EMBODIED ENERGY AS INDICATOR OF BUILDING ENVIRONMENTAL BEHAVIOR

Taking into Account Building Elements Durability

L. De Santoli[1], E. Costanzo[2], F. Cumo[1], A. Sferra[3]

[1] *Dipartimento di Fisica Tecnica, Università La Sapienza, Rome, 00184 ITALY*

[2]*ENEA, Centro Ricerche Casaccia Rome, 00060, ITALY*

[3]*Facoltà di Architettura Università La Sapienza Roma Rome, 000100, ITALY*

ABSTRACT

The paper deals with a complete procedure for the calculation of material embodied energy in the building sector using a Life Cycle Assessment (LCA) approach; the calculation of embodied energy for building material and components during the design phase takes into account both material durability and frequency of maintenance interventions. As a case study an evaluation of embodied energy for three different types of external walls is reported: external insulation coated, single stratum and multi strata. The described methodology has been developed as a part of BEEPS (Building Environmental and Energetic Performance System) programme, in cooperation with Italian Environmental Ministry.

KEYWORDS

embodied energy, environmental impacts, building elements durability, sustainability.

INTRODUCTION

Nowadays most of building environmental performance evaluation software use a Life Cycle Assessment (LCA) approach, by considering raw material acquisition, manufacture, transportation, construction, use or operation, decommissioning, disposal and re-use. [1]

[1] LCA software presently available:
Holland - *Eco-Quantum* programme, able to choose different design solution (material, components and building elements) considering environmental impact
U.K. - *BREEAM* (BRE Environmental Assessment Method for Office and Ecohomes for houses) software for building environmental and energitical labelling. BREEAM evacuate different environmental impacts (climate change, resource consumption, and energetical efficiency: CO2 production; indoor and outdoor health and comfort, transportation, materials, water) taking into account even safety and quality requirements.

U.K.- *Boustead* –software connected with a large UK. Materia data base.
France -. *TEAM* –i EcoBalance / Ecobilan (FR / US), e *Equer* , design phase - software.
France -. *ESCALE* software, made in 1999 by CSTB, works with a simplified LCA approach, considering energetical 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. Sweden - *LCAit* – developed by CIT Ekologic a division on Chalmers.
GBTool software is developed as a part of the project Green Building Challenge, as an international approach to "green buildings" concept. More then 20 countries are involved in the project.

LCA can be applied for different level of building components: materials, products, technological units, whole building. Also, different typical building processes are taken into account in LCA: industrial assembling and yard construction, management and rehabilitation phases.
Moreover it is commonly assumed in the scientific literature that LCA approach should be enforced to measure not only impacts on natural and non-natural resources (air, water, soil, energy sources, systems and services), but even on the building indoor environmental quality[2](IEQ).
If this approach is used as a design support tool, it is important to include all complex and different simultaneous choices that the planner has to manage, an environmental impact analysis being never considered without a preventive evaluation of the on-site element performance. Such a performance is connected with several requirements: safety, comfort, management, integrability, friendly use, all linked to "building quality" performance.
The analytical decomposition of building process, due to the lack of data and of previsional environmental and energetic models is presently unreliable
The paper, even using LCA limited to embodied energy (EE) shows the importance of some building quality issues on assessment results.
Energy consumption, as a part of embodied energy "recurring" in building operating and use, is also properly considered, calculated according to durability models and statistics.
A case study shows EE depending on durability of three walls widely used in Italy.

DURABILITY OF BUILDING ELEMENTS IN "EMBODIED ENERGY" EVALUATION

A sustainability issue of building elements can be quantified by energy inputs related to building products and materials combination that is their embodied energy. EE is supposed to be energy consumed by all the process units associated with the production of a building, from the acquisition of natural resources to product delivery, including mining, manufacturing of materials and equipment, administrative functions.
Choice and employ of materials, products and specific design criteria have relevant impacts on energy required to construct a building.
Materials in a building are not only the ones "assembled" during construction yard; it is necessary to add all those materials consumed during the building "running" phase for maintenance operations, replacements and substitution, or mechanical plant integration due to new regulation requirements and technological obsolescence, which are often predictable in the design phase.
Indoor environmental quality and durability aspects, connected with materials reactions in the finite products (physical and chemical layer compatibility), play an important role in building running-performance and maintenance interventions frequency; thus all those aspect are not usually involved in the material EE evaluation.

[2] Software developed for *BEEPS* programme (*Building Energy Environment Performance System)*, 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, evaluate performances on different building external walls.

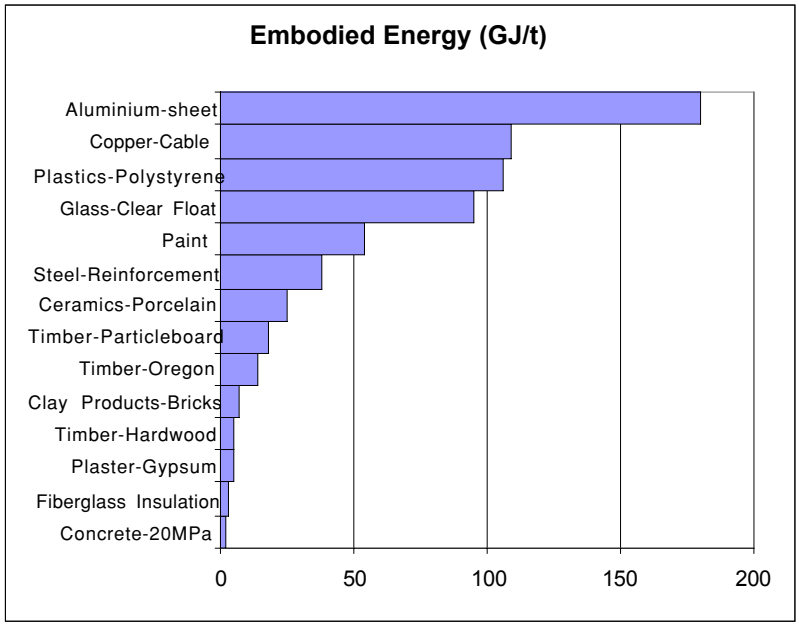


Figure 1 EE of materials used in building construction (in GJt^{-1})
Source: *CSIRO*, Australia, 2001

Maintenance cycles of designed element mean both "delivery energy" and "production and delivery energy" recurring fractions to initial EE consumed in their construction (see Figure 1).
An improved embodied energy calculation is affected by:

1) A general lack of desegregated input and output data necessary to create inventories in single LC units; exceptions are related to few countries.
2) Non standardization of a definition of boundary conditions: products and process units considered to predict embodied energy of each element (including running phase and use, after construction).
3) Scarce availability of a friendly-use and economical convenience of durability simulation software, including scheduled building element maintenance data.[3]

The first item should suggest the acquisition of primary data (on-site data). The availability of these data in Italy, considering both production industries and buildings construction yard is very poor. In this situation, it is still necessary to refer to secondary data[4] coming from technical literature or from available database.[5]
The definition of LCA, considering initial and operating recurring EE, is shown below (see Figure 2).

[3] More information regarding interactions between LCA and material and components durability are available in proceedings of the *9th International Conference on Durability of Building Materials and Components, organised by* CSIRO, Brisbane, Australia, 17-20 March 2002, http://www.dbce.csiro.au/9dbmc/conference/index.cfm
[4] This is the Italian situation where are available data only on the ANPA database I-LCA; this database collects some Europeans data banks and data measured "on site". For further details see: G.L. Baldo, Milano, 2000
[5] Sima-Pro software is a programme connected with a database; http://www.pre.nl/simapro/order_simapro.htm). IVAM (NL), http://www.ivambv.uva.nl/uk/index.htm is a complete data base developed for the LCA programme Eco-quantum.

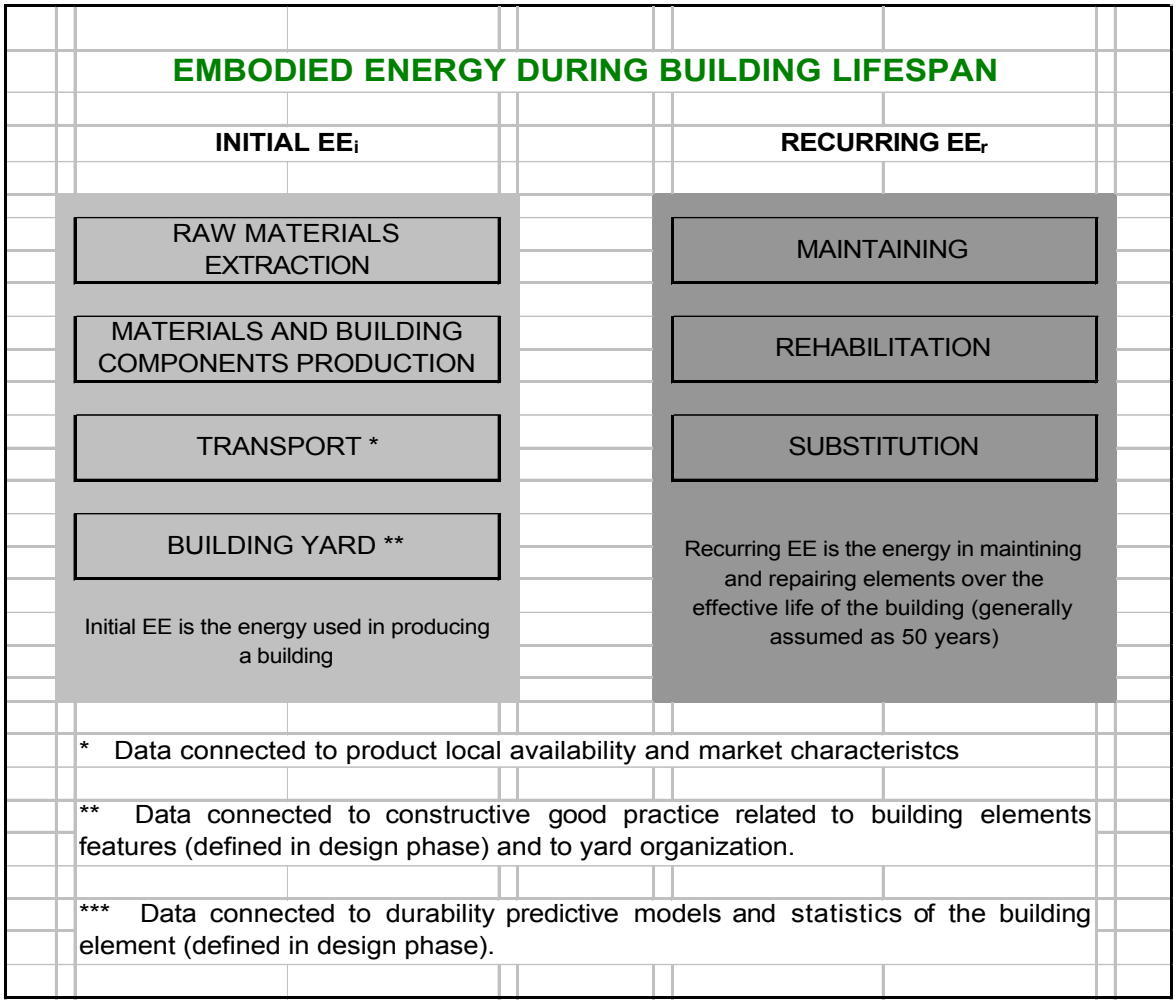


Figure 2 Life cycle phases considered in the embodied energy evaluation (EE_i=initial EE, EE_r=recurring EE)

In Figure 3 is reported the scheduled maintenance intervention frequency for some material and building components.

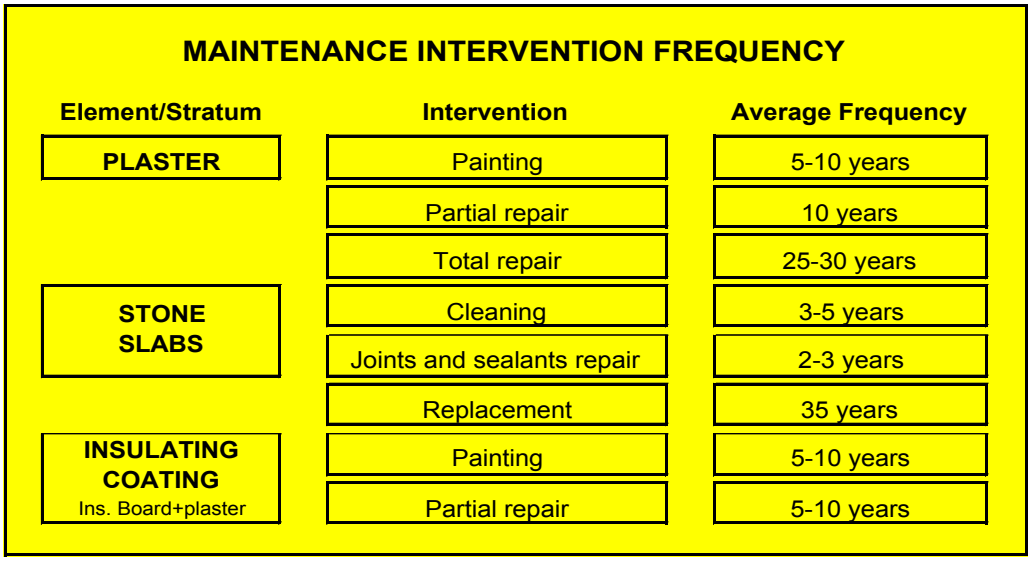
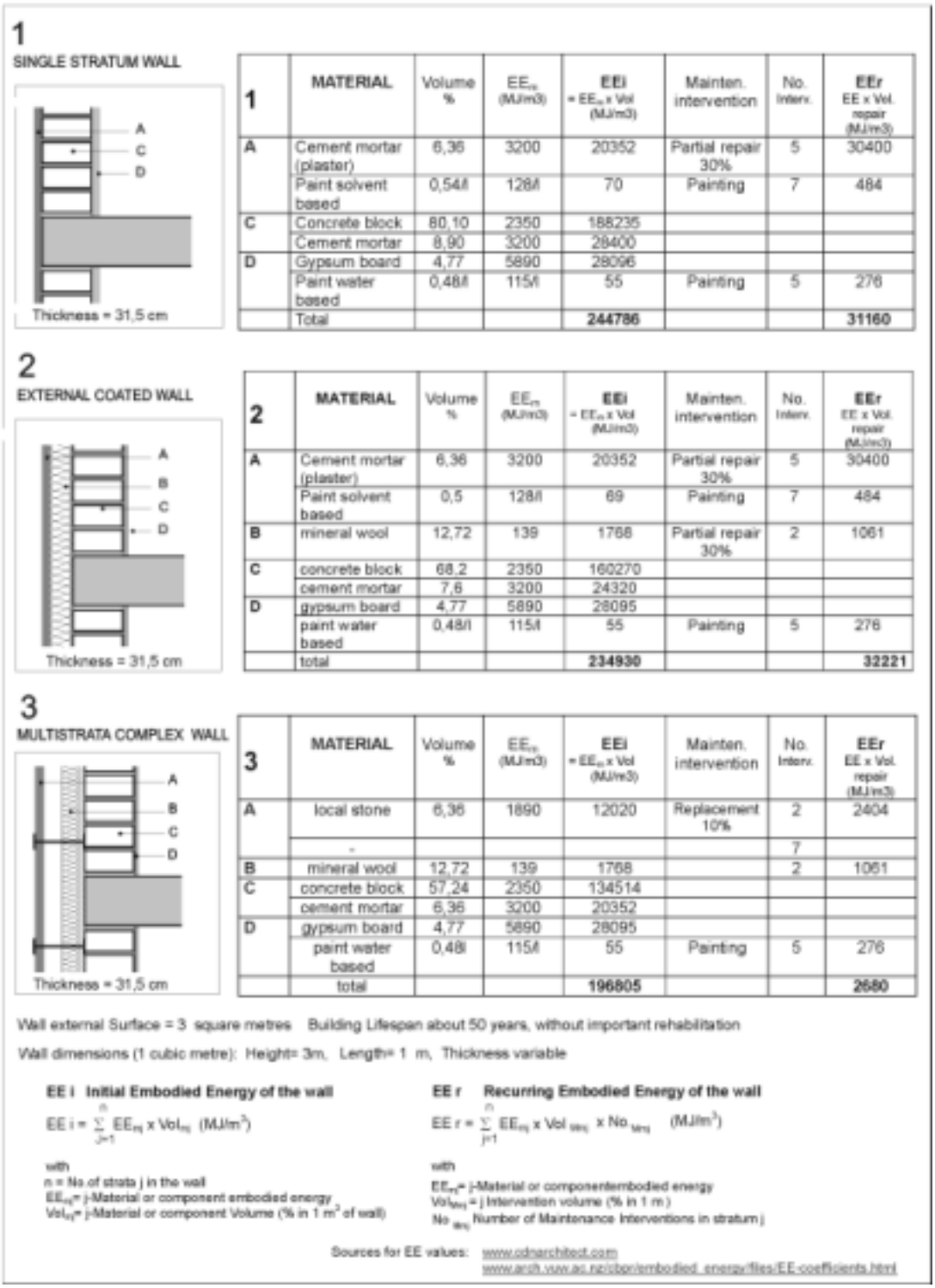


Figure 3 Maintenance intervention frequency. Source: Di Giulio, 1999, Italy

A case study

Building elements used as an example of EE evaluation are external insulation coated, single stratum, multi-strata external wall.

A Life Cycle Span of fifty years has been considered for the building. Average maintenance frequency interventions data have been considered for the element operating during building use. Few specific materials and products make up wall structures. Further material compatibility and interaction – that would be interesting – has been neglected due to data lacking. Data and results, as well as wall dimensions are summarized below (see Figure 4).



1	MATERIAL	Volume %	EE_m (MJ/m3)	EEi = EE_m x Vol (MJ/m3)	Mainten. intervention	No. Interv.	EEr EE x Vol. repair (MJ/m3)
A	Cement mortar (plaster)	6,36	3200	20352	Partial repair 30%	5	30400
	Paint solvent based	0,54/l	128/l	70	Painting	7	484
C	Concrete block	80,10	2350	188235			
	Cement mortar	8,90	3200	28400			
D	Gypsum board	4,77	5890	28096			
	Paint water based	0,48/l	115/l	55	Painting	5	276
	Total			**244786**			**31160**

2	MATERIAL	Volume %	EE_m (MJ/m3)	EEi = EE_m x Vol (MJ/m3)	Mainten. intervention	No. Interv.	EEr EE x Vol. repair (MJ/m3)
A	Cement mortar (plaster)	6,36	3200	20352	Partial repair 30%	5	30400
	Paint solvent based	0,5	128/l	69	Painting	7	484
B	mineral wool	12,72	139	1768	Partial repair 30%	2	1061
C	concrete block	68,2	2350	160270			
	cement mortar	7,6	3200	24320			
D	gypsum board	4,77	5890	28095			
	paint water based	0,48/l	115/l	55	Painting	5	276
	total			**234930**			**32221**

3	MATERIAL	Volume %	EE_m (MJ/m3)	EEi = EE_m x Vol (MJ/m3)	Mainten. intervention	No. Interv.	EEr EE x Vol. repair (MJ/m3)
A	local stone	6,36	1890	12020	Replacement 10%	2	2404
	-					7	
B	mineral wool	12,72	139	1768		2	1061
C	concrete block	57,24	2350	134514			
	cement mortar	6,36	3200	20352			
D	gypsum board	4,77	5890	28095			
	paint water based	0,48l	115/l	55	Painting	5	276
	total			**196805**			**2680**

Wall external Surface = 3 square metres Building Lifespan about 50 years, without important rehabilitation

Wall dimensions (1 cubic metre): Height= 3m, Length= 1 m, Thickness variable

EE i Initial Embodied Energy of the wall

$$EE\,i = \sum_{j=1}^{n} EE_{mj} \times Vol_{mj} \quad (MJ/m^3)$$

with
n = No.of strata j in the wall
EE_{mj}= j-Material or component embodied energy
Vol_{mj}= j-Material or component Volume (% in 1 m^2 of wall)

EE r Recurring Embodied Energy of the wall

$$EE\,r = \sum_{j=1}^{n} EE_{mj} \times Vol_{Imj} \times No_{Imj} \quad (MJ/m^3)$$

with
EE_{mj}= j-Material or componentembodied energy
Vol_{Imj} = j Intervention volume (% in 1 m)
No_{Imj} Number of Maintenance Interventions in stratum j

Sources for EE values: www.odnarchitect.com
www.arch.vuw.ac.nz/cbpr/embodied_energy/files/EE-coefficients.html

Figure 4 Case study. Comparison of E.E. (initial + recurring) of three wall types with different durability.

Some external layers are conceived as "sacrifice" strata. In order to minimize EE_r. they should have a lower EE_i before construction or have a high compatibility to other strata in the element. The more the strata are, the more some compatibility problems may occur during operating phase of the element. According to the hypothesis done, recurring EE (EE_r) is up to13% of initial embodied energy EE_i the latter being composed by rigorously interconnected strata and may be involved in the same degradation or aging effect.
Including durability statistics and predictive models in a LCA modifies results reliability. A repertory analysis on some building elements type, based on the described approach, could suggest a weighing methodology to predict recurring embodied energy fraction. Further studies will be developed in BEEPS LCA Module.

CONCLUSIONS

The present paper highlights the importance of simulation tools able to evaluate environmental impacts with particular regard to energy consumption during the life cycle of building elements.
The situation in this research field has shown some widely diffused problems due to the lack of local databases and of simple simulation models able to evaluate quality, durability and reliability of building elements.
Environmental Responsible Design and Construction instruments are based on a complex structure subdivided in different parts able to calculate all the different building performances (environmental, energy, safety, etc) which has to be supported by Public Institution and all the building involved associations.
This is the reason of the BEEPS programme which - following other similar International activity - is working to complete the development of the embodied energy calculation methodology illustrated in the paper.

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