color, national origin, religion, gender, sexual orientation, age, disability, veteran status, or any other legally protected status. Moreover, we embrace diversity and equal opportunity as a means to access a broader talent pool and foster innovation.

We understand the importance both for employees and the Company to continuously develop professional skills across the workforce. Our Talent Management Framework guides us in supporting employees to improve their performance. Through the utilization of a Performance Based Management approach, performance reviews are held twice a year for all employees. These reviews include an evaluation of how an employee contributes to the business's regional or corporate objectives through individual goals. This process allows managers to support employees in achieving expectations and identify opportunities for continued professional development. By providing resources to develop employees' knowledge and skills, we offer our people opportunities for advancement, enhance value for our customers and retain talent to further our leadership position.

We are also committed to ensuring all employees have their basic needs met to live a healthy and productive life. Our comprehensive benefits programs are designed to supplement social benefits provided by the countries in which we operate. While our benefits vary by location, typically we offer healthcare, life and accidental insurances, disability, retirement and pension plans, business travel accident insurance, medical travel insurance, vacation, holiday and leave entitlement, educational financial assistance and access to retiree medical coverage.

Fumed silica manufacturing in Tuscola, Illinois, USA.

WORKFORCE BY REGION

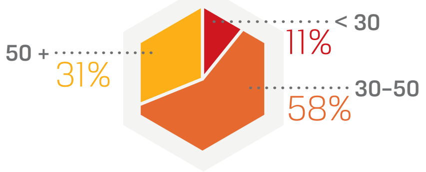
	AMERICAS	EMEA	ASIA PACIFIC
	46%	31%	23%
TOTAL	1,999	1,321	985
PERMANENT	1,988	1,312	985
TEMPORARY	11	9	–

WORKFORCE BY CONTRACT, EMPLOYMENT TYPE, AGE GROUP AND GENDER

TOTAL WORKFORCE 4,305

	PERMANENT	TEMPORARY	FULL-TIME	PART-TIME
	4,285	20	4,212	93
MALE	3,329	17	3,327	19
FEMALE	956	3	885	74

WORKFORCE BY AGE GROUP



Enhancing employee engagement

GRI 102-8

Employee engagement is the extent to which employees feel passionate, energetic and committed to their work. This state is only reached when employees can experience a sense of meaning, autonomy, growth, impact and connection in what they do. Understanding how critically important employee engagement is to developing and maintaining a sustainable workforce, we introduced a project to measure and understand the engagement of our employees. This began with a pilot study in 2016 through which we deployed an employee engagement survey across our Boston and Billerica, Massachusetts, USA sites. Results from the survey were shared with employees, and focus groups were held to gain a deeper understanding of the feedback. As a result, action plans were developed and implemented, focusing on improving communication and creating better employee development, including greater visibility to internal job openings and education on career paths and career conversations. This exercise proved to be a valuable first step to our broader outreach involving a global engagement survey scheduled to launch in 2017.

RATE OF TURNOVER AND NEW HIRES BY CATEGORY*

GRI 401-1

		TURNOVER	NEW HIRES
GENDER	MALE	11.5%	8.7%
	FEMALE	12.1%	12.8%
AGE GROUP	<30	17.1%	32.2%
	30-50	9.2%	9.2%
	50+	14.2%	2.4%
REGION	AMERICAS	10.7%	10.6%
	EMEA	13.7%	9.8%
	APAC	11.0%	7.4%

*Rates calculated based on year-end census for each category.

Transitioning mid-level managers to leadership roles

GRI 404-2

In 2016, we initiated a pilot training program with 50 mid-level professionals representing diverse functions from all of our regions to develop the necessary skills they would need to transition from being managers to assuming a leadership role. Our "Breakthrough Leadership" program draws from Harvard Business Publishing Corporate Leaders resources which guides participants through self-paced learning, study group activities, on-the-job assignments, virtual classroom sessions led by Cabot leaders and a learning action project over nine months. During this time, participants gained and practiced leadership skills, completed an action learning project with a direct impact on the company, and strengthened their internal network by working with other leaders throughout the organization. We look forward to gathering feedback and lessons learned from the pilot group to optimize and expand the program.

PEOPLE PROFILES

The approach we take to giving back to the communities in which we operate is echoed by the good work done by many of our colleagues across the globe. Our employees continue to find meaningful activities in their personal lives that make a difference.

Boston
MA, USA

Gerry Caron

Chief Counsel, Safety, Health & Environment

Gerry is actively involved with the Boston Bulldogs Running Club, a non-profit that provides a community of support for anyone adversely affected by addiction, including those in recovery as well as their families, friends and communities. The club promotes an integrated approach to wellness and self-leadership in recovery. Gerry and his family have been involved with Boston Bulldogs for two years and support for the group's mission is as critical as ever in light of the magnitude of the current opioid epidemic in the United States.

Campana
Argentina

María Luz Mayor

Senior Accounting Analyst

Maria donates her time as a volunteer at "We are Diversity," an annual day that recognizes and celebrates the value of diversity as part of the International Day of People with Disabilities. The event features a variety of workshops and activities related to art, sports, recreation and environmental care. Maria also makes regular donations to the Austral University Hospital, an important resource for several local communities. The hospital provides outstanding research and training to its doctors, and its pediatricians donate their time to members of the communities.

Altamira
Mexico

Fernando Rosas

Specialist, Maintenance Administration

Fernando regularly volunteers his time collecting clothing and medicine for local families in need. He and his wife also offer babysitting services so that the parents can work. They gather and recycle bottles and aluminum cans and use the collected money to help families afford critical medical treatments and prescriptions. In addition, they foster abandoned dogs, providing them with food, medicine and basic care while they search for a family to adopt them.

Tuscola
IL, USA

George Hostetter

Maintenance Mechanic

In June 2016, George and his wife led the Smyser Christian Church Youth Group on a mission trip in Belize. The team was comprised of 28 members from their local church, including 21 high school students. As part of the mission, the group built a concrete roof on a three-story building, lifting more than 12 tons of sand and gravel using five gallon buckets on a rope and pulley. Our site in Tuscola, Illinois, USA provided the gloves and safety glasses that the group used during their mission.

São Paulo
Brazil

Henrique Santos

IT Infrastructure Coordinator

Henrique is a volunteer at his church's "60 Club," a group whose goal is to promote social, physical and leisure activities among older members of the church and community in order to improve their quality of life. The group participates in activities including sightseeing, visits from special guests and informational lectures on relevant topics. Henrique is also a member of the Adventist Solidarity Action, an organization that assists people in need through various activities including collecting food and clothing, providing medical services, visiting orphanages and nursing homes and renovating housing.

Zaandam
The Netherlands

Harry Kramer

Senior Engineer

Harry has volunteered his time aboard the Dutch passenger ship De Zonnebloem for the past 12 years. The ship, which is specially equipped for the elderly and those who are seriously ill or disabled, provides week-long holidays up to 40 times per year. As one of 60 volunteers on board, Harry is responsible for the personal care of the guests, ensuring their safety both on board and during excursions into city shops and restaurants. He also helps lead activities such as dance and bingo to provide fun entertainment and raise guests' spirits.

Cartagena
Colombia

Reyner Babilonia

Dispatch, Shipment and Foreign Trade Coordinator

Since 2015, Reyner has donated his time to the non-profit organization Funvivir whose mission is to support children from low income families as they are battling cancer. Reyner participates in the "Love Plastic Caps Campaign," gathering plastic caps wherever he can find them and delivering them every two months to Funvivir, which then recycles them and uses the funds to further the organization's mission.

Billerica
MA, USA

Jon Siddall

Process Development Fellow

Jon enjoys working with local high schools and universities whenever he has the chance. In 2016, Jon mentored a local student who prepared a project submission for his local high school Science and Engineering Fair and contacted Cabot for help. Jon helped with subject matter knowledge, secured special materials from a supplier and worked with the student as he developed a series of prototype formulations for the project. The student went on to win first place in his local fair and participated in the Massachusetts State Science and Engineering Fair.

Riga
Latvia

Zane Andersone

Senior Internal Auditor

Animals have been a passion of Zane's since childhood and she regularly volunteers her time at local animal shelters. She visits often to deliver food, blankets and other needed items, and she spends time walking dogs and assisting the shelter staff. She adopted her first cat more than five years ago, and since then has remained committed to supporting shelters as they continue their mission of rescuing abandoned animals and caring for them until adoption.

Ville Platte
LA, USA

Rhonda Deshotels

Capital Coordinator

Rhonda has been volunteering for several years for a variety of charitable community programs. She collects can tabs for the Ronald McDonald House and the money raised by recycling them helps offset the organization's operating costs. She also leads a Toy Drive at our Ville Platte plant during the holiday season to benefit children being treated at St. Jude's Hospital in Memphis, Tennessee, USA. She is a committee member of The Gumbo Foundation and through its annual cook-off raises money to defray medical and traveling expenses for a sick child in need. Additionally, Rhonda coordinated a successful clothing drive for a local men's homeless shelter and created a library in a rural community.

Sarnia
Canada

Steve Metcalfe

Process Operator

Steve recently participated in a house building mission in El Salvador with Shelter Canada, an organization that seeks to provide safe, solid and secure homes for families in need due to extreme poverty. On this trip, Steve and other volunteers worked closely alongside local families, which contributed to a sense of friendship, community and mutual respect amongst everyone involved. Together they tore down old homes, cleared space for the new buildings and constructed brand new houses to help improve the quality of life for these local families.

COMMUNITIES

We understand the value of partnering with the communities in which we operate, and recognize that thriving and resilient communities are essential for a sustainable future. Community engagement not only benefits our neighbors, but supports our mission to be a responsible industry leader and good corporate citizen. With the generosity of our dedicated employees who offer their time and skills, we are able to go beyond charitable giving and actively support our neighbors.

COMMUNITY ENGAGEMENT

Our philanthropic activities take the forms of volunteerism, monetary gifts from our local facilities and grants distributed from our charitable giving arm, the Cabot Corporation Foundation, Inc. About two-thirds of our facilities have identified local organizations and projects to receive charitable contributions. These teams carefully consider the needs of the people and environment around them, and in 2016, these local facilities made a total of approximately $500,000 in-kind donations. With oversight from the Cabot Foundation Board of Directors, an additional total of approximately $1.1 million was pledged or donated to organizations. Preference is given to activities and organizations focused on science and technology education, community relations and civic improvements that positively impact our communities. The Foundation Board regularly evaluates the impact of this giving to ensure funds are used in ways that align with the Company's overall values and addresses the needs of our communities.

GRI 103-1
GRI 103-2
GRI 103-3
GRI 413-1

HIGHLIGHTS FOUNDATION-SUPPORTED ACTIONS

Aiding disadvantaged youth in Riga

Our EMEA Business Service Center team in Riga, Latvia provided a generous donation to support the educational needs of children at the SOS Youth House. This organization provides long-term family-based care for youth coming from disadvantaged families that need to learn how to live productively and independently. Throughout the year, our employees worked closely with the organization through the donation of clothes, books and food items while also engaging in social activities such as bowling, table games and a barbeque party.

Supporting children's rehabilitation in Shanghai

For almost ten years, our team in Shanghai, China and the Cabot Foundation have supported the Boai Children's Rehabilitation Center, which provides treatment and rehabilitation for children with disabilities. In addition, the team in Shanghai has remained involved at the center over the years. In 2016, over 40 employee volunteers accompanied a group of children from the center to the Shanghai Zoo. This recreational outing provided the children with the ability to leave the center to experience nature and various animals, while also exercising their social skills so that they can better reach their goal of going home.

Supporting children with congenital heart disease

In January, a team of volunteers from our Tianjin, China facility visited children with congenital heart disease being treated at the TEDA Cardiovascular Hospital. The team gave a donation to the hospital on behalf of the Foundation and delivered gifts and well-wishes for the New Year. To date, we have helped 20 children from underprivileged families through these donations.

HIGHLIGHTS FACILITIES IN ACTION

Engaging young girls in science, technology, engineering and mathematics (STEM)

In May 2016, a group of seven engineers from our inkjet manufacturing facility in Haverhill, Massachusetts, USA volunteered for Expanding Your Horizons, a nonprofit organization dedicated to providing middle and high school girls with STEM experiences to foster interest in future STEM careers. The team sponsored a workshop titled "Ink It Up" that taught the girls about the different types of ink, including the chemistry of inkjet ink and a demonstration on the science of surface tension that involved dropping water and isopropanol on coins. They also created a greeting card using inks that they mixed themselves.

Combining charity and sport

Our team of 14 employees in Valmez, Czech Republic continued its charity cycling tradition by raising funds for the Together by Bike for Charity initiative. From April through October, in groups of two or more, the participants conquered 20 mountain peaks. They took photos after reaching each peak and the company made a donation for every picture taken. A larger donation was made for those cyclers who conquered all 20 peaks. The money raised will provide assistance services and respite weekend stays for four disabled children.

Delivering earthquake relief in Japan

In April 2016, several earthquakes hit Kumamoto, Japan. The earthquakes and subsequent aftershocks caused deaths, injuries and widespread damage to the area's residences and infrastructure. Our team in Japan donated time and funds to the prefecture of Kumamoto. In addition to funds, the team spent time visiting different establishments in the city to further support this popular tourist destination as the city recovered.

Supporting children's health in Cartagena

Our team in Cartagena, Colombia supports the charitable organization Fundación Mamonal and its Fondo Unido program, which encourages employees and companies to carry out social projects for the benefit of community members in need. We donate a monthly contribution that provides lunch for 75 girls and boys from Nuestra Señora del Buen Aire. This educational institution evaluates the health and nutritional conditions of vulnerable children and provides workshops on healthy eating and hygiene habits to help prevent disease.

AWARDS AND RECOGNITION

As a leader in the industry, we are always striving to act as a responsible corporate citizen. We are proud of our accomplishments and honored to be recognized by organizations, publications and customers from all around the world. Below is a selection of awards we received in 2016.

Shanghai plant receives Clean and Green Advanced Technology Honor

In August, the Shanghai Resource Comprehensive Utilization Association and Shanghai Economic and Information Technology Commission conducted a survey of chemical enterprises in Shanghai, China that "adhere to green development, promote green manufacturing and develop green industry." Our Shanghai plant was selected from 29 other companies to be honored for its advanced clean technology and equipment for carbon black production and flue gas treatment. The energy-saving combustion technology has helped our Shanghai plant successfully achieve higher production efficiency. Furthermore, we have also set up an energy center which allows for the desulfurization and denitrification of tail gas and the steam produced is delivered to neighboring enterprises for resource utilization, offsetting the use of fossil fuels at those facilities.

Cabot Colombiana named "Leading Company"

In May, Cabot Colombiana was recognized as a "Leading Company" among 42 companies during the annual meeting of the Colombia Chapter of Integral Responsibility. This recognition is the result of our contributions to sustainable development through excellent performance in the protection of our people, the community, the environment, process and product safety and security in our logistics chain.

AWARDS AND RECOGNITION HIGHLIGHTS 2016

- **Gold Level Recognition** — Cabot Corporation, given by EcoVadis
- **Outstanding Pioneer in Safety Production** — Tianjin, China, given by the Tianjin Economic-Technological Development Area (TEDA)
- **Best Carbon Black Supplier** — São Paulo, Brazil, given by *Paint & Pintura*
- **Top Supplier** — Cabot Corporation, given by Kraiburg
- **Core Strategic Supplier** — Cabot Corporation, given by Linglong Tire
- **Annual Green Operation Award** — Shanghai, China, given by the 2016 Corporate Social Responsibility and Innovation Shanghai Summit
- **Clean and Green Advanced Technology Award** — Shanghai, China, given by the Shanghai Resource Comprehensive Utilization Association and Shanghai Economic and Information Technology Commission
- **12 FYP Model Enterprise in Environment Protection** — Shanghai, China, given by the China Petroleum and Chemical Industry
- **Outstanding Enterprises for Tax Contributions** — Xingtai, China, given by the Party Committee of Xingtai County and the government of Xingtai County
- **Top Ten Credible Production Enterprises** — Cabot Corporation, awarded at the 2016 Ninth China Coal Market Seminar
- **Harmonious Labor Relation Enterprise Award** — Tianjin, China, given by the Tianjin Economic-Technological Development Area (TEDA)
- **Advanced Enterprise of Safety Production Management** — Jiangxi, China, given by the People's Government of Jiujiang City
- **Advanced Technical Enterprise with Foreign Investment in Shanghai** — Shanghai, China, given by the Shanghai Municipal Commission of Commerce
- **Advanced Enterprise for Donating to Schools** — Xingtai, China, given by the Xingtai County Party Committee and Xingtai County Government
- **Best Enterprises with Social Responsibility in Shanghai Minhang District** — Shanghai, China, given by the government of the Shanghai Minhang District
- **Gold Seal** — Cabot Brasil Industria e Comercio Ltda., given by the Mutual Assistance Plan (PAM) Capuava

GRI CONTENT INDEX

GRI Materiality Disclosures
Cabot Corporation
Jun 2017 Service

GENERAL DISCLOSURES

GRI 102: General Disclosures 2016

Disclosure Number / Disclosure Title	Page / Response
102-1 Name of the organization	Cabot Corporation
102-2 Activities, brands, products, and/or services	pp. 12, 13
102-3 Location of headquarters	2 Seaport Lane, Suite 1300 Boston MA 02210 USA
102-4 Location of operations	p. 13
102-5 Ownership and legal form	Cabot Corporation is a publicly traded corporation (NYSE: CBT)
102-6 Markets served	p. 12
102-7 Scale of the organization	Refer to p. 12 for the number of employees and operations. Net revenue is listed p. 15. Total capitalization can be found in Cabot's Form 10-K filed November 23, 2016 (cabotcorp.com/2016annualreport). Part II Item 8. Financial Statements and Supplementary Data.
102-8 Information on employees and other workers	p. 32 Non-employee workers do not perform a significant portion of our activities. Only 0.5% of our workforce are on temporary contracts and we employ a small number of interns and apprentices as part of our talent acquisition process.
102-9 Supply chain	P. 6 Cabot's supply chain predominantly consists of vendors providing raw materials, chemical additives, process equipment, vehicles, packaging materials, logistics services and temporary contractors.
102-10 Significant changes to the organization and its supply chain	p. 12
102-11 Precautionary Principle or approach	Throughout our operations and our product development, we are guided by the precautionary principle and carefully take into account effects on the environment and health and safety.
102-12 External initiatives	pp. 5, 8, 28 In addition to the UNGC, Cabot participates in the Carbon Disclosure Project, and we are implementing the American Chemistry Council's (ACC) Responsible Care® program as part of our commitment to safety, health and environment (SH&E).

GRI 102: General Disclosures 2016 continued

Disclosure Number / Disclosure Title	Page / Response
102-13 Memberships of associations	Cabot is an active member of the following national and international industry/advocacy groups and associations: ◆ American Chemistry Council (ACC) ◆ Association of Synthetic Amorphous Silica Producers (ASASP) ◆ China Petroleum & Chemical Industry Federation (CPCIF) ◆ Corporate Environmental Enforcement Council (CEEC) ◆ Environmental Law Institute ◆ essenscia (Belgium) ◆ European Masterbatchers and Compounders (EuMBC) ◆ European Plastics Converters – Food Contact Regulatory Experts Panel (EuPC FREP) ◆ International Carbon Black Association (ICBA) ◆ Manufacturers Alliance for Productivity & Innovation (MAPI) ◆ Society of Toxicology ◆ Synthetic Amorphous Silica and Silicate Industry Association (SASSI) ◆ United Nations Global Compact (UNGC)
102-14 Statement from senior decision-maker	p. 4
102-16 Values, principles, standards, and norms of behavior	p. 14
102-18 Governance structure	The Board of Directors has five standing committees: Audit, Compensation, Executive, Governance and Nominating, and Safety, Health and Environmental Affairs. For additional details on the Board's composition, refer to (cabotcorp.com/2016proxystatement).
102-40 List of stakeholder groups	p. 9
102-41 Collective bargaining agreements	Across all Cabot operations, 16% of employees are covered by collective bargaining agreements. The terms of collective bargaining agreements are fully aligned with Cabot's Code of Business Ethics (cabotcorp.com/codeofbusinessethics) and Human Rights Policy (cabotcorp.com/humanrightspolicy).
102-42 Identifying and selecting stakeholders	p. 9
102-43 Approach to stakeholder engagement	p. 9
102-44 Key topics and concerns raised	p. 9
102-45 Entities included in the consolidated financial statements	Refer to Cabot's Annual Report Form 10-K filed November 23, 2016 (cabotcorp.com/2016annualreport) Part I Item 1. Business for a description of our operations and entities in which Cabot has ownership interest and exhibit 21 of Cabot's Form 10-k for a list of Cabot's subsidiaries.
102-46 Defining report content and topic boundaries	pp. 5, 6
102-47 List of material topics	p. 7

GRI 102: General Disclosures 2016 continued

Disclosure Number / Disclosure Title	Page / Response
102-48 Restatements of information	p. 20 This report reflects restated values for some of our historical environmental data. We regularly examine our site-specific data and engineering estimates to ensure we have the most accurate data possible for monitoring and reporting our performance. In conducting a review of the baseline (2012) and 2015 calculated emission estimates of sulfur dioxide and nitric oxides, we determined that the original reported data did not include emissions associated with all sources at selected facilities, most notably flare emissions. After reviewing facility mass balance equations, we are able to better quantify the total emissions, which are reflected in the numbers presented in this report. All of our current emission estimates were then compared to mass balance data to ensure the revised emissions estimates were reflective of actual emission data for all of our facilities. Water supply and wastewater data were also reviewed and updated to reflect more accurate assignment of cooling water supplied to our neighbor from our system for 2015. The remainder of the changes are not considered material. Details of the changes are shown in the table below:

Metric	Previously Reported		Updated Value		% Change	
	Absolute	Intensity	Absolute	Intensity	Absolute	Intensity
Energy (MM GJ) – 2015	124.2	–	123.9	–	-0.2%	–
GHG Intensity (MT CO_2e/MT) Scope 1 – 2015	–	2.20	–	2.21	–	0.5%
GHG Intensity (MT CO_2e/MT) Scope 2 – 2014	–	0.19	–	0.20	–	2.3%
SO_2 (KMT) | Intensity (MT/KMT) Baseline – 2012	30.2	17.0	43.2	22.6	43.1%	32.9%
2015	28.9	14.5	39.2	19.8	35.6%	36.6%
NO_x (KMT) | Intensity (MT/KMT) Baseline – 2012	8.8	5.0	14.9	7.82	69.3%	56.4%
2015	8.9	4.5	15.3	7.70	71.9%	71.1%
Non-Hazardous Waste (KMT) | Intensity (MT/KMT) - 2014	–	17.3	–	17.5	–	1.2%
2015	34.8	17.5	36.3	18.3	4.3%	4.6%
Hazardous Waste (KMT) | Intensity (MT/KMT) - 2014	374.5	182.0	373.9	183.5	-0.2%	0.8%
2015	374.8	188.0	375.2	189.4	0.1%	0.7%
Water Supply (MM m^3) / Intensity (m^3 / MT) - 2014	–	27.9	–	28.1	–	0.7%
2015	56.8	28.5	51.8	26.1	-9.7%	-8.4%
Water Supply (MM m^3) / Intensity (m^3 / MT) - 2014	–	21.2	–	21.4	–	0.9%
2015	42.4	21.3	37.0	18.7	-12.7%	-12.2%

There were no restatements of financial or other information.

Disclosure Number / Disclosure Title	Page / Response
102-49 Changes in reporting	p. 6
102-50 Reporting period	p. 5
102-51 Date of most recent report	p. 5

GRI 102: General Disclosures 2016 continued

Disclosure Number / Disclosure Title	Page / Response
102-52 Reporting cycle	p. 5
102-53 Contact point for questions regarding the report	Inquiries or comments concerning the content of this report may be directed to sustainability@cabotcorp.com.
102-54 Claims of reporting in accordance with the GRI Standards	p. 5
102-55 GRI Content Index	This complete GRI Content Index meets the intent and format required by the GRI Standards.
102-56 External assurance	p. 5

MATERIAL TOPICS — ECONOMIC

◆ECONOMIC PERFORMANCE

GRI 103: Management Approach 2016

Disclosure Number / Disclosure Title	Page / Response
103-1 Explanation of the material topic and its boundaries	Refer to p. 15 for a description of the materiality and boundaries of economic performance. The Board of Directors has the primary objective of protecting long-term interests of shareholders by seeking opportunities for growth in Cabot's core business. With support from the Management Executive Committee, the Board oversees financial performance and strategy, capital structure and market exposure, as well as the Company's overall risk profile. Our approach is guided by Cabot's Code of Business Ethics (cabotcorp.com/codeofbusinessethics). Cabot's financial performance is evaluated closely by our investors and the broader investment community. Cabot's annual statements are audited annually by an independent registered public accounting firm. Grievance mechanisms include the Cabot open door policy for employees to raise concerns and report violations of corporate policies or the law. Employees may approach supervisors, the Office of Compliance, or use the Cabot hot-line. Stockholders or other interested parties may contact the Board of Directors with accounting or other concerns (cabotcorp.com/company/about-cabot/governance).
103-2 The management approach and its components	
103-3 Evaluation of the management approach	

GRI 201: Economic Performance 2016

Disclosure Number / Disclosure Title	Page / Response
201-1 Direct economic value generated and distributed	p. 15 For additional information, refer to Cabot's 2016 Annual Report on Form 10-k (cabotcorp.com/2016annualreport).
201-2 Financial implications and other risks and opportunities for the organization's activities due to climate change	p. 15 For additional information, refer to Cabot's 2016 Carbon Disclosure Project filing (cdp.net).
201-4 Financial assistance received from government	Cabot does not receive financial support from governments.

MATERIAL TOPICS — ENVIRONMENT

GRI 103: Management Approach 2016

Disclosure Number / Disclosure Title	Page / Response
103-1 Explanation of the material topic and its boundaries	Cabot's approach to environmental topics focuses on operations under our direct control. See pp. 20, 21, 22, 24, 25, 26, and 27 for an overview of materiality, our management approach, and evaluation process for environmental topics. This management approach applies to the following topics: energy, water, effluents and waste, emissions, and environmental compliance. The SH&E Committee of Cabot's Board of Directors oversees environmental issues at the highest governance level. The Senior Vice President for SH&E is responsible for the technical guidance on all matters related to SH&E performance and oversees a global team of SH&E professionals including regional SH&E directors. Cabot's SH&E Policy lays out guidelines for environmentally-responsible practices, and company-wide performance goals have been established for environmental non-conformances, energy, air emissions and GHG, and waste. Grievance mechanisms include the Cabot open door policy for employees to raise concerns and report violations of corporate policies or the law. Employees may approach supervisors, the Office of Compliance, or use the Cabot hot-line. Our manufacturing facilities have opportunities to engage the local community, including the use of a Community Advisory Panel (CAP), and "Open Days" where community members may visit sites and speak directly with Cabot employees regarding their concern. In addition, Cabot welcomes feedback from suppliers and customers should they have any concerns or questions about our products and practices.
103-2 The management approach and its components	
103-3 Evaluation of the management approach	

◆ ENERGY

GRI 302: Energy 2016

Disclosure Number / Disclosure Title	Page / Response
302-1 Energy consumption within the organization	p. 22 Energy use is managed at several levels throughout the organization, including corporate-level strategy, analysis, goal-setting, capital programs designed to build and invest in energy efficient facilities, waste energy capture and plant-level management practices to optimize operations and implement efficiency measures as new technologies become available. Data is collected through energy use monitoring and analyzed using standard factors and methods including U.S. Environmental Protection Agency, Chemical Engineering Handbook, and Cabot-specific engineering calculations. Our total energy consumption in 2016 was 126.1 MM GJ which was sourced from natural gas (3.6%), liquid fuels (0.05%), raw materials (94.4%), purchased electricity (1.9%) and steam (0.09%). For more information about our fuel sources refer to our 2016 CDP disclosure (cdp.net).
302-3 Energy Intensity	p. 22 Our total energy intensity for 2016 was 62.9 GJ / MT of production. Energy consumption includes all forms of energy consumed by facilities under Cabot's operational control, as reported under Disclosure 302-1.

◆ WATER

GRI 303: Water 2016

Disclosure Number / Disclosure Title	Page / Response
303-1 Water withdrawal by source	p. 27 Sources of water included purchased municipal water, surface water, ground water, and gray water. Gray water is a new metric included in our data collection as of 2016 and represents water recovered from offsite sanitary systems. **Sources by Percent of Total Volume Used** Surface 72% Purchased 23% Ground 4% Gray 1%
303-3 Water recycled and reused	p. 27 Three of our facilities have zero wastewater discharge, reusing wastewater which would otherwise be discharged in the process. The supplied water to these facilities is among the lowest in our carbon black manufacturing operations.

GRI 306: Effluents and Waste 2016

Disclosure Number / Disclosure Title	Page / Response
306-1 Water discharge by quality and destination	p. 27 The majority (94%) of the water discharged is to surface discharge, the remaining volume is discharged to public or private sewers (5%) or groundwater/other (2%). For all water discharged from our facilities, we carefully monitor the quality and if needed, treat outgoing water to meet local regulatory standards.

◆ AIR POLLUTANTS / GHG

GRI 305: Emissions 2016

Disclosure Number / Disclosure Title	Page / Response
305-1 Direct (Scope 1) GHG Emissions	p. 24 Our greenhouse gas calculations were completed in accordance with The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standards (Revised Edition), and drawing guidance from the IPCC Guidelines for National Greenhouse Gas Inventories - 2006, and The Climate Registry: General Reporting Protocol. Emissions were calculated using the operational control approach and IPCC Second Assessment Report 100-year global warming potentials, and included emissions of CO_2, CH_4, N_2O. We maintain databases that track monthly usage volumes of feedstock materials, and fossil fuels, as well as production volume. Our 2015 and 2016 GHG emissions were verified in alignment with the principles of ISO-14064-3:2006(E) Specifications with Guidance for the Validation and Verification of Greenhouse Gas Assertions under a Limited Level of Assurance by Cameron-Cole.
305-2 Indirect (Scope 2) GHG Emissions	p. 24 See Disclosure 305-1 in the GRI Content Index for a description of GHG monitoring methods.
305-4 GHG emissions intensity	p. 24 GHG intensity is calculated as MT CO_2e emissions / MT of product. The intensity of our GHG emissions is calculated for all Scope 1 and 2 emissions produced by facilities under Cabot's operational control, as reported under Disclosure 305-1 and 305-2.
305-7 Nitrogen oxides (NO_x), sulfur oxides (SO_x)	p. 25 Data reported has been calculated using actual test measurements based on country specific or U.S. EPA methods, Cabot engineering estimates, U.S. EPA or similar emission factors.

WASTE & SPILLS

GRI 306: Effluents and Waste 2016

Disclosure Number / Disclosure Title	Page / Response
306-2 Waste by type and disposal method	p. 26 Disposal methods for waste generated by Cabot in 2016 include 88% disposed of through deep well injection at one location, 5% reused or recycled for use or energy, 6% landfilled, 0.3% incinerated without energy recovery, 0.3% other disposal methods.
306-3 Total number and volume of significant spills	In calendar year 2016, there were two reportable spills of hazardous materials to the environment at our Franklin, Louisiana, USA facility. One spill involved a release of 1,512 gallons of carbon black feedstock which was contained on-site and cleaned up. The second spill involved the release of 178.5 pounds of hydrogen sulfide and 97.6 pounds of carbon disulfide from raw carbon black tailgas vented to the atmosphere.

ENVIRONMENTAL COMPLIANCE

GRI 307: Environmental Compliance 2016

Disclosure Number / Disclosure Title	Page / Response
307-1 Non-compliance with environmental laws and regulations	p. 22 Adhering to local environmental laws and regulations is the responsibility of facility general managers as well as site environmental managers located at each facility. In support of compliance efforts, resources include a robust database to track near-miss and ENC events and corrective actions, as well as over $30MM in capital spending in FY 2016 which was dedicated to improving facilities and reducing ENCs.

SUPPLIERS' SUSTAINABILITY

GRI 103: Management Approach 2016

Disclosure Number / Disclosure Title	Page / Response
103-1 Explanation of the material topic and its boundaries	p. 6 Cabot indirectly contributes to upstream impacts through our relationships with suppliers. The sustainability performance of our suppliers is a topic recently identified as material and therefore an area we will be looking to evolve over the coming years. Cabot's Supplier Code of Conduct provides additional details on supplier expectations (cabotcorp.com/suppliercodeofconduct). Cabot's Global Purchasing Department is responsible for ensuring that suppliers receive and agree by the terms of the Supplier Code of Conduct.
103-2 The management approach and its components	
103-3 Evaluation of the management approach	Grievance mechanisms include the Cabot open door policy for employees to raise concerns and report violations of corporate policies or the law. Employees may approach supervisors, the Office of Compliance, or use the Cabot hot-line. In terms of supplier-specific grievances, employees are also encouraged to provide feedback on supplier performance criteria through a dedicated platform on the Company intranet. We also have an open door policy for suppliers and welcome their feedback should they have any concerns or questions.

GRI 308: Supplier Environmental Assessment 2016

Disclosure Number / Disclosure Title	Page / Response	Omission
308-1 New suppliers that were screened using environmental criteria	p. 6 Because this topic was first identified as highly material in 2016, systems have not yet been put in place to accurately report this information. We will explore the development of a screening process for critical suppliers that includes assessments of environmental and social criteria.	Information unavailable

GRI 414: Supplier Social Assessment 2016

Disclosure Number / Disclosure Title	Page / Response	Omission
414-1 New suppliers that were screened using social criteria	p. 6 Because this topic was first identified as highly material in 2016, systems have not yet been put in place to accurately report this information. We will explore the development of a screening process for critical suppliers that includes assessments of environmental and social criteria.	Information unavailable

PRODUCT SUSTAINABILITY

GRI 103: Management Approach 2016

Disclosure Number / Disclosure Title	Page / Response
103-1 Explanation of the material topic and its boundaries	p. 16 Product health, safety, and environmental impacts occur primarily downstream from Cabot's operations through the activities of our customers and in some cases through end-use by consumers, and for an overview of materiality, our management approach, and evaluation process for product sustainability. The key responsibility for this effort resides with Cabot's Product Support and Toxicology Group of the Safety, Health, and Environment (SH&E) Department, as well as the business and research and development teams.
103-2 The management approach and its components	
103-3 Evaluation of the management approach	Grievance mechanisms include the Cabot open door policy for employees to raise concerns and report violations of corporate policies or the law. Employees may approach supervisors, the Office of Compliance, or use the Cabot hot-line. In addition, Cabot welcomes feedback from customers should they have any concerns or questions about our products and practices.

GRI 416: Customer Health and Safety 2016

Disclosure Number / Disclosure Title	Page / Response
416-1 Assessment of the health and safety impacts of product and service categories	p. 16 100% of significant product categories are assessed for health and safety impacts using best available information.

MATERIAL TOPICS — SOCIAL

EMPLOYMENT, DIVERSITY, & TRAINING

GRI 103: Management Approach 2016

Disclosure Number / Disclosure Title	Page / Response
103-1 Explanation of the material topic and its boundaries	Refer to p. 31 for an overview of materiality and boundaries, our management approach, and evaluation process for the following topics: employment, training and education, diversity and equal opportunity, and non-discrimination. Reporting to the CEO and senior executive management committee, the Senior Vice President and Chief Human Resources Officer oversee programs to recruit, retain and support employees at Cabot. The Human Resources Department assists managers across the company with the performance review process, and implementation of Cabot's Code of Business Ethics and Human Rights Policy, which establish expectations for professional conduct, strict adherence to labor practices and human rights laws, and creation of a safe and healthy workplace. Refer to Cabot's Code of Business Ethics (cabotcorp.com/codeofbusinessethics) and Human Rights Policy (cabotcorp.com/humanrightspolicy) for details.
103-2 The management approach and its components	
103-3 Evaluation of the management approach	Grievance mechanisms include the Cabot open door policy for employees to raise concerns and report violations of corporate policies or the law. Employees may approach supervisors, the Office of Compliance, or use the Cabot hot-line.

GRI 401: Employment 2016

Disclosure Number / Disclosure Title	Page / Response
401-1 New employee hires and employee turnover	p. 33
401-2 Benefits provided to full-time employees	p. 31

GRI 404: Training and Education 2016

Disclosure Number / Disclosure Title	Page / Response
404-1 Average hours of training per year per employee	Average training hours are tracked by three main employee function categories: ◆ Clerical / Technical: 24 hours/employee ◆ Professional / Supervisor: 27 hours/employee ◆ Management / Experienced: 19 hours/employee
404-2 Programs for upgrading employee skills and transition assistance programs	pp. 31, 33 Our training program is managed on a site-by-site basis, according to the unique mix of each employee's experience and skill set, career interests, and the core business objectives of the company. Our Developing Leaders and Plant Engineer Development programs offer flexible online learning modules to promote mentoring and management skills, technical abilities, and cross-functional learning between different disciplines. Career transitioning is handled with sensitivity and commonly includes outplacement services for future employment opportunities or retirement.
404-3 Percentage of employees receiving regular performance and career development reviews	73.4% of employees received performance and career development reviews in 2016: **By Gender:** ◆ Male: 69.3% ◆ Female: 87.6% **By Employee Category:** ◆ Clerical / Technical: 58.3% ◆ Professional / Supervisor: 89.4% ◆ Management / Experienced: 93.4%

GRI 405: Diversity and Equal Opportunity 2016

Disclosure Number / Disclosure Title	Page / Response
405-1 Diversity of governance bodies and employees	For a description of our approach to diversity of employees, refer to p. 31. Diversity of employees at the end of 2016: **By Gender:** ◆ Male: 78% ◆ Female: 22% **By Age Group:** ◆ Under 30: 11% ◆ 30-50: 58% ◆ Over 50: 31% Diversity of the Board of Directors at the end of 2016: **By Gender:** ◆ Male: 82% ◆ Female: 18% **By Age Group:** ◆ Under 30: 0% ◆ 30-50: 9% ◆ Over 50: 91%

GRI 406: Non-discrimination 2016

Disclosure Number / Disclosure Title	Page / Response
406-1 Incidents of discrimination and corrective actions taken	No incidents of discrimination were reported in 2016.

◆ OCCUPATIONAL HEALTH AND SAFETY

GRI 103: Management Approach 2016

Disclosure Number / Disclosure Title	Page / Response
103-1 Explanation of the material topic and its boundaries	p. 28 Cabot's approach to occupational health and safety encompasses all direct impacts occurring in facilities under our operational control, including employees, contractors, and visitors. Refer to p. 28 for an overview of materiality, our management approach, and evaluation process for occupational health and safety. Within our Board, the SH&E Committee oversees the safety of products and manufacturing processes. The Senior Vice President of SH&E provides day-to-day management of SH&E programs and also regularly reports to the SH&E Committee. Cabot's SH&E Policy lays out our guiding principles (cabotcorp.com/SHEpolicy). Grievance mechanisms include the Cabot open door policy for employees to raise concerns and report violations of corporate policies or the law. Employees may approach supervisors, the Office of Compliance, or use the Cabot hot-line. Our manufacturing facilities have formal processes to engage the local community, including the use of a Community Advisory Panel (CAP), and "Open Days" where community members may visit sites and speak directly with Cabot employees regarding their concern.
103-2 The management approach and its components	
103-3 Evaluation of the management approach	

GRI 403: Occupational Health and Safety 2016

Disclosure Number / Disclosure Title	Page / Response
403-1 Workers representation in formal joint management – worker health and safety committees	All manufacturing locations, regional offices, and service centers have joint health and safety committees operating at the site level and reporting up to the corporate SH&E department. These committees represent all workers and contractors.
403-2 Types of injury and rates of injury (IR), occupational diseases (ODR), lost days (LDR), absenteeism (AR), and number of work-related fatalities	p. 29 Methods for calculating each metric are provided below: ◆ **Total Recordable Incident Rate (TRIR)**: Number of injuries (employees and contractors) per 100 employees ◆ **Lost Time Incident Rate (LTIR)**: Number of lost time injuries (employees and contractors) per 100 employees ◆ **Severity Rate**: Number of lost work days (employees and contractors) per 100 employees ◆ **Process Safety Events (PSE)**: Defined by the Center for Chemical Process Safety as a "release of material or energy from a process that resulted in injury, fire or explosion, or release of flammable, combustible or toxic chemicals." PSEs are subdivided into tiers: a Tier 1 event is a loss of containment resulting in consequences including worker injuries that require lost days, fatalities, or direct monetary loss of $25,000 due to a fire or explosion. A Tier 2 event is a loss of containment resulting in less severe consequences such as a recordable injury or loss of $2,500 due to fire or explosion.
103-1 Explanation of the material topic and its boundaries	Refer to p. 36 for a description of Community Engagement materiality and boundaries, management approach, and evaluation. Grievance mechanisms include the Cabot open door policy for employees to raise concerns and report violations of corporate policies or the law. Employees may approach supervisors, the Office of Compliance, or use the Cabot hot-line. Our manufacturing facilities have formal processes to engage the local community, including the use of a Community Advisory Panel (CAP), and "Open Days" where community members may visit sites and speak directly with Cabot employees regarding their concerns.
103-2 The management approach and its components	
103-3 Evaluation of the management approach	

GRI 413: Local Communities 2016

Disclosure Number / Disclosure Title	Page / Response
413-1 Operations with local community engagement, impact assessments, and development programs	p. 36

CABOT

ENVIRONMENTAL PRODUCT DECLARATION

ISO 14025 ISO 21930 EN 15804

epd-norge.no
The Norwegian EPD Foundation

Eier av deklarasjonen	Norcem AS
Program operatør	Næringslivets Stiftelse for Miljødeklarasjoner
Utgiver	Næringslivets Stiftelse for Miljødeklarasjoner
Deklarasjonens nummer	NEPD-1217-383-NO
Godkjent dato	16.10.2013
Gyldig til	16.10.2018

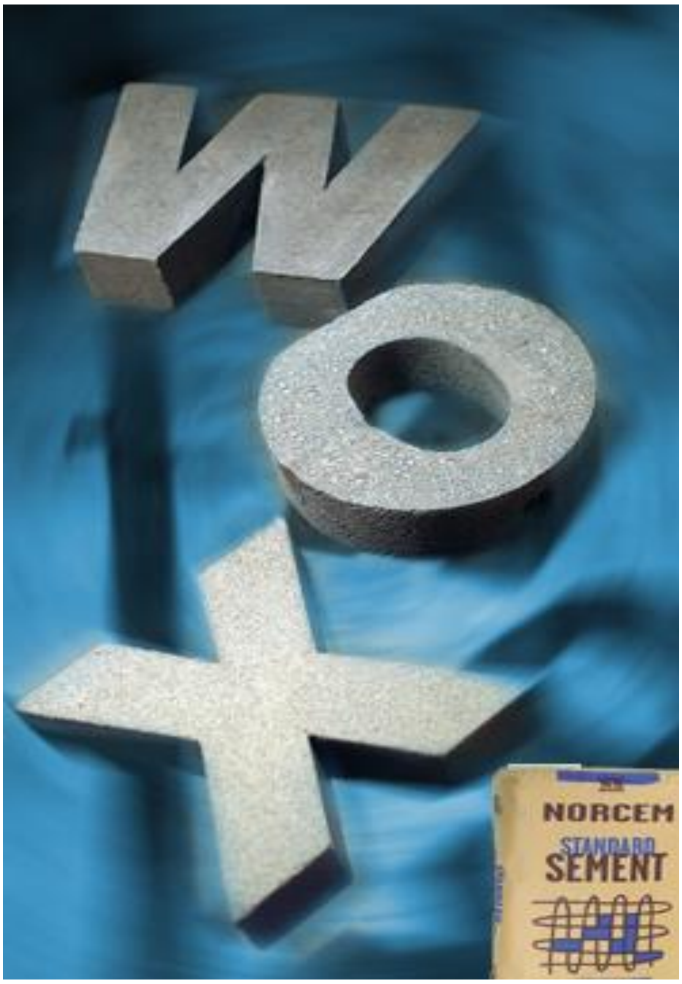
CEM I, Anleggsement (CEM I 52,5N), Industrisement (52,5R) og Standardsement (CEM I 42,5R)

Produkt

Norcem AS

Produsent

NORCEM
HEIDELBERGCEMENTGroup



Generell informasjon

CEM I, Anlegg-, Industri- og Standardsement
Produkt

Norcem AS
Produsent

Program operatør:
Næringslivets Stiftelse for Miljødeklarasjoner
Postboks 5250 Majorstuen, 0303 Oslo
Tlf: +4723088000
e-post: post@epd-norge.no

Eier av deklarasjon:
Norcem AS
Kontakt person: Ida husum
Tlf: +47 35 57 22 40 (Brevik)
e-post: ida.husum@norcem.no

Deklarasjon nummer: NEPD-1217-383-NO

Produksjonssted:
Brevik

Deklarasjonen er basert på PCR:
CEN Standard EN 15804 er brukt som kjerne PCR, i tillegg til Requirements on an Environmental Product Declaration (EPD) for Cement, Bau-Umwelt

Kvalitet/Miljøsystem:
Miljøstyringssystem ISO 14001-sertifisert (S-007)
Kvalitetsstyringssystem ISO 9001-sertifisert (S-006)

Deklarert enhet
1 tonn sement fra råvaeruttak til port

Org. no.:
No-934949145 MVA

Deklarert enhet med opsjon:

Godkjent dato:
16.10.2013

Funksjonell enhet:

Gyldig til:
16.10.2018

Miljødeklarasjonen er utarbeidet av:

Mie Vold

Mie Vold

Østfoldforskning

Sammenlignbarhet:
EPD av byggevarer er nødvendigvis ikke sammenlignbare hvis de ikke samsvarer med EN 15804

Årstall for studien:
2013

Verifikasjon:
Uavhengig verifikasjon av data og annen miljøinformasjon er foretatt etter ISO 14025. 8.1.3.

eksternt ☑ internt ☐

Seniorforsker, Cecilia Askhem
(Uavhengig verifikator godkjent av EPD Norge)

Godkjent i tråd med ISO 14025, 8.1.4

Sverre Fossdal

Dr. ing Sverre Fossdal
(Verifikasjonsleder i EPD-Norge)

Deklarert enhet
1 tonn sement fra råvaeruttak til port

Nøkkelindikatorer	Enhet	Anlegg A1-A3	Industri/Standard A1-A3	Transport to warehouse (50km)
Global oppvarming	kg CO_2	758	748	3
Total energibruk	MJ	5 617	5 484	37
Farlige stoffer fra REACH Kandidatliste	*			

* Produktet inneholder ingen stoffer fra REACH Kandidatliste eller den norske prioritetslisten

Produkt

Produktbeskrivelse:
Grå portland sement

Produktspesifikasjon
Kalkstein fra eget dagbrudd og gruve , samt dagbrudd i Verdal er viktigste råvare i tillegg til gips. Råvaresammensetningen i CEM I er som følger

	Enhet	Anlegg	Industri og standard
Klinker	kg/DE	909	909
Flyveaske	kg/DE		
Kalkmel	kg/DE	36	36
Gips	kg/DE	49	49
Annet	kg/DE	6	6

Tekniske data:
Standardsement (EN 197-1, CEM I 42,5R), Anleggsement (EN 197-1, CEM I 52,5N) og Industrisement (EN 197-1, CEM I 52,5R)

Ytterligere informasjon finnes på:
www.norcem.no

Markedsområde:
Norge

Levetid:
Avhenger av bruksområde

LCA: Beregningsregler

Deklareret enhet
1 tonn sement fra råvaeruttak til port

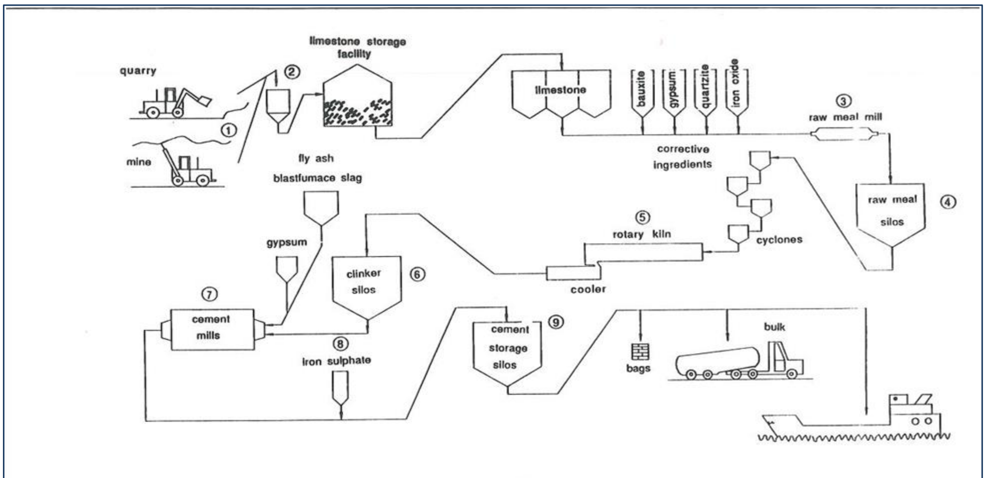
Produksjonsfasen for produktet

• Hovedprosessene ved Norcem Brevik er uttak av kalkstein fra to felt i nærheten av bedriften: Dalen gruve og Bjørntvet dagbrudd, i tillegg til dagbrudd i Verdal.

• Kalksteinen tilsettes korreksjonsmaterialer, som kisavbrann, kvarts, oxiton, bauxitt og gips, og males og brennes ved høye temperaturer (1450oC) til klinker.

• Klinkeren finmales til sement. I maleprosessen tilsettes mindre mengder gips, jernsulfat og kalkmel

Systemgrenser:
Fra råvareuttak til marked



1. Mining of limestone from quarries or mines
2. Limestone crushing
3. Grinding of limestone and additives to produce raw meal
4. Silos for storage and homogenisation
5. Burning of clinker in a rotary kiln where the temperature of the materials reaches up to a 1450°C
6. Silos for clinker storage
7. Grinding of clinker with gypsum and other additives to produce cement
8. Addition of iron sulphate to dechromatise the cement
9. Storage, dispatch of cement

Datakvalitet:

Råvaregruppe	Datakvalitet	Kilde	Alder for data
Klinker	Spesifikke data	Norcems egne tall	2012
Flygeaske	Ikke relevant		-
Kalkmel	Spesifikke data	Norcems egne tall	2012
Gips	Databasedata	EcoInvent	2006
Annet	Under Cut-off		

Spesifikke data er brukt for de materialer som er utgjør vesentlige bidrag til miljøpåvirkning.

Allokering:
For produksjonen hos Norcem er totalt forbruk for 2012 er registrert og fordelt på produserte produkter på vektbasis .
I de tilfeller det benyttes et avfallsprodukt fra annen produksjon, allokeres forhold knyttet til framstilling til den opprinnelige produksjonen.
Alternativ brensel anses som avfallsprodukter fra annen produksjon. Påvirkninger knyttet til framstilling er allokert til den opprinnelige produksjonen, mens påvirkninger ved forbrenning er allokert til virksomheten som drar nytte av energien.Alt utslipp og forbruk av ressurser knyttet til produksjonen av elektrisitet og fremstilling av andre energibærere som er benyttet i produksjon ved råvarene i produktet er allokert til råvarene og derved produktet i neste omgang.

Cut-off kriterier:
Masser som utgjør mindre enn 1% er ikke tatt med

LCA: Scenarier og annen teknisk informasjon

Følgende informasjonen beskriver scenariene for modulene I EPDen.

Tilleggsinformasjon:	Scenario for transport til marked i Norge	50	km
	Transporten skjer med Norcems egen bulkbåt for sement		

Annen teknisk informasjon

Ikke relevant

LCA: Resultater

I modul A1 inngår produksjon av råvarer fra uttak av ressurser. A2 inkluderer transport av råvarer til Norcem, A3 inkluderer produksjonsprosessen hos Norcem.

Systemgrenser (X = inkludert, MID = modul ikke deklarert, MIR = modul ikke relevant)

Produktfase			Konstrusjon installasjon fase		Bruksfase							Sluttfase				Etter endt levetid
Råmaterialer	Transport	Tilvirkning	Transport	Konstrusjon installasjon fase	Bruk	Vedlikehold	Reperasjon	Utskiftinger	Oppussing	Operasjonell energibruk	Operasjonell vannbruk	Demontering	Transport	Avfallsbehandling	Avfall til deponi	Gjenbruk-gjenvinning-resirkulering-potensiale
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
x	x	x	MID	MID	MID	MID	MID	MID	MID	MID	MID	MID	MID	MID	MID	MID

Miljøpåvirkning

Parameter		CEM I Anlegg				CEM I Industri og Standard			
		A1	**A2**	**A3**	**A1-A3**	**A1**	**A2**	**A3**	**A1-A3**
GWP	kg CO2-eqv	1,51	15,78	741	758	1,33	6,03	740,54	747,90
ODP	kg CFC11-eqv	1,32E-07	1,91E-06	2,73E-06	4,76E-06	9,07E-08	6,92E-07	2,73E-06	3,51E-06
POCP	kg ethene-eqv	0,018	0,021	0,060	0,099	0,018	0,008	0,060	0,086
AP	kg PO_4^{-3}-eqv	0,10	0,14	1,07	1,31	0,10	0,06	1,07	1,23
EP	kg SO2-eqv	0,025	0,023	0,32	0,37	0,02	0,01	0,32	0,36
ADPM	kg Sb eqv	3,01E-04	5,09E-06	1,66E-04	4,72E-04	3,93E-05	2,67E-06	1,66E-04	2,08E-04
ADPE	MJ	17,79	238	2 899	3 155	13,49	106,54	2 899,07	3 019,09

GWP Globalt oppvarmingspotensial (kg CO2-ekv.); **ODP** Potensial for nedbryting av stratosfærisk ozon (kg CFC11-ekv.); **POCP** Potensial for fotokjemisk oksidantdanning (kg C2H4-ekv.); **AP** Forsurningspotensial for kilder på land og vann (kg SO2-ekv.); **EP** Overgjødslingspotensial (kg PO4-3-ekv.); **ADPM** Abiotisk uttømmingspotensial for ikke-fossile ressurser (kg Sb -ekv.); **ADPE** Abiotisk uttømmingspotensial for fossile ressurser (MJ)

Lese eksempel: 9,0 E -03 = 9,0 * 10-3

Ressursbruk

Parameter	Enhet	CEM I Anlegg				CEM I Industri og Standard			
		A1	**A2**	**A3**	**A1-A3**	**A1**	**A2**	**A3**	**A1-A3**
FPEE	MJ	7,45	1,02	791,28	799,75	10,29	0,51	791,28	802,08
FPEM	MJ	-	-	-	-	-	-	-	-
TFE	***MJ***	7,45	1,02	791,28	799,75	10,29	0,51	791,28	802,08
IFPE	MJ	19	239	2 992	3 250	15	107	2 992	3 114
IFPM	MJ	-	-	-	-	-	-	-	-
TIFE	MJ	19	239	2 992	3 250	15	107	2 992	3 114
SM	Kg	5,79	-	0,00	5,79	18,01	-	0,00	18,01
FSB	MJ	-	-	-	-	-	-	-	-
IFSB	MJ	-	-	1 567,54	1 567,54	-	-	1 567,54	1 567,54
Bruk av vann	m^3	18,46	5,01	1 240,73	1 264,21	23,22	2,51	1 240,73	1 266,47

FPEE Fornybar primærenergi brukt som energibærer (MJ); **FPEM** Fornybar primærenergi brukt som råmateriale (MJ); **TFE** Total bruk av fornybar primærenergi (MJ); **IFPE** Ikke fornybar primærenergi brukt som energibærer (MJ); **IFPM** Ikke fornybar primærenergi brukt som råmateriale (MJ); **TIFE** Total bruk av ikke fornybar primærenergi (MJ); **SM** Bruk av sekundært materialer (kg); **FSB** Bruk av fornybart sekundært brensel (MJ); **IFSB** Bruk av ikke fornybart sekundært brensel (MJ); **V** Netto bruk av drikkevann (m3)

Livsløpets slutt - Avfall

		CEM I Anlegg				CEM I Industri og Standard			
Parameter	**Enhet**	**A1**	**A2**	**A3**	**A1-A3**	**A1**	**A2**	**A3**	**A1-A3**
FA	Kg	2,33E-04	6,96E-05	9,11E-04	1,21E-03	2,34E-04	2,84E-05	9,11E-04	1,17E-03
IFA	kg	1,72E-01	1,55E-01	7,56E+01	7,59E+01	1,74E-01	7,90E-02	7,56E+01	7,58E+01
RA	kg								

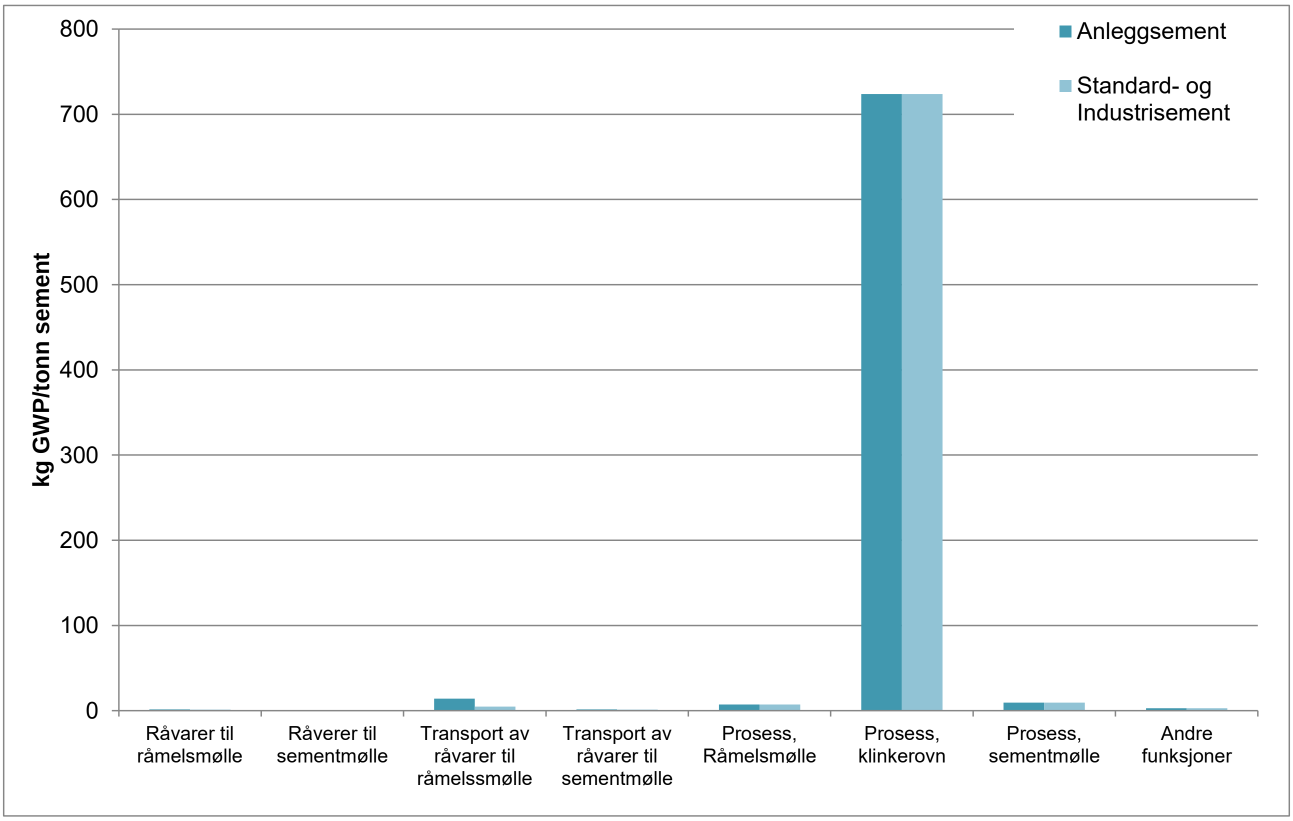
FA Avhendet farlig avfall (kg); **IFA** Avhendet ikke-farlig avfall (kg), **RA** Avhendet radioaktivt avfall (kg)

Livsløpets slutt - Utgangsfaktorer

		CEM II Anlegg FA				CEM II Standard FA			
Parameter	**Enhet**	**A1**	**A2**	**A3**	**A1-A3**	**A1**	**A2**	**A3**	**A1-A3**
KG	kg								
MER	kg								
MEG	kg								
EEE	MJ								
ETE	MJ								

KG Komponenter for gjenbruk (kg); **MR** Materialer for resirkulering (kg); **MEG** Materialer for energigjenvinning (kg); **EEE** Eksportert elektrisk energi (MJ); **ETE** Eksportert termisk energi (MJ)

En ser av figur 1 at det er A3, fremstilling av råvarer, som har største påvirkning klima



Figur 1: Utslipp av klimagasser per modul i fra hhv Anlegg og Industri/Standard

Spesifikke norske krav

Elektrisitet

Nordisk produksjonsmix

El-miks	0,0458	kg CO_2 ekv/MJ

Farlige stoffer

Produktet er ikke tilført stoffer fra REACH kandidatliste (pr.16.10.2013) over stoffer av svært stor bekymring, stoffer på den norske Prioritetslisten (pr.16.10.2013) og stoffer som fører til at produktet blir klassifisert som farlig avfall. Det kjemiske innholdet i produktet er i samsvar med den norske produktforskriften.

Transport

Transport fra Produksjonssted til sentrallager i Norge er 50 km

Inneklima

Materialet har ingen relevant påvirkning på inneklima

Klimadeklarasjon

Foreligger ikke

Bibliografi

NS-EN ISO 14025:2006	*Miljømerker og deklarasjoner - Miljødeklarasjoner type III - Prinsipper og prosedyrer.*
NS-EN ISO 14044:2006	*Miljøstyring - Livsløpsvurderinger - Krav og retningslinjer*
NS-EN 15804:2012	*Bærekraftig byggverk - Miljødeklarasjoner - Grunnleggende produktkategoriregler for byggevarer*
ISO 21930:2007	*Sustainability in building construction - Environmental declaration of building products*
Vold [2013]	*Oppdaterte EPDer med 2012-tall for Norcem Brevik, Bakgrunnsrapport for verifisering ,* Mie Vold, Østfoldforskning, Fredrikstad, Mai 2013
Institut Bauen und Umwelt e.V. (2012-1)	*Requirements on an Environmental Product Declaration (EPD) for Cement*
Institut Bauen und Umwelt e.V. (2012-2)	*Calculation Rules for the Life Cycle Assessment and Requirements on the Background Report,*

epd-norge.no The Norwegian EPD Foundation	**Utgiver** Næringslivets Stiftelse for Miljødeklarasjoner Postboks 5250 Majorstuen, 0303 Oslo Norge	Tlf: e-post: web	+4723088000 post@epd-norge.no www.epd-norge.no
epd-norge.no The Norwegian EPD Foundation	**Program operatør** Næringslivets Stiftelse for Miljødeklarasjoner Postboks 5250 Majorstuen, 0303 Oslo Norge	Tlf: e-post: web	+4723088000 post@epd-norge.no www.epd-norge.no
NORCEM HEIDELBERGCEMENTGroup	**Eier av deklarasjonen** Norcem AS Postboks 143 Lilleaker 0216 Oslo	Tlf: Fax e-post: web	47 22 87 84 00 +47 22 87 84 01 firmapost@norcem.no www.heidelbergcement.com/no
Østfoldforskning	**Forfatter av Livsløpsrapporten** Mie Vold Østfoldforskning as Gamle Beddingvei 26, 1671 Kråkerøy	Tlf: Fax e-post: web	414 69 800 69 34 24 94 mie@ostfoldforskning.no www.ostfoldforskning.no

Miljødeklarasjon - EPD

DYNAMON NRG-700

Concrete admixtures – Plasticisers and Superplasticisers

EPD-EFC-20150091-IAG1-EN

Den Europeiske Federation of Concrete Admixtures Associations (EFCA) har utviklet miljødeklarasjoner (Model EPD) for ulike produktkategorier. Disse deklarasjonene er blitt verifisert i henhold til EN 15804 og ISO 14025, og publisert av det uavhengige forskningsinstituttet for konstruksjon og miljø i Tyskland (IBU). EPD' ene er også tilgjengelige for nedlasting fra EFCA's webside.

Mapei AS er medlem av Norsk komite for tilsetningsstoffer til sement, mørtel og betong (NCCA), som er nasjonal medlemsforening av EFCA. Dette gir bedriften rett til å benytte EFCA miljødeklarasjoner. Dette gjøres med en IBU godkjent prosedyre som bekrefter at et gitt produkt er innenfor rammene av den gjeldende produktkategori EPD. Data for levetidsanalyser og annet innhold i produktkategori EPD gjelder for de navngitte produktene, og kan bli benyttet for miljøanalyser av konstruksjonsprodukter og prosjekter der disse benyttes.

Dan Arve Juvik

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Nordic & Baltic

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04/05 16

Dato: 02.Mai 2016

ENVIRONMENTAL PRODUCT DECLARATION

as per ISO 14025 and EN 15804

Owner of the Declaration	European Federation of Concrete Admixtures Associations Ltd. (EFCA)
Programme holder	Institut Bauen und Umwelt e.V. (IBU)
Publisher	Institut Bauen und Umwelt e.V. (IBU)
Declaration number	EPD-EFC-20150091-IAG1-EN
Issue date	9/14/2015
Valid to	9/13/2020

Concrete admixtures – Plasticisers and Superplasticisers

European Federation of Concrete Admixtures Associations Ltd. (EFCA)

Institut Bauen und Umwelt e.V.

www.bau-umwelt.com / https://epd-online.com

EFCA

1. General Information

European Federation of Concrete Admixtures Associations Ltd. (EFCA)

Programme holder

IBU - Institut Bauen und Umwelt e.V.
Panoramastr. 1
10178 Berlin
Germany

Declaration number

EPD-EFC-20150091-IAG1-EN

This Declaration is based on the Product Category Rules:

Concrete admixtures, 07.2014
(PCR tested and approved by the SVR)

Issue date

9/14/2015

Valid to

9/13/2020

Bossenmayer

Prof. Dr.-Ing. Horst J. Bossenmayer
(President of Institut Bauen und Umwelt e.V.)

Lehmann

Dr. Burkhart Lehmann
(Managing Director IBU)

Concrete admixtures – plasticisers and superplasticisers

Owner of the Declaration

European Federation of Concrete Admixtures Associations Ltd. (EFCA)
Radius House, 51 Clarendon Road, Watford,
Herts, WD17 1HP United Kingdom

Declared product / Declared unit

1 kg of plasticisers and superplasticisers, density: 1 - 1.6 kg/l

Scope:

This validated Declaration entitles EFCA to bear the symbol of the Institut Bauen und Umwelt e.V. It exclusively applies for the product groups referred to for plants operated in Belgium, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, Turkey and the United Kingdom by companies that are members of EFCA National Associations in these countries and for a period of five years from the date of issue. It involves a Model EPD where the product displaying the highest environmental impact in a group was selected for calculating the Life Cycle Assessment. Please refer to the EFCA website www.efca.info for a list of National Associations.

The application of this EPD is only possible for member companies of EFCA's member associations and only for specific formulations with a total score below the declared maximum score for a product group according to the associated guidance document.
The owner of the declaration shall be liable for the underlying information and evidence; the IBU shall not be liable with respect to manufacturer information, life cycle assessment data and evidences.

Verification

The CEN Norm /EN 15804/ serves as the core PCR

Independent verification of the declaration according to /ISO 14025/

☐ internally ☒ externally

M. Schulz

Matthias Schulz
(Independent verifier appointed by SVR)

2. Product

2.1 Product description

Admixtures are liquid or powdery agents that are introduced in small amounts (< 5% by mass of the cement content) to concrete while it is being mixed and that enhance the properties of the fresh and/or hardened concrete.
Plasticisers and superplasticisers are admixtures which reduce the water content of mixed concrete without detriment to its consistency or enhance its slump with or without change to the water content or cause both effects simultaneously. They can also display a retarding effect when used as combination products.
The results of the Life Cycle Assessment provided in this declaration have been selected from the product with the highest environmental impact (worst-case scenario).

2.2 Application

Concrete admixtures are used as constituent materials for the production of concrete, mortar and grout (unreinforced concrete, reinforced and prestressed concrete, site-mixed and ready-mixed concrete, precast concrete). Their application should be in line with the manufacturer's technical documents and Declaration of Performance.

2.3 Technical Data

Plasticisers and superplasticisers must comply with the general requirements of /EN 934-1:2008/ and the additional requirements of /EN 934-2:2009+A1:2012/.

The corresponding requirements in line with /EN 934-1:2008/ and /EN 934-2:2009+A1:2012/ must be maintained.

Constructional data

Name	Value	Unit
Density /ISO 758/	1 - 1.6	g/ml
Solids content /EN 480-8/	-[1]	M.-%
pH value /ISO 4316/	-[1]	- $\log_{10}(a_{H+})$
Chloride content /EN 480-10/	Maximum value to be declared by the manufacturer	M.-%
Alkali content /EN 480-12/	Maximum value to be declared by the manufacturer	M.-%
Corrosion behavior /EN 934-1/, /EN 480-14/	-[2]	µ A/cm^2
SiO2 content /EN 192-2/	-[3]	M.-%
Air content of fresh concrete /EN 12350-7/	Test mix ≤ 2% by volume above control mix unless stated otherwise by the manufacturer	Vol.-%
Compressive strength /EN 12390-3/	-□	N/mm^2
Water reduction /EN 12350-2/, /EN 12350-5/ Plasticiser	Test mix ≥ 5% compared to control mix Superplasticiser: Test mix ≥ 12% compared to control mix	mm
Increasing / maintaining of consistence /EN 12350-2/, /EN 12350-5/ Superplasticiser	-□	mm
Setting time /EN 480-2/ Accelerator/Retarder	-□	min
Air void Characteristics in hardened concrete /EN 480-11/ Air entrainer	-□	mm
Capillary water absorption /EN 480-5/ Densifier	-□	g/mm^2

[1] Value will be made available to user on request

[2] No corrosion behaviour test is required for admixtures which only contain active substances in the list of approved substances to /EN 934-1/, Annex A.1 and in the list of declared substances to /EN 934-1/, Annex A.2.

[3] Maximum value must only be indicated when SiO_2 percentage by mass > 5%

□ Details not relevant for this type of admixture

□ Concrete plasticiser:

At 7 and 28 days: Test mix ≥ 110% of control mix

Superplasticiser (tested at equal consistence):

At 1 day:

Test mix ≥ 140% of control mix

At 28 days:

Test mix ≥ 115% of control mix

Superplasticiser (tested at equal w/c ratio): At 28 days: Test mix ≥ 90% of control mix

□ Increase in consistence

Increase in slump ≥ 120 mm from initial (30 ± 10) mm

or

Increase in flow ≥ 160 mm from initial (350 ± 20) mm

Retention of consistence 30 min after the addition: the consistence of test mix ≥ initial consistence of the control mix

2.4 Placing on the market / Application rules

For products placed on the market in the European Economic Area (EEA) the Construction Product Regulation (Regulation (EU) No 305/2011) applies /CPR/. Outside of the EEA, the corresponding national regulation applies. Admixture products placed on the market under the CPR require a Declaration of Performance and CE marking taking consideration of /EN 934-2:2009+A1:2012/.

For the application and use of the products the respective national provisions apply.

2.5 Delivery status

Plasticisers and superplasticisers are usually supplied in liquid, paste or powder form in containers made of steel or plastic.

Typical container sizes are canisters containing approx. 25 kg, drums with approx. 200 kg or Intermediate Bulk Containers (IBC) with 1000 kg. The containers are shipped on wooden pallets.

For larger applications, loose deliveries in tank trucks with a capacity in excess of 1 tonne are also used.

2.6 Base materials / Ancillary materials

Plasticisers and superplasticisers essentially contain ether lignosulphonate, naphthalene sulphonate, melamine sulphonate and polycarboxylate/polycarboxylic or mixtures thereof. Defoaming agents and preservatives are added as minor components and auxiliaries.

Active substance concentration lies between 10 and 40% by mass. The typical dosage of plasticisers lies between 0.2 and 0.5% by mass in relation to the cement weight. The typical dosage of superplasticisers lies between 0.4 and 2.0% by mass in relation to the cement weight.

The products covered by this EPD typically contain the following proportions by mass of constituent materials and auxiliaries referred to:

Lignosulphonate*:	max. 35%
Naphthalene sulphonate*:	max. 30%
Melamine sulphonate*:	max. 45%
Polycarboxylate*:	max. 35%
Additives:	max. 5%
Water:	approx. 55 - 75%

**Solid content*

These volumes are average values and the composition of products complying with the EPD can deviate from these concentration levels in individual cases.

Note: For companies to declare their products within the scope of this EPD it is not sufficient to simply comply with the product composition shown above. The application of this EPD is only possible for member companies of EFCA's member associations and only for specific formulations with a total score below the declared maximum score for a product group according to the associated guidance document.

Small volumes (< 0.5% by mass) of biocides with functional chemical groups for example isothiazolinones or dioxahexane are used as preservatives in concrete admixtures during storage. More detailed information is available in the respective manufacturer's documentation (e.g. product data sheets, safety data sheets).

Unless indicated on the safety data sheet, concrete admixtures do not contain any substances in concentrations of more than 0.1% which are included in the list of Substances of Very High Concern (SVHC) for inclusion in Annex XIV of the REACH regulation.

No flame retardants are used in concrete admixtures.

2.7 Manufacture

Concrete admixtures are usually manufactured by mixing ingredients together in batch mode and filling containers for dispatch. The process follows quality standards outlined in /EN 934-6:2001+A1:2005/.

2.8 Environment and health during manufacturing

As a general rule, no environmental or health protection measures other than those specified by law are necessary.

2.9 Product processing/Installation

During concrete manufacture, concrete admixtures are usually added along with the mixing water or included in premixed concrete.
Health and safety measures (eye protection, hand protection, possibly respiratory equipment and body protection) are to be taken and consistently adhered to in accordance with the information on the safety data sheet and conditions on site.

2.10 Packaging

Reusable containers are, where practicable taken back by the manufacturer and redirected into the production circuit. Empty plastic or steel containers which can no longer be used are recyclable.
Wooden reusable pallets are, where practicable taken back by the manufacturer or building material trader who returns them to the building product manufacturer redirecting them into the production process.

2.11 Condition of use

During the use phase, concrete admixtures are firmly bound into the cement matrix in hardened concrete. Concrete admixtures make an essential contribution towards optimising the physical and chemical properties of concrete enhancing its performance, durability, economic value and sustainability.

2.12 Environment and health during use

During the use phase, concrete admixtures are firmly bound into the cement matrix in hardened concrete.
No relevant risks are known for water, air and soil if the products are used as designated.

2.13 Reference service life

Not relevant as this declaration relates to a preliminary product.

2.14 Extraordinary effects

Fire
Not relevant as this declaration relates to a preliminary product.

Water
Not relevant as this declaration relates to a preliminary product.

Mechanical destruction
Not relevant as this declaration relates to a preliminary product.

2.15 Re-use phase

Not relevant as this declaration relates to a preliminary product.

2.16 Disposal

Empty, dried containers are directed to the recycling process where practicable.
Residue must be directed to proper waste disposal taking consideration of local guidelines.

2.17 Further information

More information is available in the manufacturers' product or safety data sheets on the manufacturers' Web sites or on request.
An electronic version of this declaration is available at www.efca.info and www.bau-umwelt.de

3. LCA: Calculation rules

3.1 Declared Unit

This EPD refers to the declared unit of 1 kg concrete admixture with a density of 1-1.6 kg/l in accordance with the IBU PCR 07.2014 Part B for concrete admixtures. The results of the Life Cycle Assessment provided in this declaration have been selected from the product with the highest environmental impact (worst-case scenario).
Depending on the application, a corresponding conversion factor such as the density to convert volumetric use to mass must be taken into consideration.

3.2 System boundary

Modules A1, A2 and A3 are taken into consideration in the LCA:

- A1 Production of preliminary products
- A2 Transport to the plant
- A3 Production incl. provision of energy, production of packaging as well as auxiliaries and consumables and waste treatment

The Declaration is therefore “cradle-to-gate”.

3.3 Estimates and assumptions

For this EPD formulation and production data defined by EFCA were considered. Production waste was assumed to be disposed of to landfill without credits as a worst case.
An average of plastic containers and wooden pallets was considered in the LCA.

3.4 Cut-off criteria

All raw materials submitted for the formulations and production data were taken into consideration.
The manufacture of machinery, plant and other infrastructure required for production of the products under review was not taken into consideration in the LCA.
Transport of packaging materials is also excluded.

3.5 Background data

Data from the GaBi 6 data base was used as background data.

3.6 Data quality

Representative products were applied for this EPD and the product in the group displaying the highest environmental impact was selected for calculating the

LCA results. The data sets are no more than 4 years old.
Production data and packaging are based on details provided by the manufacturer. The formulation used for evaluation refers to a specific product.
The data quality of the background data is considered to be good.

3.7 Period under review

Representative formulations were compiled by EFCA in 2011.

3.8 Allocation

No allocations were applied for production.

3.9 Comparability

Basically, a comparison or an evaluation of EPD data is only possible if all the data sets to be compared were created according to /EN 15804/ and the building context, respectively the product-specific characteristics of performance, are taken into account.

4. LCA: Scenarios and additional technical information

In accordance with the IBU PCR 07.2014 Part A, no scenarios are indicated as only Modules A1-A3 are declared.

5. LCA: Results

DESCRIPTION OF THE SYSTEM BOUNDARY (X = INCLUDED IN LCA; MND = MODULE NOT DECLARED)

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement[1]	Refurbishment[1]	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND

RESULTS OF THE LCA - ENVIRONMENTAL IMPACT: 1 kg plasticisers and superplasticisers

Parameter	Unit	A1-A3
Global warming potential	[kg CO$_2$-Eq.]	1.88E+0
Depletion potential of the stratospheric ozone layer	[kg CFC11-Eq.]	2.30E-10
Acidification potential of land and water	[kg SO$_2$-Eq.]	2.92E-3
Eutrophication potential	[kg (PO$_4$)$^{3-}$-Eq.]	1.03E-3
Formation potential of tropospheric ozone photochemical oxidants	[kg ethene-Eq.]	3.12E-4
Abiotic depletion potential for non-fossil resources	[kg Sb-Eq.]	1.10E-6
Abiotic depletion potential for fossil resources	[MJ]	2.91E+1

RESULTS OF THE LCA - RESOURCE USE: 1 kg plasticisers and superplasticisers

Parameter	Unit	A1-A3
Renewable primary energy as energy carrier	[MJ]	1.51E+0
Renewable primary energy resources as material utilization	[MJ]	0.00
Total use of renewable primary energy resources	[MJ]	1.51E+0
Non-renewable primary energy as energy carrier	[MJ]	2.66E+1
Non-renewable primary energy as material utilization	[MJ]	4.82E+0
Total use of non-renewable primary energy resources	[MJ]	3.14E+1
Use of secondary material	[kg]	0.00
Use of renewable secondary fuels	[MJ]	0.00
Use of non-renewable secondary fuels	[MJ]	0.00
Use of net fresh water	[m^3]	6.04E-3

RESULTS OF THE LCA – OUTPUT FLOWS AND WASTE CATEGORIES: 1 kg plasticisers and superplasticisers

Parameter	Unit	A1-A3
Hazardous waste disposed	[kg]	5.17E-6
Non-hazardous waste disposed	[kg]	2.56E-2
Radioactive waste disposed	[kg]	9.00E-4
Components for re-use	[kg]	0.00
Materials for recycling	[kg]	0.00
Materials for energy recovery	[kg]	0.00
Exported electrical energy	[MJ]	0.00
Exported thermal energy	[MJ]	0.00

6. LCA: Interpretation

When considering upstream production and transport of pre-products as well as manufacturing of the concrete admixture (modules A1-A3), the main driver of impacts in all categories is production of pre-products (module A1).

In the categories of ozone depletion potential (**ODP**), renewable primary energy demand (**PERT**), radioactive waste, and acidification potential (**AP**) a fairly important contributor is the European electricity grid mix, which also has minor influence on photochemical ozone creation potential (**POCP**).

The plastic packaging of the concrete admixture also makes a minor contribution, especially to abiotic depletion potential for fossil resources (**ADPF**), photochemical ozone creation potential (**POCP**), and non-renewable primary energy demand (**PENRT**), as do wooden pallets (in the case of **PERT**).

Generally, treatment of production waste has negligible influence on results in all impact categories for this product type.

7. Requisite evidence

As this involves a declaration of preliminary products, special tests and evidence within the framework of drawing up this Model Environmental Product Declaration have not been carried out or provided.

8. References

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General principles
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ISO 14025
DIN EN ISO 14025:2011-10: Environmental labels and declarations — Type III environmental declarations — Principles and procedures

EN 15804
EN 15804:2012-04+A1 2013: Sustainability of construction works — Environmental Product Declarations — Core rules for the product category of construction products

CPR
Construction Production Regulation (EU) No 305/2011 of the European parliament and of the council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC

EN ISO 9001:2008
Quality management systems – Requirements (ISO 9001:2008)

GaBi 6 software & documentation
Data base for Life Cycle Engineering LBP, University of Stuttgart and thinkstep AG, documentation of GaBi 6 data sets http://documentation.gabi-software.com/, 2014

EN 196-2:2013
Test methods for cement – Part 2: Chemical analysis of cement

EN 206:2013
Concrete – Part 1: Specification, performance, production and conformity

EN 480-1:2014
Admixtures for concrete, mortar and grout – Test methods – Part 1: Reference concrete and reference mortar for testing

EN 480-2:2006
Admixtures for concrete, mortar and grout – Test methods – Part 2: Determination of setting time

EN 480-4:2005
Admixtures for concrete, mortar and grout – Test methods – Part 4: Determination of bleeding of concrete

EN 480-5:2005
Admixtures for concrete, mortar and grout – Test methods – Part 5: Determination of capillary absorption

EN 480-6:2005
Admixtures for concrete, mortar and grout – Test methods – Part 6: Infra red analysis

EN 480-8:2012
Admixtures for concrete, mortar and grout – Test methods – Part 8: Determination of the conventional dry material content

EN 480-10:2009
Admixtures for concrete, mortar and grout – Test methods – Part 10: Determination of water-soluble chloride content

EN 480-11:2005
Admixtures for concrete, mortar and grout – Test methods - Part 11: Determination of air void characteristics in hardened concrete

EN 480-12:2005
Admixtures for concrete, mortar and grout – Test methods – Part 12: Determination of the alkali content of admixtures

EN 480-14:2006
Admixtures for concrete, mortar and grout – Test methods – Part 14: Determination of the effect on corrosion susceptibility of reinforcing steel by potentiostatic electro-chemical test

EN 934-1:2008
Admixtures for concrete, mortar and grout – Part 1: Common aspects

EN 934-2:2009+A1:2012
Admixtures for concrete, mortar and grout – Part 2: Concrete admixtures – Definitions, requirements, conformity, marking and labelling

EN 934-5:2007
Admixtures for concrete, mortar and grout – Part 5: Admixtures for sprayed concrete – Definitions, requirements, conformity, marking and labelling

EN 934-6:2001+A1:2005
Admixtures for concrete, mortar and grout – Part 6: Sampling, conformity control and evaluation of conformity

EN 12350-2:2009
Testing fresh concrete – Part 2: Slump test

EN 12390-3:2009
Testing hardened concrete – Part 3: Compressive strength of test specimens

EN 12350-5:2009
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Elkem
Silicon Materials

To : Our valued customers
Copy : Quality Manager Arne Skagen
From : REACH compliance manager Dr. Bernd Friede
Date : 02 Febuary 2015

Microsilica: Carbon footprint and environmental product declaration (EPD)

Microsilica, or silica fume (CAS # 69012-64-2, EC # 273-761-1) is a by-product of the industrial silicon and ferroalloy production.

Commission regulation (EU) No 601/2012[1] on the monitoring and reporting of greenhouse gas emissions and related official guidance documents do not clearly define a methodology for a CO_2 allocation of by-products.

With regard to the EU climate legislation, silica fume is today covered both by the carbon leakage list[2] and by the Guidelines for Environment State Aid under NACE code 2013[3].

Until further legislation or guidelines are provided by EU regulators, the European silica fume producers, represented by their trade union Euroalliages, have a common position and allocate all greenhouse gas emissions to the main product silicon and ferrosilicon.

As a consequence, only CO_2 emissions related to packing and transport would be attributed to silica fume.

B Friede

Dr. Bernd Friede
REACH compliance manager

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[1] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:181:0030:0104:en:PDF

[2] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014D0746&from=EN

[3] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014XC0628(01)&from=EN

European
Commission

Science for Environment Policy

Stronger concrete is more environmentally-friendly

Using high-strength concrete in construction could help to reduce its impact on the environment, according to a study by French researchers. The researchers compared the environmental impacts of bridges built from ordinary and high-strength concrete and found that the high-strength solution had a lower impact on the environment overall.

In Europe, **the weight of minerals extracted** each year to make concrete for buildings is equivalent to 4.8 tonnes per person. Globally, 5-10% of carbon dioxide (CO_2) emissions from human activity are produced by the building materials sector, mostly from concrete manufacturing[1]. According to previous research, using renewable fuels, improving kilns and alternative binding materials to cement could halve emissions, which is a valuable but insufficient contribution to cuts in CO_2 recommended by the IPCC, who advise that global emissions should be reduced by at least 75% across all sectors to avoid uncontrolled climate change.

This study suggested that emissions could be further reduced by increasing concrete's strength, because the volume of concrete required is lower overall. However, concrete affects the environment in other ways besides producing greenhouse gas emissions. Therefore, the researchers took into account a range of environmental effects of building a bridge from ordinary concrete (with low cement content) compared to a similar bridge built from superior strength concrete (with high cement content). They used a life cycle assessment (LCA) method to compare two existing bridges in France, both typical of highway crossing bridges, each around 50 metres long and around 10 metres wide. The LCA approach they used was based on a widely used International Organization for Standardization (ISO) method that has been used in the building sector previously.

In their assessment, the researchers' estimated that the high performance concrete bridge used around two thirds less concrete than the standard concrete bridge (around 280 cubic metres versus around 840 cubic metres). Their assessment considered production of the main materials (concrete, steel and asphalt) used in the construction of the bridge, transport of these materials, and energy required for the construction, maintenance and demolition phases. Each bridge was assessed based on environmental indicators related to material consumption, acidification, eutrophication, global warming, ozone layer depletion, air pollution and toxicity to humans and ecosystems.

The results suggest that the production and maintenance phases make the biggest contributions to environmental impacts for both bridges. For the high-strength concrete bridge, the environmental impacts are about 15% lower for most categories. This is mainly because less cement is used overall, even though the content per cubic metre is higher. This also leads to energy savings in transport of materials, a shorter construction process and easier demolition. However, uncertainties in the data exist because some factors could not be accurately estimated. For example, the researchers did not know exactly how far the materials were transported and the levels of pollutants emitted during cement production vary from plant to plant.

Overall, the difference in impacts between the two bridges was greatest for global warming. According to the researchers, a bridge made with high performance concrete should have a global warming impact (based on CO_2 emissions) that is between 3 to 40% lower than a conventional bridge - depending on various factors, such as the distance between the production site and building site.

When only the global warming impact of concrete production was considered, the saving compared to conventional methods was 50%. The researchers conclude that promoting the use of high performance concrete for bridges is an efficient effort towards the goal of sustainable building.

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Redox Kinetics and Diffusion in Lithium Niobate

Jianmin Shi,*[a] and Klaus-Dieter Becker[a]

Keywords: Kinetics, Diffusion, Optical in-situ spectroscopy, Lithium niobate

Lithium niobate single crystals (LN) are widely used oxide materials in electro-optical devices. In order to extend the applications of LN to piezoelectric sensors and actuators at high temperatures, knowledge of the defect chemistry and transport properties at high temperatures are crucial for such applications. Chemical reduction of lithium deficient LN results in the coloration of the transparent crystals, which is explained by the optical absorption of electronic defects in the Vis- and NIR range, i.e., free and bound electron polarons. In this presentation, we report an investigation of the optical absorption of electronic defects as well as of the redox kinetics of lithium niobate single crystals using in-situ UV-Vis-NIR optical spectroscopy at high temperatures. The equilibrium optical absorption spectra at high temperatures under reducing conditions can be fitted by two electron polaron bands with the dominance of the free electron polaron absorption at about 0.9 eV. Diffusion coefficients of lithium vacancies were obtained from the reduction and oxidation processes upon sudden changes in oxygen activity. The activation energy of vacancy diffusion processes in lithium deficient LN has been determined to be about 1.43 eV from the redox kinetics at different temperatures.

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Nachhaltigkeit in der Bauindustrie durch Einsatz von Microsilica

Bernd Friede,*[a] and Per Fidjestøl[a]

Keywords: Microsilica, pozzolan, CO_2 reduction

Microsilica oder silica fume ist ein Nebenprodukt der Silicium- und Ferrosilicium-produktion. Mit einer durchschnittlichen Partikel-größe von 150 nm weist diese sphärische Form amorphen Siliciumdioxids eine hohe Puzzolan-aktivität auf. Die besonderen chemisch-physikalischen Eigenschaften von Microsilica sorgen in Beton für höhere Druckfestigkeiten, Chemikalienresistenz und Erosionsbeständigkeit. Dies ermöglicht eine leichtere Bauweise. Der Einsatz von Microsilica in Betonkonstruktionen reduziert somit den Bedarf an Zement bei gleichzeitig signifikanter Erhöhung der Langlebigkeit des Bauwerks (> 200 Jahre). Im Vergleich zu konventioneller Bauweise reduziert sich die CO_2-Emission durch Verwendung von Microsilica-haltigen Spezialbeton um bis zu 50 %. Betonkonstruktionen verursachen 5–10 % der weltweiten CO_2-Emissionen!

Tabelle 1. Einfluss Microsilica-haltigen Betons

	Gebäude 1 k-Beton$^{a)}$	Gebäude 2 MS-Beton$^{b)}$	Gebäude 3 k-Beton$^{a)c)}$	Gebäude 4 MS-Beton$^{b)c)}$
% CO_2 Reduktion	0	33,6	28,6	54,5
Standzeit [Jahre]	53	206	53	206
Baukosten [EUR]	720.000	830.000	645.000	625.000

a) konventioneller Beton. b) Microsilica-Beton. c) Bubble Deck Konstruktion

[1] B. Friede, P. Fidjestøl, *Nachr. Chem.* **2011**, *59*, 965–958.
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