ROYAL INSTITUTE OF TECHNOLOGY

ACADEMIC YEAR 2011-2012

course

LIFE CYCLE ASSESSMENT

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LIFE CYCLE ASSESSMENT OF TWO DIFFERENT TYPES OF FAÇADES

16 December 2011

Group number 7

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Abstract

In this project, the aim is to compare two different types of façades, one that is considered to be conventional and one that is environmentally friendly. The overall aim is to see what environmental impacts the two façades have, and to look at how the choice of façade will affect the total energy use. In order to do this, a life cycle assessment has been performed, starting at the extraction of raw materials for the production, continuing through the maintenance phase and finally ending up at the waste disposal phase at the end of the façades' life. Sensitivity analyses were performed to add yet other dimensions to the research. The results show that the environmentally friendly façade does in general have less environmental impact than the conventional façade. The difference in energy consumption between the façades can reach 1 GJ per m^2. Our calculations show that in comparison with the overall demand of a prototype villa the energy savings when adopting environmentally friendly materials can be at least 5%. If the same approach is used for the other building components (windows, roof, etc.) a higher rate of savings is possible.

In conclusion, it becomes clear that the choice of materials does affect the environmental impact, the energy use and the CO_2-emissions. Therefore it appears worthy to invest in alternative materials in addition to the efforts for reducing the thermal properties of the façades. The authors also advocate for more regulations and legislation for the deconstruction phase of the buildings, as this could make the manufacturers more cautious about their environmental impact, and also make the waste disposal more just and optimized.

Table of contents

Abbreviations

OSB – Oriented Strand Board

EPS – Expanded Polystyrene

PE – Polyethylene

E.F. – Environmentally Friendly

F.C. – First Coating

S.C. – Second Coating

BBR – Boverkets byggregler (Boverket's building regulation)

1 Goal and scope

1.1 Goal of the study

In today's society, there is a growing concern for the environmental impact that our human activities have. Many are trying to find ways in which to limit these, for example, through optimizing or changing building materials. The emergence of so-called environmentally friendly façades (E.F.) is a new path, and we want to see just what environmental impacts this new façade may have, compared to a conventional one.

We want to compare different façades for buildings, one that is considered environmentally friendly and one that is conventional. The reason to do this is to see differences in terms of energy use and environmental impacts from each façade. Furthermore, we want to compare these results with the overall energy demand of a simple building prototype, placed near Stockholm, for one single family. In this way we can understand the relative effect of choosing one façade or the other given that they have the same thermal transmittance. The concept of thermal transmittance will be further elaborated in the section "Functional unit", below.

In order to see what environmental impact the façades have, a main research question has been set:

- *What is the overall environmental impact for an environmentally friendly façade and a conventional façade respectively?*

We think that the best way to approach this is through a life cycle assessment (LCA) that is accounting and comparative. Since the LCA provides a good tool for decision-making, we see our intended audience ranging from architects, physical planners and consultant agencies to the final client and consumer as long as they wish to show the difference in environmental impacts between the façades.

1.2 Functional unit

The function of our product, the façade, is to provide shelter for the users within a building. A way to measure the shelter is through the so-called thermal transmittance. What the thermal transmittance really describes is the heat and cold flow resistance of the façade. It is therefore considered to be the most important measure of performance of the façade and it does also affect the energy demand to a great degree. The functional unit is 1 m^2 of façade with a specific thermal transmittance for 50 years (lifetime).

The thermal transmittance is 0,144 W/m^2K. According to Boverket's building regulation (BBR) the maximum value for the thermal transmittance for a façade should not exceed 0,18 W/m^2K (Boverket, 2006).

1.3 System boundaries

We have set the geographical boundaries to Stockholm, as our building is placed there. For the LCA, we consider the "cradle" of this system as being the extraction of raw materials. The rest of the life cycle is the production of the façade, potential maintenance during its life, and the "grave" in the system is a waste disposal scenario, as shown in Figure 1. In the flowchart of the system, potential material recovery has been modelled (connected through a dotted line), but this is something that will be calculated for as "avoided burdens" in our system, and not exact material recovery or use. The reason for using a dotted line is because this is a potential material recovery, and not something that is an absolute certainty.

Flowchart

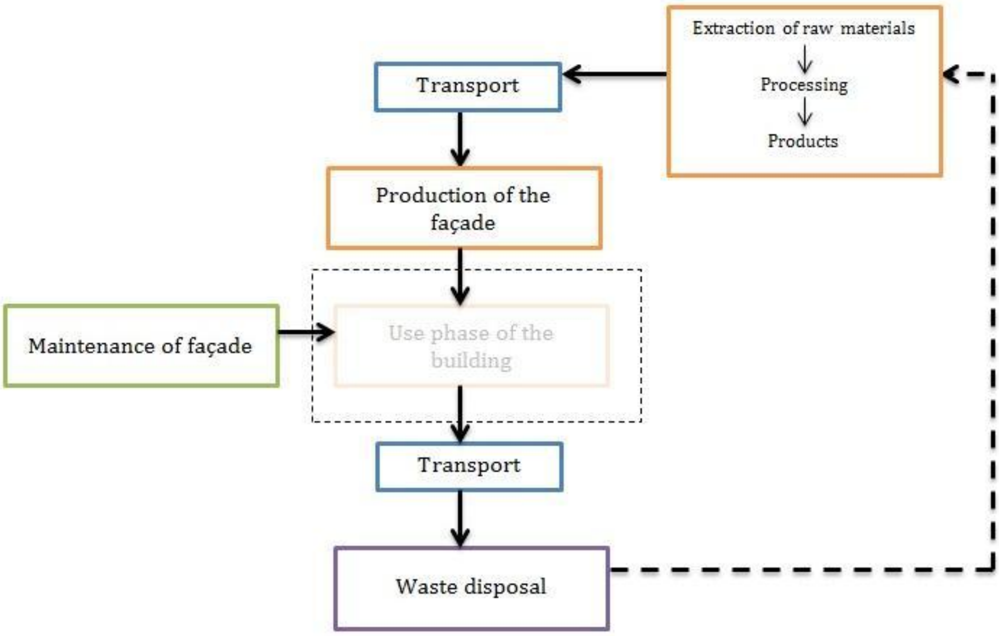

Figure 1, The simplified flowchart shows the different processes within the system and life cycle of the façades.

The flowchart shows the different steps and processes within the system, and how these are related. The three main parts of the life cycle is the *Production of the façade, Maintenance of façade* and *Waste disposal*. All these parts have sub-processes respectively. The use phase is not included in our LCA analysis as it is assumed to be the same for both façades. For this reason in the flowchart it is displayed half transparent. Several assumptions and limitations have been made for these processes, and these will be further described in *Assumptions and limitations.*

We try to keep extraction of raw material and manufacturing as close to Stockholm as possible, even if it certain materials have to be extracted and manufactured elsewhere and then transported. The dimension of the final building is 12m x 12m x 4m ($576m^2$). Our time perspective for the LCA is a period of 50 years. This choice is motivated by the decreasing lifetime of nowadays buildings that are replaced after more or less that period. Besides, the structures of residential buildings in Europe are certified to last 50 years so this time perspective seems reasonable and the 50-year perspective is also consistent with recent scientific articles on the topic (Favre & Citherlet, 2008; Börjesson & Gustavsson, 2000).

The production will take place on site in Stockholm. The efficiency of this process varies greatly depending on factors such as the builder's personal knowledge and how well the materials fit the building requirements. Materials are sometimes produced according to pre-determined standard measures, and these can be different from what is required for the project, leading to excess materials being cut off. Each material used has the potential to generate waste. The rate of waste is both design specific for the building itself and for each material. Either way, this can potentially lead to waste being generated. For simplification reasons, the potential waste generated at the production site has been excluded as a system limitation.

We do also disregard ant thermal bridges that may occur. For an explanation of thermal bridges and thermal masses, see Figure 2.

Thermal bridge = Is a part where the heat flow is different compared to the rest of the façade. It affects the internal surface temperatures, for example (Tadeu, Simões, Simões, & Prata, 2011).

Thermal mass = The ability of building materials to store, absorb and later release heat (Sustainable Energy Authority Victoria, 2002).

Figure 2, Explanation of the concepts of thermal bridges and thermal masses.

Cut-off

The use phase of the façade (building) has been excluded, as we assume that it is the same for both the conventional and E.F. façade.

Allocation procedure*:* The authors have avoided the use of allocation procedures and instead made a system expansion whenever needed. This was the case for some of the waste streams in the waste disposal scenario. Two examples of when system expansion was used is the case of bricks and cellulose insulation. Bricks are inert material and can be recycled as inter aggregated for roads. Cellulose insulation can also be recycled, and used in the production of new cellulose insulation as a raw material.

1.4 Assumptions and limitations

For this project, we have made several assumptions and limitations.

We assume that:

- The production at the site in Stockholm operates at 100% efficiency, generating no waste.
- All the material produced in Europe is transported either by lorry (an average European standard lorry) or by barge (an average European standard barge). No other transportation means have been considered, as it is the authors' belief that the above-mentioned options are the most realistic ones, especially considering flexibility and the quantities that are being transported.
- For the façade, all potential additional parts for holding the façade together have been disregarded. This includes any screws, nails, metals or glue that could have been used for this purpose. We have only considered the materials themselves and their thermal transmittance.
- Any paint/wall paper/inner construction to the façade (facing the room) is excluded as it is considered to more of an aesthetic purpose rather than necessary to maintain the performance of the façade.
- Potential thermal bridges and thermal masses have been excluded even though they can affect the final energy consumption. The reason for excluding them is that they are parameters that are highly dependent on the real, actual climatic conditions at the building site. The thermal bridges, for example, also depend on the builders' skills, the overall envelope of the building (including structure, windows, doors etc.)
- Other materials that might be needed for the building (tools, light, safety equipment) and maintenance (brushes) or waste disposal (deconstruction equipment) have all been excluded as the processes are assumed to be similar for both façades, except the maintenance which only applies to the E.F façade, and they can therefore be disregarded. The impact of the brushes for the maintenance phase is considered to not have any significant impact on the results, and has therefore also been excluded.
- In the model, no economic factors have been included.
- Limitations for our system include: exclusion of manpower and machinery needed and energy required for the different processes. Furthermore, no consideration has been taken to the volume of the materials, only weight. This could affect the transport calculation.

Some materials were considered to be more environmentally friendly and others more conventional. However, it should be noted that *no* standard exists for either type of façade. The choice of materials for the different façades is based on the authors' previous knowledge about the topic and this is supported by information provided by two independent façade constructers. The conventional facade consists of materials like bricks, mortar, plaster and EPS that are associated with a more traditional way of construction (Wienerberger). The environmentally friendly façade refers to a light system with natural materials generally considered more positive for the environment (Wolf Haus, 2011)

For the conventional façade, the following materials were chosen: plaster, clay bricks, vapour barrier, EPS, façade bricks and mortar. All these are illustrated in Figure 3.

For the environmentally friendly façade, the following materials were chosen: gypsum, OSB, vapour barrier, cellulose insulation, wood structure, fibre wood, wood façade and paint. All these are illustrated in Figure 4.

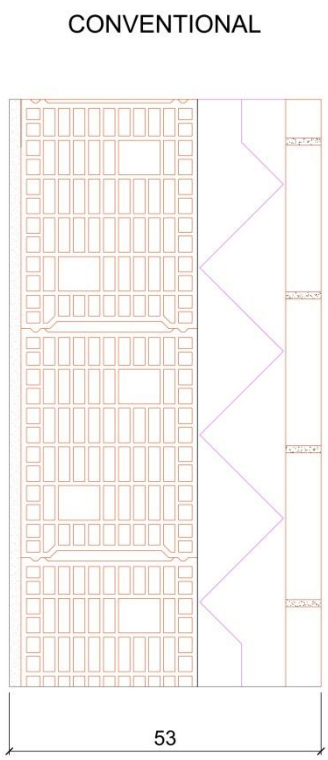

Figure 3, illustration of the structure of the conventional façade. The thickness is in cm (53 cm).

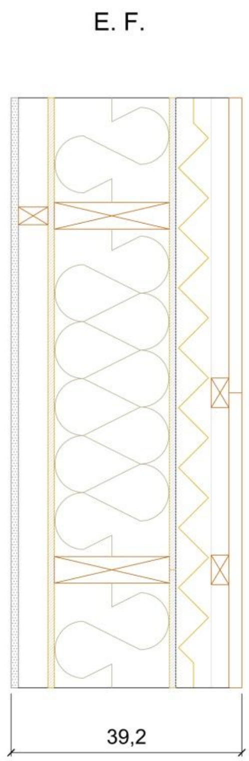

Figure 4, illustration of the structure of the environmentally friendly façade. The thickness is in cm (39,2 cm).

1.5 Impact categories and impact assessment method

We have used ReCiPe Midpoint Hierarchist V1.05 as implemented in SimaPro 7 as our impact assessment method, as was suggested by the course-coordinator(lcia-recipe, 2010). For our project it is also important to show how the energy consumption is, so this factor was searched in other assessment methods, as it is not part of the original ReCiPe method. We used then Cumulative Energy Demand V1.08 that focus its attention just on the primary energy associated to the LCA(Cumulative Energy Demand, 2011). Moreover we made use of the Greenhouse Gas Protocol V1.01 that assesses just the CO_2 emitted(Greenhouse Gas Protocol, 2011). The reason for choosing the Greenhouse Gas Protocol is that it shows the carbon uptake and biogenic carbon emissions, something that is *not* included in the climate change impact category in ReCiPe. Furthermore, it provides a more detailed view of the CO_2-emissions as this is the only focus of the method, and not one out of 18 categories, like in the case of ReCiPe, for example.

The impact categories considered in our model is therefore:

ReCiPe Midpoint H

1. Climate change
2. Ozone depletion
3. Human toxicity
4. Photochemical oxidant formation
5. Particulate matter formation
6. Ionizing radiation
7. Terrestrial acidification
8. Freshwater eutrophication
9. Marine eutrophication
10. Terrestrial ecotoxicity
11. Freshwater ecotoxicity
12. Marine ecotoxicity
13. Agricultural land occupation
14. Urban land occupation
15. Natural land transformation
16. Water depletion
17. Metal depletion
18. Fossil depletion

Cumulative Energy Demand

1. Non-renewable, fossil
2. Non-renewable, nuclear
3. Non-renewable, biomass
4. Renewable, biomass
5. Renewable, wind, solar, geothermal
6. Renewable, water

Greenhouse Gas Protocol

1. Fossil CO_2 eq
2. Biogenic CO_2 eq
3. CO_2 from land transformation
4. CO_2 uptake

1.6 Normalization and weighting

For the method, we have used the ReCiPe Midpoint H, which means that European normalization is used. This normalization is based on an average European citizen's resource use and emissions during one year.

Weighting is not available in the ReCiPe Midpoint H, and was therefore not performed. However, for the Cumulative Energy Demand, each impact category is given the weighting factor 1. For the Greenhouse Gas Protocol, the weighting factor was also 1 for all categories *except* for the carbon uptake, where it was changed to -1.

2 Life cycle inventory analysis

2.1 Process flowchart

The detailed flowchart, see Figure 5, illustrates all the processes in the life cycles of the two different types of façades. The dotted boxes highlights different sub-processes, with the first one being *production.* In the production, the extraction of raw material, processing (manufacturing of products *and* façade) and transport from the extraction sites to the production site in Stockholm is calculated for. The main difference between the two façades is mainly the *maintenance* phase, as there are no maintenance requirements for the conventional façade but this process is calculated for in the E.F. façade. The third and last phase for the process is *waste disposal*. Here, both façades are demolished in a similar way, with recycling, incineration or landfill as options for the material, depending from case to case. Any avoided burdens are here illustrated as "material recovery".

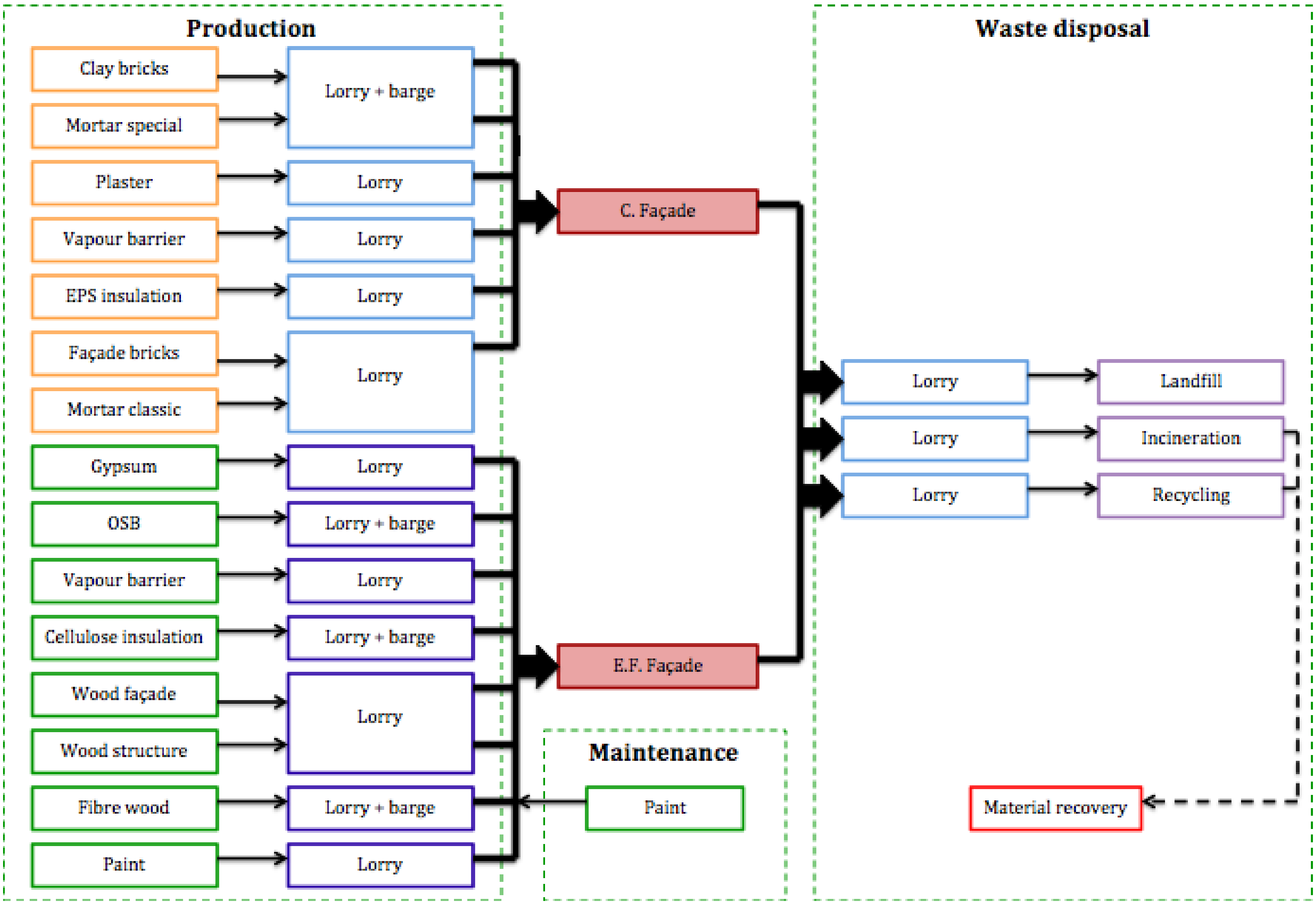

Figure 5, the detailed flowchart of the system showing the material flows and processes in the life cycles of both façades.

2.2 Data

Our data has been gathered from manufacturers directly to as great extent as possible with the addition of scientific articles. When no other data was found, the Ecoinvent 2.0 database and ELCD 2.0 database as implemented in SimaPro were used (Frischknecht, o.a., 2007). The data used for each of the three phases (and two systems) are described below. The data used for the calculations of the conventional façade are shown in Table 1. The calculations for the E.F. façade are shown in Table 2. The specific environmental impact of each assembly (material) is shown in Appendix 6.4.

The quantity of each material has been obtained from the thermal transmittance of the façade (see Appendix 5.2.3). The thickness of the layers has been chosen to provide the desired thermal property. Knowing the density of each component the resulting weight has been calculated. The data includes information about the properties of the materials, what resources are needed to produce and transport them. Data do also include information about the maintenance procedure. Two separate tables have been produced to show the waste data.

Table 1, Conventional façade and the data used for the modelling

Material	Amount	Transport distance	Transport towns	Data (material and transport)
Plaster	30 kg	3 km by lorry	Stockholm* – Stockholm	Material: Ecoinvent; Gypsum plaster (CaSO4 alpha hemihydrates) DE S Transport: Transport, lorry 7.5-16t, EURO5/RER S
Clay bricks	193,6 kg	1210 km (1191 km by lorry and 19 km by barge)	Wefensleben - Stockholm	Material: Ecoinvent; Light clay brick, at plant/DE S Transport: Ecoinvent; Transport, lorry 16-32t, EURO5/RER S *AND* Transport, barge/RER S
Vapour barrier	0,18 kg	613 km by lorry	Malmö - Stockholm	Material: Ecoinvent; Polyethylene, HDPE, granulate, at plant/RER S Transport: Ecoinvent; Transport, lorry 16-32t, EURO5/RER S
EPS	3,2 kg	517 km by lorry	Laholm - Stockholm	Material: Ecoinvent; Polystyrene foam slab, 45% recycled, at plant/CH S Transport: Ecoinvent; Transport, lorry 16-32t, EURO5/RER S
Façade bricks	82,5 kg	80 km by lorry	Enköping - Stockholm	Material: Ecoinvent; Brick, at plant/RER S Transport: Ecoinvent; Transport, lorry 16-32t, EURO5/RER S
Cement mortar	18,53 kg	80 km by lorry	Enköping - Stockholm	Material: Ecoinvent; Cement mortar, at plant/CH S Transport: Ecoinvent; Transport, lorry 16-32t, EURO5/RER S
Light mortar	7,6 kg	1210 km (1191 km by lorry and 19 km by barge)	Wefensleben - Stockholm	Material: Ecoinvent; Light mortar, at plant/CH S Transport: Ecoinvent; Transport, lorry 16-32t, EURO5/RER S *AND* Transport, barge/RER S

Table 2, Environmentally Friendly façade and the data used for the modelling

Material	Amount	Transport distance	Transport towns	Data (material and transport)
Gypsum	11,25 kg	189 km by lorry	Örebro - Stockholm	Material: Our own, based on; Gypsum fibre board, at plant/CH S Modification: Reduced CO_2 Emissions Used data: Gypsum fibre board EF Transport: Ecoinvent; Transport, lorry 16-32t, EURO5/RER U
OSB	14,08 kg	557 km (17 km by lorry and 540 km by barge)	Bolderaja - Stockholm	Material: ELCD; Oriented strand board, OSB III, production mix, at plant, 4,8% water content EU-27 S Transport: Ecoinvent; Transport, lorry 16-32t,
Vapour barrier	0,18 kg	613 km by lorry	Malmö - Stockholm	Material: Ecoinvent; Polyethylene, HDPE, granulate, at plant/RER S Transport: Ecoinvent; Transport, lorry 16-32t,
Cellulose insulation	6,825 kg	1883 km (1810,8 km by lorry and 72,2 km by barge)	Hartberg - Stockholm	Material: Our own, based on; Cellulose fibre, inclusive blowing in, at plant/CH U Modification: Generic transport and relative distance has been eliminated to insert the accurate value. Used data: Cellulose fibre EF Transport: Ecoinvent; Transport, lorry 16-32t,
Wood structure	8,22 kg	309 km by lorry	Moelven - Stockholm	Material: Our own, based on: Sawn timber, hardwood, raw, air dried, u=20%, at plant/RER S Modification: Conversion from a data in m^3 to kg. Density used 480 kg/m^3. Used data: Sawn timber, hardwood, raw, air dried, u=20%, at plant/RER S Group 7 Transport: Ecoinvent; Transport, lorry 16-32t,
Fibre wood	8,4 kg	1849 km (1776,8 km by lorry and 72,2 km by barge)	Waldshut-Tiengen - Stockholm	Material: Our own, based on: Fibreboard soft, at plant (u=7%)/CH U Modification: Conversion from a data in m^3 to kg. We assumed the density to be 140 kg/m^3. Adaptation from a wet process to a dry process. Tap water excluded and paraffin values reduced. Used data: Fibreboard soft, at plant (u=7%)/CH U Group 7 Transport:

				Ecoinvent; Transport, lorry 16-32t,
Wood Façade	10,56 kg	309 km by lorry	Moelven - Stockholm	Material: Our own, based on: Sawn timber, hardwood, planed, air / kiln dried, u=10%, at plant/RER S Modification: Conversion from a data in m^3 to kg. Density used 480 kg/m^3. Used data: Sawn timber, hardwood, planed, air / kiln dried, u=10%, at plant/RER S Group 7 Transport: Ecoinvent; Transport, lorry 16-32t,
Paint	1,3 kg	220 km by lorry	Falun - Stockholm	Material: Our own see dedicated section (2.3 Paint (Swedish red paint)) Transport: Ecoinvent; Transport, lorry 16-32t,

2.3 Waste disposal and data gathering

2.3.1 Materials References

For some of the materials, external references were used. For example, data for the *Swedish red paint* came from a report by Häkkinen et al. (1999). This report also addresses the waste disposal scenarios for building materials *with* the paint, suggesting that 46% of the wood should be incinerated after deconstruction, and the rest go to landfill. The authors added another 3% to the incineration percentage, adding up to 49%. This assumes that *all* wooden waste would be either incinerated or go to landfill and not be recycled or reused. It is also assumed that the paint does not affect this, and that it stays on the wood all through the process. For the *OSB*, specific data could not be obtained. However, the sources were consistent with European legislation, claiming that landfill should be avoided and recycling and/or incineration should be promoted (Institut Bauen und Umwelt, 2011). The authors therefore opted for a 20-80 ratio, meaning that 80% of the OSB is incinerated for energy recovery. According to an environmental declaration of Norgips Plasterboard 12, 5 mm, Type A (following the ISO 14025 and ISO 21930 standards) 25% of gypsum is recycled (Norgips Norway AS, 2009). The rest goes to landfill.

For all other materials, the authors made as realistic assumptions as possible, based on previous knowledge and external sources of information whenever possible. Due to the deconstruction process, it is not realistic to assume that plaster, mortar and vapour barrier will be separated from the other material (bricks in particular) as these are often merged together and contaminate each other during the deconstruction phase. Based on this, the materials have all been calculated for as bricks. There is no reference for the recycling and landfill ratio for bricks, only suggestions of waste management according to the US EPA, which argues for recycling of the bricks and avoidance of landfill (United States Environmental Protection Agency, 2000). The authors have therefore assumed that a 50/50 ratio between recycling and landfill is reasonable.

For EPS, the European Manufacturers of EPS (2002) argue that a large portion of EPS ends up in landfills, even though it is possible to recycle and/or incinerate it. The authors have therefore assumed that due to technical limitations, 70% will go to a landfill and 30% will be recycled.

Finally, for the cellulose insulation, it is possible to incinerate it with other municipal waste, if it is not contaminated (Isocell, 2011). The authors have assumed that 30% of the material will be contaminated during the deconstruction and will therefore end up at a landfill. The remaining 70% will be incinerated for energy recovery. The data used for the waste disposal modeling for the conventional façade can be seen in Table 3. The data that was used to model the waste disposal for the E.F. façade is seen in Table 4.

2.3.2 Waste Scenario of the façade: need of a sensitivity analysis

The recycling of the materials is highly dependent on what kind of deconstruction system that is applied. The two main options are *selective deconstruction* where each material is treated separately in its own waste stream. The other option is more *"general" deconstruction*, where all materials are mixed during the process and only fractions that are not contaminated are recycled, if possible. In contrast to the production phase of the façade, where there are several building guidelines and rules, there seems to be a lack of regulation and legislation when it comes to the deconstruction of the building. It varies from site to site and on what abilities and values that the society has. Some rules exist for the waste disposal, but not for the deconstruction itself. No scientific reports describe the current situation on this issue. In order to give the results some more validity, and to better understand the consequences of the assumptions made, sensitivity analysis was performed for each type of façade. For detailed figures see Appendix 6.3.

The first type of sensitivity analysis that was performed was a scenario called "All recycling". In this scenario, all materials were recycled at 100%, but the recycling process was set to run at 95% efficiency, as this is more realistic. This sensitivity analysis represents the selective deconstruction, and the results show that for the conventional façade the environmental impact was lower than the original scenario. However, for the E.F. façade this was not the case as some materials were now incinerated and this increased the environmental impacts, leading to higher values than if part of the waste stream goes to landfill, like in the original scenario.

The second type of sensitivity analysis that was performed represented the general deconstruction, and in this case, a "No recycling" scenario was used. This means that materials are not recycled at all, they all go to landfill to as high degree as possible. However, some materials were still incinerated in this scenario, such as cellulose insulation and EPS. This deconstruction method affected both façades negatively, showing higher environmental impacts than in the other deconstruction scenarios. For the conventional façade, this is probably mainly due to the non-recycling of the bricks, which now became a big impact compared to being recycled in the other scenarios. For the E.F. façade, the increased use of fossil fuels was the main impact, which made this scenario the one with the highest environmental impacts.

Table 3 Showing the data used for the waste disposal of the conventional façade

Material	Waste Type 1	%	Waste Type 2	%
Plaster	Disposal, plastic plaster, 0% water, to inert material landfill/CH S Our own, based on: Fibreboard soft, at plant (u=7%)/CH U Modification: Conversion from a data in m^3 to kg. We assumed the density to be 140 kg/m^3. Adaptation from a wet process to a dry process. Tap water excluded and paraffin values reduced. Used data: Fibreboard soft, at plant (u=7%)/CH U Group 7	50	Disposal, building, brick, to recycling/CH S Group 7 Outputs to technosphere Gypsum fibre board EF – 0.95 kg Inputs from technosphere Transport, lorry 16-32t, EURO5/RER S – 0.54 tkm Electricity, medium voltage, production SE, at grid/SE S – 0.6 kWh	50
Clay bricks	Disposal, building, brick, to final disposal/CH S	50	Disposal, building, brick, to recycling/CH S Group 7 Based on: Disposal, building, brick, to recycling/CH Outputs to technosphere Gravel, crushed, at mine/CH S– 1 kg	50
Vapour barrier	Disposal, vapour barrier, flame-retarded, 4.5% water, to municipal incineration/CH S Group 7 Based on: Disposal, vapour barrier, flame-retarded, 4.5% water, to municipal incineration/CH S Outputs to technosphere Heat from waste, at municipal waste incineration plant/CH S – 9.4 MJ/kg Electricity from waste, at municipal waste incineration plant/CH S – 4.69 MJ/kg	100		
EPS	Disposal, expanded polystyrene, 5% water, to municipal incineration/CH S Group 7 Based on: Disposal, expanded polystyrene, 5% water, to municipal incineration/CH S Outputs to technosphere Heat from waste, at municipal waste incineration plant/CH S – 7.39 MJ/kg Electricity from waste, at municipal waste incineration plant/CH S – 3.67 MJ/kg	70	Recycling EPS Outputs to technosphere Polystyrene foam slab, 45% recycled, at plant/CH S – 0.95 kg	30
Façade bricks	Disposal, building, brick, to final disposal/CH S	50	Disposal, building, brick, to recycling/CH S Group 7 Based on: Disposal, building, brick, to recycling/CH Outputs to technosphere Gravel, crushed, at mine/CH S– 1 kg	50
Cement mortar	Disposal, plastic plaster, 0% water, to inert material landfill/CH S	50	Disposal, building, brick, to recycling/CH S Group 7 Outputs to technosphere Pulp chips, from dried lumber, at planer mill, US PNW/kg/US– 1 kg Inputs from technosphere Electricity, medium voltage, production SE, at grid/SE S – 0.6 kWh	50
Light mortar	Disposal, plastic plaster, 0% water, to inert material landfill/CH S	50	Disposal, building, brick, to recycling/CH S Group 7	50

Table 4 Showing the data used for the waste disposal for the Environmentally Friendly façade

Material	Waste Type 1	%	Waste Type 2	%
Gypsum	Disposal, gypsum, 19.4% water, to inert material landfill/CH S	75	Recycling Gypsum Outputs to technosphere Gypsum fibre board EF – 0.95 kg Inputs from technosphere Transport, lorry 16-32t, EURO5/RER S – 0.54 tkm Electricity, medium voltage, production SE, at grid/SE S – 0.6 kWh	25
OSB	Disposal, wood untreated, 20% water, to municipal incineration/CH S Group 7 Based on: Disposal, wood untreated, 20% water, to municipal incineration/CH S Outputs to technosphere Heat from waste, at municipal waste incineration plant/CH S – 2.74 MJ/kg Electricity from waste, at municipal waste incineration plant/CH S – 1.3 MJ/kg	80	Recycle Wood EF Outputs to technosphere Gypsum fibre board EF – 0.95 kg Inputs from technosphere Transport, lorry 16-32t, EURO5/RER S – 0.54 tkm Electricity, medium voltage, production SE, at grid/SE S – 0.6 kWh	20
Vapour barrier	Disposal, vapour barrier, flame-retarded, 4.5% water, to municipal incineration/CH S Group 7 Based on: Disposal, vapour barrier, flame-retarded, 4.5% water, to municipal incineration/CH S Outputs to technosphere Heat from waste, at municipal waste incineration plant/CH S – 9.4 MJ/kg Electricity from waste, at municipal waste incineration plant/CH S – 4.69 MJ/kg	100		
Cellulose insulation	Disposal, paper, 11.2% water, to municipal incineration/CH S group 7 Based on: Disposal, vapour barrier, flame-retarded, 4.5% water, to municipal incineration/CH S Outputs to technosphere Heat from waste, at municipal waste incineration plant/CH S – 9.4 MJ/kg Electricity from waste, at municipal waste incineration plant/CH S – 4.69 MJ/kg	20	Recycling Cellulose Outputs to technosphere Cellulose fibre EF– 0.95 kg	80
Wood structure	Disposal, wood untreated, 20% water, to municipal incineration/CH S Group 7 Based on: Disposal, wood untreated, 20% water, to municipal incineration/CH S Outputs to technosphere Heat from waste, at municipal waste incineration plant/CH S – 2.74 MJ/kg Electricity from waste, at municipal waste incineration plant/CH S – 1.3 MJ/kg	49	Disposal, wood untreated, 20% water, to sanitary landfill/CH S	51
Fibre wood	Disposal, wood untreated, 20% water, to municipal incineration/CH S Group 7 Based on: Disposal, vapour barrier, flame-retarded, 4.5% water, to municipal incineration/CH S Outputs to technosphere Heat from waste, at municipal waste incineration plant/CH S – 2.74 MJ/kg Electricity from waste, at municipal waste incineration plant/CH S – 1.3 MJ/kg	80	Recycle Wood EF Outputs to technosphere Pulp chips, from dried lumber, at planer mill, US PNW/kg/US– 1 kg Inputs from technosphere Electricity, medium voltage, production SE, at grid/SE S – 0.6 kWh	20
Wood	Disposal, building wood, chrome preserved, 20% water, to municipal incineration/CH S Group 7	49	Disposal, wood untreated, 20% water, to sanitary landfill/CH S	51

Façade	Based on: Disposal, building wood, chrome preserved, 20% water, to municipal incineration/CH S Outputs to technosphere Heat from waste, at municipal waste incineration plant/CH S – 2.74 MJ/kg Electricity from waste, at municipal waste incineration plant/CH S – 1.3 MJ/kg			
Paint	Landfill/CH S	100		

2.4 Paint (Swedish red paint)

For the paint of the environmentally friendly façade Swedish red paint was chosen due to its characteristics. The paint allows for maintenance of the façade by re-painting, without additional chemicals or processes needed besides the paint itself. According to Häkkinen et al. (1999) the Swedish red paint is the paint with lowest environmental impacts, compared to acrylate paint, water borne stain, yellow linseed oil paint and white linseed oil paint. The paint is also considered a traditional and popular colour in Sweden, and therefore a potentially realistic choice.

Table 5, showing the components for producing 1kg of red powder

	Kg
Paint (ready-made)	1
Red powder	0.75
Silica	0.37
Iron III oxide	0.28
Free silica	0.04
Aluminium oxide	0.06
Calcium oxide	0.022
Inorganic lead compounds	0.003
Inorganic copper compounds	0.003
Inorganic zinc compounds	0.002
Starch glue	0.085
Cellulose derivate	0.015
Ferric sulphate	0.08
Highly refined mineral oil	0.04

The data itself was gathered directly from the manufacturers' website. The amounts for the substances for the mixing of the paint (powder, water, linseed oil and liquid soap) needed were calculated from the product information about the red paint powder (Stora Kopparbergs Bergslags AB, 2011).

The components and amounts of the red powder itself were taken from the security data sheet about the red powder, see Table 5 (Stora Kopparbergs Bergslags AB, 2007). These were calculated for 1 kg of ready-made paint, see Table 6. For each component of the red powder, the extraction processes were calculated for. Any packaging or additional machinery and manpower were all excluded. The paint is produced in Falun, and transported by lorry to Stockholm.

When it is time for the maintenance of the façade, no additional chemicals or processes are needed besides the paint itself. A single coat is added every 15th year (three times in total). For the first coating, two layers of paint are needed. The amount of paint required was calculated according to the manufacturers' standards, giving 97 L paint needed for the first coating, and 65 L per maintenance time. The datasheet can be seen in the Appendix 6.1.

Table 6, showing what additives that are needed, in what amounts, to make ready-made paint for the first and second coating from the red powder.

Litres of painting	***4***	***1***	***FC***	***SC***
Powder (kg)	1	0.25	0.042	0.028
Water (l)	3	0.75	0.126	0.085
Linseed oil (l)	0.4	0.1	0.017	0.011
Liquid soap (l)	0.1	0.025	0.004	0.003

3 Life cycle interpretation

3.1 Results

ReCiPe Midpoint H

The method required to analyse the products (façades) of the LCA was ReCiPe Midpoint H Europe. When analysing the differences between the two façades it becomes evident that the conventional one has a higher impact on the majority of the impact categories such as Climate change, Ozone depletion and Metal and Fossil depletion to give a few examples (see Figure 6). The E.F. one does however have higher environmental impacts on some categories, namely Agricultural and Urban land occupation, Natural land transformation, Water depletion and Ionising radiation. The results show that in total, the conventional façade has a larger negative environmental impact than the E.F. façade.

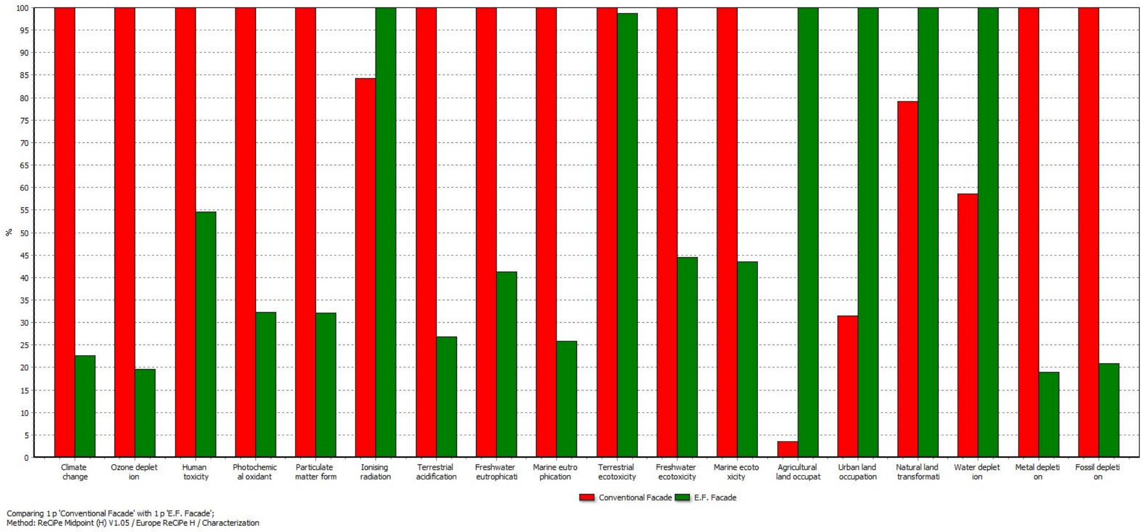

Figure 6, Characterization Comparison ReCiPe Midpoint H Europe

When the results from this project are compared to the average European citizen's resource use and emissions during one year, some of the impact categories seem to be higher. One should note that this is only another approach, and not necessarily accurate. Some of the most important impact categories where the environmental impact exceeds the European citizen's standard values are Natural land transformation, Freshwater ecotoxicity and Agricultural land occupation (see Figure 7).

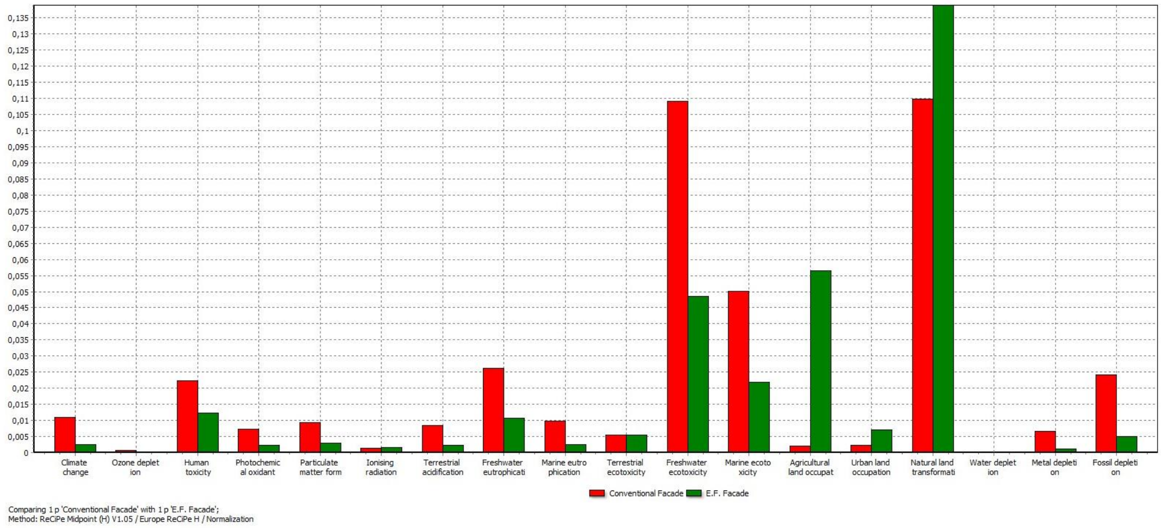

Figure 7, Normalization Comparison ReCiPe Midpoint H Europe

Cumulative Energy Demand V1.08

In order to better suit our purposes and to add deeper more dimensions to the research problem, two additional methods of analysis were used. The method Cumulative Energy Demand was used to look at the primary energy consumed for the production and the disposal of the two façades. The method Cumulative Energy Demand has been selected due to its single score approach and, of course, because of its focus on energy use. This method uses six impact categories that are divided under Non-Renewable (fossil, nuclear, biomass) and Renewable (biomass, wind-solar-geothermal, water).

From the Characterization comparison one can infer that there is a difference in the typology of sources (see Figure 8). The Conventional façade uses more Non-Renewable energy while the E.F. façade are mostly associated with Renewable sources. These results are consistent with the weighting bar, which shows that the conventional façade uses more non-renewable energy sources and the E.F. façade more renewable energy sources (see Figure 9).

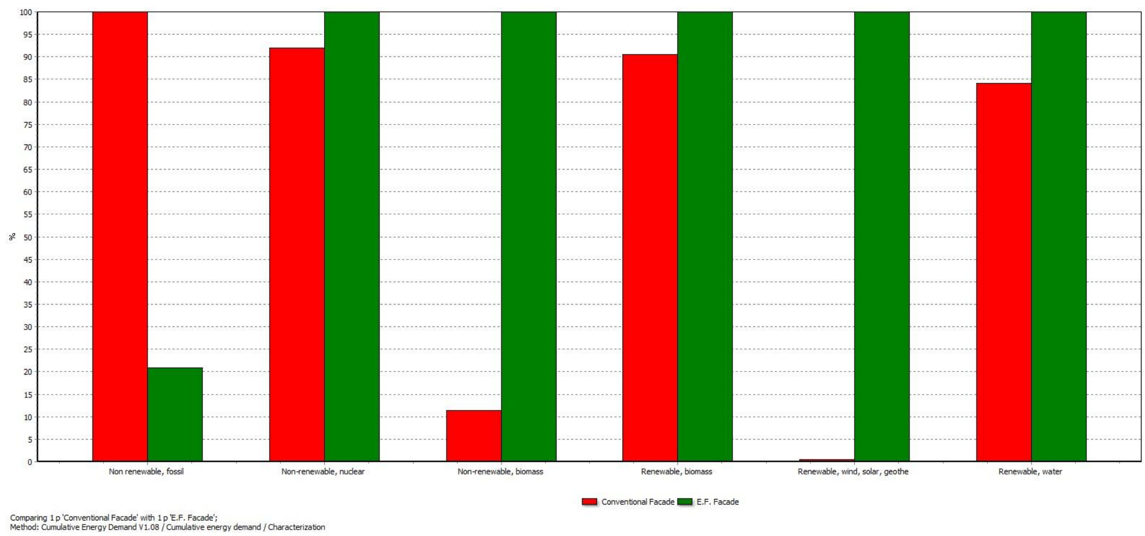

Figure 8, Characterization Comparison Cumulative Energy Demand V1.08

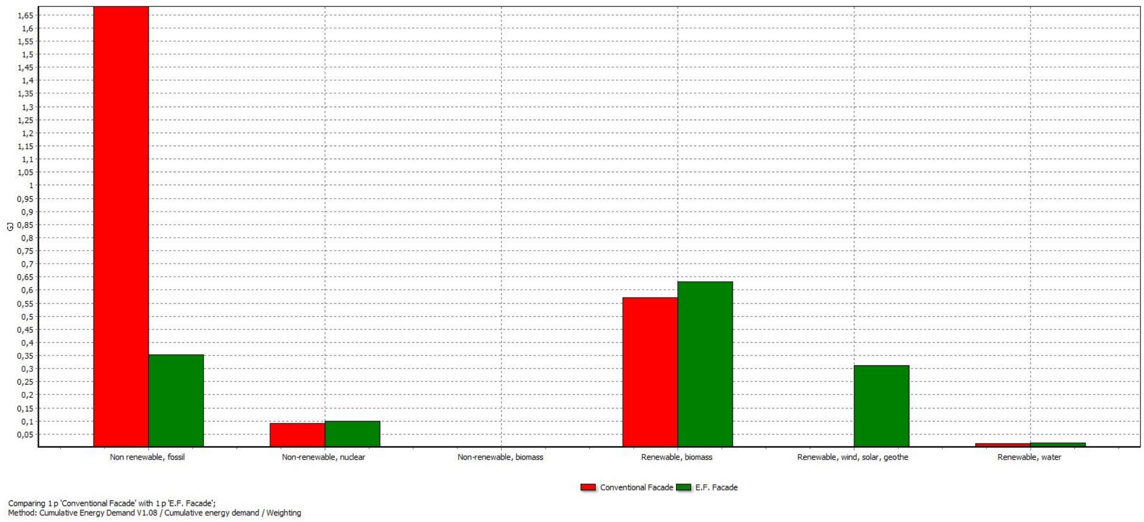

Figure 9, Weighting Comparison Cumulative Energy Demand V1.08

To make the comparison more comprehensive, a Single Score Comparison was made. This gives the total amount of energy related to the façades, and does therefore make it possible to see the overall difference between the two façades (see Figure 10). From the table, one can see that the difference between the façades is almost 1GJ. Once again, as seen in the characterization comparison, it becomes clear that there is a division between the Conventional façade and its related use of Non-renewable Fossil sources one the one hand, and the E.F. façade and its use of Renewable sources on the other.

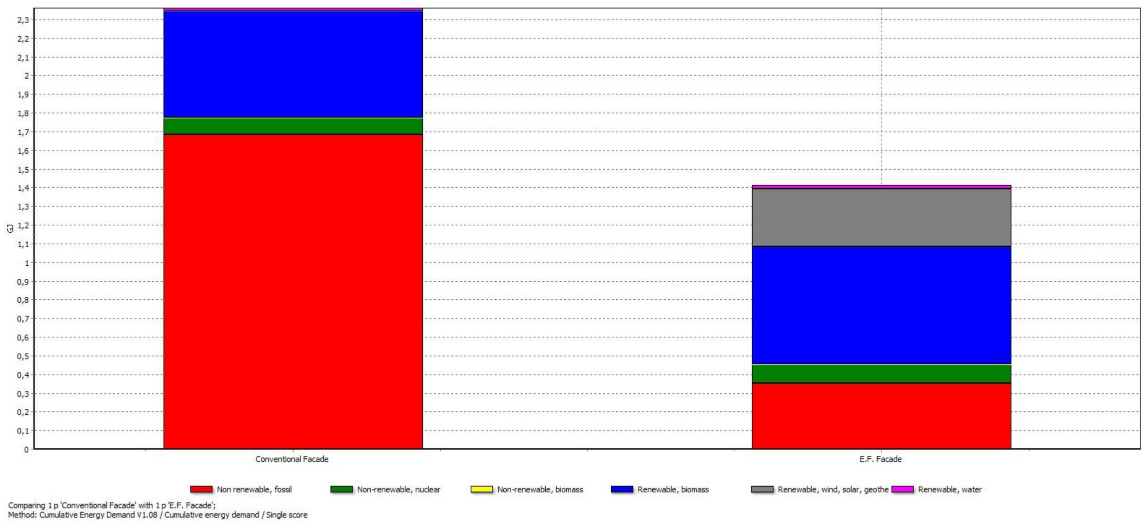

Figure 10, Single Score Comparison Cumulative Energy Demand V1.08

Looking into the general results is it possible to confirm what previously stated. For the conventional facade, the main contribution is due to bricks, Porotherm and façade bricks. The Porotherm brick has to be transported from Germany and, being the heaviest material it has a large influence in the results. For the environmental façade the OSB is the material with more energy consumed. Also the wood structure and wood facade has a relevant impact. They all has a very high percentage of recycling energy (see Appendix 5.41).

Greenhouse Gas Protocol V1.01

The other analysis method that was used was the Greenhouse Gas Protocol. This method focuses on CO_2-emissions, something that is becoming increasingly important in today's society and is also closely related to the energy use. This method shows in detail the CO_2 equivalent emissions divided in fossil, biogenic, relative to land transformation and finally absorbed. The Weighting comparison shows that the E.F. façade has lower emissions and higher uptakes of CO_2 equivalents than the conventional façade (see Figure 11).

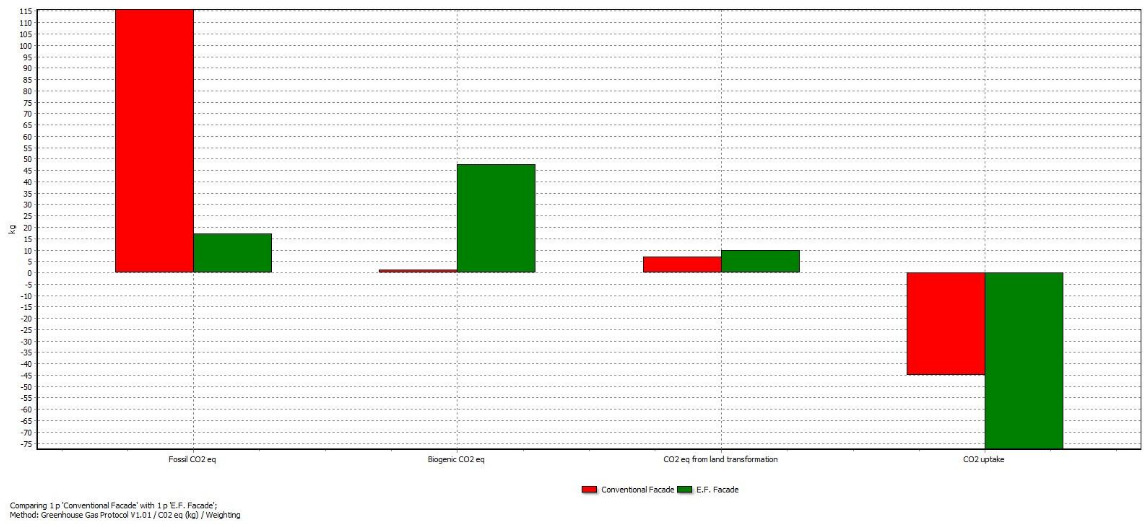

Figure 11, Weighting Comparison Greenhouse Gas Protocol V1.01

3.2 Comparison with the energy demand of a prototype-building

In order to understand the order of magnitude of savings with the overall energy demand of buildings, the results has been compared with the energy demand of a prototype villa placed in Stockholm. A commitment to use environmental materials could not be justified if what gained is not relevant for the whole building prospective. To the primary energy for the materials calculated with Simapro, has been added the operational energy to run the villa for all its lifetime.

Figure 12, Typical Villa in Sweden

The details of the energy simulation performed with the software Consolis Energy+ are reported in the Appendix 6.2 (Jóhannesson, 2005). The calculations do not take in consideration the other elements of the building, like roof, ground floor, windows, installations, hot tap water, electricity, etc…

The calculation result is an overall demand for one year of 65 kWh/m^2. Summing the heating and the cooling demand for the conventional and the E.F. façade, the result is respectively 59.8

kWh/m²yr and 63.3 kWh/m²yr. Although they are different, the hypothesis is that the thermal bridges of the first one are higher. Moreover the resistance of the external air for the environmental façade was not considered. In conclusion this has led to assume a final value of 65 kWh/m²yr common for both the façades.

The Table 7 shows the total energy demand of the two façades, excluding the usage phase calculated with the energy simulation program. The same values can be inferred by Figure 10.

Table 7, Energy demand calculated with SimaPro for production, maintenance and disposal

Impact category	*Unit*	*Conventional Facade*	*E.F. Facade*
Energy Demand	MJ	2361,5949	1412,3368
Savings	MJ	**949,2581**	

The total amount of operational energy has been deduced for a lifetime of 50 years (see Table 8). Electricity and hot tap water has not been considered because they are not attributable to the façade but to the occupant behaviour and the installations. The final value refers to the primary energy and assumes that the heat and cold are supplied by biofuel, whose conversion factor is 1.46MJ/MJ. Conversion from MJ to kWh is 0.2777778.

Table 8, Calculation of overall operational primary energy of the villa

Energy Consumption	65	*kWh/m²*
Years	50	
Floor Surface	144	*m²*
Facade Surface	158,4	*m²*
Usage phase	**683280**	*kWh*

Finally the usage phase energy has been summed to the energy related to the Production, Maintenance and Waste disposal of the two façades (PMW). Relatively to the total amount, it is possible to understand the contribution of this phase. Building with environmentally friendly materials leads to savings that account for 5.31% of the total energy compared to building with conventional materials (see Table 9).

Table 9, Energy Demand Incidence

	PMW	**Total**	**Ratio**
	kWh	*kWh*	**%**
Conventional ED	103910	787190	13.20%
Environmentally Friendly ED	62143	745423	8.34%
Savings	41767	**41767**	**5.31%**

$$Incidence = \frac{Savings}{Tot.En.CF} = \frac{41767\text{ kWh}}{787190\text{ kWh}} = 0.0531 = 5.31\%$$

If the same approach is applied to the other elements that make up the building and environmental materials are chosen over others more conventional, savings can reach one third of the PMW energy that is around 5% of the whole energy demand.

4 Conclusions and recommendations

The goal for this project was to answer the question *what is the overall environmental impact for an environmentally friendly façade and a conventional façade respectively?* Our study has shown that both façades have a certain amount of environmental impacts. According to the ReCiPe Midpoint H, they do both in particular have a negative effect on the Natural land transformation and Freshwater ecotoxicity. Results from the Cumulative Energy Demand method show that the conventional façade requires more Non-renewable energy and that the environmentally friendly façade requires more Renewable energy. Furthermore, the total energy demand is about 2/3 for the environmentally friendly façade compared to the conventional façade. According to the Greenhouse Gas Protocol method, the environmentally friendly façade emits less CO_2 during its lifetime.

When performing the waste disposal modelling, unexpected results came from the incineration process of the environmentally friendly façade. The authors expected an increase in recycling (and therefore incineration) as opposed to landfill to cause less environmental impacts. However, results indicated that increased incineration had a greater impact than disposal to landfill. The authors believe that this is probably due to methodological presumptions in the model given that avoided burdens were considered. These avoided burdens were *electricity from waste* and *heat from waste,* based on standard values in SimaPro.

Possible shortcomings in the data used for the waste disposal scenario, and recycling and incineration in particular, have been noticed. For future projects within this area, this is something that could be further improved. A LCA-study could be performed for each material in itself as they are complex.

The analysis of energy consumption showed that the choice of material does affect the energy demand of a building. By opting for environmentally friendly materials, it is possible to make savings of at least 7% compared to when conventional materials are used. Overall, it can be said that the choice of material greatly affects the environmental impact. This is true for general impact categories as well as energy demand and CO_2-emissions and it should therefore be done with consideration.

Recommendations

- More research about each material
- An increase of regulation and legislation within the deconstruction sector for buildings
- Develop standards for what is considered environmentally friendly within the building sector
- Develop site specific solutions for production of materials and waste disposal scenarios
- An economic LCC performed on this subject would be interesting to see and it would add yet another dimension the results.

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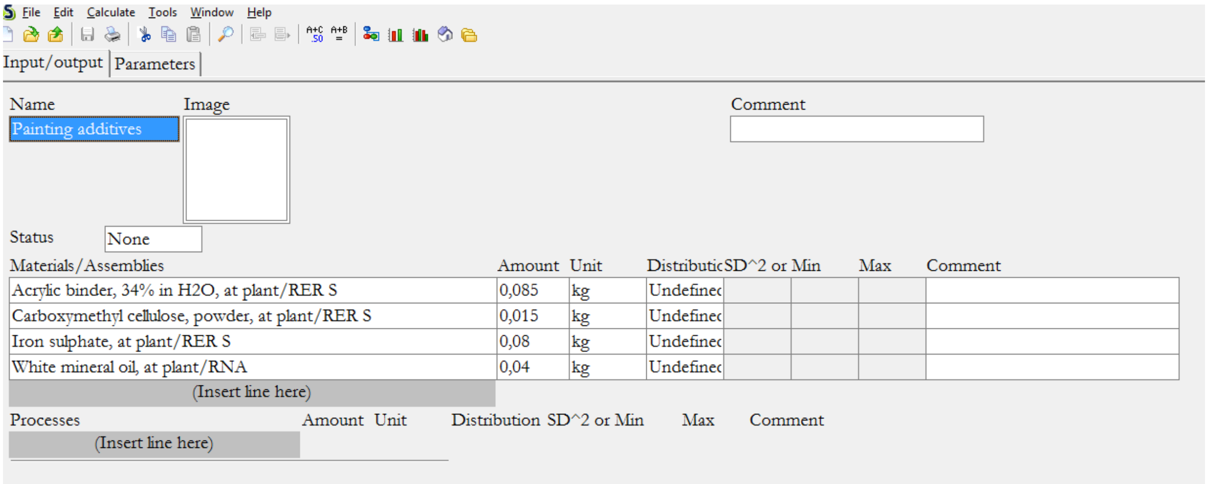
6 Appendix

6.1 Painting



File Edit Calculate Tools Window Help

Input/output | Parameters

Name: Painting additives

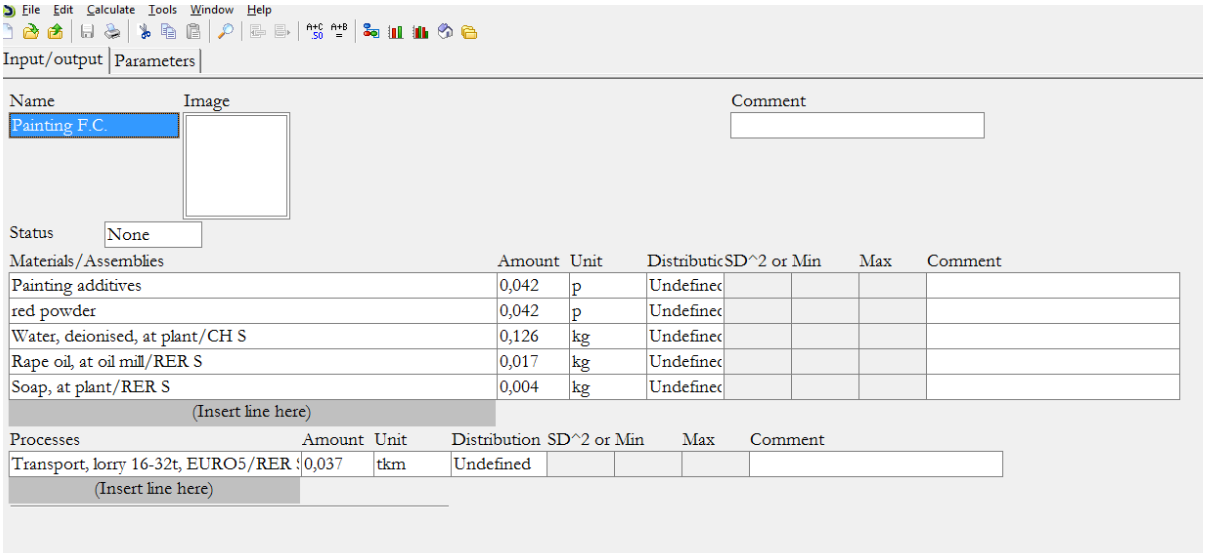
Image

Comment

Status: None

Materials/Assemblies	Amount	Unit	Distributic	SD^2 or Min	Max	Comment
Acrylic binder, 34% in H2O, at plant/RER S	0,085	kg	Undefinec			
Carboxymethyl cellulose, powder, at plant/RER S	0,015	kg	Undefinec			
Iron sulphate, at plant/RER S	0,08	kg	Undefinec			
White mineral oil, at plant/RNA	0,04	kg	Undefinec			
(Insert line here)						

Processes	Amount	Unit	Distribution	SD^2 or Min	Max	Comment
(Insert line here)						



File Edit Calculate Tools Window Help

Input/output | Parameters

Name: Painting F.C.

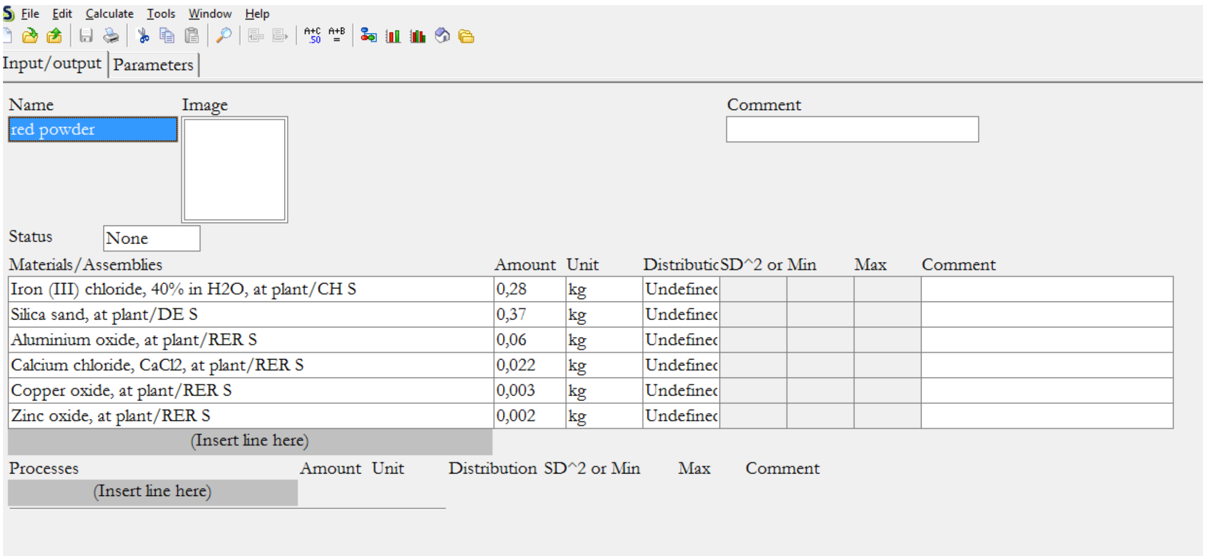
Image

Comment

Status: None

Materials/Assemblies	Amount	Unit	Distributic	SD^2 or Min	Max	Comment
Painting additives	0,042	p	Undefinec			
red powder	0,042	p	Undefinec			
Water, deionised, at plant/CH S	0,126	kg	Undefinec			
Rape oil, at oil mill/RER S	0,017	kg	Undefinec			
Soap, at plant/RER S	0,004	kg	Undefinec			
(Insert line here)						

Processes	Amount	Unit	Distribution	SD^2 or Min	Max	Comment
Transport, lorry 16-32t, EURO5/RER :	0,037	tkm	Undefined			
(Insert line here)						



File Edit Calculate Tools Window Help

Input/output | Parameters

Name: red powder

Image

Comment

Status: None

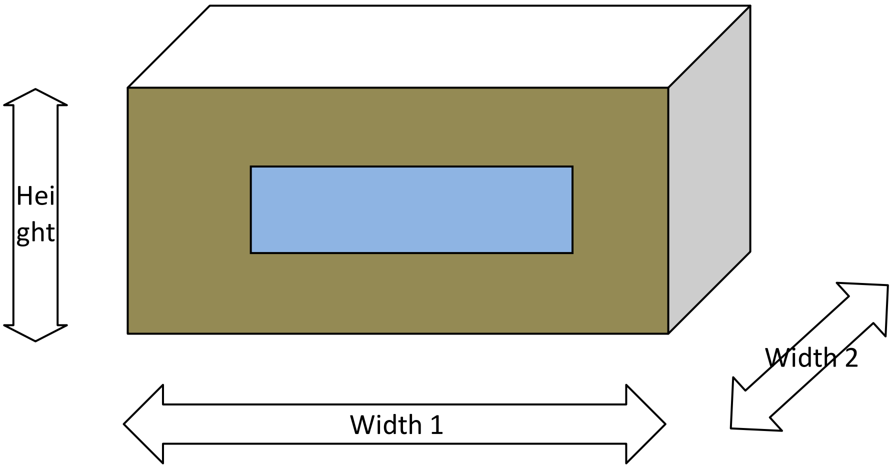
Materials/Assemblies	Amount	Unit	Distributic	SD^2 or Min	Max	Comment
Iron (III) chloride, 40% in H2O, at plant/CH S	0,28	kg	Undefinec			
Silica sand, at plant/DE S	0,37	kg	Undefinec			
Aluminium oxide, at plant/RER S	0,06	kg	Undefinec			
Calcium chloride, CaCl2, at plant/RER S	0,022	kg	Undefinec			
Copper oxide, at plant/RER S	0,003	kg	Undefinec			
Zinc oxide, at plant/RER S	0,002	kg	Undefinec			
(Insert line here)						

Processes	Amount	Unit	Distribution	SD^2 or Min	Max	Comment
(Insert line here)						

6.2 Energy Simulation

To calculate the overall energy demand of the single-family building placed in Stockholm has been used the software Consolis Energy+. The values adopted are standards suggested by the program.

6.2.1 Geometry



Input Parameters	
Height [m]	4
Width 1 [m]	12
Width 2 [m]	12

	Facade S	**Facade W**	**Facade N**	**Facade E**	**Total**	**Horizontal**
Walls Area [m2]	48	48	48	48	192	144
Windows percentage	20	20	10	20	-	0
Windows Area [m2]	9.6	9.6	4.8	9.6	33.6	0

Building global	
Perimeter [m]	48
Ground area [m2]	144
Roof area [m2]	144
Perimetral walls area (including windows) [m2]	192
Volume [m3]	576

6.2.2 Input data

		Conv.	E.F.	
Temperature inside	Min	21	21	^0C
	Max	25	25	^0C
Hot solar screening angle		5	5	
Mean effect of internal heat load		5	5	W/m^2
Internal heat load profile		1	1	
Heated floor area		12	12	m^2
Ground area (Footprint)		12	12	m^2
Perimeter against the free		12	12	m

Ventilation

	Towards ambient atmosphere		
Ventilation flow in	52.00	52.00	
Ventilation flow out	52.00	52.00	
Leakage flow (At 50 Pa pressure)	35.00	35.00	
Air leakage at 50 Pa q_{50}	11.00	11.00	l/s
Temperature efficiency outlet air	0.6	0.6	
Temperature efficiency inlet air	0.6	0.6	
Electricity use for property and household	37.28	37.28	kWh/m2yr
Energy use for domestic hot water	30.50	30.5	kWh/m2yr

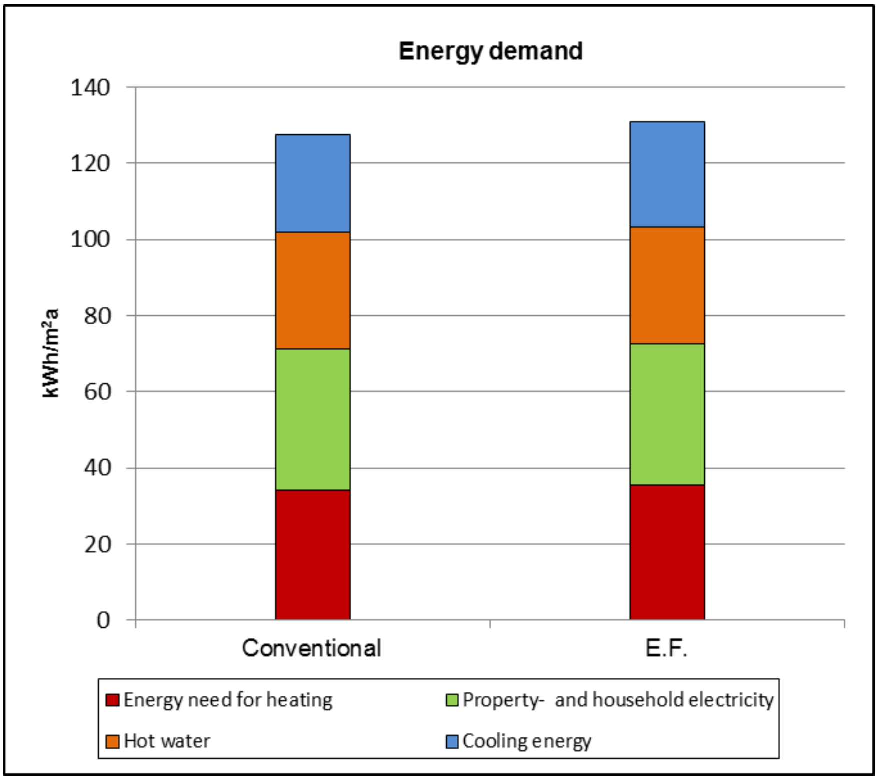
6.2.3 Materials

Traditional wall			
Materials	**Thickness [m]**	**λ [W/mk]**	**R=S/ λ [m²k/W]**
Internal Air			0,13
Plaster with gypsum	0,02	0,7	0,029
Brick blocks 24,8x30x24,9 plan type POROTHERM T12	0,3	0,126	2,381
Vapor barrier	0,0002		0,000
Expanded polystyrene insulation	0,16	0,037	4,324
Bricks (250x60x62) associated with mortar	0,06	1	0,060
External air			0,040
	Total R		**6,964**
	Transmittance U [W/m²K]		**0,144**

Passive wall			
Materials	**Thickness [m]**	**λ [W/mk]**	**R=S/ λ [m²k/W]**
Internal Air			0,13
Gypsum board	0,0125	0,21	0,060
Wood substructure (5x3)	0,05		
Air	0,05		0,180
Oriented Strand Board	0,011	0,15	0,073
Vapour barrier	0,0002		0,000
Wooden Structure (45x195)	0,195	0,15	1,300
Insulation in cellulose	0,195	0,04	4,875
Oriented Strand Board	0,011	0,15	0,073
Insulation in fibre wood	0,06	0,039	1,538
Air	0,03		0,180
Wood substructure (5x3)	0,03		
External façade (22x95)	0,022	0,15	0,147
External air			0,040
	Total R		**6,970**
	Transmittance U [W/m²K]		**0,143**

6.2.4 Results

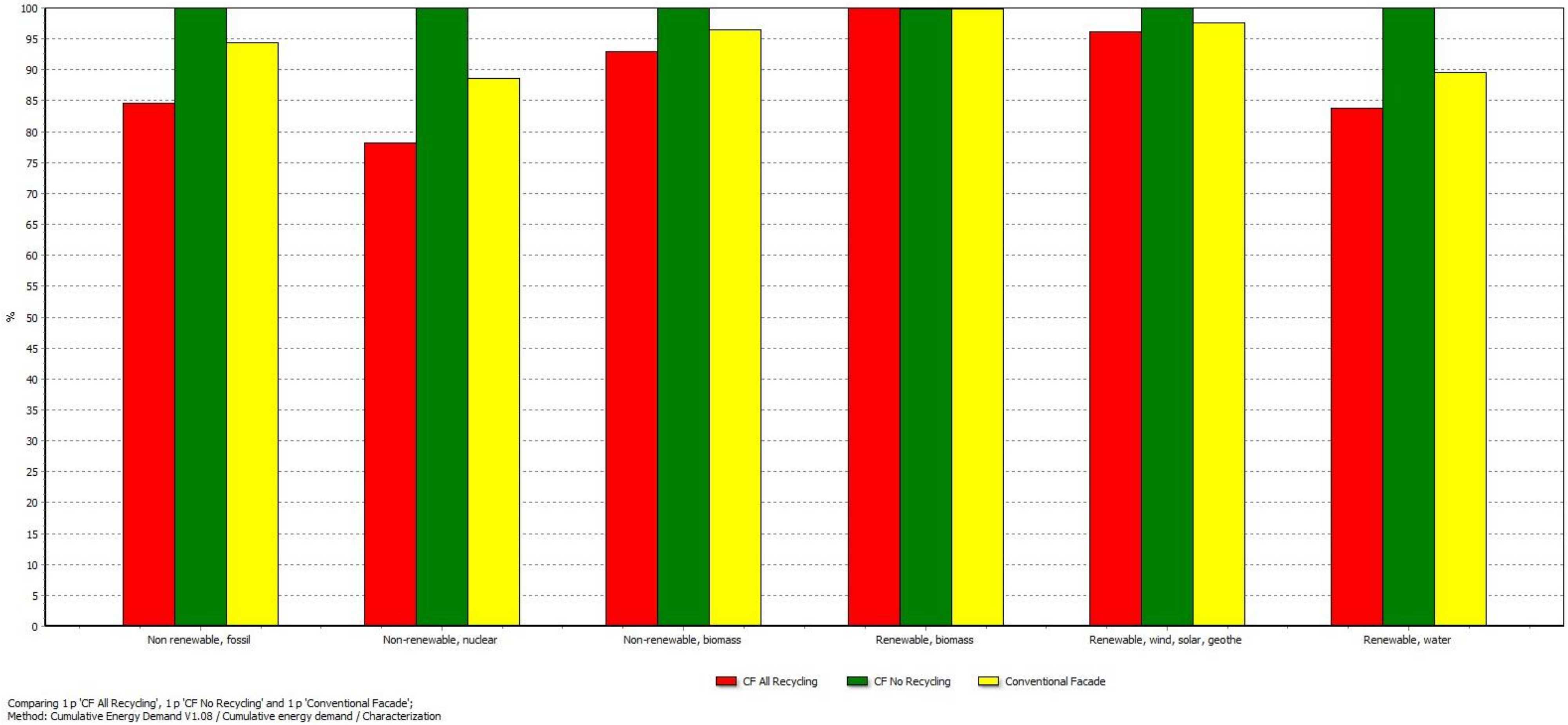
Calculation according to ISO 13790*		
	Conventional	**E. F.**
Energy need for heating	36.9	41.0
Property- and household electricity	37.3	37.3
Hot water	30.5	30.5
Total	104.6	108.8
Surplus energy (indication)	23.5	23.5
Calculation according to the dynamic method		
	Conventional	**E. F.**
Energy need for heating	34.0	35.4
Property- and household electricity	37.3	37.3
Hot water	30.5	30.5
Total	101.8	103.2
Cooling energy	25.7	27.8



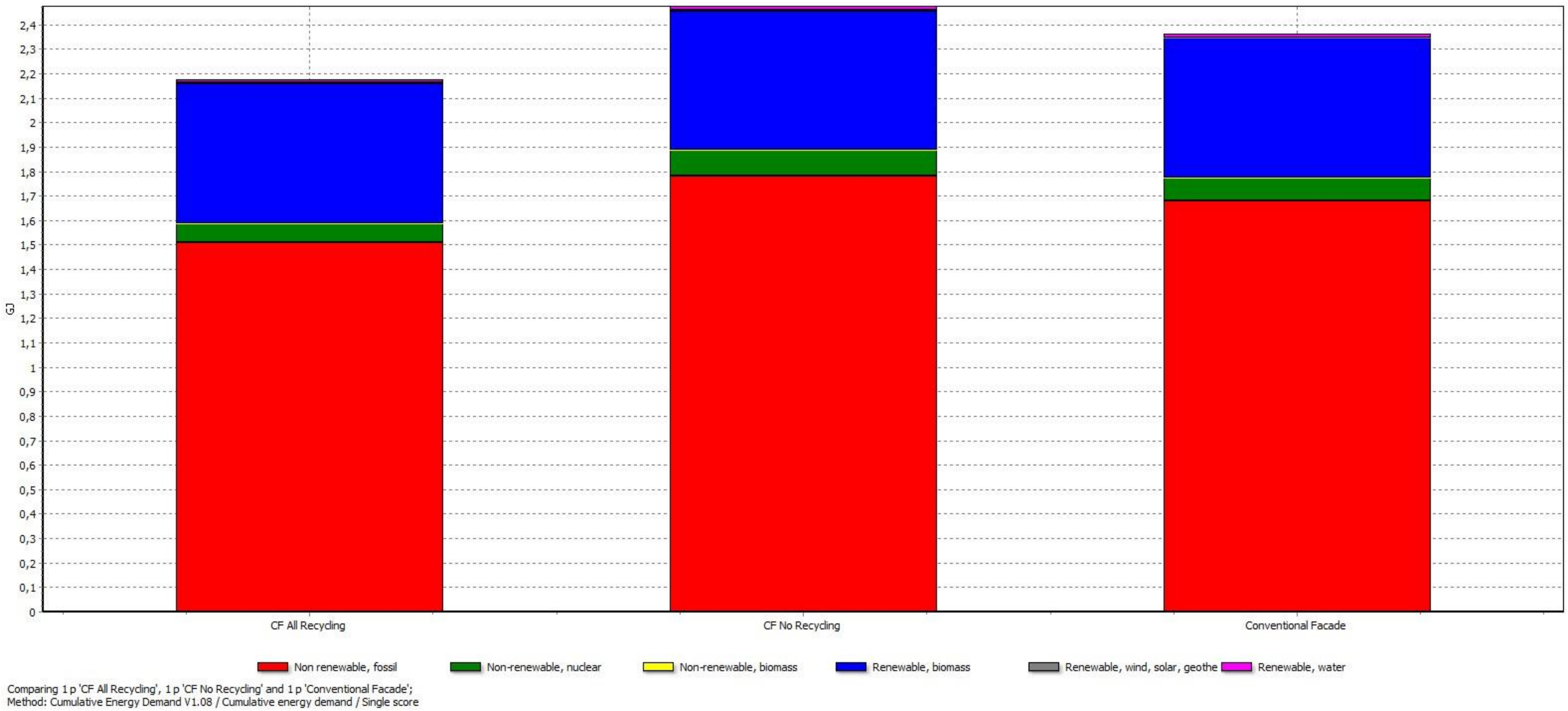
6.3 Sensitivity Analysis

6.3.1 Conventional Façade

Characterization Comparison: Standard, All Recycling, No Recycling

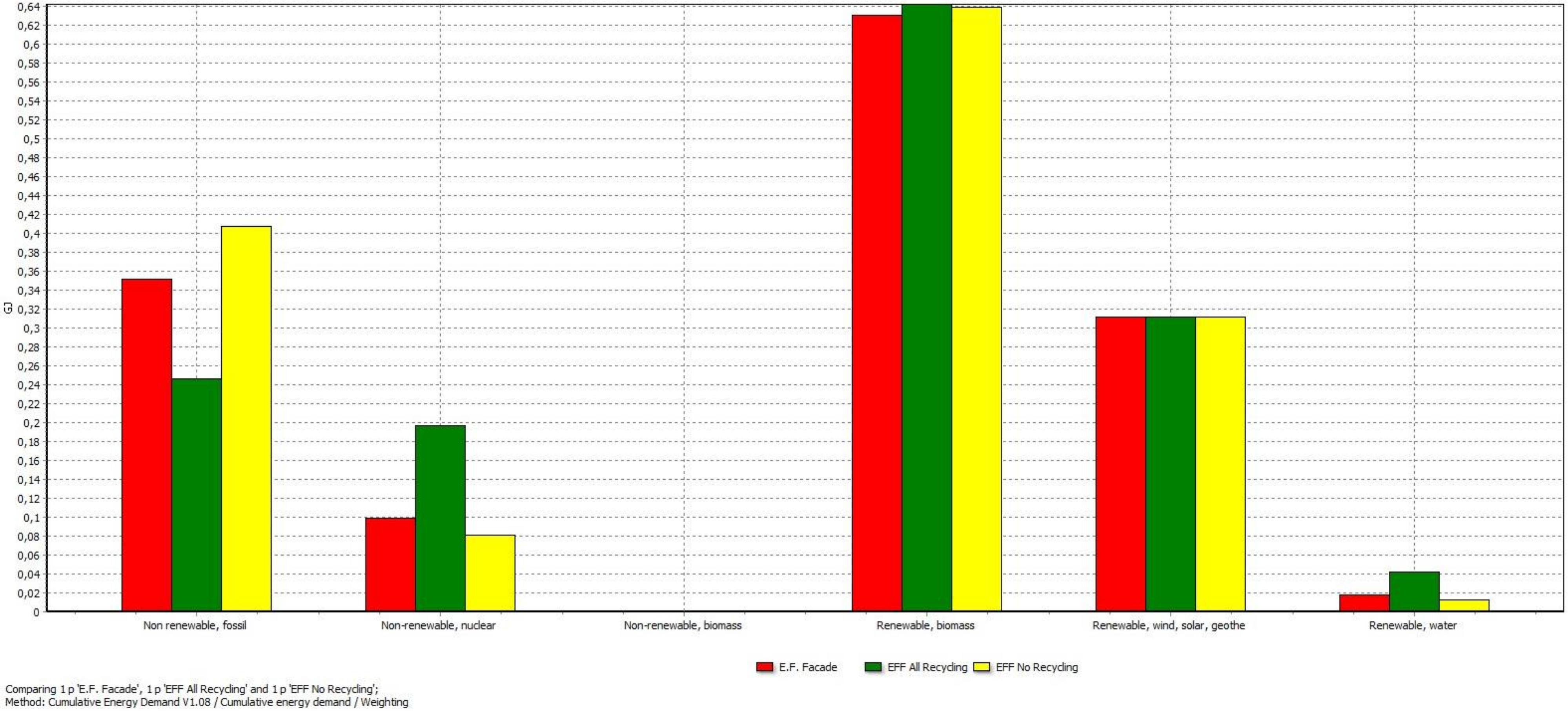


Single Score Comparison: Standard, All Recycling, No Recycling

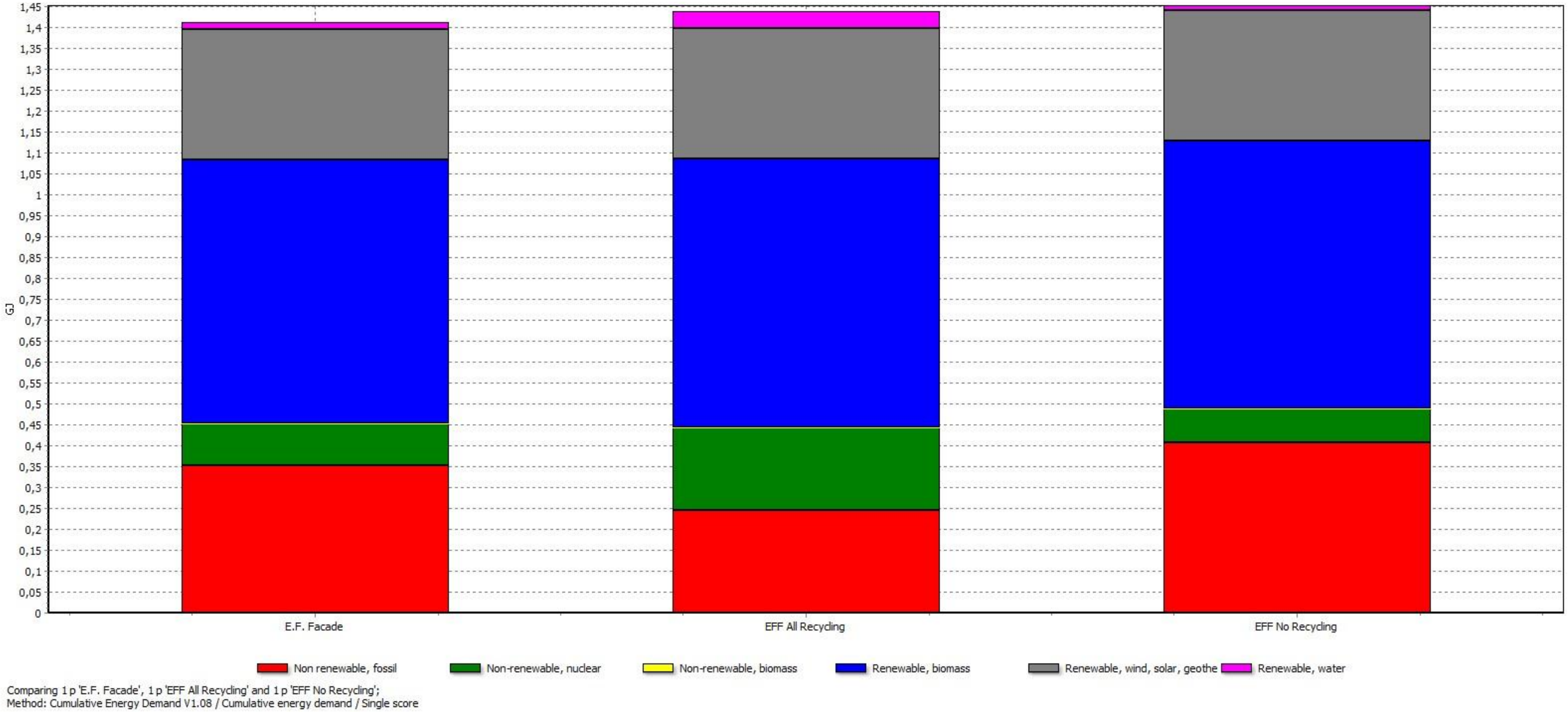


6.3.2 Environmentally Friendly Façade

Weighting Comparison: Standard, All Recycling, No Recycling



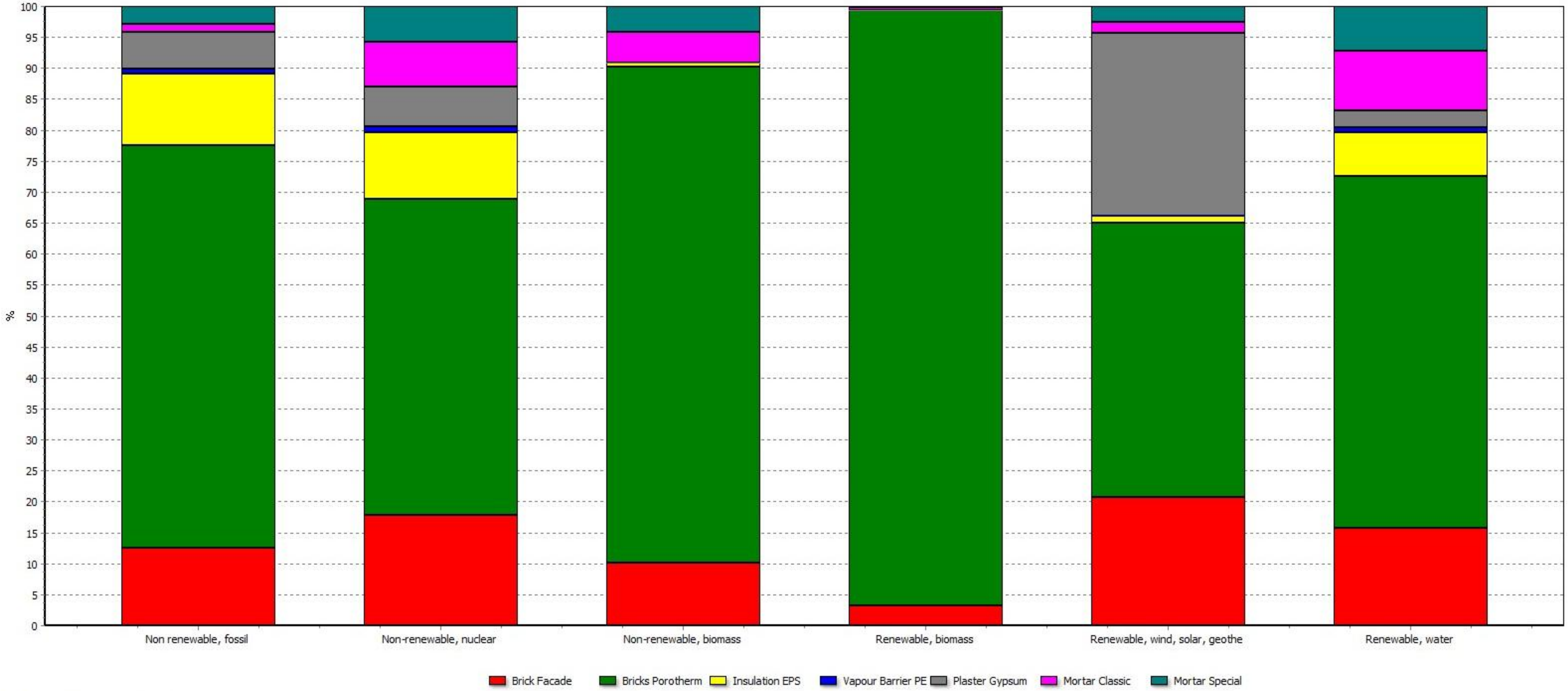
Single Score Comparison: Standard, All Recycling, No Recycling



6.4 Assembly Results

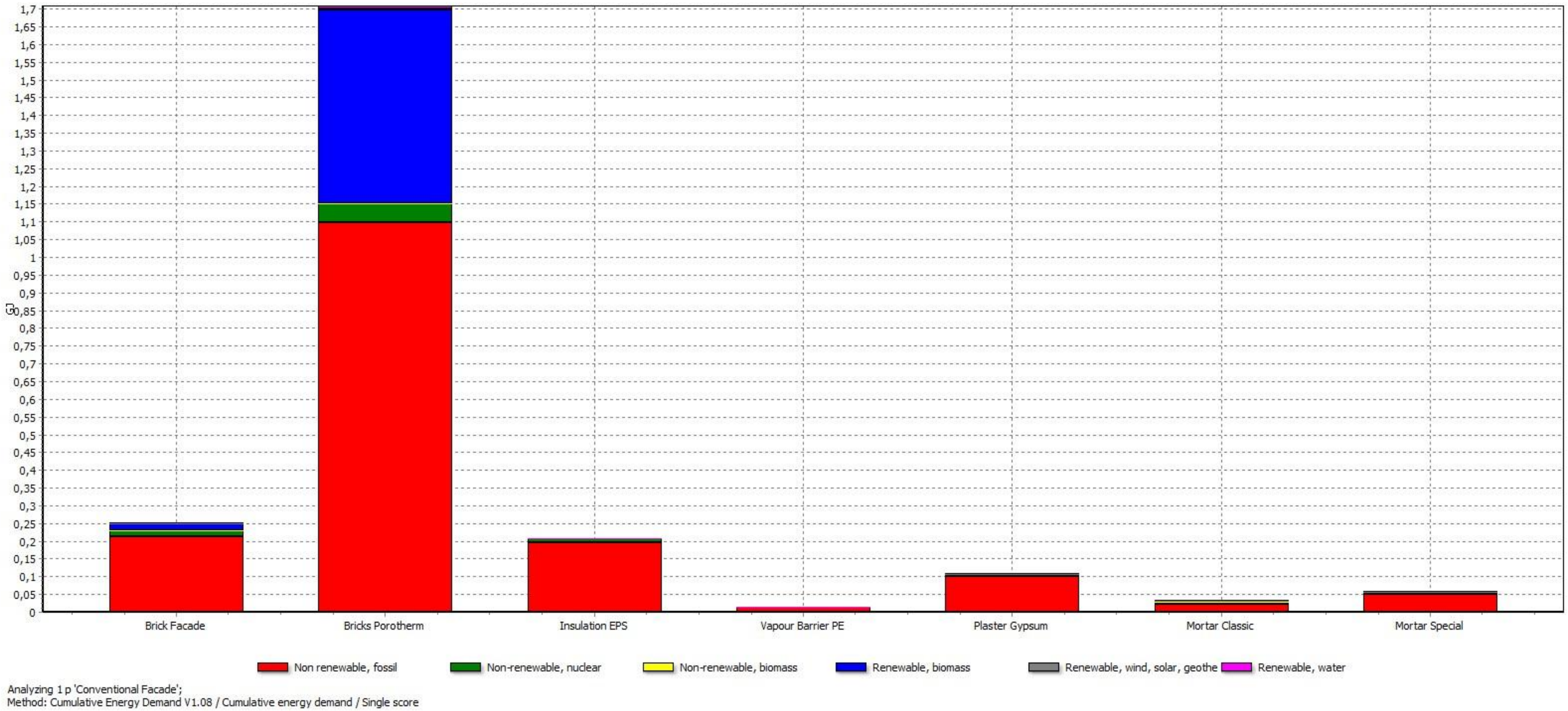
6.4.1 Conventional Façade

Characterization Comparison

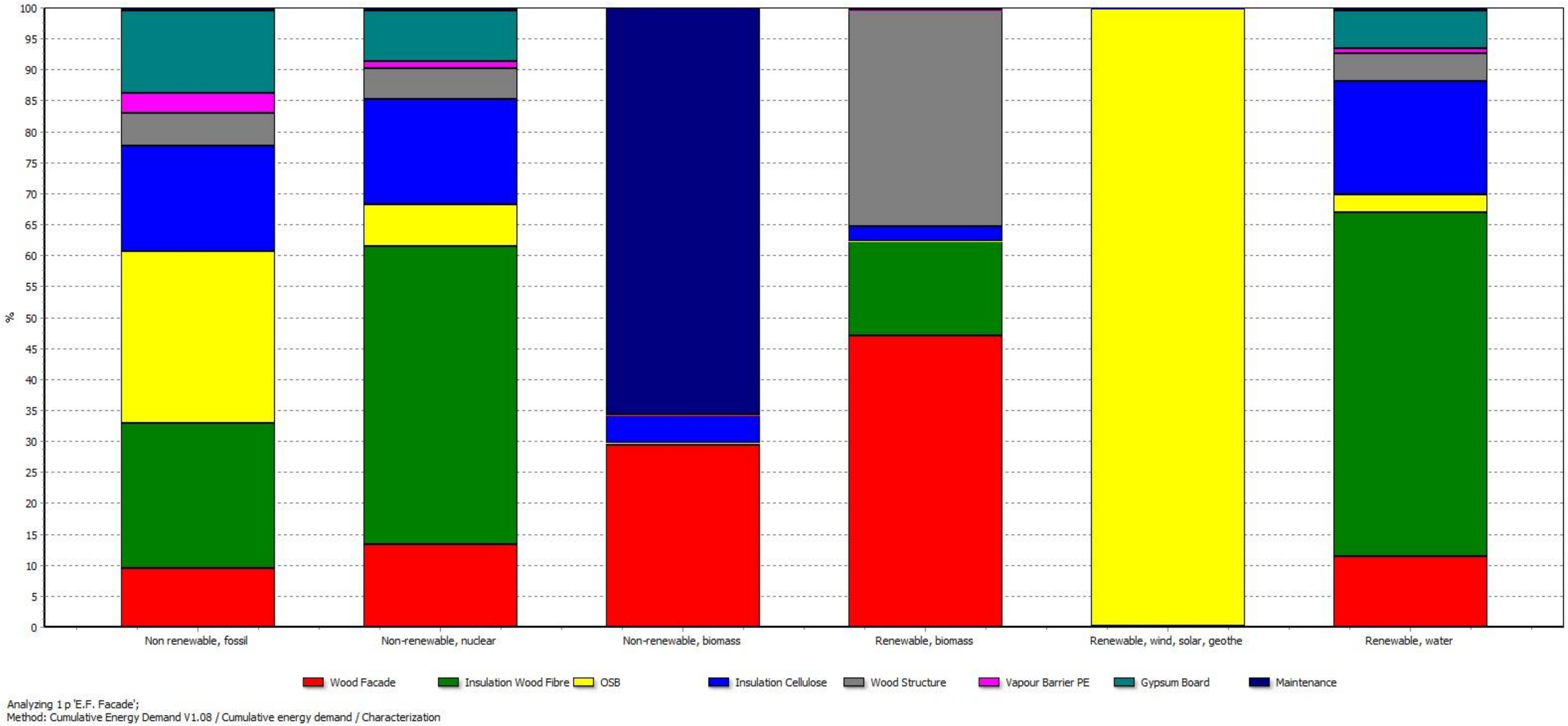


Analyzing 1 p 'Conventional Facade';
Method: Cumulative Energy Demand V1.08 / Cumulative energy demand / Characterization

Weighting Comparison



Characterization Comparison



Weighting Comparison