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Energy consumption and environmental impact of buildings

Case study of traditional and modern wooden buildings

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PREFACE

This paper was written for the Oslo Roundtable Conferance and Ministerial session, 6th – 10th February 1995, and is showing a comparative study of energy consumption and environmental impact of traditional and modern wooden buildings.

Mr. Aage Blegen, Directorate for Cultural Heritage, Mr. Terje Apneseth, Mr. Tore Opdal, The Norwegian Institute of Wood Technology and Mr. Erik Algaard, Multiconsult A/S have contributed to the paper as a referance group.

The energy conlculations have been carried out by Mr. Erik Algaard, Multiconsult A/S.

Oslo, May 1995

Sverre Fossdal   Knut Ivar Edvardsen

CONTENTS

1 Introduction

Wood has for centuries been the principal building material in Norway. Carpentry traditions go back more than 1000 years. The stave churches and the Viking ships are living proofs of the versatility and durability of timber in building. Log construction has been the principal method for providing shelter for people and domestic animals for most of the same period. Even today, thousands of Norwegians live in log houses - some of which are several hundred years old. Log construction also have a fair share of the market for holiday houses.

As a consequence of the cheaper sawn timber and industrialisation of the building process, new construction techniques, which were first introduced about a hundred years ago, slowly reduced the share of new log construction. In the post war period the requirements with regard to the thermal performance of buildings have gradually become more strict and thus disfavoured log houses. Another factor has been the price level which for a new log house has been considerably higher than for a similar timber frame house.

Today 98 % of Norwegian low rise housing construction is in timber frame, a construction technique which has reached a high level of perfection with regard to thermal efficiency, air tightness, speed of erection etc.

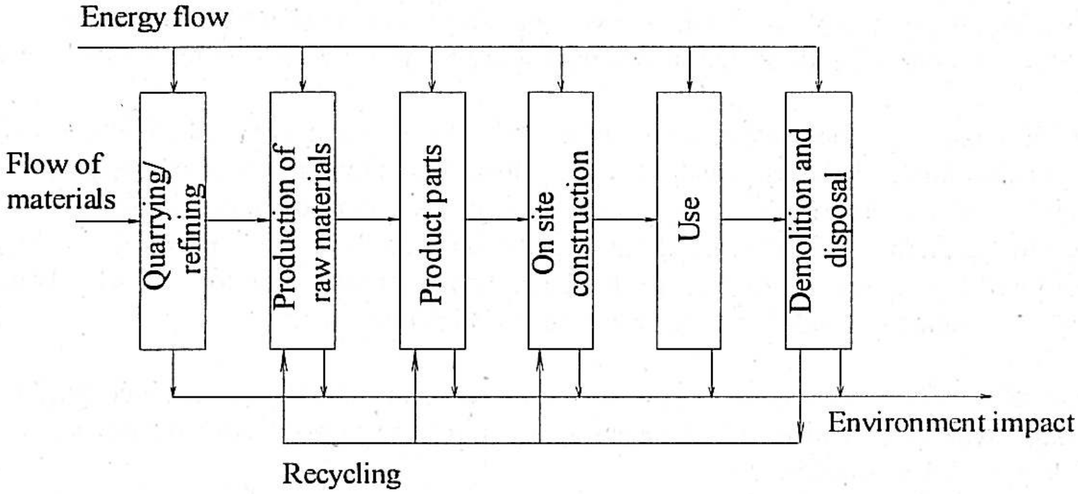
As a consequence of growing pollution and the global warming problems, the building sector is engaged in finding more sustainable approaches for future construction and management of the building stock. So far, a lot of effort has been made to reduce energy consumption. Today it is obvious, that looking at energy saving alone is not enough, and that comprehensive life cycle analysis will give a better understanding of the environmental consequences of a building project.

With the increasing interest for renewable and natural materials we have in the last few years seen a growing market for log houses and a revitalisation of traditional skills and construction techniques. It is therefore of great interest to compare the performance of a modern log house with a timber frame house both of which meets the current Norwegian building regulations.

Buildings in a life cycle perspective are of major importance in connection with energy consumption and environmental impacts. Such concerns have created a need for new data and methods to provide a basis for choosing between alternative design, materials, construction methods etc. This paper presents "a state of the art" with regard to carry out such studies in their full context. The examples are chosen to demonstrate the methodology and not for ranking one building type before the other.

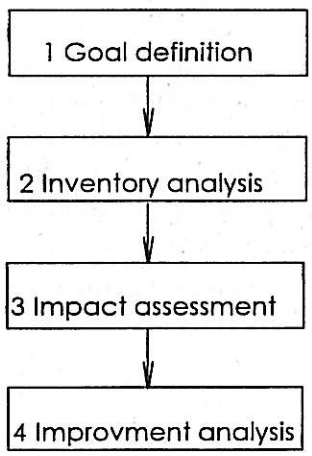
2 Life cycle analysis

Life cycle analysis is a systematic way of assessing the influence on health, environment and resources throughout the whole life cycle of a product. The life cycle of a building consists of several phases.



In all these phases energy is consumed and emissions to air, water and soil take place. The service life is very long compared with other products and is subject to many uncertainties throughout the lifetime. In comparing these two houses the lifetime has been chosen to be 50 years, even if the real lifetime of buildings normally will be longer. The reason for this choice is that the requirements to buildings change more rapidly today than in the past and work carried out by CEN/TC88/WG2 has set 50 years as a minimum lifetime for homes.

According to SETAC (Society of Environmental Toxicology and Chemistry) [1] a life cycle assessment consists of four steps.



In Norway, energy consumption is normally expressed in kWh/m^2 (MJ/m^2)and air flow in m^3/h m^2 for buildings, hence the definition of functional unit has been chosen to be per m^2 and 50 years.

The purpose of the life cycle assessment has been to compare the environmental impacts of a timber frame house and a log house of the same size throughout their whole life. The assessment is based on energy and environmental data for building materials produced in Norway [2]. Collection of these data have been based on principles and guidelines that SETAC and EPA (US Environmental Protection Agency) [3] have worked out.

Wood is considered to be CO_2- neutral, i.e. the photosynthesis of CO_2 during the growing of the tree and the liberation of CO_2 when the wooden material is burned or decomposed will be equal. The collection of data has therefore been limited to energy, distinguishing between hydro electric power and fossil fuel, and emissions of CO_2, SO_2, NO_x, VOC and dust. Calculation of VOC are based on emissions from transport of the materials. The emissions have been classified in different impact categories and the contribution from the different emissions has been quantified. The following categories have been assessed.

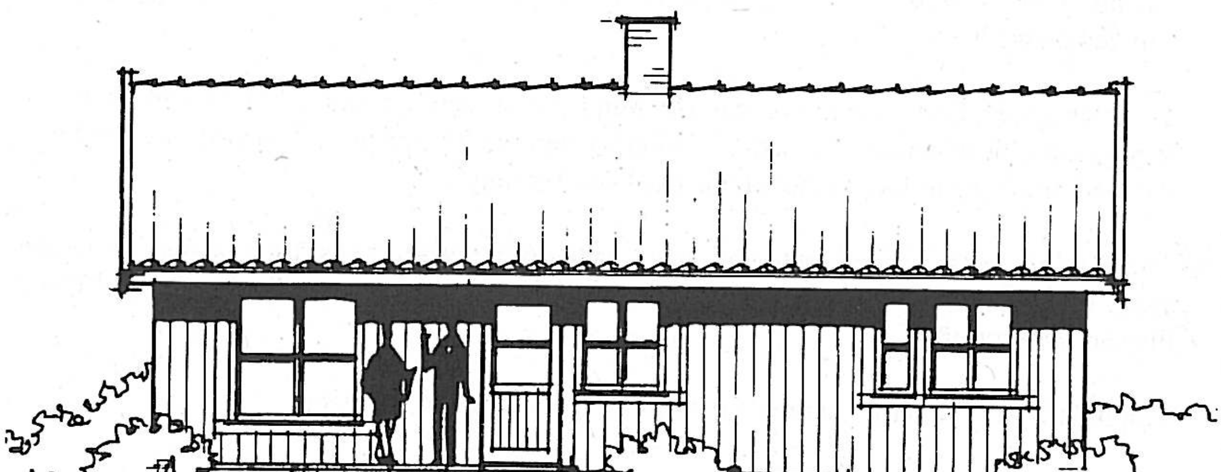
1) Global warming caused by CO_2- emissions
2) Acidification caused by emissions of SO_2 and NO_x
3) Photo-oxidant formation caused by VOC from transport
4) Eutrophication from NO_x
5) Depletion of fossil resources

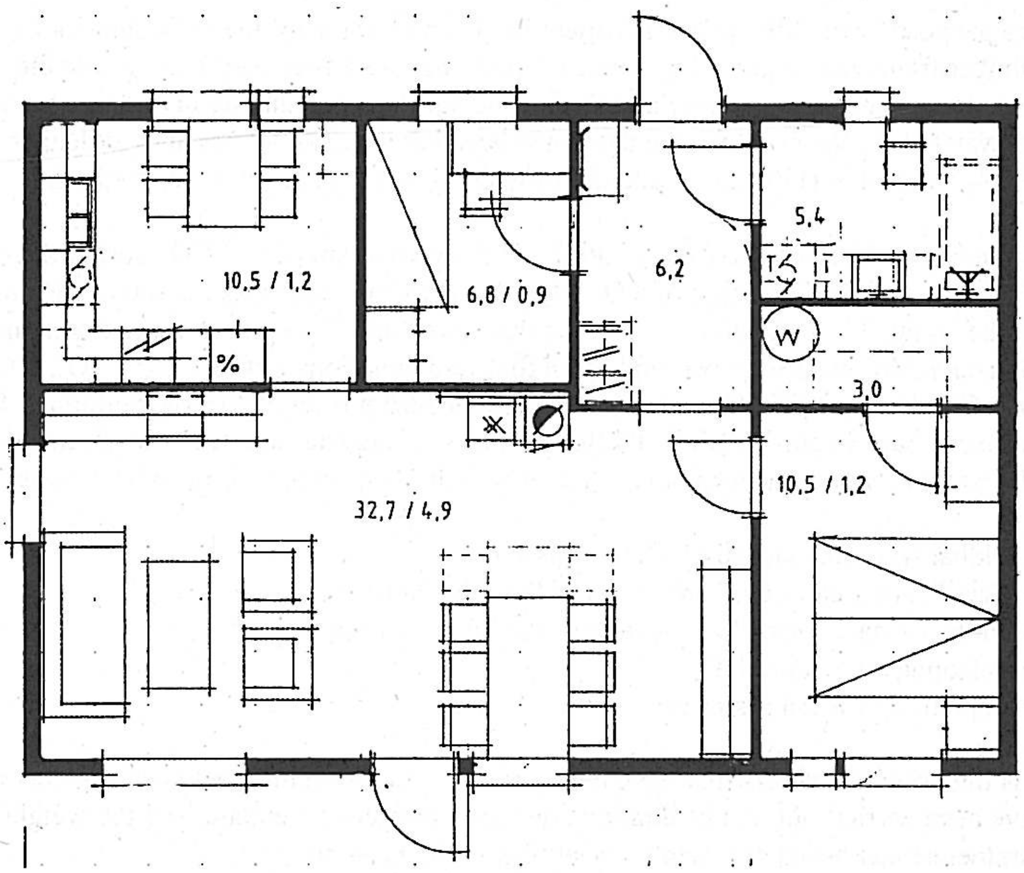
It is the potential effects that have been assessed. No evaluation between these categories have been carried out. An evaluation consist of subjective elements and the weighting parameters can never be based on scientific methods alone.

3 The timber frame house

3.1 Description

The timber frame house, shown in the figure, has a gross floor area of 85 m^2. It is heated with electric panel heaters and has passive stack ventilation supplemented with an exhaust fan above the kitchen stove. The electric distribution system is hidden in walls and ceilings.





External timber frame walls have 150 mm mineral wool insulation, an external wind barrier of 12 mm bitumen impregnated porous fibreboard and a vapour barrier on the inside of 0,15 mm polythene film. The internal lining is 13 mm plasterboard. On the outside there is a vertical ventilated timber cladding with cover boards. Internal walls are also in timber frame and have the same lining as the external walls. The windows have an area of 10,7 m^2 and are made of wood with sealed double glazing. They have a U-value of 1,9 W/m^2K.

The roof has a load bearing system with W-roof trusses, a sheathing of 4 mm high density asphalt impregnated fibre boards and a concrete tile roofing. The ceiling is insulated with 200 mm mineral wool and has the same vapour barrier as the external wall. There is a 12 mm chipboard lining.

The timber joist floor accommodates 200 mm mineral wool insulation. 12 mm bitumen impregnated fibreboards are used as a wind barrier and 22 mm particle boards are used as the load bearing subfloor. Linoleum is used for flooring.

The building rests on a concrete perimeter wall, 1,6 m deep to resist frost heave. The crawl space below the floor is ventilated and protected from rising moisture by 0,2 mm polythene film on the ground.

Chipboards are the basic materials of wardrobe and kitchen cabinets.

3.2 Materials

The table shows the building materials used in the timber frame house. The specification covers the envelope and the foundation, doors and windows, interior walls, floor coverings, kitchen cabinets, wardrobe cabinets, technical equipment, sanitary pipes and equipment and electric cables.

Materials	Mass tons
Concrete	38,9
Timber	5,6
Chip- and plasterboard	4,6
Mineralwool insulation	1,0
Metals	1,1
Tiles and china	2,1
Linolum and plastics	0,9
Glas	0,3
Breathing paper and paint	0,3
Total	55,0

The mass include cut-offs and replacements for a period of 50 years. The foundation represent more than 70 % of the total mass.

3.3 Energy and emissions

Calculations of the energy consumption have been carried out according to NS 3031 and NS 3032. In addition hot water consumption of 12500 MJ/year is assumed. The house is located in Oslo and infiltration is chosen to be 0,2 airchange/h and the ventilation flow is 75 m^3/h.

The table shows the calculated energy consumption of the timber frame house.

	MJ/m^2 year
Heating	480
Ventilation	163
Infiltration	81
Hot water	155
Lighting	94
Equipment	85
Free energy (sun, persons)	-289
Total energy consumption	771

The total energy consumption for a period of 50 years will be 38540 MJ/m^2

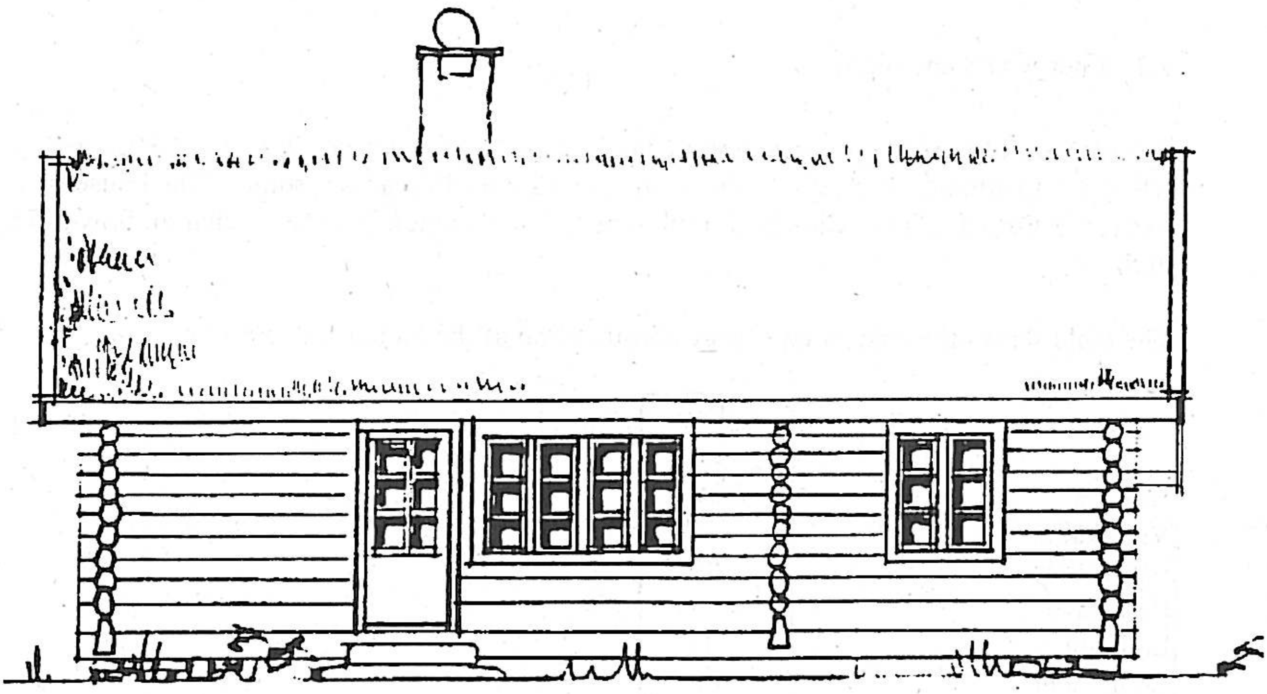
The energy account, split in consumption of hydroelectric and fossil energy, and emission of CO_2, SO_2, NO_x and dust are shown in the table. The table covers all the phases from quarrying to on-site construction. The total energy includes also the use of bioenergy.

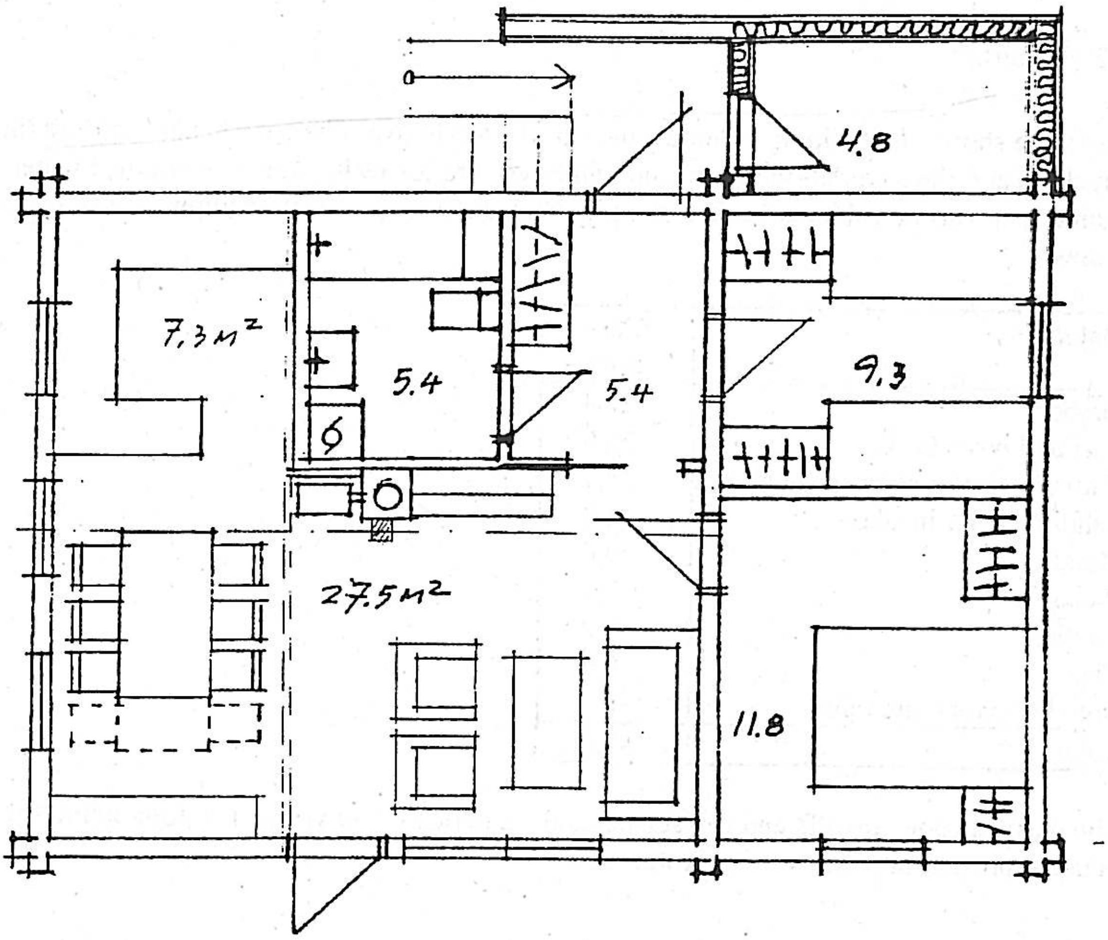
Mass kg/m²	Electricity MJ/m²	Fossil MJ/m²	Total MJ/m²	CO2 g/m²	SO2 g/m²	NOx g/m²	Dust g/m²
676	589	1159	1972	114558	118	538	129

4 The log house

4.1 Description

The log house is shown in the figure. It has a heated gross floor area of 77 m^2 and an unheated store-room of 6,6 m^2. The heating and ventilating system is the same as for the timber frame house. The electric distribution system is open (visible).





The external walls (and the internal cross wall) are in traditional log construction with no additional thermal insulation or cladding. The other internal walls are in timber framed with timber panel lining. Each individual log has been trimmed manually to an oval cross-section, giving the finished wall an average thickness of 190 mm (U-value 0,55 W/m^{2}K). The windows have an area of 8,4 m^2 and are made of wood with coupled frames accommodating a single pane in the outer frame and a sealed double glazed unit in the inner frame. The U-value is 1,5 W/m^{2}K

Roof rafters rest on a log beam supported by the gable walls and the internal cross wall. There are 300 mm cellulose fibre insulation between the rafters. A building paper with a thin plastic coating is used as a vapour check on the inside and ordinary breather paper as a wind barrier on the outside. The roof has a traditional turf roof, 150 mm thick, resting on a loadbearing sub-roof of T & G boards. Water proofing is secured with 8 layers of birch bark between the turf and the boarding.

The timber joist floor is filled with 250 mm thick cellulose fibre and have a breather paper on each side to prevent air infiltration. Wood strip flooring is nailed directly to the joists.

The foundation method is similar to the one used for the other house, but natural rubble stone is used for the visible part of the perimeter wall whilst the "under ground" part is merely mechanically crushed rock compacted directly into the 1,6 m deep ditch.

Wardrobe and kitchen cabinets are made of wood.

4.2 Materials

The table shows the building materials used in the log house. The specification covers the envelope and the foundation, doors and windows, interior walls, floor coverings, kitchen cabinets, wardrobe cabinets, technical equipment, sanitary pipes and equipment and electric cables.

Materials	Mass tons
Timber	27,4
Turf and birch bark	27,0
Natural rubble and crushed rock	20,1
Cellulose fiber insulation	3,8
Metals	0,6
China	0,3
Plastics	0,2
Glas	0,4
Breather paper and paint	0,5
Total	80,3

The mass include cut-offs and replacements for a period of 50 years. The foundation for this house represent only 25 % of the total mass.

4.3 Energy and emissions

Calculations of the energy consumption have been done according to NS 3031 and NS 3032. In addition a hot water consumption of 12500 MJ/year is assumed. The house is located in Oslo and infiltration is for this house also chosen to be 0,2 airchange/h and the ventilation flow is 75 m^3/h. Recent measurements indicate that the air tightness of a log house may be as good as for a timber frame house.

The table shows the calculated energy consumption of the log house.

	MJ/m^2 year
Heating	606
Ventilation	181
Infiltration	105
Hot water	172
Lighting	94
Equipment	85
Free energy (sun, persons)	-298
Total energy consumption	946

The total energy consumption for a period of 50 years will be 47280 MJ/m^2

Energy account, split in consumption of hydroelectric and fossil energy, and emission of CO_2, SO_2, NO_x and dust are shown in the table. The table cover all the phases from quarrying to on-site construction. The total energy includes also the use of bioenergy.

Mass kg/m²	Electricity MJ/m²	Fossil MJ/m²	Total MJ/m²	CO2 g/m²	SO2 g/m²	NOx g/m²	Dust g/m²
1094	239	676	1744	47660	65	501	51

5 Demolition and waste

Demolition of buildings have so far mainly implied demolishing the building as quickly and cheaply as possible and to transport the materials to a waste disposal site. Shortage of resources and environmental considerations will, however, in the future require reuse and recycling of building waste.
At the end of its life cycle, the log house will normally be dismantled and reused somewhere else and the foundation loaded on trucks and taken away. In this paper it is assumed that the timber frame house will be demolished and transported to a disposal site, while the log house will be dismantled and probably reerected on another location. Metals will, however, be recycled and wooden materials will be reused or burned.
Energy consumption for demolition and dismantling of buildings like this will be small. The transport distance for the two houses is assumed to be the same.

6 Complete account for the timber frame house and the log house

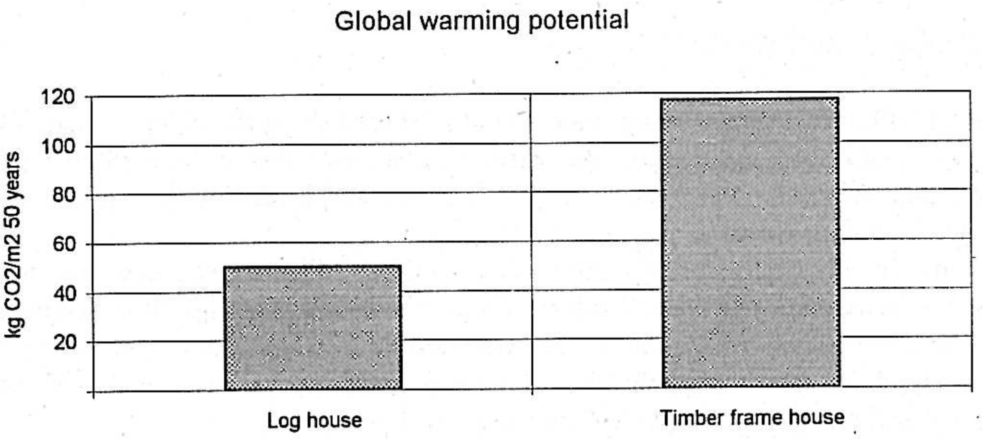
Timber frame house	Electricity MJ/m²	Fossil MJ/m²	Total MJ/m²	CO2 g/m²	SO2 g/m²	NOx g/m²	Dust g/m²
Production/maintenance	590	1159	1973	114682	119	537	129
Use	38538		38538				
Demolition/dismanteling		34	34	2515	0	2	0
Total	39128	1193	40545	117198	119	538	129
Log house	Electricity MJ/m²	Fossil MJ/m²	Total MJ/m²	CO2 g/m²	SO2 g/m²	NOx g/m²	Dust g/m²
Production/maintenance	239	676	1744	47660	65	501	51
Use	47279		47279				
Demolition/dismanteling		31	31	2327	0	1	0
Total	47518	707	49055	49987	65	502	51

The two houses are heated with electric panel heaters, but no emissions of CO_2, SO_2, NO_x and dust will take place since the production of electricity is based on hydropower. The energy used in the buildings during the service life (50 years) account for more than 95 % of the total energy consumption throughout the life cycle for these houses since no heat recovery equipment is installed.

7 Environmental impact assessment

7.1 Global warming potential

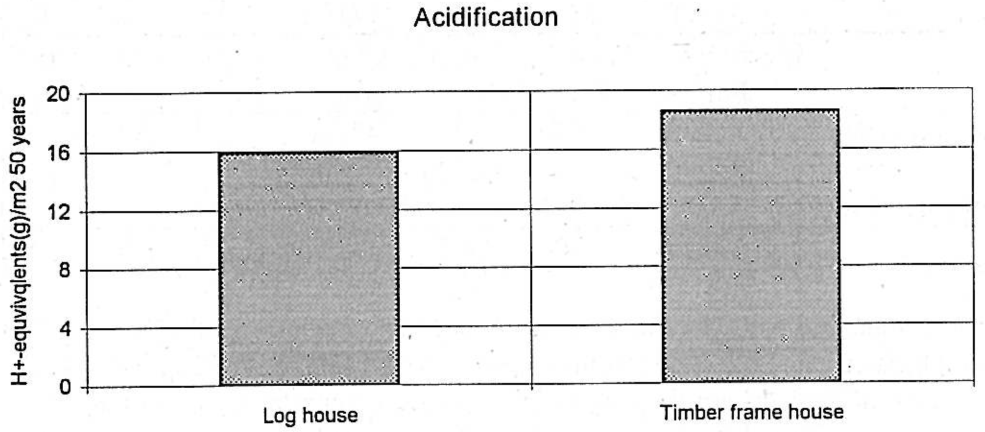
The global warming potential is calculated in CO_2 - equivalents. The figure shows the emissions of CO_2 for the two houses. Since it in this case only will be the CO_2 that cause the global warming, the CO_2 - equivalents are identical to emissions of CO_2 throughout the life cycle of the houses.



The global warming potential, expressed in CO_2 - equivalents, is more than twice as high for the timber frame house as for the log house.

7.2 Acidification

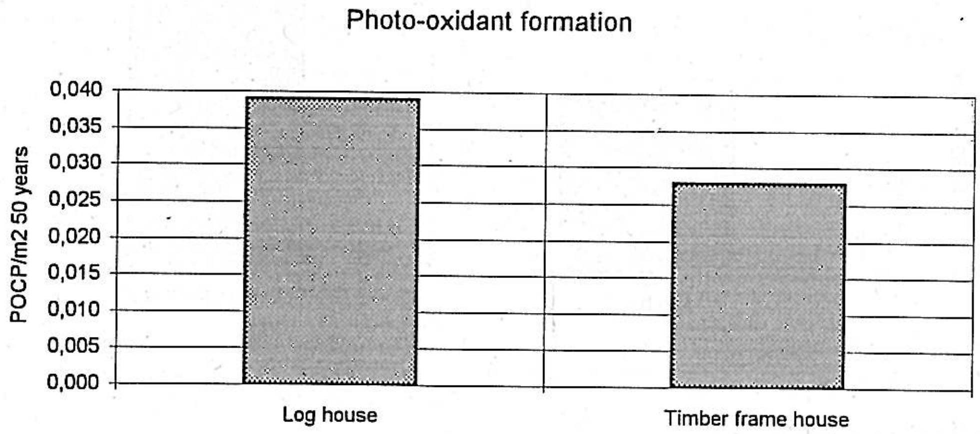
Acidification is expressed as H+-equivalents and the effect is calculated from the emissions of SO_2 and NO_x. SO_2 contributes with 2 mol of protons for each mol of sulphur and NO_x contributes with 1 mol of protons for each mol of nitrogen. It is assumed that NO_x consist of 50 % NO and 50 % NO_2.



The figure shows that the acidification, expressed in H+equvivalents, is 20 % higher for the timber frame house than for the log house when it is assumed that all the NO_x emissions contribute to acidification.

7.3 Photo-oxidant formation

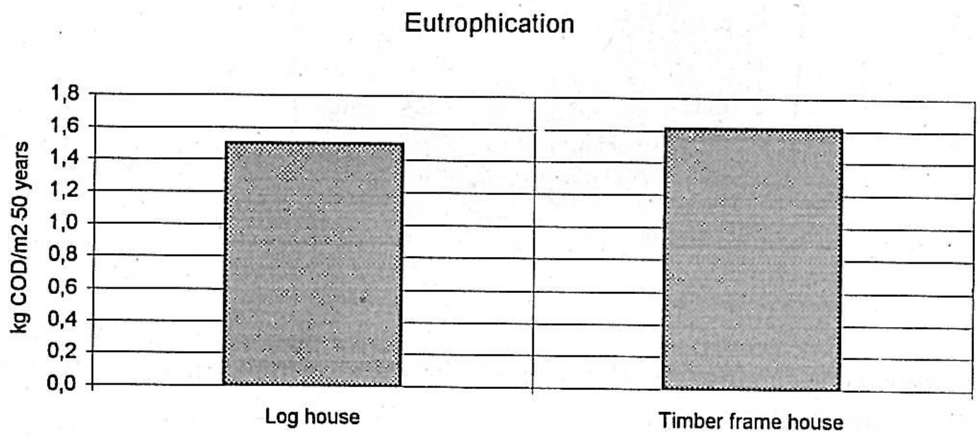
Photo-oxidant formation, i.e. the production of ozone under the influence of solar radiation, is expressed in POCP (Photochemical Ozone Creation Potentials) also called ethene-equivalents. Formation of ozone can be limited by either VOCs or NO_x. For a large part of Europe it is expected that NO_x is more important than VOC for the ozone production. In assessing the two houses only the VOC emissions have been considered.



The figure shows that the photo-oxidant formation potential is approx. 40 % higher for the log house than for the timber frame house. Since the emissions of VOC only come from transportation and that the total weight of the log house is 50 % higher than for the timber frame house this could be expected.

7.4 Eutrophication

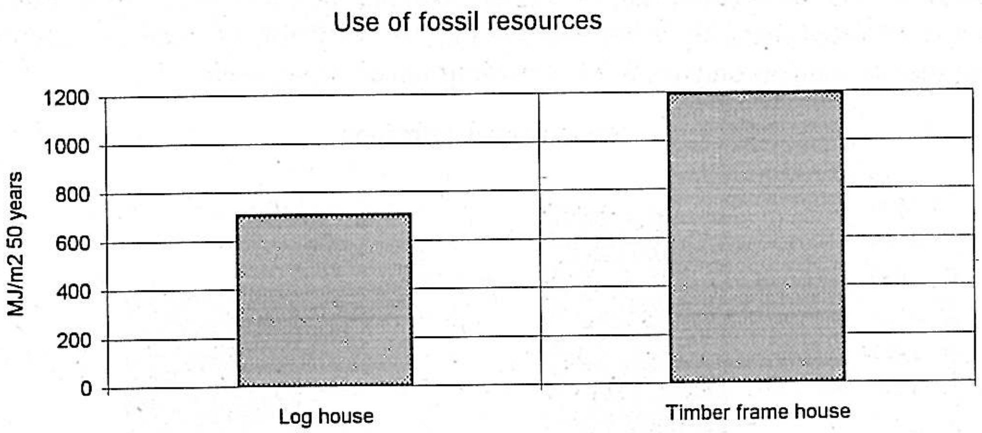
Eutrophication is considered only for emissions of No_x. Their contribution to eutrophication can be calculated to COD (chemical oxygen demand). It is assumed that NO_x exist as NO_2 and the consumption of oxygen is 8,6 mol for each mol of nitrogen.



The timber frame house contributes 10 % more to eutrophication of land, water and water systems than the log house. It is the potential effects that have been calculated.

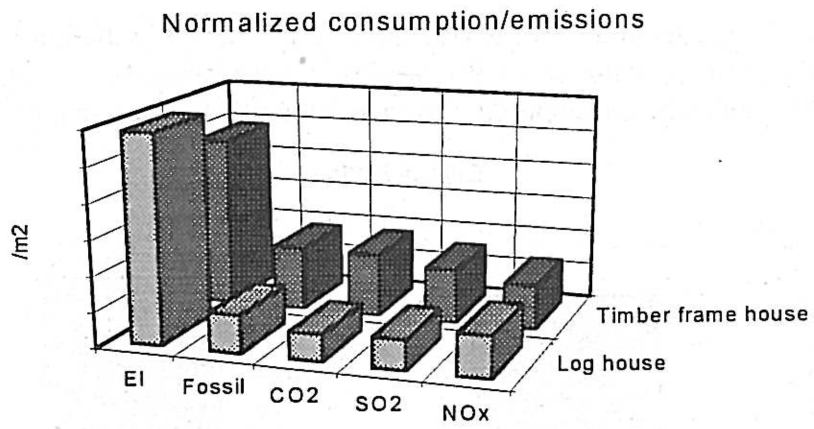
7.5 Consumption of fossil resources

The figure shows that the consumption of fossil recources for production and maintenance of the timber frame house is approx. 70 % higher than for the log house.



7.6 Overall ecoprofile

An overall ecoprofile for the two houses throughout their whole life cycle are normalised and shown in the figure. Normalising the data is done by dividing the consumption of electricity and fossil fuel and emissions of CO_2, SO_2 and NO_x for the two houses with the total consumption of electricity and fossil fuel and emissions of CO_2, SO_2 and NO_x in Norway in 1993.



NB! The shown consumption of electric energy in a 50 year life-span will be 10 times higher than what the figure shows.

8 Conclusion.

With respect to most of the categories considered in this paper the log house contribute to smaller environmental impacts than the timber frame house. The Photo-oxidant formation is higher for the log house, but this comes from transportation and is explained by the differences in weight between the two buildings. There are significant differences between the two houses on consumption of fossil resources and emission of CO_2 and SO_2 to the benefit of the log house. The total energy consumption for the log house is, however, 20 % higher than for the timber frame house. The building materials used in the log house are mainly sustainable materials and are to a certain extent used in their natural form and therefore create a minimum of waste.

9 References

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