Environmental and durability performance of building elements—assessment through a LCA tool application

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ABSTRACT
Building environmental performance evaluation should make use, as commonly assumed by now, of a Life Cycle Assessment (LCA) approach, by considering all building process phases: raw material acquisition, manufacture, transportation, construction, use or operation, disposal and re-use. Such an approach is intended to measure not only impacts on external environment but also building indoor environmental quality. The building 'running' phase—maintenance operations, replacements and substitution, or mechanical plant integration due to new regulation requirements and technological obsolescence—is strongly tied to health, safety and well-being standards and requirements which assure minimum IEQ levels.

This paper will show, by implementing operating, maintenance and durability issues in a well-known LCA tool, how all these aspects are linked in existing building management. The case study takes into account maintenance and repair of an external wall.

INDEX TERMS
Environment performance; Building maintenance and durability; Health effects and indoor quality

INTRODUCTION
The choice and usage of materials, products and specific design criteria, which determine building elements durability and performance, have different impacts on external environmental quality, safety and health during the building process, from cradle to grave.

The application of LCA to building elements has been carried out in many tools and methods since the 1990s:[1] environmental parameters generally considered are resource use, energy use, emissions to air and water, non-material emissions and waste generation.

In these tools, furthermore, process stages are raw material extraction, manufacture, transportation, industrial assembly and production (more seldom yard construction), decommissioning, disposal and reuse. The environmental impacts of the use phase (cleaning and maintenance) are often omitted (see Figure 1).

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[1] *Design EPS Method*, developed in Sweden; the *Environmental Theme Method* and *Eco-Quantum* programme, able to choose different design solution (material, components and building elements) considering environmental impact, developed in the Netherlands; the *Ecological Scarcity Method*, developed in Switzerland; *BREEAM* software for building environmental and energy labelling, which evaluates different environmental impacts (climate change, resource consumption, energy efficiency, CO_2 production; indoor and outdoor health and comfort, transportation, materials, water) taking into account even safety and quality requirements, developed in UK; *ESCALE* software, with a simplified LCA approach, considering energy resources, wastes large scale pollution (global warming, acid rain, ozone, radioactive waste), local pollution (air, water, soil), comfort (thermal, acoustic, visual, IAQ), health, environmental management, maintenance, developed in France.

	LC Stage	1	2	3	4a	4b	5
Type	Tool	Client brief	Design	Construction	Use	Refurb.	End-of-life
1	Detailed LCA modelling tools - material and product analysis		√			√	√
2	LCA design tools - eco point aggregation		√			√	√
3	LCA CAD based tools		√				
4	Building assessment and rating schemes		√	√			
5	Checklists and guides	√	√	√	√		√
6	Input/Output	√	√				

Figure1 Life cycle stages and LCA tool relevance (RMIT, Australia 2001).

LCA extended to use stage in Building & Construction (B&C) industry has to take into account not only IEQ requirements such as: safety, friendly use, health and well being (thermo-hygrometric comfort, IAQ, psychological and visual comfort) but also management economy.

Usage processes—cleaning, maintenance, replacement, repair interventions—are necessary not only to guarantee IEQ, occurring with a frequency connected to durability and building elements lifetime, but also contribute to external environmental impact (Costanzo *et al.*, 2002).

The method[2] presented here is intended to take into account such topics in order to show the relationship between elements performance linked to IEQ and external environmental impact:

- At building scale, by considering technical and environmental performances in use, that supply specific levels of IEQ.
- At a larger scale, by considering building the impact on the following damages:[3] resources (depletion of fossil fuels and of minerals), ecosystem quality (land use, acidification/eutrophication, ecotoxicity) and health climate change (carcinogens, respiratory organics and inorganics, climate change, radiation and ozone layer depletion), which are also caused by recurrence of interventions in use.

MAINTENANCE AND DURABILITY AS IEQ INDIRECT FACTORS IN LCA

Methodology

SimaPro5 Software,[4] has been adopted to analyse the life cycle of building elements (in the case study below, an external wall) and calculate the associated environmental effects.

Complex products can be analysed by the software and its databases can be modified and integrated without limits. Moreover, the software clearly shows the way the results are generated in relationship to inputs and outputs due to various stages and processes.

[2] The method has being developed for *BEEPS* programme (*Building Energy Environment Performance System,* http://www.beeps.it), overseen by the Ministry for the Environment and the Department of Technical Physics at the Università La Sapienza of Rome, regarding the energy certification of existing buildings, in order to evaluate performances in different building external walls.

[3] Damage and impact categories typical of Eco-indicator '99 Method:
HH Human Health (unit: DALY = Disability adjusted life years; this means different disabilities caused by diseases are weighted)
EQ: Ecosystem Quality (unit: PDF*m2yr; PDF = Potentially Disappeared Fraction of plant species).
R: Resources (unit: MJ surplus energy Additional energy requirement to compensate lower future ore grade).

[4] Sima-Pro software is a program connected with a database (http://www.pre.nl/simapro/order_simapro.htm). It belongs to a range of 'detailed LCA modelling tools' (see Figure 1) with inbuilt and customizable material and process databases, usually including a range of impact assessment models (other examples: Gabi, Boustead). It is complete as regards LCA B&C relevance, LCA covers (production, use, disposal, etc.), impact category use, possibility of LCC and variety of products in DB. IVAM (NL), http://www.ivambv.uva.nl/uk/index.htm is a Data Base, B&C oriented, developed for the LCA programme Eco-quantum and also compatible to SimaPro.

In some methodologies and tools, as already mentioned, typical (use) cleaning and maintenance cycles of building elements, as well as refurbishment over their lifetime are included.[5]

The possibility to include indoor climate effects as an impact category has also been taken into account: VOCs emitted per time and surface are recalculated to be suitable for LCA input, and critical volumes could be used as a basis for comparison, i.e. the volume unsustainable or polluted up to the limit value by the load of functional unit (Jönsson, 2000a,b).

We are integrating and adapting the available Software—since it is a detailed, modifiable and versatile modelling tool—on these purposes. Management interventions of building elements in use have been considered to calculate replacement and repair rates. When a replacement interval for an element is less than the lifetime of the building, replacement or repair will take place a certain number of times and can be dictated by taste, law obsolescence and keeping or restabilizing IEQ standards. Standards and indicators which link IEQ threshold standards to number of interventions are still in study (see Figure 2).

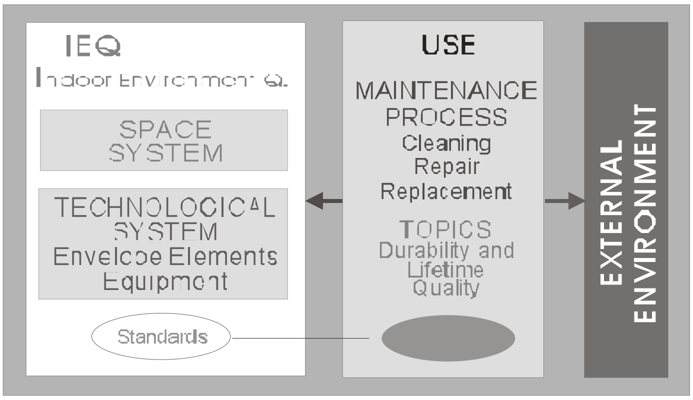


Figure 2 Links between indoor and outdoor environment in building use stage.

Environmental impact assessment is carried out through the Eco-indicator 99 E/W method. Some variations have been introduced and added to the method: elements ‘durability’ has also been taken into account (measured in years). It is, in the modified method E/W(T), a new impact category, associated to a damage category. As the characterization method links emissions to each impact category, we forced ‘lifetime’ as a non-material emission contributing to the ‘durability’ impact category. In such a hypothesis we assumed: characterization factor equal to 1; normalization factor equal to the inverse of building lifetime (50 years).

External Coated Wall: Inventory Analysis

The functional unit of the case study is an *external coated wall* of a building (1 m^2).

Main functions of the element which have been taken into account are: protections from external and internal agents, natural or artificial, supplying proper indoor comfort.

In the wall inventory analysis most elements make use of SimaPro Standard database referring to period 1996–1999, as well as IVAM database. For other elements, materials and

[5] Cleaning seems to account for at least 1.25% of a building’s total environmental impact over a 50-year lifetime, being multiplied by a large factor owing to the influence of building’s lifetime and internal surface area and to the presence of VOCs in detergents (Anderson and Edwards, 2000).

processes have been developed on purpose.[6] The results of the inventory analysis are calculated per unitary surface of coated wall over building life cycle.

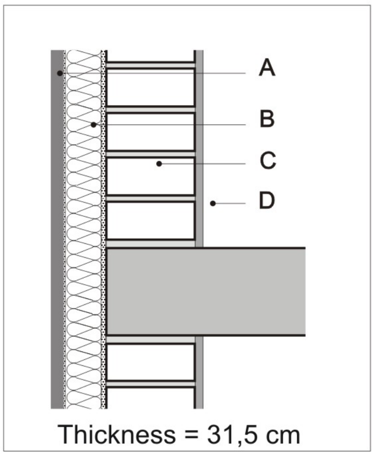
According to comfort (absence of dust, thermo-hygrometric comfort) and in order to guarantee minimum levels of building energy efficiency, some replacement and repair intervention rates have been assumed. Fundamental elements for the building structure (bricks linked by mortar, in the support stratum) have a lifetime that is equal to the building's life. Other elements, finishes typically, entail the following rates (Di Giulio, 1999):

- External coat: two times in the building lifetime (in order to guarantee internal thermal comfort and energy efficiency).
- Internal painting: five times, for visual requirements, but also for a certain percentage of moulds and dust on indoor surface in the volume.

Such a durability *scenario* has been taken into account by defining durability processes for the wall *strata* (*No. interv.* in Figure 3).

In Figure 3, the LCA process of the coated wall unit—coming from the inventory analysis stage of the software—is shown.

EXTERNAL COATED WALL



	MATERIAL	Mainten. intervention	No. Interv.
A B	Finish Plastic Paint Board (EPS)	Replacement	2
C	Bricks and cement mortar		
D	Cement Plaster Acrylic Water Based Paint	Painting	5

MATERIALS/FUELS

Finish Plastic Paint: 4,2 kg
Board EPS: 1,2 kg
Brick (clay): 150 kg
Cement Mortar: 34,65 kg
Cement Plaster: 18 kg
Acrylic Water Based Paint: 0,96 kg

OUTPUTS
Waste to treatment:

Solid waste 5,76 kg	reuse of building material (avoided discharge - painting)
Solid waste 202,65 kg	reuse of building material (avoided discharge - Bricks, Cement Mortar and Cement Plaster)
Solid plastics 15,60 kg	Incinerator Plastics (excl. PVC) External Coat

REPAIR REPLACEMENT

External Painting: 2 times
Coat Replacement (AB): 2 times
Internal Painting: 5 times

Figure 3 Inventory. The process external coated wall (materials, durability, end of life).

Each repair or replacement intervention implies inputs and outputs, generally assumed in literature. Partial reuse of some building materials has also been considered.

LCA Results

The main results of LCA are shown in Figure 4, where the influence of each process in the wall lifetime is linked to environmental impact categories.

The maintenance and replacement processes, considered during the wall lifetime, are: external painting (*ritinteggiatura esterna*), insulating board substitution (*ripristino cappotto*

[6] In Bianconi* F., Neri P.** & Others, *Ecodesign di una costruzione in linea*, ENEA Thesis, PROT-P135-001. * Student in Building Engineering at University of Bologna, **ENEA Researcher, PROT-INN, Bologna.

isolante), internal painting (*ritinteggiatura interna*) and the processes defined as durability (*durata*), which make up the maintenance scenario.

Negative values are due to reuse of building materials with avoided discharge.

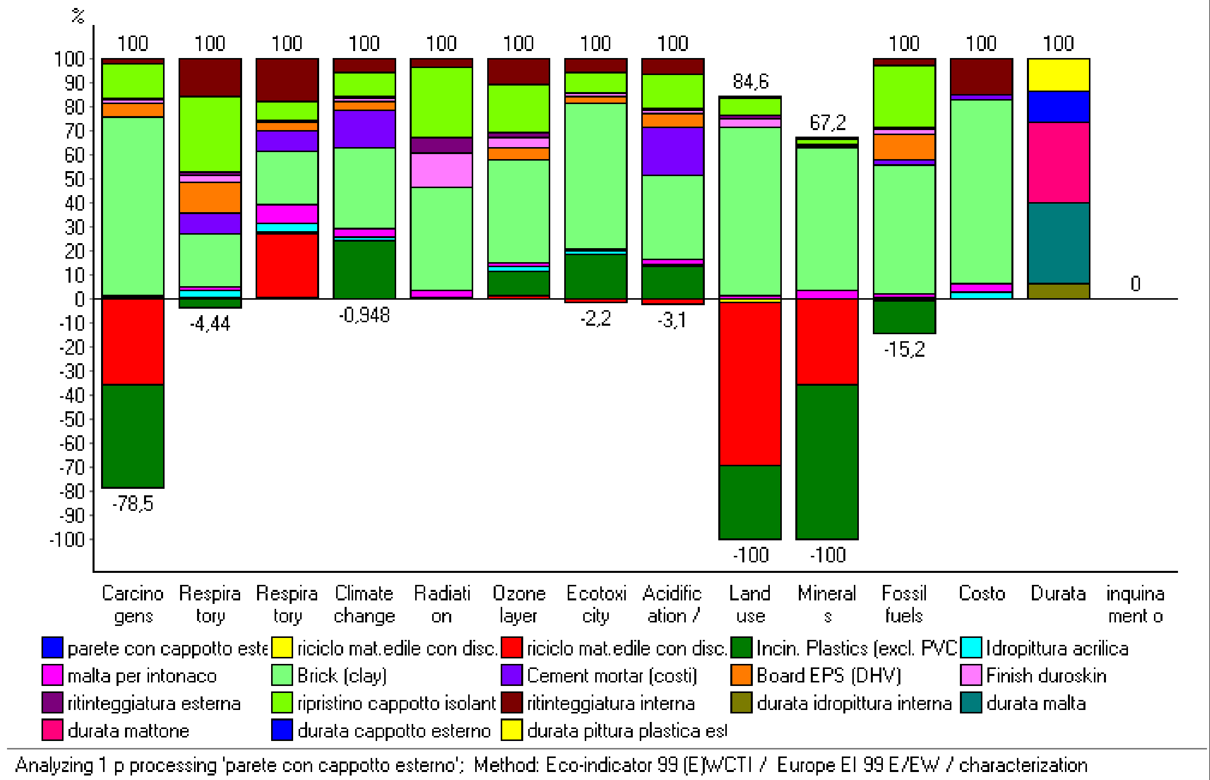


Figure 4 Characterization diagram of the process *external coated wall*.

As the figure shows, in damage category *Human Health* is relevantly influenced by impact category *Respiratory inorganics* (8.17E-5 DALY), mainly due to the reuse process of building materials that causes emission of 203 g of dust (SPM, suspended particulate matter).

Acidification/eutrophication (1.75 PDFm^2y) impact category mainly weighs on *Ecosystem Quality* damage, owing to brick production process (brick clay). The same process determines high *Fossil Fuels* (77 MJ Surplus, from natural gas) consumptions, mostly influencing damage category Resources.[7]

Maintenance cycle iterations (replacement of external coat = 'ripristino cappotto isolante', internal painting cycles = 'ritinteggiatura interna') and connected new material production relevantly influence damage category *Human Health* with particular regard to *Respiratory inorganics*.

CONCLUSIONS

The influence of the average lifetime of the elements and their durability estimated as *scenario* in the methodology is illustrated. The following step is to link cleaning, repair and replacement rates to IEQ standards, surface of moulds, thermo-hygrometric comfort, surface temperature of elements, indoor air quality—that is, finding the connection between minimum indoor standards and maintenance rates.

This allows, through the LCA method shown, to simultaneously analyse indoor and outdoor environmental impacts.

[7] See note 3.

What has been described in the paper are partial results of the BEEPS (Building Environmental and Energetic Performance System) programme, carried out by University *La Sapienza* of Rome in cooperation with Italian Environmental Ministry.

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REFERENCES

Anderson, J. and Edwards, S. (2000). *Addendum to BRE Methodology for Environmental Profiles of Construction Materials, Components and Buildings*. DETR, UK.

CIT Energy Management AB (1999). *Life Cycle Assessment for Building Services Systems—a Survey*. OPET Finland (Request Ref. Ruhrmann, 11 November 1998, No. 10).

Costanzo, E., De Santoli, L., Cumo, F. and Sferra, A. (2002). Embodied energy as indicator of building environmental behavior. Taking into account building elements durability. *EPIC 2002 AIVC Conference, 'Energy Efficient & Healthy Buildings in Sustainable Cities'*, Hilton Lyon, France, October.

Di Giulio, R. (1999). *Manuale di Manutenzione Edilizia. Valutazione del degrado programmazione e interventi di manutenzione*. Maggiolo Editore, Rimini, I.

Howard, Edwards and Anderson (1999). *Methodology for Environmental Profiles of Construction Materials, Components and Buildings*. BRE, UK.

Jönsson, Å. (2000a). Tools and methods for environmental assessment of building products—methodological analysis of six selected approaches. *Building and Environment* **35**, 223–238.

Jönsson, Å. (2000b). Is it feasible to address indoor climate issues in LCA?. *Environmental Impact Assessment Review* **20** (2), 241–259.

RMIT University (2001). LCA Tools, Data and Application in the Building and Construction Industry. Background Report for Department of Environment and Heritage, Australia.