EU framework programme

eco buildings

ANNEX I
Life Cycle Assessment (LCA) of the BRITA demo building retrofits

Guidelines
2008

1 Introduction

11 Aims and methodology

This study applies the Life Cycle Assessment (LCA) methodology to six projects of the BRITA in PUBS "demo building".

Due to the large quantity of data that each partner was assigned to collect and to the complexity of the building retrofit actions, a detailed analysis was not possible. Therefore, the study has been configured as an initial/rough estimation of life-cycle impacts, focusing on the main retrofit components. The following elements have been included in the analysis:

- ✓ Construction materials and components utilised during retrofits
- ✓ Main components of traditional and renewable energy-based plants
- ✓ Impacts related to construction work.

The main aim of the research was to assess the "environmental quality" of the engaged actions and, in particular:

- ✓ to highlight components and steps of the project that have the greatest impacts;
- ✓ to trace a balance of energy and environmental benefits and drawbacks concerning the retrofit actions..

12 Data survey

BRITA Partners have been asked to collect and report information about their projects according to a questionnaire prepared by the LCA research team. An example of the questionnaire is attached to the end of the paper.

Questionnaires included both information from the design stage and information collected during the retrofit implementation. The questionnaire was intended to guide partners through the data collection and to coordinate the LCA results as much as possible.

Questionnaires included several sheets concerning the following elements:

- ✓ Building materials used for retrofit work, with particular attention to thermal insulation
- ✓ Window typologies and characteristics
- ✓ Lighting equipment
- ✓ Innovative and traditional heating systems
- ✓ Photovoltaic (PV) and solar thermal collectors
- ✓ Ventilation systems
- ✓ Pipes and ducts
- ✓ Energy consumption of machinery utilized during retrofit work
- ✓ Waste produced during construction works.

Data from the questionnaires have been input into SimaPro LCA software [Prè, 2006]. LCA inventory analysis has been carried out on the basis of several international databases [Ecoinvent, 2000; Bousted, 2001; GABI, 2006; Gemis 2007] in order to utilize updated and representative data as much as possible.

13 Data quality

As stated previously, this analysis represents a simplified LCA study concerning the main benefits and drawbacks related to building energy retrofits. The analysis deals with the inventory of the main components and materials utilised during the retrofit work, as computed or estimated by the project partners.

The main assumptions of the study are as follows:

- ✓ Impact due to construction materials refers to average European data as presented in the international LCA database (quality of assessment: very good)
- ✓ Impacts of windows and other building components were assessed by similar construction typologies included in the environmental databases. Data have been modified proportionally to their surface (quality of assessment: medium)
- ✓ Impacts of PV and solar plants were assessed from similar data recorded in the databases and have been modified proportionally to their surface or installed power (quality of assessment: rough estimation);
- ✓ Impacts of heating and ventilation systems have been assessed from information concerning similar plants (quality of assessment: rough estimation);
- ✓ Impact due to wastes management refers to disposal processes used in average European contexts (quality of assessment: medium).

Further assumptions are:

- ✓ When measured data have been not available, heat and electricity energy savings have been estimated by the partners[2]. Predicted savings are reported in the project guidelines [BRITA, 2005]

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[2] Measured data refer to the case studies of Hol and Plymouth.

- ✓ Some correction of the initial energy saving values has been performed on the basis of monitored data;
- ✓ The ecoprofiles of electicity refer to the average national energy mix of each different country.

It is important to note that the obtained results strictly depend on the global life-cycle energy savings. Therefore, the assumption regarding the lifetime of each plant/component/technology is fundamental. The main assumptions of lifetimes were:

- ✓ Lighting equipment: 3 years;
- ✓ Small wind turbines: 15 years;
- ✓ Heating and ventilation plants: 15 years
- ✓ Solar thermal collectors and plants: 15 years;
- ✓ PV plants: 20 years;
- ✓ Building retrofit: useful lifetime 35 years.

14 Environmental Idexes

The results of the environmental assessment are presented according to the data format of the Environmental Product Declaration (EPD) scheme [MSR, 1999]. The reported environmental impacts include:

- ✓ *The Gross Energy Requirement* (**GER**) represents the entire demand, valued as primary energy, which arises in connection with every life-cycle step of an economic good (product or service). The index is expressed in terms of kWh of primary energy;
- ✓ *The Global Warming Potential* (**GWP**) is a measure of the relative, globally averaged warming effect arising from the emissions of particular greenhouse-gas. The GWP represents the “time integrated commitment to climate forcing from the instantaneous release of 1 kg of a trace gas expressed relative to that from 1 kg of carbon dioxide”. The characterisation factors are expressed as kg of “CO_2 equivalent” and are referred to a period of 100 years;
- ✓ *The Acidification Potential* (**AP**) takes into account the emissions of acidifying gases. The AP is expressed as “kg of SO_2 equivalent”
- ✓ *The Ozone Depletion Potential* (**ODP**) of a chemical compound represents the relative amount of degradation to the ozone layer that it can cause per unit mass emission, with trichlorofluoromethane (CFC-11) being fixed as reference substance with an unitary ODP value.
- ✓ *The Photochemical Ozone Creation Potential* (**POCP**). Despite playing a protective role in the stratosphere, at ground-level ozone is classified as a damaging trace gas. Photochemical ozone production in the troposphere, also known as summer smog, causes damages to vegetation and material. High concentrations of ozone are toxic to humans. The POCP is referred to in ethylene-equivalents ($C_2H_{4\text{-eq}}$).
- ✓ *The Nutrification Potential* (**NP**): Nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilised farmland accelerate the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen resulting in oxygen deficiency and fish kill. Nutrification potential translates the quantity of emission of substances into a common measure expressed as kg of PO_4 equivalent.

The energy and environmental performance of retrofit actions have been finally synthesized by three indexes, described as follows.

- ✓ *The Energy Payback Time* (**E_{PT}**), that is defined as the time during which the system must work to harvest as much energy (considered as primary energy) as it required for its production and disposal. The harvest energy is considered as net of the energy expenditure for the system use

  The E_{PT} is likewise as the time necessary for a demo-building action to save as much energy (valued as primary) as that consumed during all the life-cycle phases of each component of the retrofit actions:

  where:

  - GER = Primary energy consumed during all the LCA phases [kWh];

  - Eyear = Yearly primary saved energy [kWh per year].

- ✓ The *Emission Payback Time* (**EM_{PT}**): the global impacts during the life cycle and the saved emissions can be summarised by the Emission Payback Time (EM_{PT}). It is defined as the time during which the avoided emissions thanks to the employment of the retrofit actions are equal to those released during each life-cycle step of each component itself. It is possible to calculate the EMPT relatively to the pollutant “i” as:

  where:

  - EM_i = Global emissions of generic pollutant “i” related to the each life-cycle phase of retrofit compo-

  $$EM_{PT-i} = \frac{EM_i}{EM_{S-i}}$$

  nents [kgi];

  - $EM_{S\text{-}i}$ = Yearly emission saving of generic pollutant “i” [kgi /year].

  The Emission Saving ($EM_{S\text{-}i}$) represents the emissions avoided thanks to the retrodit actions. The EM_S depends on the typology and efficiency of previously utilized plants. The EM_S has been estimated on the basis of the yearly saved energy (Eyear) previously assessed and on the basis of the emission factors of traditional gas fired heating plants (data are referred to international LCA databases). In our study we calculated the Emission Payback Time referred to greenhouse gases emissions.

- ✓ *The Energy Return Ratio* (**ER**): it represents how many times the energy saving overcomes the global energy consumption.

$$E_R = \frac{E_{Overall}}{GER}$$

where:

- $E_{Overall}$ = Global primary energy saving during the overall life-time of retrofit components [kWh].

This index is particularly significant because it encompasses both the GER and global energy savings during the overall useful life.

The following paragraph presents the environmental results related to the LCA of retrofit case studies.

2 Results of the analysis

A brief description of the retrofit actions of demo partners is presented in this chapter.

- *Brno*. The retrofit was done on the Brewery, an old industrial-type building in a historical area that has been restored for Brno University. The actions included structural renovation of some building parts (these had been not considered in this section) and an energy retrofit of the building, including insulation, high-efficiency windows and lighting systems, installation of high efficiency heating and cooling systems, condensing gas boilers, control systems, and a PV plant.
- *Hol*. The retrofit was done on an ancient timber church. The actions included the removal of rotted timber and installation of rockwool insulation, the introduction of a solar thermal system to reduce electric power use for heating, a PV system to run fans for warm air transport, and installation of energy efficient light bulbs.
- *Plymouth*. The retrofit was done at Plymouth college with installation of two wind turbines on the roof of the building. Each turbine has a power of about 6 kW, at about 21m above ground level. It is important to note that the measured electricity output of the turbines was much lower than predicted values due to local disruption of air currents.
- *Proevehallen*. The site is an old industrial area that is being completely reshaped and modernised. The roof and external walls have been insulated, new and better performance windows have been designed, heating and ventilation systems have been renovated, and solar PV and solar PV/thermal systems have been installed.
- *Stuttgart*. The retrofit included a large series of integrated renovation initiatives that included the construction of a new building wing. Actions also included energy retrofit of structures, insulation of walls, substitution of old facades with high performance windows, and installation of high performance heating and ventilation systems. Furthermore, plants exploiting renewable energy sources have been installed, including PV panels and solar thermal collectors.
- *Vilnius*. The actions mainly involved substitution of old wall insulation with new and a better performing materials and the installation of high efficiency windows with selective glasses and low thermal transmittance.

The main environmental indices resulting from the LCA analysis are shown in Table 1.

Index		Brno	Hol	Plymouth	Proevehallen	Stuttgard	Vilnius
GER	[kWh]	399.550	44.898	26.653	914.888	486.983	1.215.899
GWP	[ton CO2-Eq.]	69	10	7	180	101	217
NP	[kg PO4]	53	7	2	91	46	111
AP	[kg SO2]	556	56	32	802	629	1.253
ODP	[kg CFC11]	0,03	0,001	0,07	0,02	0,04	0,16
POCP	[kg C2H4]	63	6	4	297	105	151
E-PT	[year]	0,6	0,5	0,7	1,3	0,3	2,0
EM-PT	[year]	0,5	0,6	0,9	1,1	0,3	1,9
ER	0	37,1	58,0	22,7	8,9	40,5	16,3

Table 1: LCA Environmental Indexes

The analysis showed significant energy and environmental convenience of the accomplished retrofits. In particular, the energy and environmental payback times that resulted were very low, with values varying from 0.3 to 2 years (Figure 1). This means that in a relatively small time period, the global energy and environmental investments are fully repaid by the obtained benefits. The relatively long useful time of the retrofits therefore produces large energy consumption savings and avoidance of emissions of large quantities of pollutants.

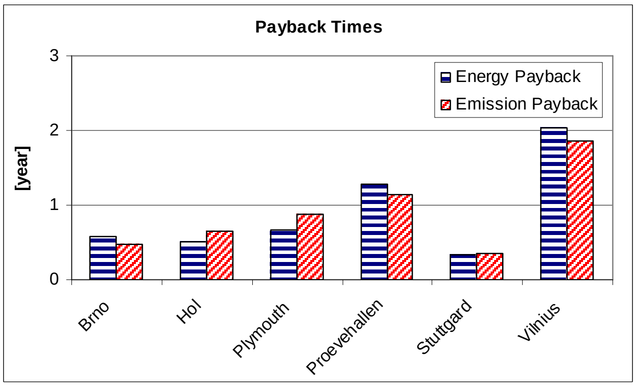

Figure 1: Energy and Environmental Payback Times [year]

It is interesting to note that the largest benefits are generally related to the insulation of the buildings: high efficiency windows, mineral wool, and glass wool sheets, in fact, insulation allows great energy savings over a long period with a relatively short life-cycle impact (Figure 2). Even renovation of heating plants and lighting systems produces large benefits. In contrast, the use of renewable energy had lower benefits due to the low productivity of plants, with outputs sometimes lower than expected at the design stage.

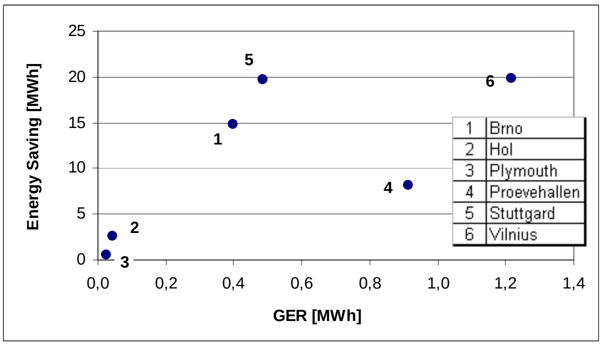

Figure 2: Comparison among GER and Energy saving

To summarize all of the global energy benefits, it is also interesting to observe the Energy Return Ratio Index that shows how many times the life-cycle energy consumption is repaid by the overall energy benefits (Figure 3). Results showed an average of about 30 times, with values generally higher than 10 times and an optimum close to 60 times.

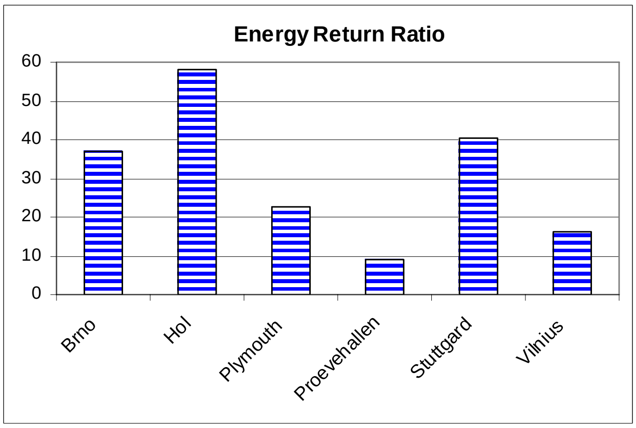

Figure 3: Energy Return Ratio Index

3 Exemplary Questionnaire

31 Data survey format

The following tables (Tables A1 – A14) show an exemplary format for the survey of main data necesary for the LCA of the retrofit action.

Table A1: Insulation

	Typology of material	Quantity (m^2)	Thickness (mm)	Density (kg/m^3)	Notes
Basements					
Cellar ceiling/cellar wall					
Roof					
Upper ceiling					
Walls (external insulation)					
Walls (internal insulation)					
Other..					

Table A2: Building Materials (used for retrofit works)

Type	Quantity (kg)	Notes
Concrete		
Bricks		
Steel		
Wood		
Other..		

Table A3: Lighting system (energy-efficient)

	Type	Quantity (number)	Power (W)	Notes
Lamp				Insert a description of the typology of lighting system
Other..				

Table A4: Window typology

	Quantity (number)	Size (cm^2)
Type A		
Type B		
Type C		

Table A5: Window characteristics

	Type A	Type B	Other	Notes
Glass typology				Enclose technical report if avalaible
Glass area (m^2)				
Glass thickness (mm)				
Framework material				
Framework mass (kg)				
Insulation type				
Insulation mass (kg)				

Table A6: PV plant

Type	Technical notes	Quantity (m^2)	Power (kWp)	Notes
				Enclose technical report if avalaible

Table A7: Heating system

Technical characteristics	Thermal Power (kW)	Electrical Power (kW)	Utilized energy source	Notes
				Enclose technical report if avalaible

Table A8: Heating System - details

Main components	Typology of materials	Quantity (kg)	Notes
Radiators			Insert a description about quantity and typology of materials
Insulation			
Other..			

Table A9: Solar plant

	Technical characteristics	Quantity (m^2)	Power	Notes
Thermal solar plant				Enclose technical report if avalaible

Table A10: Ventilation system

	Technical characteristics	Notes
Ventilation system		Enclose technical report if avalaible

Table A11: Ventilation system - details

Main components	Typology of materials	Quantity (kg)	Thickness (mm)	Notes
Insulation				
Fan				
Other..				

Table A12: Pipes (heating-ventilation system)

Material	Diameter (mm)	Lenght (m)	Thickness (mm)	Insulation type (material and quantity [kg])	Notes

Table A13: Construction/demolition Waste

Typology	Quantity (kg)	Notes
Concrete		Insert a description of quantity and typology of materials
Glass		
Iron		
Other metals		
Wood		
Other..		

Table A14: Machineries utilized for retrofit works

Type (electric, diesel)	Power (kW)	Diesel consumpion (l/h)	Utilized hours per day e total duration of the works	Notes
				Insert a description of used machinery and the related impacts