Life-Cycle and Sustainability of Civil Infrastructure Systems – Strauss, Frangopol & Bergmeister (Eds)

Ecological and economic impact of various materials and constructions for buildings over the whole life-cycle

A. Hafner & S. Winter
Chair of Timber Structures and Building Construction, Technische Universität München, Munich, Germany

ABSTRACT: This work looks at the environmental and economic effects of different materials and constructions in the complete life cycle of buildings. The evaluation was carried out on a reference building with an array of construction methods. The comparison of the various standard constructions for the complete life cycle showed only minor differences in both environmental and economic aspects. This means, that the impact of the operation period is far bigger (70 to 90%) today than the construction itself. Differences in the materials are small and will only have an effect, if energy efficiency is increased to a high level. Because of these results the different construction principals were also compared without operation period and maintenance to locate the differences in materials. Here for example the massive timber construction comes forward in the categories of global warming potential and renewable primary energy.

1 INTRODUCTION

Calculations of life cycle assessment and life cycle cost are becoming increasingly important in the building process, mainly due to the rise of sustainability certifications in the building sector. There is a wide range of different studies available in this field, looking at the influence of different materials in buildings and their embodiment in life cycle analysis. Most of the studies are driven by particular interests of the commissioning material lobby. Different determining factors make comparison of studies impossible.

This paper looks at the environmental and economic effects of different materials and constructions in the complete life cycle of buildings. A single building is used for reference, with the same determining factors for all constructions. The calculations are not carried out for general purpose and not any lobby-group in particular.

2 BOUNDARIES

2.1 *Method*

The evaluation was carried out on a reference building - a two story detached family house (Sohm 2009). Only the building is used in the calculations, the outdoor space is not taken in account. Necessary installations on the site outside the house for sewage, etc. are not included. For the building an array of construction methods is considered and calculated. The construction methods are as follows: solid construction with timber framing, massive timber construction, thermal insulation composite system and brickwork. A standard construction for each construction method is defined and a comparable quality of the thermal building envelope is always considered.

The calculations are carried out with the computer tool LEGEP. The program LEGEP is a tool for integral life cycle analysis in the building sector.
With this tool it is possible to calculate the costs and the environmental impacts over the whole lifecycle. All calculations can be conducted for the whole lifecycle or separated as individual phases like erection of building, operation, cleaning, maintenance und end of life.

The tool works with a database system and is separated into five modules: building costs, lifecycle costs, heat and energy, environmental and economic efficiency. All data complies with German codes. This means: building costs are regulated according to DIN 276, operation costs according to DIN 18960. There are various data basis available for environmental calculations like for example Ecoinvent from Switzerland and ökobau.dat from Germany. They have in parts a different dataset stored in the data base and differ to a certain extent in allocation. Here the ökobau.dat is used as environmental data. Ökobau.dat is a comprehensive data basis for ecological evaluation of buildings the assessment of sustainability and published by the Federal Ministry of Transport, Building and Urban Development (BMVBS). Its freely available and is maintained by the BMVBS. For building certifications this database is compulsory in Germany and therefore was used.

LEGEP is organised hierarchically (König 2009). The life cycle inventory data is, at basic level, integrated in the program, followed by material data, positions, working time and costs. It is possible to work with fine subdivisions in material layers or on a large-scale with macro elements like window or roof structure. This depends on the design stage. All calculation results can be looked at any time. The analysis can be made for the whole life cycle or divided into the different stages of the life cycle and ecological categories.

The advantage of LEGEP is that it is an integral planning tool. Building information is put into the program once and is held and changed on a central position in the program. All elements in the data base do already have the essential information attached for environmental and economic calculations. After the building is entered and the necessary information on elements and quantities are provided, it is possible to evaluate life cycle costs, and environmental calculations.

The results in life cycle analysis includes global warming potential (GWP), acidification potential (AP), primary energy renewable (PE e) and non renewable (PE n.e.) In addition to this, the weight of the construction is always calculated. The economic calculations are worked out in Euros.

2.2 *Lifecycle*

The following phases are calculated: erection of building, utilization phase, end-of-life. The phase of utilization includes the operation of the building and the services and maintenance of the construction over a period of 80 years.

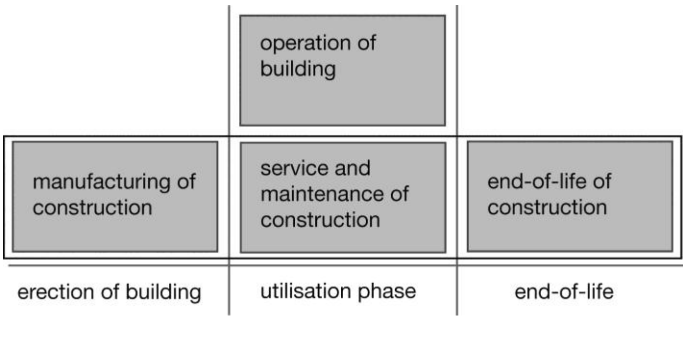


Figure 1. Phases in the life cycle to understand the allocation in the calculations.

In the production phase all materials are calculated with their environmental impact. The basis for this calculation is the Ökobau.dat, which refers to environmental product declarations, and in part verified LCA calculations.

End-of-Life data is solely available for environmental assessment due to a lack of reliable data in the economic calculations of future end-of-life scenarios.

The possible end-of-life scenarios for environmental assessment are recycling (for metal), energy recovery (wood, plastic), landfill, demolition and waste conditioning.

In the operation of the building, the energy for heating, ventilation etc. is calculated over 80 years. The building envelope is relevant for energetic level, together with the building equipment. The reference building is calculated around 65 kWh/m²a. The cleaning of the building is also part of the operation. Maintenance of the construction means that various materials have to be replaced after a set number of years. In Germany the durability of the different materials is defined by the BMVBS – see public available durability sheets (BMVBS 2011). The cycles stated there, are used in the calculations. This means for example that wooden weather boarding has to be replaced after 40 years. This causes output in the end of life for both the existing construction and the new material with its environmental footprint. Both phases have to be calculated in environmental and economic terms.

3 GENERAL CONDITIONS

3.1 *Reference building*

The evaluation was carried out on a reference building with numerous of construction methods. The various construction methods are explained in detail in 3.2. The reference building is a two story detached family home without basement; floor plans and elevations are shown in figure 2 and 3. Firstly a standard construction for all four methods is established. Then the reference building is calculated for the four construction methods with the floor plans, the cubature, roof style. The technical specifications of building equipment is always the same. For ventilation, sanitary and electrical installation standard finish is included.

All the buildings have the same construction of floor slab – concrete with insulation. The windows are made of timber/aluminium, the doors made of timber and the flooring is made of wood/ tiles. Although the construction of walls and roofs may vary slightly, the energetic standard for all variations is almost the same. The roof is always made with timber rafters and insulated with mineral wool in between. For heating, a gas fired central heating is used.

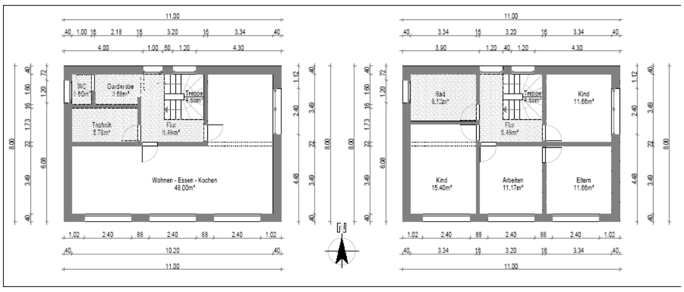


Figure 2. Reference building, ground floor, first floor.

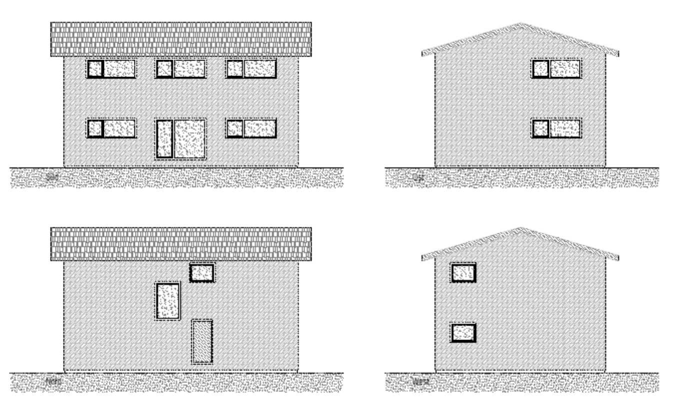
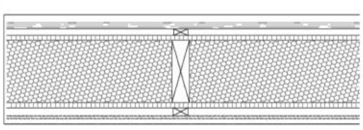


Figure 3. Reference building elevations.

3.2 *Construction methods*

The construction methods were as follows: timber framing (EL), massive timber construction (MH), external wall with external thermal insulation composite system (DF) and masonry construction (ES). A standard construction for each construction method was developed. The layer constructions for the different external walls are shown in figure 4 to 7.

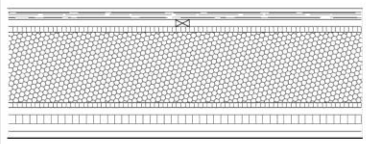
The first construction is a timber framing (figure 4) with timber framing walls as interior walls also. The ceiling is a wooden beam ceiling with wooden floor on top.



external wall	U = 0,20 W/m²K	
EL - elemet construction	*thickness*	*building materials*
	22 mm	bevel siding / weather boarding
	24 mm	lathing 24/48 / battening
	19 mm	softboard
	240 mm	wooden support 60/240 + mineral wool
	19 mm	OSB
	30 mm	lathing 30/50 + air space
	12,5 mm	gypsum plasetrboard

Figure 4. Construction of external wall element construction (EL).

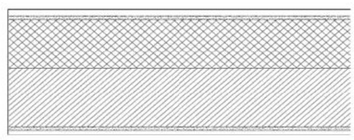
The second construction is a massive timber construction with cross laminated timber elements as bearing structure for the external walls (figure 5) and the ceiling.



external wall	U = 0,17 W/m²K	
MH – massiv timber construction	*thickness*	*building materials*
	22 mm	bevel siding / weather boarding
		vapor barrier / retarder
	24 mm	lathing 24/48 + air space
	19 mm	softboard
	240 mm	wooden support 60/240 + mineral wool
	15 mm	OSB
	80 mm	cross laminated timber

Figure 5. Construction of external wall massive timber construction (MH).

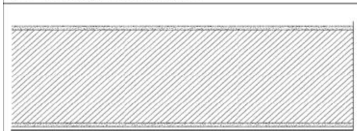
The third construction is a construction built with lime-sand bricks and external thermal insulation composite system for external walls (figure 6) and concrete ceiling.



external wall	U = 0,22 W/m²K	
DF – external thermal insulation composite system	*thickness*	*building materials*
		silicate coating
	12 mm	lime-cement plaster
	200 mm	mineral wool
	240 mm	lime-sand brick λ=0,70
	19 mm	thin plaster
		silicate paint

Figure 6. Construction of wall with external thermal insulation composite system (DF).

The fourth construction is an masonry construction for the external walls (figure 7) with vertical coring bricks and concrete ceiling.



external wall	U = 0,19 W/m²K	
ES – masonry construction	*thickness*	*building materials*
		silicate coating
	23 mm	lime-cement plaster
	490 mm	vertical coring brick
	20 mm	mortar plaster
		silicate paint

Figure 7. Construction of external wall masonry construction (ES).

4 RESULTS

4.1 *Comparison of the compete life cycle*

The environmental calculations were carried out for the following impact categories: global warming potential, acidification potential, renewable primary energy and non-renewable primary energy. Economic calculations were divided into the life cycle stages of construction of the building, operation, cleaning, servicing and maintenance. The calculations were conducted for the whole life cycle and inputs from the construction of the building, the utilisation phase of 80 years and end-of life.

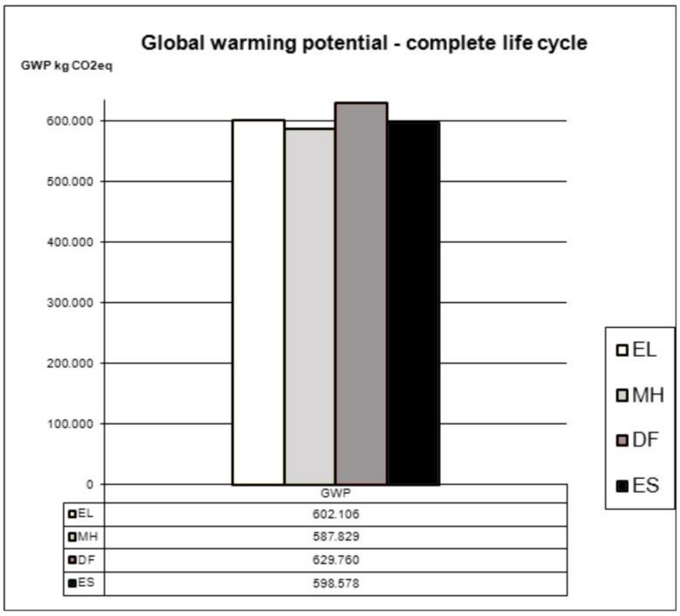


Figure 8. Different constructions in terms of global warming potential– complete life cycle.

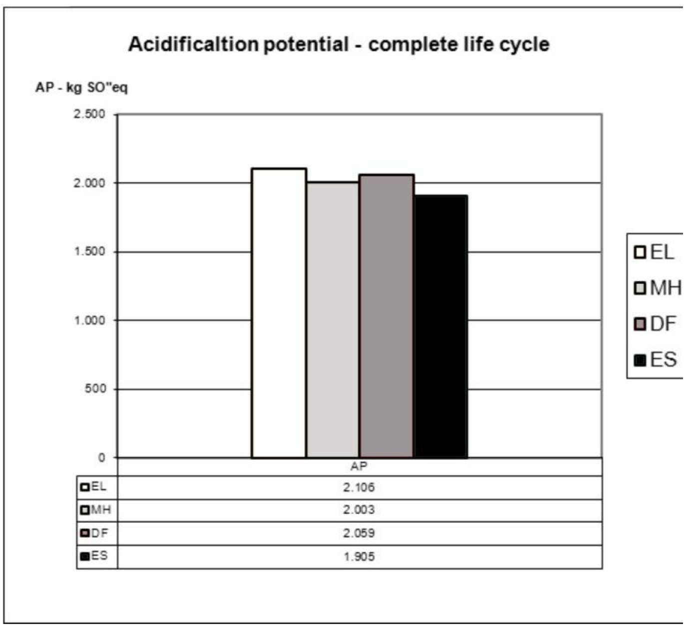


Figure 9. Different constructions in terms of acidification potential – complete life cycle.

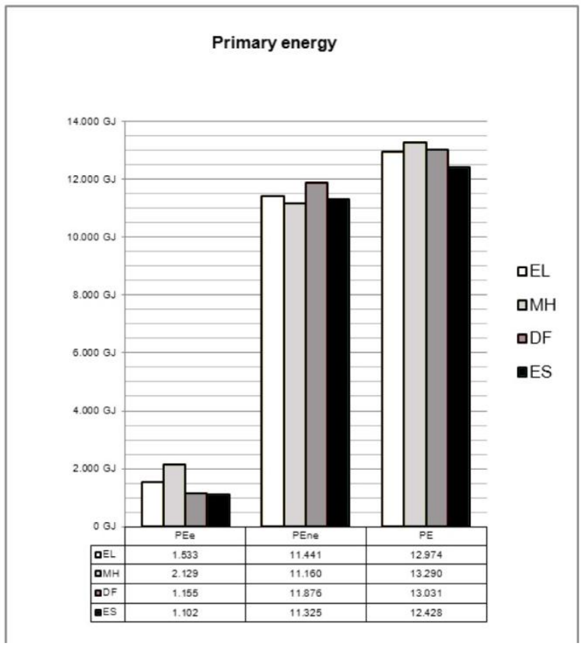


Figure 10. Different constructions in terms of primary energy renewable and nonrenewable – complete life cycle.

Figure 8 and 9 show the differences in the constructions in terms of global warming potential and acidification potential. The differences over the whole life cycle in these categories are only a few percent. These calculations do not lead to favor certain constructions. The comparison in primary energy (figure 10) shows an increase in primary energy renewable for timber constructions and especially for the massive timber construction. The categories primary energy non renewable and primary energy altogether are very similar in output. The visual rise in renewable energy of wooden constructions can be explained with the calorific value of wood included in the calculations [4]. On the part of primary energy nonrenewable and there are no major differences.

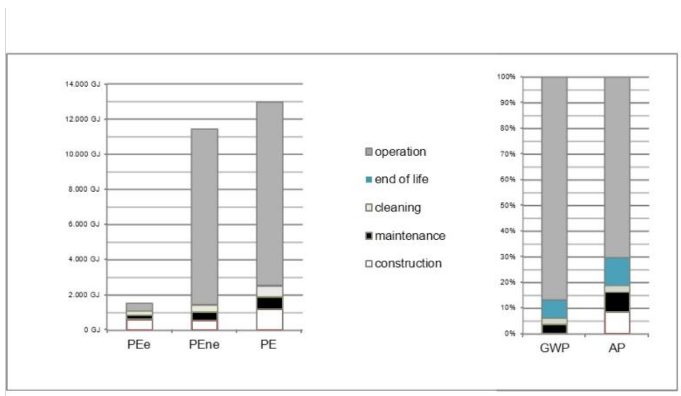


Figure 11 Allocation of primary energy renewable and nonrenewable and global warming potential and acidification potential in the life cycle phases.

The graph on figure 11 and 12 shows, that in terms of primary energy and global warming potential the main output can be seen in the operation phase.

The costs are calculated over the complete life cycle and therefore only account for minor differences in the various constructions.

4.2 *Conclusion of comparison*

The comparison of the various standard constructions for the complete life cycle only shows minor differences (in between 1-3%) in both environmental and economic aspects. This means, that the impact of the operation period is far bigger (70 to 90%) today than that of the construction itself. Differences in the materials are small and will only have an effect, if energy efficiency is increased to a very high level.

4.3 *Comparison of the production phase only*

The small differences in the environmental calculations meant, that the construction principals were also compared without operation period and maintenance to locate the differences in material itself. Comparisons are shown below.

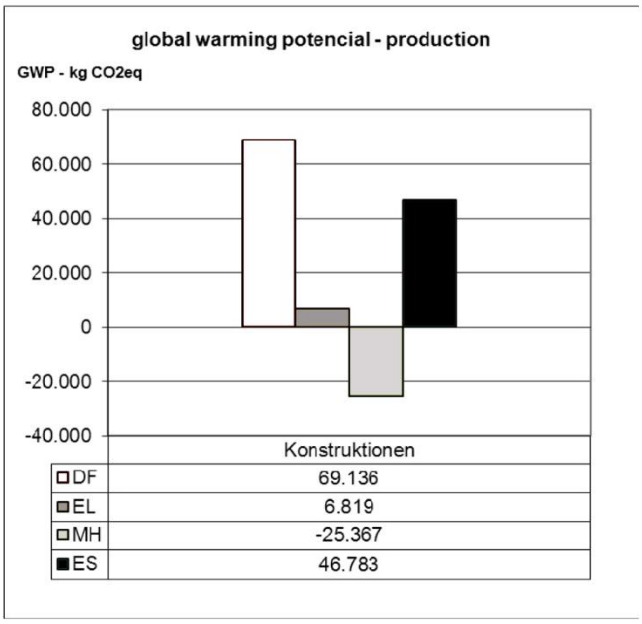


Figure 13. Different constructions in terms of global warming potential – comparison production phase.

Massive construction stands out in terms of global warming potential because of its negative impact. This is due to the energy stored in the wood (carbon storage).

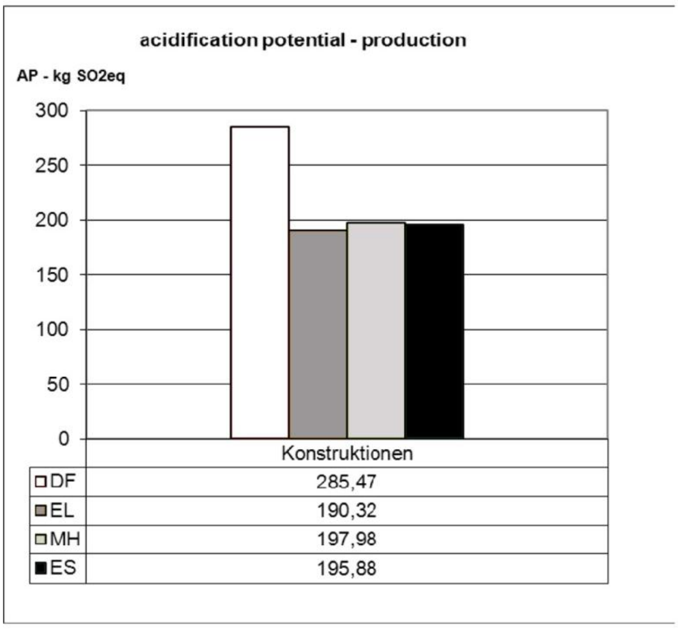


Figure 14. Different constructions in terms of acidification potential – comparison production phase.

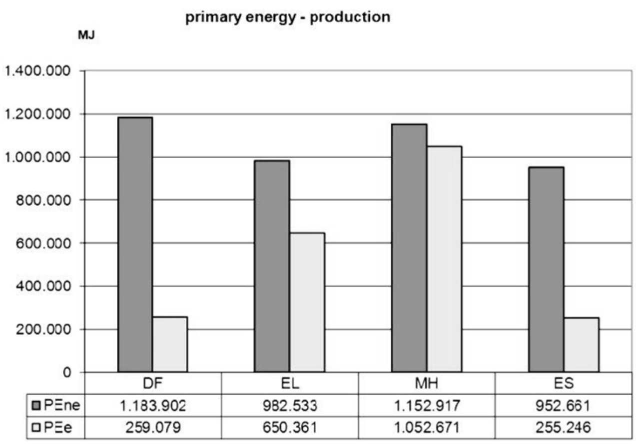


Figure 15 Different constructions in terms of primary energy non-renewable and renewable – comparison production phase.

4.4 *Variations in construction*

The reference building with the element construction (EL) was utilised to find out differences in insulation material and cladding material in terms of environmental and economic issues. In order to do this, the construction of the reference building was used, but the insulation of the exterior wall was exchanged. Separate calculations for the use of mineral wool, cellulose, softboard and polystyrene were obtained. Results are shown in the table below.

Isolation: Here the construction with soft boards comes forward in the categories of GWP and renewable primary energy. This is due to the stored carbon in the softboard. This stored carbon will be released at the end-of-life of the construction. In the categories of acidification potential there are no mayor differences.

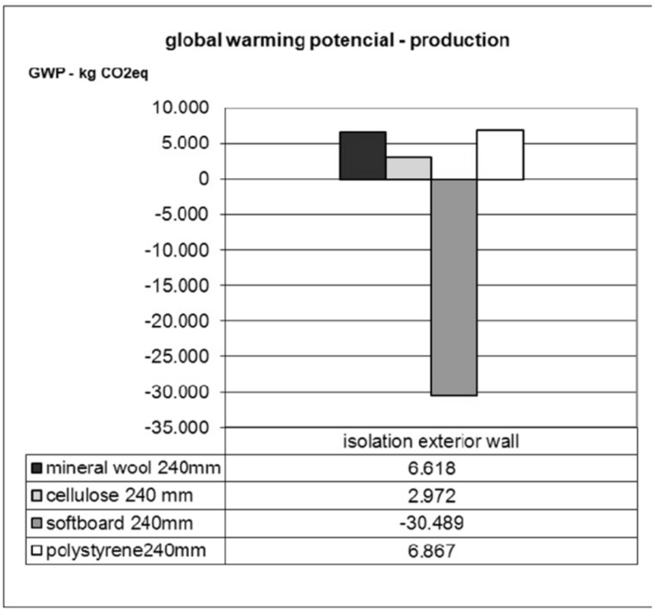


Figure 16. Different insulation material: global warming potential– comparison production phase only.

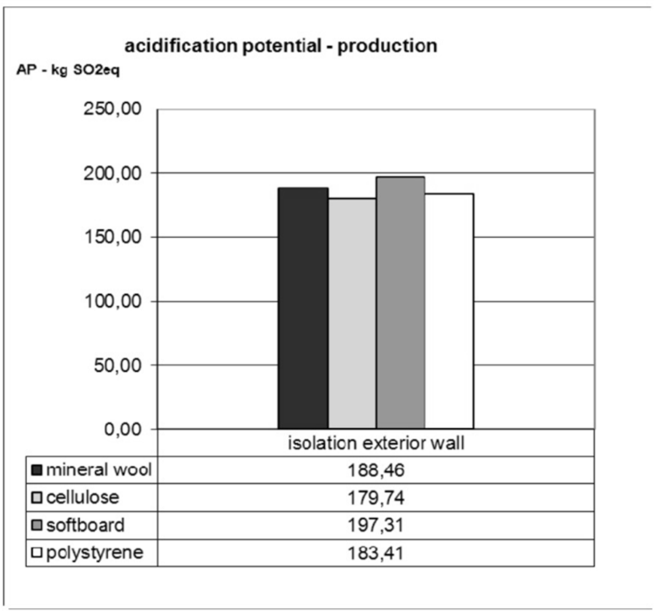


Figure 17. Different insulation material: acidification potential – comparison production phase only.

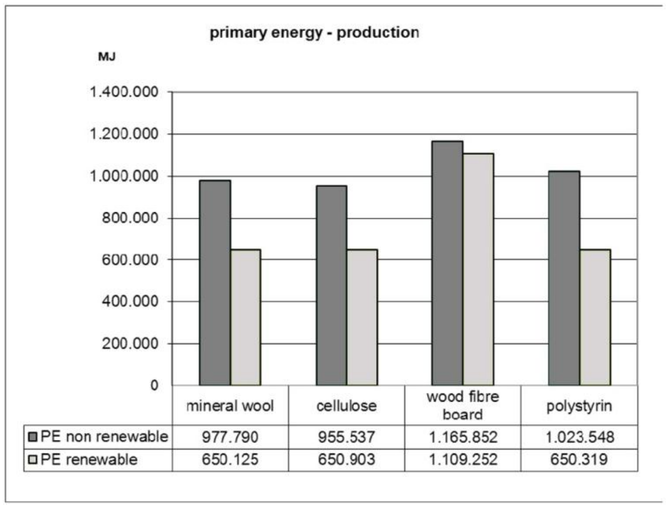


Figure 18. different isolation material: primary energy non-renewable and renewable – comparison production phase only.

Façade surfacing: Different materials were compared for the façade surfacing. They were as follows: bevel siding, fibre-cement and plaster. Results are shown in the table below. The only relevant difference is the global warming potential. The other criteria are very similar.

There are no major differences in the overall output, as the façade surfacing has only a minor mass of the whole building.

The important factors for environmental impact are primary construction and the construction material of exterior walls (construction and insulation)

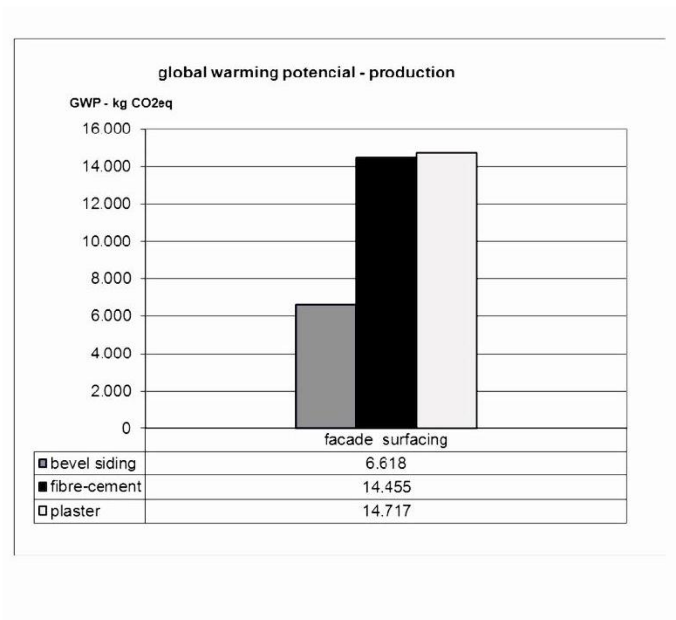


Figure 19. different façade surfacing: global warming potential– comparison production phase only.

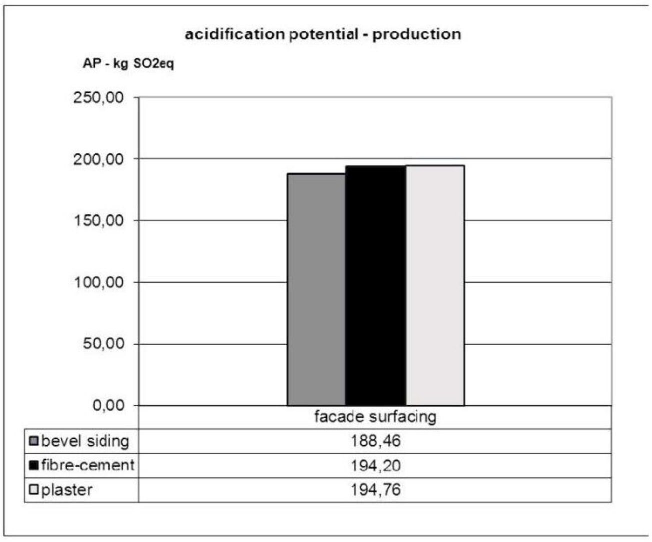


Figure 20. Different façade surfacing: acidification potential – comparison production phase only.

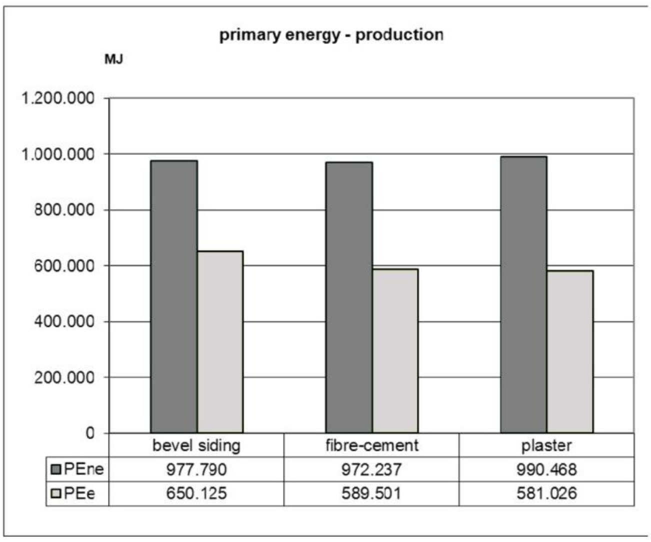


Figure 21. Different façade surfacing: primary energy non-renewable and renewable – comparison production phase only.

5 FURTHER DETAILS

The impacts of various heating systems and roof styles on the timber framing work were also analysed also.

5.1 *Impact of heating systems*

The different energy sources used for heating are: gas, oil, wood peletts, wood chips, heat pump (water/water), district heating. In case of district heating there are two variations pictured: district heating (n.re.) production through fossil fuels and district heating (re.) production with 100% renewable energies (wood, waste). The systems have different loss within the heating system in generating the heat.

The choice of heating systems resulted in enormous differences calculated over the complete life cycle. All systems need some primary energy for construction and end-of-life. Major differences can be seen in the operation phase. High primary energy (renewable) for wood pellets heating result in high complete primary energy too. This is due to the calculation methodology of wooden products. The calorific value of wood is included in the calculations as renewable energy (Linkosalmi 2011).

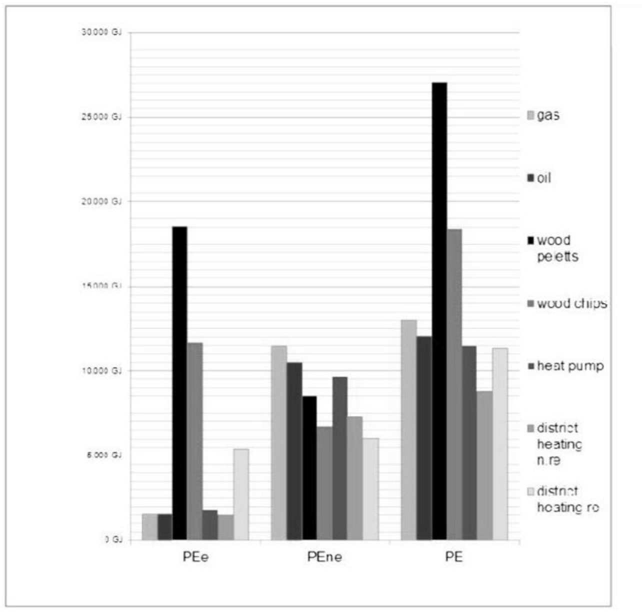


Figure 22. Different heating systems- complete life cycle.

5.2 *Impact of roof style*

The different styles of roof (flat roof, single-pitch roof, pitched roof) cause only minimal differences in the environmental impact and life cycle costs. No favorite option in terms of roof can be assumed because of these results.

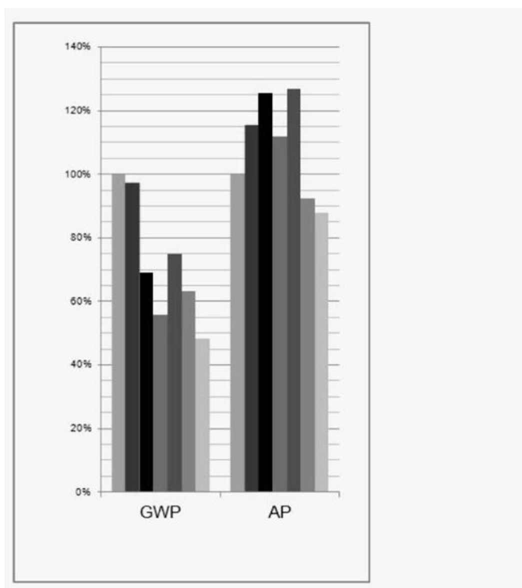


Figure 23. Different roof styles – complete life cycle.

6 CONCLUSION

The comparison of the various standard constructions for the complete life cycle showed only minor differences (in between 1-3%) in both environmental and economic aspects. This means, that the impact of the operation period is far bigger (70 to 90%) today than the construction itself. Differences in the materials are small and will only have an effect, if energy efficiency is increased to a high level.

Because of the minor differences the different construction principals were also compared without operation period and maintenance to locate the differences in materials. In this category the massive timber construction stands out in the categories of GWP and renewable primary energy.

The impact of various heating systems and roof styles on the timber framing work were also analysed. variations of heating systems resulted in enormous differences. The roof style caused only minimal differences in the environmental impact and life cycle costs. Advanced constructions to reduce environmental and economic impacts only result in minor differences.

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