View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Infoscience - École polytechnique fédérale de Lausanne

Zurich, June 15-17 2016
Sustainable Built Environment (SBE) regional conference
Expanding Boundaries:
Systems Thinking for the Built Environment
SBE SERIES 2016-17

INTRODUCTION OF A DYNAMIC INTERPRETATION OF BUILDING LCA RESULTS: THE CASE OF THE SMART LIVING BUILDING IN FRIBOURG, SWITZERLAND

E. Hoxha[1]*, T. Jusselme[1], M. Andersen[2], E. Rey[3]

[1] Ecole Polytechnique Fédérale de Lausanne (EPFL), Smart Living Building Research Group, Fribourg, Switzerland

[2] Ecole Polytechnique Fédérale de Lausanne (EPFL), Interdisciplinary Laboratory of Performance-Integrated Design (LIPID), School of Architecture, Civil and Environmental Engineering (ENAC), Lausanne, Switzerland

[3] Ecole Polytechnique Fédérale de Lausanne (EPFL), Laboratory of Architecture and Sustainable Technologies (LAST), School of Architecture, Civil and Environmental Engineering (ENAC), Lausanne, Switzerland

*Corresponding author; endrit.hoxha@epfl.ch

Abstract

Although a building lifetime is not predictable, it is an essential data in the yearly impact calculation. Yet, in the assessment of the environmental impacts of building the lifetime is considered as a fixed value.

The purpose of this study is to introduce a new dynamic interpretation of LCA results, which aims at improving the reliability of assessment of buildings' environmental impacts.

To that end, are compared:

- the environmental impacts assessed for 50, 70 and then 100 years of the building's lifetime;
- and environmental impacts assessed for anytime during the first 100 years of building's lifetime.

Since the impacts depend on the type of the building's components and their quantity, in this study two scenarios have been applied: one compares two building projects that differ from each other on the shape and functionality; the other compares two projects that differ only on components and systems employed in the building. Possible projects of the smart living building have been selected as case studies. This building aims at reaching the goals of the 2000-watt society vision and will be built by 2020 in Fribourg, Switzerland. The dynamic interpretation of building's impacts shows that the LCA results could vary up to 20%, according to the assumed building's lifetime and thus, completely change the conclusion in the comparison of the impacts of different building projects when the projects differ from the components and systems. The dynamic interpretation assessed more reliable LCA-results, that are useful for strengthen comparisons in the decision making process.

Keywords:
Dynamic LCA; Building; Lifetime.

1 INTRODUCTION

It is well known that buildings are counted as the responsible of 40% of global energy used, and as much as one third of global greenhouse gas emissions. But what is particularly worrying is the rate of growth of emissions. Under the IPCC's growth scenario, by 2030 the environmental impacts incurred from buildings will be doubled [1].

To prevent such scenario and to aspire a sustainable and equitable use of the world's raw materials, the Swiss Federal Institute of Technology promoted the vision of a "2000 watt per capita society". According to this vision, todays' impacts of primary energy, non-renewable energy and greenhouse gases should be reduced respectively by a factor 2, 3 and 4 by 2050 year [2, 3]. Because of buildings play a key role in the global energy used and greenhouse gas emissions, the assessment of the environmental performance is important in new construction for communicating their influence on sustainable development. For more than 20 years, life cycle assessment (LCA) method has been used as the tool for the assessment of the environmental impacts of building. Based on ISO-14040 [4] LCA methodology consists in four distinct analytical steps: defining the goal and scope, creating the life-cycle inventory, assessing the impact and finally interpreting the results.

In the literature a large number of studies can be found where the LCA methodology has been used for the assessment of the environmental impacts of building. The objectives, the methodological issues as well as the buildings cases are quite variable from one study to another [5]. According to the LCA method, the studies differ in general from each other as a function of the boundaries of the study (the components and systems of building taken into consideration), the database used for calculation, the functional unit of the building (description of the building: functionality, work hours and conditions of use) or the lifetime of the building. The lifetime is determined by how long the building lasts or is useful.

In the ensclic Building project [6], for the assessment of the environmental impacts of four houses, nine residential buildings and five offices the lifetime is considered to be 50 years. Hoxha [7] has considered a lifetime of 60 years in the assessment of the environmental impacts of 16 houses and 16 residential buildings. In the HQEperformance [8] the environmental impacts of 24 offices, 17 residential buildings and 22 individual houses were assessed for a building lifetime equal to 50 years and 100 years.

Depending on the type of building, in literature its lifetime vary from 25 to 100 years. Generally the building' lifetime is considered to be 50 years, but there is also a certain number of studies where the lifetime is considered to be 70 or 100 years [9]. Although a building lifetime is not predictable, it is essential data in the yearly impact calculation by having a preponderant influence in the reliability of the results calculated [10]. Thus, the research hypothesis of this paper is that we should not limit the assessment of building impacts to one or two building lifetime, but provides a LCA for any years of its lifetime in order to enhance the robustness of the conclusions. This approach is what we call a dynamic interpretation.

2 METHODS

To introduce the dynamic interpretation of LCA results, we have compared:

- environmental impacts assessed for a building lifetime equal to 50, 70 and then 100 years;

- environmental impacts assessed for anytime during the first 100 years of the building lifetime.

In the early design phase the scenarios of building can differ from each other, from the components and systems employed and the shape. Due to that, in this study two scenarios have been applied: one compares two building projects that differ from each other only by the shape and functionality; the other compares two projects that differ only by the chosen components and systems.

The assessment of impacts is undertaken according to European standard EN-15978 [11]. This standard proposes to calculate the environmental impacts of building in accordance with its life cycle phase: production, construction, use, exploitation and end of life.

2.1 Goal and scope definition

The smart living building has been chosen as the most appropriate case study. This building aims at reaching the 2050 goals, according to the 2000-watt society vision and will be built by 2020 in Fribourg, Switzerland. Two possible architectural scenarios are considered in this study as presented in Figure 1.

Fig. 1: Two possible projects of smart living building.

The first scenario (PR-1) has an expected energetic reference area of around 6200 m² (2000 m² of houses; 1200 m² of experimentation areas; 2700 m² of offices; 300 m² of other) and the second (PR-2) around 4000 m² (1250 m² of houses; 750 m² of experimentation areas; 1500 m² of offices; 500 m² of other). The wood is the main material used in both scenarios (PR-1 and PR-2) that differ from each other only by the shape and functionality. A third scenario PR-1/A considered in this study has the same shape as PR-1 but the main material used is the reinforced concrete. More details about the components and systems used in these three scenarios are presented in Table 1. All the phases of the building life-cycle are considered in the assessment of the impacts of building.

2.2 Inventory

A1–A3: Production phase: In the production phase the whole process of the extraction of raw materials from the earth is included, as well as transportation to the factory, production of the building's components and systems.

A4 & A5: Construction phase: In this module, the transportation of components and systems to the site of construction is considered. The distance of transportation from the factory to the site of construction of components and systems of building are presented in the table 1 and 2. These values are inspired by Lehman [12]. The amount of material of production phase are increased with 5% for considering the process of construction, but the energy consumption at the site has not been considered.

B1–B5: Use phase: The process of maintenance, repair, replacement and refurbishment, are included within the use stage. Based in the lifetime of a building's components and systems presented in table 1 and 2, the maintenance and the number of replacement rates are calculated according to standard EN-15978 [11]. The process of repair is considered to be every 50 years. Here we consider that 10% of materials and components with a lifetime equal to that of the building will be repaired.

B6 & B7 Exploitation phase: In this module we include energy and water consumed during the use phase of the building for heating, cooling, ventilation, hot water, lighting and appliances. More details about these inputs can be found in Jusselme et al. [15]. The energy consumed in the exploitation phase is simulated in a dynamic regime using the software Lesosai software [16]. The results obtained are presented in Table 2. The electricity produced by the PV panels is used for covering the need of electricity for lighting, ventilation and appliances.

C1–C4 End of life: Based in KBOB [13] database, the whole end-of-life process (demolition of building, transportation of materials to recycling site, treatment or elimination of materials) is considered in the study.

2.3 Impact assessment

The environmental impacts are assessed with the help of KBOB database [13]. The KBOB code presented in table 1 and 2 provides information about inputs, used for assessing the impacts of each material and system. Only the global warming potential (GWP) indicator is calculated in this study.

Table 1: Inputs used for the calculation of impacts (lifetime of materials and systems inspired from KBOB database [13] and HOXHA et al [14]). LB-Lifetime of building.*

Inventory data	Quantity of components and systems				Trans (km)	Lifetime (year)	KBOB (code)
	Unit	PR-1	PR-2	PR-1/A			
Excavated land	m^3	955	idem	idem	20	LB *	62.001
Gravel	kg	168320	idem	idem	200	30 *	3.012
Gravel	kg	42000	idem	idem		50 *	
Poor concrete	m^3	22.83	idem	idem	80	LB *	1.005
Concrete CEM II	m^3	45.62	18.78	112.15		50 *	11.005
Concrete CEM II	m^3	6.87	idem	idem		LB *	1.013
Concrete CEM III	m^3	27.5	idem	idem		LB *	
Cellular concrete	kg	24596	idem	idem		LB *	2.006
Fired clay	kg	-	-	162012		LB *	2.001
Mortar	kg	3024	idem	idem		15 *	4.001
Mortar	kg	-	-	63983		40 *	
Mortar	kg	72135	69123	15850		50 *	4.002
Mortar	kg	-	-	5072		LB *	4.001
Steel	kg	704.4	388	9157	130	40 *	6.003
Galvanized steel	kg	16272	10795	6492		LB *	6.011
Reinforcing steel	kg	1650	1650	66643	80	LB *	6.003

Table 2: Inputs used for the calculation of impacts (lifetime of materials and systems inspired from KBOB database [13] and HOXHA et al [14]). LB-Lifetime of building.*

Inventory data	Quantity of components and systems				Trans (km)	Lifetime (year)	KBOB (code)
	Unit	PR-1	PR-2	PR-1/A			
Hardwood	kg	28126	25775	-	130	25 *	7.013
Hardwood	kg	751	557	-		30 *	
Hardwood	kg	15620	7732	9573		40 *	
Hardwood	kg	1084	615	-		45 *	
Hardwood	kg	281123	300997	90456		LB *	
Chipboard OSB type	kg	163744	127205	63469		LB *	7.008
Cellulose fibre	kg	68618	509430	26321		LB *	10.01
Parquet flooring	kg	7022	4210	5680		50 *	11.011
Bituminous waterproofing	kg	277	277	277	1000	15 *	9.003
Bituminous waterproofing	kg	9258	9258	13099		30 *	
Adhesive	kg	32	23	14		50 *	8.001
Sanitary ceramics	kg	6425	1722	4259	80	60 *	3.014
Expanded polystyrene	kg	504	504	504	380	15 *	10.004
Expanded polystyrene	kg	-	-	12397		40 *	
Glass wool	kg	2525	idem	idem		30 *	10.001
Glass wool	kg	2254	1683	-		40 *	
Glass wool	kg	4195	2260	4195		LB *	
Polyurethane	kg	-	-	31027		40 *	10.006
PVC	kg	880	idem	idem	200	50 *	13.004
Plaster cardboard	kg	145070	79496	132577	1000	40 *	3.008
Reinforced plaster	kg	78656	42388	78656		LB *	3.007
Polyethylene	kg	259	142	-		25 *	9.007
Polyethylene	kg	321	315	-		30 *	
Wood paint	kg	2520	1549	89		10 *	14.001
Wood paint	kg	2040	1602	756		25 *	
Steel paint	kg	0.94	0.64	0.33		25 *	14.006
Carpet	kg	3106	2840	-		10 *	11.024
Doors	m²	253	137	253	100	45 *	12.001
Windows (20% wood frame)	m²	1409	1056	-		30 *	5.002 & 5
Windows (15% aluminium frame)	m²	-	-	1409		40 *	5.002 & 4
Heat distribution, residential	m² SRE	1927	1460	1927	-	25	31.021
Heat distribution, administration		3757	2438	3757		25	31.022
Heat production 30 W/m²		5685	3898	5685		25	31.002
Office ventilation sheet metal channels (2m³/h)		3021	2800	-		15	32.005
Air exhaust kitchen and bathroom		105	30	-		15	32.003
Sanitary equipment of offices		120	77	120		25	33.001
Sanitary equipment of residential		110	74	110		25	33.003
Electrical equipment of offices		3163	2438	3163		25	34.002
Electrical equipment of residential		2521	1460	2521		25	34.001
Solar collectors	m²	102	57	100		25	31.009
Photovoltaic panels	kWp	161	137	161		25	34.027
Space heating	MJ/m² SRE	72.5	130	72.5	-	In function of lifetime of building	42.003
DHW		12.3	13.1	12.3			42.003
Electricity for ventilation		14	16	14			45.020
Electricity for lighting		22	18	22			45.021
Electricity for appliances		59	5	59			45.022
PV panels		70	39	70			-

3 RESULTS

The results for the GWP indicator of PR-1 are presented in Figure 2. Comparisons of the CO_2-eq emissions with the 2050' goal [3] shows that the project reaches the objectives for 50, 70 and 100 year building's lifetime. The building has lower impacts per year when the building lifetime is considered 100 years instead of 50 years, but higher impacts for a building's lifetime equal to 70 years. At the same time the results confirm that the impacts of building life cycle phase varies in function of its lifetime. For a building lifetime equal to 50 years, the results show that the production phase (A1-A3), and exploitation phase (B6-B7) have the same weight. But this is not true for a building lifetime of 100 years, where the use phase (B1-B5) has the biggest weight, and is around three times bigger, compared to the production phase (A1-A3).

Fig. 2: CO_2-eq emissions on the 50th, 70th and 100th year of the buildings.

To better understand the impacts of building life cycle phase the CO_2-eq emissions are calculated for anytime during the first 100 years of building lifetime. These calculations represent a dynamic way of interpreting the results. The observation of results presented in Figure 3 shows that the phases of buildings can be classified in three groups. In the first group we can classify the phases (A1-A5 & C1-4) for which the impacts per year decrease by increasing the building's lifetime. In the second group we classified the exploitation phase (B6 & B7) for which the impacts are constant for all building' lifetimes. And in the third group we can classify the phases (B1-B5), for which the impacts per year rise by increasing the building' lifetime. At the same time the results show that the lifetime of the building can significantly influence the ability to reach fixed objectives in very efficient buildings. For a lifetime up to 20 years, the impacts of building per year are strongly decreased by the influence of its lifetime. For a lifetime between 20 and 75 years the impacts of building are lightly decreased by the influence of its lifetime, and for values higher than 75 years the building' lifetime doesn't have any significance influence.

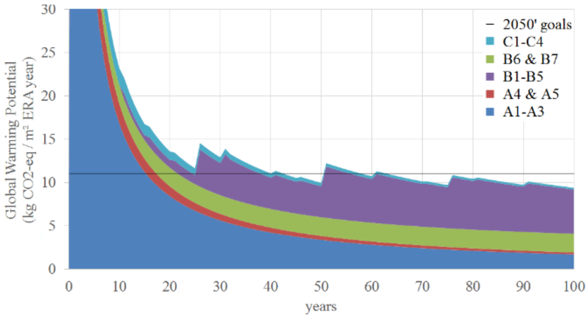

Fig. 3: CO_2-eq emissions during the first 100 years of the building lifetime.

It seems that the building reaches the 2050' goals for a building' lifetime between 45-50 years and 60 years. Assuming such building's lifetime in the yearly impact calculation bring to non-reliable conclusion, because in reality the building can last 55 years.

For building's lifetime greater than 65 years we can conclude that the building has reached the objectives. Only starting from a 65 years lifetime the environmental impacts of buildings are always lower than the 2050' goals.

The dynamic interpretation of results influence also in the decision making process. In Figure 4 we present the comparison of impacts of two building scenarios different from each other only by the shape.

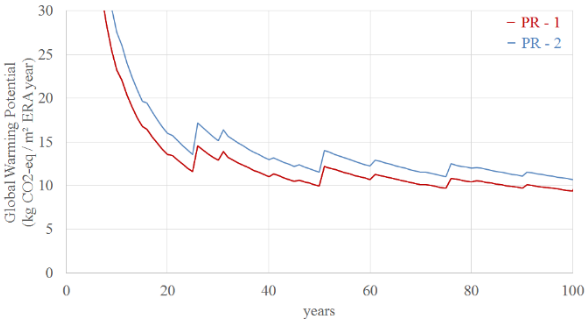

Fig. 4: Comparison of dynamic CO_2-eq emission of two building projects that are different from each other only by the shape and functionality.

Two interesting results can be obtained from Figure 4. First, we can observe that the shape that affect also the functionality of building has a significant influence on the impacts of a building, even if the performance is evaluated per m² of energetic reference area (ERA). For the scenarios presented in this study, the shape and functionality can reduce the impact with 15% for the unit kg CO_2-eq/m² ERA year. Secondly, the results show that the dynamic interpretation of results has no influence in the decision making process when the building's scenarios are different by the shape and functionality. The scenario that has lower impacts will always be the best solution whatever the value of the building's lifetime is. In Figure 5, are presented the environmental impacts of two scenarios that differ from each other from the building' components and systems.

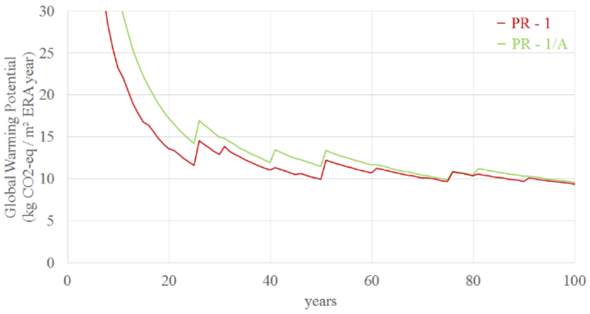

Fig. 5: Comparison of dynamic CO_2-eq emission of two building projects that are different from each other only by the chosen components.

The results obtained show that the PR-1 does not have always lower impacts compared to those of PR-1/A, even though the difference of impacts where 20% at 25 year lifetime of the building. The results show that starting from 60 years of building' lifetime, the impacts of the two scenarios are not significantly different.

4 CONCLUSIONS

The dynamic interpretation of building LCA results is a powerful way to better understand the environmental impacts of buildings. It shows the progression of buildings' impacts over time and helps the LCA-practitioner to understand in which phase and in which period of the building they should focus efforts for minimizing impacts.

An unexpected outcome of the study was the intersections of the environmental impacts of building projects. In the comparison of environmental impacts of two building projects, the one with lower impacts for a certain lifetime will not have always lower impacts for other values of lifetimes. So the main usefulness of the dynamic interpretation of LCA results is to identify these intersections. It strengthens the reliability of comparisons of scenarios in the decision making process and should therefore be used.

Further developments are necessary to set up the methodology for comparing scenarios with intersected environmental impacts.

5 REFERENCES

1. UNEP SBCI. Sustainable Buildings & Climate Initiative. Buildings and Climate Change: Summary for Decision-Makers. 2009. United Nations Environment Programme.

2. Jochem E., et al., Step towards a sustainable development: A white book for R&D of energy-efficient technologies. 2004. Novatlantis.

3. SIA 2040. La voie SIA vers l'efficacité énergétique. 2011. Société des ingénieurs et architectes. Zürich.

4. ISO 14040. Environmental management - Life cycle assessment - Principles and framework. 2006. International standard.

5. Ramesh, T., et al., Life cycle energy analysis of buildings: An overview, 2010. Energy Building: 42(10) 1592-1600.

6. CIRCE. Energy Saving through Promotion of Life Cycle Assessment in Building. 2010, enslic Building, Europe.

7. Hoxha, E. Amélioration de la fiabilité des évaluations environnementales des bâtiments. 2015, PhD thesis. Université Paris-Est.

8. Lebert, A., et al., Capitalisation des résultats de l'expérimentation HQE Performance. 2013 : Rapport intermédiaire, CSTB, France.

9. Ghattas, R., et al. Life cycle assessment for residential buildings: A literature review and gap analysis. 2013, Massachusetts Institute of Technology. USA.

10. Aktas, C. B., and Bilec, M. M. Impact of lifetime on US residential building LCA results, 2012. The International Journal of Life Cycle Assessment, 17(3), 337-349.

11. European Committee for Standardization (CEN). Sustainability of construction works-assessment of environmental performance of buildings-calculation method. 2001, FprEN 15978:2011.

12. Lehmann, U., Analyse du cycle de vie du "Green-Offices". 2011, Université de Lausanne. Switzerland.

13. KBOB et al. KBOB, eco-bau and IPB (2012) Ökobilanzdaten im Baubereich, Stand Juli 2012. Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren c/o BBL Bundesamt für Bauten und Logistik, retrieved from: http://www.bbl.admin.ch/kbob/00493/00495/index.html?lang=de.

14. Hoxha, E., et al., Method to analyse the contribution of material's sensitivity in buildings' environmental impact. 2014. Journal of Cleaner Production, 66, 54-64.

15. Jusselme, T., et al. Building 2050: Scientific concept and transition to the experimental phase, 2015. EPFL-Fribourg, Switzerland.

16. E4tech. Lesosai Software, 2008. Available from: http://www.lesosai.com/en/index.cfm.