COMPARISON OF EUROPEAN LCA-BASED BUILDING ASSESSMENT AND DESIGN TOOLS

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ABSTRACT

Eight LCA-based building-related environmental assessment and design tools were compared in order to present recommendations to improve existing or to develop future tools. The study was a contribution to the work of members of a European Network (PRESCO: Practical Recommendations for Sustainable Construction) who aim to define a European Code of Practice for Sustainable Building.
After a short description of each tool, an analysis was made of its assessment of a simple geometrical structure composed of concrete and reinforcing steel. The aim was to examine the variability of results from different tools when the number of construction materials was restricted. Assessments were then compared for a complete building made from wood, concrete or brick. Both studies showed variation of 10 to 25% about the mean value for greenhouse gas emissions from each material used. In a virtual exercise, a number of PRESCO recommendations were applied individually to the concrete house. The contribution of each recommendation to the total result was very small. A clear improvement was achieved when several recommendations were applied together. A list of recommendation is presented for the improvement of existing and future building related environmental assessment and design tools.

KEYWORDS

LCA, Sustainable, Building, Tool, PRESCO

INTRODUCTION

Various methods have been proposed for evaluation of the environmental quality of buildings. These attempt to integrate issues of concern such as protection of human health, protection of climate, fauna and flora and the efficient use of resources (energy, water, materials). Their precision and relevance is often questioned. The aim of the work presented here was the development of recommendations for rationalising LCA-based assessment tools for buildings. The work was performed within the European thematic network PRESCO and based on the final report of Work Package 2 (Peuportier et al. (2005)).

METHODS

Assessment tools were compared in three studies. The first was an examination of assessments of a simple geometrical structure composed of concrete and steel including the use phase over 50 years. These results allowed analysis and comparison of the materials and energy datasets included in the different assessment tools. The second study was a comparison of assessments of a complete building (FUTURA house) made of one of three different structural materials: wood, concrete or brick. This study mainly helped to analyse the model used within the different assessment tools. The third study was a virtual exercise in which a number of general recommendations for sustainable construction of the concrete house were applied and the sensitivity of the assessment tools was compared.
The assessment tools studied were:

- ECO-QUANTUM (W/E Sustainable Building, The Netherlands) - http://www.ivam.uva.nl/uk/producten/product7.htm
- LEGEP (ASCONA, Germany) - http://www.legoe.de/
- OGIP (EMPA, Switzerland) - http://www.the-software.de/Ogipen.html
- EQUER (ARMINES, France) - http://www-cenerg.ensmp.fr/english/themes/cycle/index.html
- ENVEST (BRE, United Kingdom) - http://envestv2.bre.co.uk/
- Eco-Soft (IBO, Austria) - http://www.ibo.at/ecosoft.htm (only in German)
- BeCost (VTT, Finland) - rem.e21.fi/files/files/becost.doc
- ESCALE (CSTB, France) - http://www.uni-weimar.de/scc/PRO/TOOLS/fr-escale.html

Input data included a description of the building (geometry, techniques, materials…) and its context (e.g. electricity production mix). The LCI (Life Cycle Inventory) data connected to the different models was derived from either the SimaPro database Goedkop & Oele 2001, the "Ökoinventare für Energiesysteme" from the ETH (Swiss Federal Institute of Technology) in Zürich (Frischknecht et al. 1996) or national databases. The output was a multi-indicator comparison of alternatives to support decision making. Assessment indicators among the tools were mainly CML 92 classifications. Some were aggregated indicators such as energy consumption, water consumption, waste, direct and/or external costs, etc. Some included routine calculation of annual energy consumption.

STUDY 1 - REINFORCED CONCRET CUBE

The first case study involved consideration of a simple reinforced concrete cube structure without windows and doors but with electric heating (a European electricity production mix). The service life was assumed to be 50 years. Information was obtained about the methods incorporated into the tools for assessment of the material components (reinforcing steel, concrete, electricity production and distribution) and the LCI data (building process, transport, infrastructure, demolition process, etc.). Two of the results are shown in Fig. 1 and 2:

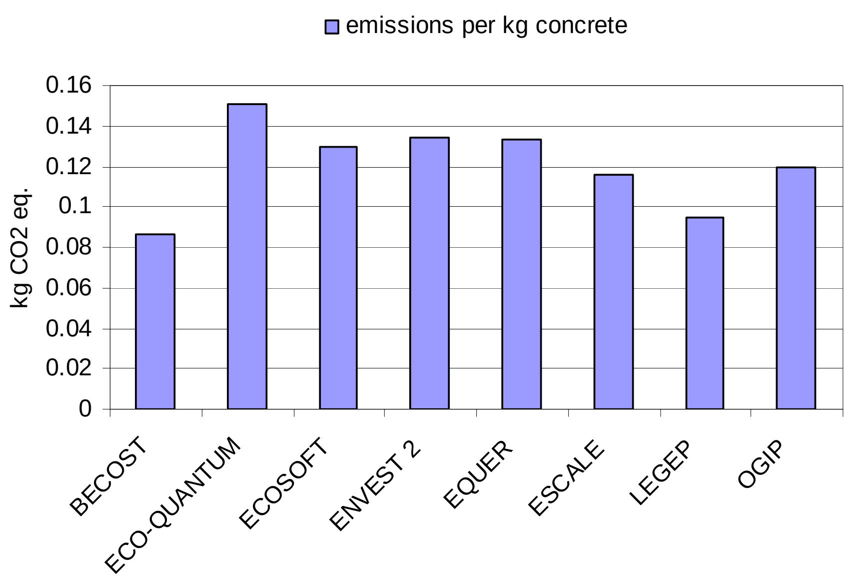

Fig. 1 Predicted Greenhouse gas emissions over 50 years from 1 kg of concrete

Fig. 2 Predicted Greenhouse gas emissions over 50 years from a simple cube structure composed of reinforced concrete.

For 1 kg of concrete (Fig. 1) variation of +/- 20% around the mean emission value for all tools was related to the type of concrete, amount and type of cement, different production processes and the nature of energy production and allocation process.

The heat loss calculation was based on the location “Switzerland”, a thermostat set point 20°C (constant), a ventilation rate of 0.6 ach (air change per hour), a conductivity of concrete of 1.28 W/mK and of steel of 46 W/m/K, absorption factor of the surfaces of 0.6 and emission factor of 0.9, a north and south orientation of the larger facades and a ventilated crawl space under the floor. This resulted in a total heating load of 38,900kWh or 700kWh/m2/a. This high amount is mainly due to the uninsulated concrete external walls and the requirement of 24 hour heating on 20°C. This fictive example has been used to identify differences due to different heat loss calculation tools.

Figure 2 shows predicted greenhouse gas emissions associated with the construction and operation of the entire cube. Two tools (BeCost and ENVEST) assumed a national electricity mix instead of the European mix. This accounted for the large difference between BeCost and the other tools because Finnish electricity is modelled as heat and electricity co-generation and was probably included in energy allocation. If allocation is expressed as exergy or economic revenue instead of energy, greenhouse gas emissions for electricity increase. The electricity mix used by ENVEST seemed to correspond to the European mix. Excluding BeCost, the overall variation was +/- 10% of the mean value. Analysis of the construction phase showed that the structural materials (concrete and reinforcing steel) had the greatest effect. Discrepancies between the tools were related to:

- Quantities of materials used
- Amount of surplus or waste
- Steel content of reinforced concrete
- Assumption made about the use of recycled steel
- Transport of materials during construction and at end of building life)
- Life span of building components
- End of life processes

STUDY 2 – THE SWISS FUTURA HOUSE

The second case was based on a low energy building, prefabricated in Switzerland and known as FUTURA (Fig. 3). It is a single-family house with two levels (210 m^2 heated area), well insulated, with a high solar aperture. Gas is used for space heating and domestic hot water, demand being related to the Swiss climate. A European electricity mix is used. A detailed description of the building was provided to all tool developers, who performed a life cycle assessment based on 80 year operation period. Three different construction materials (wood, brick, concrete) were considered separately.

Fig. 3: The Swiss "FUTURA" house considered in the study

The impact of the whole building is influenced by different parameters (see Appendix). This made it difficult to come up with specific recommendations on the building level. Therefore a comparison on the "lowest" building level has been added. The impact on the basis of the greenhouse gas emission (expressed as a weight of equivalent CO2 emission) which is the only common indicator between all tools (except OGIP) from the same materials (e.g. brick) and from the used heating system has been analysed .The results are summarised in following Table 1.

Functional unit	Mean CO_2-eq.	Relative difference for the lowest value	Relative difference for the highest value
1 kg brick	0.255 kg	-15%	+25%
1 TJ gas (end energy)	64 400 kg	-15%	+15%
Whole house, wood structure, 80 years	550 t	-10%	+10%

Tab. 1: Variability of results from 7 assessment tools used to appraise the environmental sustainability of the FUTURA house, one specific materials and the used heating system

Comparing the huge variation on the level of one material and the smaller variation on the level of the whole building shows that the differences cancel each other out. This shows how difficult it is to make recommendations on the building level.

Wood as a building material was assumed differently by different tools. Some considered carbon dioxide uptake in the forest during timber growth as well as carbon dioxide and methane release to the atmosphere at the end of life. Disposal of wood always ends in releasing the stored amount of CO_2 through rotting (sooner or later), processing (e.g. fermentation and burning of the ethanol) or just burning. Other tools took neutrality as the starting point and ignored uptake and release of biogenic carbon dioxide. Over the whole life cycle the result was the same but problems arose when an assessment did not take the disposal phase into account (from cradle to gate).

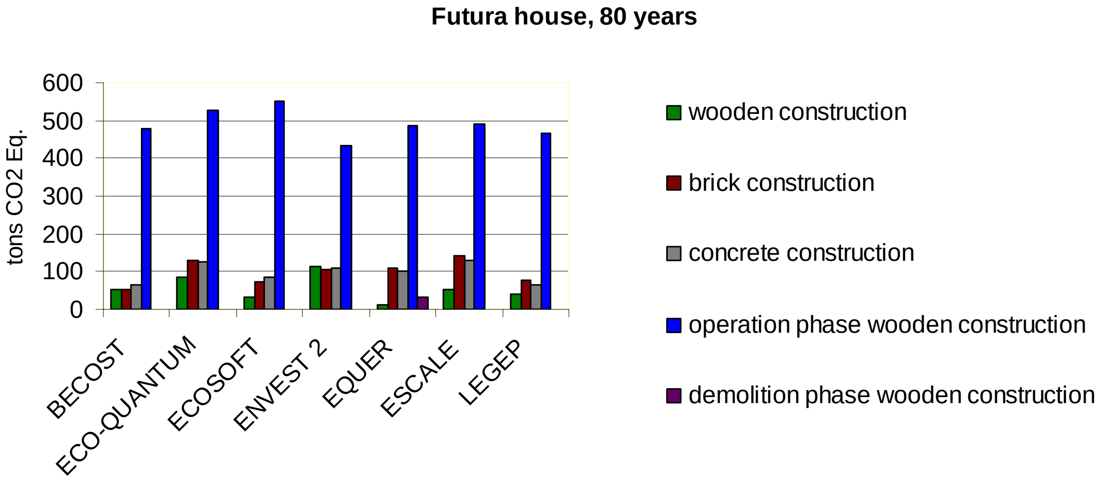

Fig. 4: Predicted global warming potential for the FUTURA house when constructed from different materials. Explanation of the legend

- Wooden construction: Complete building with a timber frame support structure
- Brick construction: Complete building with a brick support structure
- Concrete construction: Complete building with a reinforced concrete support structure
- Operation phase wooden construction: Operation phase for all the building types as they have the same heat losses
- Demolition phase wooden construction: Only different for the building with a timber frame support structure

All assessment tools except ENVEST showed that wood construction produced the lowest greenhouse gas emissions. Results for brick and concrete were similar to each other. During the operation phase, emissions were similar for all three construction types (results not illustrated). Tools including negative carbon dioxide values for wooden parts during the construction phase (e.g. EQUER) accounted separately for release at the end of life. Looking at the results for the EQUER tool it shows a very small amount of CO_2 emitted by the whole timber frame building. This is mainly due to the high amount of timber with biogenic, stored “negative” CO_2. As this value does not represent the demolition phase and therefore the CO_2 realease from disposed wood it has to be shown separatly (see Fig. 4, EQUER). Emissions from the operation phase of the timber framed house were similar for all 7 tools (+/- 5% about the mean value). All tools indicated that the operation phase produced greater greenhouse gas emissions than the construction or demolition phases (results not illustrated)

STUDY 3 - APPLICATION OF SUSTAINABILITY RECOMMENDATIONS TO THE CONCRETE FUTURA HOUSE

The result of another work package within the PRESCO Network came up with a list of about 350 recommendations to improve houses to a higher level of sustainability. Some of these recommendations have been adapted to the model of the concrete based FUTURA house. In general LCA-based building assessment tools mainly deal with environmentally relevant recommendations and therefore unfortunately only a small part of the overall PRESCO recommendations towards more sustainable constructions were applicable. Furthermore the fact that most of these recommendations are described qualitatively reduced the number of applicable recommendations additionally.

Following examples have been applied and its impact on the overall result presented:

1. *Replacement of double glazing by windows with triple glazing*. Energy consumption in the operation phase was reduced by 11 to 13%). Additional expenditure was required. The effect of improving the windows on the overall result was comparable for all assessment tools.
2. *Reduction of water consumption (e.g. water save fittings).* The amount of hot and cold water and therefore the amount of energy was reduced. The effect of application on the overall result was comparably small for all assessment tools.
3. *Reduction of the need to transport materials from source to building site.* The effect of application on the overall result was very small according to all assessment tools.
4. *Use of renewable energy for heating (Gas replaced by wood).* The effect of application on the overall result differed between assessment tools. This is because most wood-firing processes produce more emissions than gas-firing processes.
5. *Reduction of drinking water consumption by use of rain water for closet flushing*. The effect of application differed between assessment tools because some included greater amounts of infrastructure components than others.
6. *Replacement of rock wool insulation with renewable raw materials (e.g. cellulose fibre).* The effect of application differed between assessment tools. Alternative materials produced different quantities of emissions.

In general there was good agreement that each of the recommendations had a limited or marginal individual effect on greenhouse gas emissions. Combining several recommendations within a certain project is likely to improve the ecological quality of a building.

CONCLUSIONS

Results of the three studies have suggested a long list of recommendations for improving existing assessment tools and for designing new tools. Important examples are:

- LCI data should be consistent and clear (e.g. same system boundary; clear allocation methods; no mixing of data from different sources).
- LCI data should be up to date and specific with a clear user area.
- All transportation including the upstream process related transportation should be included. If no exact data are available, specific national default values should be used.
- Cut-off rules: All input and output materials with a mass greater than 2%of the end product must be included, regardless of environmental relevance. If relevance can be proved, materials with less than 2% of end product mass must be taken into account.
- Use of recycled material in construction phase and potential recycling processes at the end of life should be accounted for in a consistent and transparent way.
- If possible, land-use should be included as part of each process step from cradle to gate.
- Water consumption should be included in assessments although it is not an indicator of environmental impact.
- Rationale for the choice of the impact assessment indicators should be provided. Cumulated indicators (e.g. EcoIndicator 99, H/A, total) should be used with caution because different categories of impact (e.g. on ecosystem and human health) are calculated into one value.
- Substitution of materials must be taken into account after service life. Be aware that no substitution will be made during the period immediately prior to demolition.

OUTLOOK

Further work is needed to harmonise and facilitate the development of environmental assessment and design tools for buildings. End-users of these tools (architects, civil engineers, etc.) must be trained to interpret results. There is a need for tools to be easier to use and for their relevance to be more transparent.

There will be a strong future need for New Zealand to develop its own building assessment tool. The main driver will be the new building Code which plans to publish requirements for energy and Gobal Warming Potential for the construction, operation and disposal. It is recommended to build up its own assessment tool with focus on timber framed residential houses. The knowledge of this comparison helps Scion to work out a NZ specific building assessment tool.

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APPENDIX

Type of Construction		Material		Standard Wood Construction	unit	Standard Brick/Concrete construction	unit
Description of project							
Type of house				single family house, with basement, ground floor and upper floor, pitched flat roof with thermal insulation. Basement only accessible by outside			
Location				CH-4524 Günsberg / SO, 623 m ü. M. (climatic region 4, station Biel), flat protected valley			
Surface on ground							
Ref. surface for energy consumption				210 m2		210 m2	
Heated volume				434 m3		434 m3	
Main living surface (heated)				201 m2		201 m2	
Auxiliary surfaces (unheated)				100.5 m2		100.5 m2	
Total usable surface				301.5 m2		301.5 m2	
Element 1	Basement floor		area	100.5 m2		100.5 m2	
	ground slab	concrete		20 cm		20 cm cm	
	thermal insulation	polystyrene high-resistance foam board		60 + 50 mm		60 + 50 mm	
	plaster	anhydride cast plaster floor		50 mm		50 mm	
Element 2	Floor above basement		area	100.5 m2		100.5 m2	
			U-value	0.34 W/m2K		0.34 W/m2K	
	floor slab	reinforced concrete		20 cm		20 cm	
	thermal insulation	polystyrene high-resistance foam board (2 layers)		50 + 20 mm		50 + 20 mm	
	impact sound insulation	glass wool		20 mm		20 mm	
	plaster	anhydride cast plaster floor		50 mm		50 mm	
Element 3	Floor above ground floor		surface area	100.5	m2	100.5 m2	
	ceiling	wooden beam		44 cm			
		particle board		22 mm			
	thermal insulation	polystyrene high-resistance foam board (2 layers)		50 + 20 mm			
	floor slab	reinforced concrete				20 cm	
	thermal insulation	rock wool				100 mm	
	impact sound insulation	glass wool		20 mm		20 mm	
	underfloor plaster	cement				60 mm	
	plaster	anhydride cast plaster floor		50 mm			
Element 4	External walls below ground		area	92.5 m2		92.5 m2	
	filter slab	concrete		70 mm		70 mm	
	coating	bitumious		2 kg/m2		2 kg/m2	
	thermal insulation	polystyrene high-resistance foam board, extruded		100 mm		100 mm	
	wall construction	reinforced concrete, waterproof		20 cm		20 cm	
Element 5	External walls above ground		total surface	213 m2		213 m2	
			U-value	0.22 W/m2K		0.22 W/m2K	
	cladding panels	larch boards		21 mm			
	ventilation spacing 30 mm	lattice grid		2 mm			
	sheeting	OSB panel		15 mm			
	wood frame	wood studs		19 cm			
	thermal insulation	mineral wool		160 mm			
	sheeting	OSB panels		15 mm			
	plaster	gypsum plaster board		15 mm			
	plaster					3.9 kg/m2	
	wall construction	brick/concrete facing				17 cm	
	plastered external thermal insulation	fibrous insulating material				180 mm	
	cover coat	silicate cover coat				5 mm	
Element 6	flat roof		area	100.5 m2		100.5 m2	
			U-value	0.2 W/m2K		0.21 W/m2K	
	roof covering	gravel		10 cm		10 cm	
	coating	bitumious		1.7 kg/m2		1.7 kg/m2	
	sheeting	particle board		22 mm			
	pitch and ventilation	wood lattice		11.25 mm			
		wood fiber board		22 mm			
	beams	wood		3 cm			
	thermal insulation	rock wool		160 mm			
	sheeting	wooden boards		27 mm			
	thermal insulation	rock wool				180 mm	
	roof slab	reinforced concrete				20 cm	

Tab. 2: First part of the materials and parameters used for the calculation of the impact of the FUTURA house

Type of Construction			Material	Standard Wood Construction	unit	Standard Brick/Concrete construction	unit
Element 7	Windows	assumption: 15% of area: frame and 85%: glass	total surface	32.4	m2	32.4	m2
			U-value	1.5	W/m2K	1.5	W/m2K
		window north	heat protection glass (2 glasses 4mm, air-filled, coated)	2.4	m2	2.4	m2
		window east	heat protection glass (2 glasses 4mm, air-filled, coated)	1.7	m2	1.7	m2
		window south	heat protection glass (2 glasses 4mm, air-filled, coated)	26	m2	26	m2
		window west	heat protection glass (2 glasses 4mm, air-filled, coated)	4	m2	4	m2
Element 8	Exterior door	facing north	total surface	2	m2	2	m2
			U-value	2.6	W/m2K	2.6	W/m2K
		insulated door	wood	2	m2	2	m2
Element 9	interior walls (not painted)		total surface	99.5	m2	99.5	m2
		plaster board	gypsum	15	mm		
		sheeting	OSB panels	15	mm		
		insulation	rock wool	60	mm		
		wooden frame	wood studs	10	cm		
		sheeting	OSB panels	15	mm		
		plaster board	gypsum	15	mm		
		plaster				10	mm
		wall	brick/concrete			15	cm
		plaster				10	mm

Technical equipment

Use	single family housing			
Energy source; not better: power generation	combination furnace			
for heating	Gas heating<100kW, Low NOx			
for hot water	Gas heating<100kW, Low NOx			
Energy demand for hot water production	60	MJ/m2a	60	MJ/m2a
Total electrical energy used	80	MJ/m2a	80	MJ/m2a

Energy computation acc. Swiss Soc. of Arch. and Eng.
(calculated with OGIP)

Total energy for heating	222	MJ/m2a	226	MJ/m2a
Total energy for hot water production	71	MJ/m2a	71	MJ/m2a
Total electrical consumption	80	MJ/m2a	80	MJ/m2a
heating energy demand	177	MJ/m2a	179	MJ/m2a
permissible value acc. SIA-standard 380/1	342	MJ/m2a	342	MJ/m2a

Tab. 3: Second part of the materials and other parameters used for the calculation of the impact of the FUTURA house