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► **To cite this version:**

Bruno Peuportier, Aurore Wurtz. Application of life cycle assessment to a building sample in order to help in projects evaluation. Climamed, REHVA, May 2021, Lisbon (Online Event), Portugal. hal-04193942

**HAL Id: hal-04193942**

**<https://hal.science/hal-04193942>**

Submitted on 1 Sep 2023

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# Application of life cycle assessment to a building sample in order to help in projects evaluation

Aurore Wurtz<sup>1\*</sup>, Bruno Peuportier<sup>1</sup>

1: Mines ParisTech, PSL Research University

CES – Centre for Energy efficiency of Systems, 5 rue Léon Blum 91120 PALAISEAU, France  
web: <http://www.mines-paristech.eu/Research-valorization/Fields-of-Research/Energy-and-processes/>

\*e-mail: [aurore.wurtz@mines-paristech.fr](mailto:aurore.wurtz@mines-paristech.fr),

**Keywords:** Life cycle assessment (LCA), Building Energy Simulation (BES), environmental label

## Abstract:

*Life cycle assessment (LCA) is particularly adapted to evaluate the environmental performance of buildings thanks to its multi-criteria approach on the entire life cycle. This method constitutes a basis for the eco-design of buildings and will play a key role in meeting current environmental challenges; it is therefore necessary to have reliable LCA tools which allow an easy interpretation of the results.*

*This communication presents an aid in the evaluation of projects by developing performance benchmarks for several environmental indicators. On the principle of the European energy label, different levels of environmental impacts are evaluated and classified on a scale from A to G. The study is carried out over the entire life cycle, based on samples of buildings (housing and offices) with various construction dates from 1880 to 2016.*

*Extreme values of environmental indicators are first calculated for each sample, corresponding to the best and the worst environmental performance of these building types. Then intermediate environmental performances are obtained by varying some parameters in a large number of simulations, particularly: the structure of the building (concrete or timber), the heating energy (gas, electricity or wood), the thickness of the walls and the type of windows. These simulations are carried out using a python program associated to dynamic energy simulation and LCA models of the software Pléiades, with the ecoinvent 3.4 database.*

*Results present environmental labels corresponding to twelve environmental indicators: primary energy, CO<sub>2</sub>, health, biodiversity... The large number of simulations provides distribution functions for the samples, from A to G levels.*

## 1. INTRODUCTION

The building sector represents the biggest part of the final energy consumption in France. In the current context of energy transition, countries have to reduce their energy consumption and improve buildings environmental performance.

Today's decisions are determining environmental impacts for the next decades, due to the long building life span. This paper proposes LCA benchmarks for three samples of buildings: single family houses, apartment and office buildings to provide an order of magnitude of impact indicators and help designers to evaluate the environmental performance of their projects.

For each sample of buildings extreme values of environmental indicators are calculated, corresponding to best and worst environmental performance. Then, a parametric variation is carried out using a python program and the Pléiades software (Peuportier, 2015) to create an

environmental label, using the ecoinvent 3.4 database.

Results present environmental classes from A to G for each environmental indicator studied, over the whole life span of the buildings.

## **2. SCOPE OF THE STUDY**

### **2.1. Objectives of the life cycle assessment**

The methodology of life cycle assessment allows evaluating environmental impacts of materials, systems and processes over their entire life cycle. Building LCA takes into consideration all existing flows, from raw materials extraction to the end of life of a building, including the transport of materials, construction, use and renovation stages. The goal is to avoid pollution displacement in time (e.g. reducing fabrication impacts by avoiding a photovoltaic system but increasing operation impacts), in location (avoiding local impacts by electric vehicles but increasing impacts at the electricity plant) or between impact categories (for example reducing CO<sub>2</sub> emissions but increasing radioactive waste).

One aim of LCA is to identify the stage and contributors of the life cycle which generate the biggest part of impacts, in order to help designers to define priorities. But once the designer has improved a project, is it sufficient or should further efforts be performed? This study contributes to answer this question by establishing benchmarks, which can also be used to evaluate existing buildings.

This requires to compare harmonized functional units, for instance defining benchmark indicators per m<sup>2</sup> net area and per year, related to an occupancy scenario and comfort level according to the use (residential, office, etc.).

Environmental indicators are evaluated contextualizing the ecoinvent 3.4 database, and include: cumulative energy demand, greenhouse effect, water used, waste, radioactive waste, damage to health, damage to biodiversity, abiotic resources depletion, land use, acidification, eutrophication and photochemical ozone production.

### **2.2. Digital tools**

Pléiades software was used in this study, including Building energy simulation (BES) and LCA tools intended for eco-design and optimisation of projects. The optimisation module, called Amapola, allows varying some design parameters like the type and thickness of insulation which was adapted for this study.

## **3. METHODOLOGY**

This project is part of the Annex 72 of the International Energy Agency's Energy in Buildings and Communities Programme. The objectives are the establishment of a common methodology for LCA and the creation of benchmarks for different types of buildings in order to help building designers. LCA methodology needs common assumptions; this paper doesn't consider occupant transport, household waste or furniture impacts because they are not related to the performance of the building itself, which is studied here. However, impacts of foundations, plumbing and electric equipment, are added using a ratio per area. The life span of each material is also defined, as well as systems efficiency, water consumption and end of life processes.

This section presents the methodology applied; first extremes levels (A and G) were calculated and parametric variation was performed in a second step.

### 3.1. Calculation of levels A and G

Three samples of buildings were used in this study, individual and collective housing, and office buildings. Existing buildings were selected to evaluate the worst and the best environmental performance of each sample. Then, buildings used to calculate level A have a high insulation, double or triple glazed windows, photovoltaic panels and are located in Nice, South of France; whereas buildings for level G are not insulated, with simple glazed windows and are located in Trappes (coldest zone considered in the regulation). The samples are presented in table 1.

Table 1: Presentation of buildings chosen to establish benchmarks

	Single family houses	Apartments buildings	Office buildings
Level A	Energy positive house, 2018	Residential building, 2016	High energy performance offices, 2015
Level G	Uninsulated house, 1950	Hausmann building without renovation, 1880 Social housing without renovation, 1960	Variant without insulation nor PV system

First, a set of LCA calculations is performed on each cell of Table 1 with the following variations: building structure (concrete, wood or limestone), heating energy (electricity, gas or wood), presence of photovoltaic panels or not for level A. Levels A and G are then established for each environmental indicator; the value of level A corresponds to the lowest of all simulations, and the one with the biggest impact defines level G.

### 3.2. Parametric variation

Parametric variations are performed using BES coupled with LCA. Parameters are modified to expand samples of buildings to different heating loads and materials, and simulations provide a range of environmental impacts for each indicator.

A Python program is used to generate the parametric variation, coupled with the Amapola module and the software Pléiades calling Building Energy Simulation (BES) and LCA. Impacts of the use stage are calculated for each new building performance and integrated in the LCA results. This way allows carrying out many simulations automatically, starting from a few typical archetype models.

## 4. RESULTS AND DISCUSSION

### 4.1. Establishment of levels A and G

Values corresponding to level G for the apartments buildings sample were established comparing nine simulations; heating energy of both representative buildings was changed, as well as the structure of one building. Regarding level A, twelve simulations were run, varying the structure, heating energy and the presence of photovoltaic panels. These variations were also performed for the two others samples and the following results were obtained.

Table 2: Environmental classes A and G established for the three samples of buildings

Environmental impact /m <sup>2</sup> /year	Collective housing		Individual housing		Office buildings	
	Label A	Label G	Label A	Label G	Label A	Label G
Greenhouse effect (100 years) (kgCO <sub>2</sub> eq.)	1,46E+01	1,60E+02	1,48E+01	3,64E+02	6,54E+00	1,18E+02
Acidification (kg SO <sub>2</sub> eq.)	1,88E-01	1,46E+00	1,99E-01	3,25E+00	1,55E-01	1,09E+00
Cumulative energy demand (kWh)	2,20E+02	1,33E+03	2,83E+01	2,77E+03	-1,94E+02	8,29E+02
Water used (m <sup>3</sup> )	3,10E+00	3,70E+00	2,96E+00	5,11E+00	9,47E-02	8,43E-01
Wastes (t)	1,54E-02	5,63E-02	1,51E-02	1,11E-01	1,24E-02	3,95E-02
Eutrophication (kg PO <sub>4</sub> eq.)	4,94E-02	9,45E-02	5,19E-02	1,58E-01	2,54E-02	6,85E-02
Photochemical ozone production (kg d'éthylène eq.)	5,18E-02	7,10E-01	5,76E-02	1,82E+00	3,36E-02	5,51E-01
Radioactive wastes (cm <sup>3</sup> )	2,47E+00	1,36E+01	-1,03E+00	2,65E+01	-3,81E+00	7,52E+00
Land use (m <sup>2</sup> .year)	7,52E-01	4,26E+01	1,03E+00	1,13E+02	9,64E-01	3,38E+01
Abiotic resource depletion (kg d'antimoine eq.)	8,64E-03	1,55E-02	9,10E-03	9,12E-03	1,79E-02	1,89E-02
Damage to biodiversity (PDF.m <sup>2</sup> .year)	1,10E+01	6,23E+01	1,23E+01	1,35E+02	7,27E+00	4,46E+01
Damage to health (DALYs)	1,36E-04	4,32E-04	1,43E-04	9,57E-04	8,40E-05	3,09E-04

## 4.2. Presentation of environmental labels

### 4.2.1. Single family houses

Level G of this sample corresponds to a house located in Ile-de-France, which has a low energy performance. A parametric variation is performed, progressively increasing the performance; variations carried out represent more than 700 variants. Environmental labels of greenhouse gas emissions, water used and radioactive wastes are presented in figure 1.

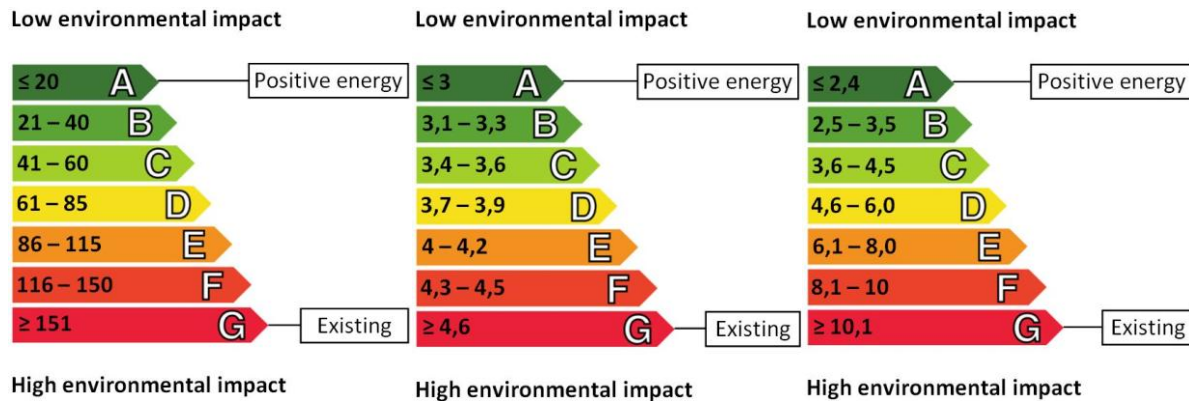


Figure 1: Environmental labels of single family houses, for CO<sub>2</sub> emissions (on the left) in kgCO<sub>2</sub>/m<sup>2</sup>/year, water used (in the middle) in m<sup>3</sup>/m<sup>2</sup>/year and radioactive waste (on the right) in cm<sup>3</sup>/m<sup>2</sup>/year

### 4.2.2. Apartment buildings

Three archetype buildings are considered in this sample. The type of windows and insulation thickness are then varied. CO<sub>2</sub> emissions vary between 13 and 110 kgCO<sub>2</sub> eq./m<sup>2</sup>/year in this sample. Following labels present benchmarks for CO<sub>2</sub> emissions and damage to biodiversity generated by collective housing.

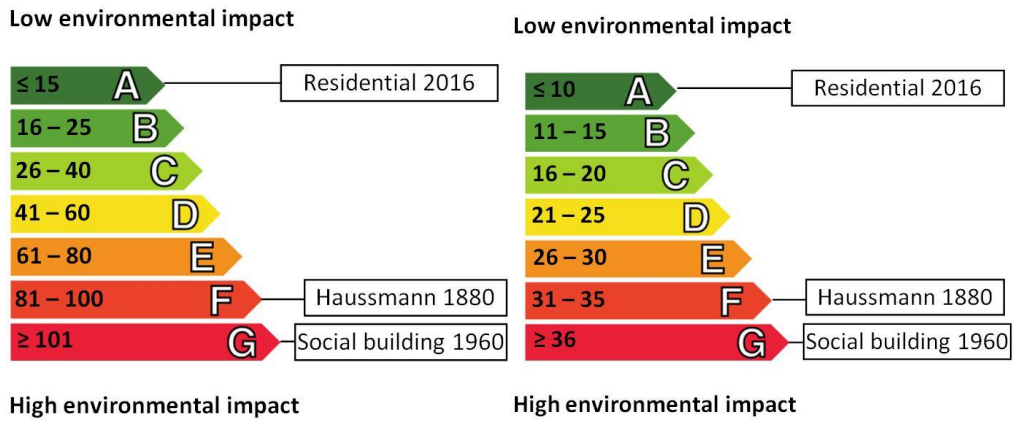


Figure 2: Environmental labels of apartment buildings, for CO<sub>2</sub> emissions (on the left) in kgCO<sub>2</sub>/m<sup>2</sup>/year and damage to biodiversity (on the right) in PDF.m<sup>2</sup>.year/m<sup>2</sup>/year

#### 4.2.3. Office buildings

A parametric variation was also carried out for this sample, based upon an existing high-performance building. CO<sub>2</sub> emissions vary between 10 and 100 kg of CO<sub>2</sub> eq./m<sup>2</sup>/year. Environmental labels of CO<sub>2</sub> and primary energy demand are presented in Figure 3.

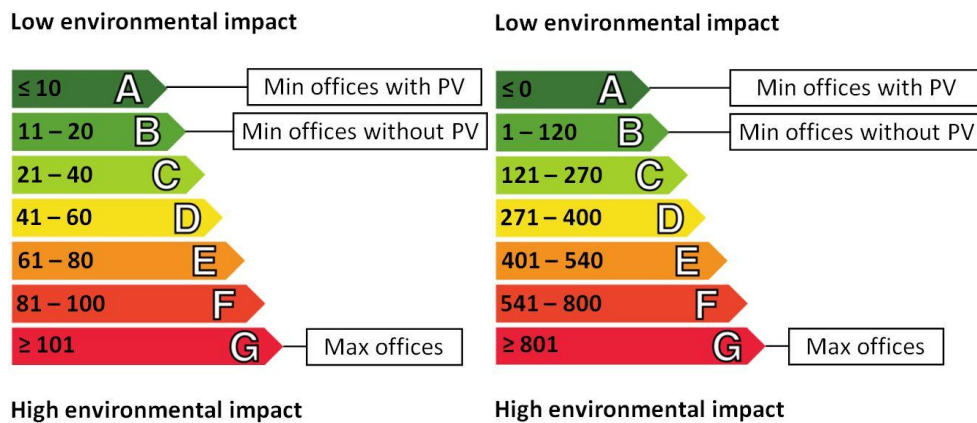


Figure 3: Environmental labels of office buildings for CO<sub>2</sub> emissions (on the left) in kgCO<sub>2</sub>/m<sup>2</sup>/year and primary energy demand (on the right) in kWh/m<sup>2</sup>/year

As an example, an office building was studied in the Annex 72; CO<sub>2</sub> emissions were evaluated to 15 kg CO<sub>2</sub> eq./m<sup>2</sup>/year, which corresponds to the environmental class B.

## 5. CONCLUSION

In this study, environmental labels of three samples of buildings were established for twelve environmental indicators through many simulations carried out using a Python program, based on typical archetypes. Environmental levels A and G were first established and then parametric variations (around 2000 simulations) allowed representing a part of the existing building stock. The project is currently pursued to improve the results including more parameters, and expand the labels to other samples of buildings. Finally, approaches in different countries are compared in the Annex 72 project.

## ACKNOWLEDGEMENTS

This work was supported by ADEME and the lab research environment VINCI ParisTech.

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