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Environmental impact of industrial prefabricated buildings: Carbon and Energy Footprint analysis based on an LCA approach.

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Abstract

The world-wide effort to reduce the environmental impact associated to the industrial sector is quickly producing an increasing feedback on national and international decision makers. In this context, the analysis of life-cycle based assessments on the main impact categories associated to the pre-production, production, assembly, use, and end-of-life phases represents a powerful tool towards a holistic interpretation of the footprint from industrial buildings.
The Italian prefabricated building sector, characterized, on average, by local enterprises with regional coverage, has been investigated in order to study the Carbon and Energy Footprints. Data from a large company, running several facilities spread on the national territory, have been collected and analyzed in order to provide a parameterized evaluation of the GHG emission and the energy consumption associated to the single phases of the building life cycle as a function of the sensible design requirements.
The quantification of the Carbon and the Energy footprint, associated to the prefabricated industrial building sector, is presented. The assessment procedure is performed through a parametric modeling of the building properties bases on the analysis of different sizes and designs. A detailed discussion of the outputs is presented, including the comparison of the environmental performance depending on different construction requirements.

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1. Introduction

The application of the life-cycle approach is fundamental to understand the real impact of the construction sector on the environment, especially for industrial buildings, which represent an important

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portion of the overall environmental impact, with still a few contributions investigating their life-long environmental behavior. The life-cycle assessment (LCA) is a widely accepted approach to quantify the environmental impacts of products or processes [1]. Various studies were carried out with the aim of investigating the interaction that the industrial sector has with the environment.

San-José Lombera et al. [2] presented a set of studies to define the sustainability criteria evaluating the environmental performance of industrial buildings. Their proposed new method is expected to overcome a series of shortcomings while contributing a range of improvements to the tools that are currently used to conduct environmental studies about LCA approach in the construction industry.

Cihat Onat et al. [3] analysed carbon footprint of the U.S. residential and commercial buildings with an input-output hybrid life-cycle assessment approach. As a result, they obtained that the emissions of the use phase are the highest of the overall life cycle of U.S. buildings, with 91% of the total emissions, while the end-of-life phase has a negligible contribution to the overall life-cycle energy use and carbon emissions.

Aye et al. [4] evaluated the life-cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules. In particular they quantified the embodied energy of modular prefabricated steel and timber multi-residential buildings in order to determine if these two forms of construction provide an improved environmental performance with respect to concrete construction methods. They found out a significant potential for the reuse of materials in the prefabricated steel building, representing up to an 81% saving in embodied energy and 51% materials saving by mass.

In this perspective, starting from the recent methodological works in the field of LCA, this paper answers the question of understanding the life-cycle impact of one of the most diffuse and impacting construction type: industrial and commercial prefabricated buildings. To this aim, this work presents the results of a carbon- and energy-footprint study on prefabricated standardized precast concrete industrial buildings in Italy, taking into account each phase of the building life cycle as a function of the key design requirements and building sizes.

2. The case study

The evaluation of two representative footprints, associated to the entire life cycle of prefabricated buildings has been carried out using specific and site-specific data provided from a large Italian company covering almost the entire national territory with four main construction and assembly sites. Since design requirements may vary within a large number of options, depending mainly on the destination of use and the installation site of the prefabricated building, particular attention has been dedicated to the identification and the parameterization of the characterizing features.

Two main impact categories were chosen:

- the *Carbon Footprint*, which quantifies the sum of direct and indirect emission of GHGs associated to the prefabricated building life cycle;
- the *Energy Footprint*, which similarly quantifies the primary energy.

Both impact categories (CF and EF), were assessed based on an LCA approach, including the end-of-life stage (i.e. cradle-to-grave). For each category, the impact was divided according to five main phases:

- *Plant production;*
- *On-site assembly;*
- *Transport;*
- *Use;*
- *End-of-life.*

All the processing phases, inputs, and outputs were considered, using 1% of the as a general cut-off rule.

2.1. Data collection and parameterization procedure

With the aim of providing an overview of the environmental footprint as a function of the typical design choices, a survey of the company building processes and available construction options were performed. Typical floor areas span from 1,000 up to 25,000 m^2, the roof-top height is between 7 and 12 m. Four different-sized prefabricated buildings have been selected and analyzed in detail to have a representative coverage. Table 1 contains information on the four buildings appearance.

A reference building was obtained averaging the properties of the four buildings, and letting them varying with the size. The results presented in the next section are relative to the reference building, which is a virtual building characterized by typical design features. The impact from input/output materials and processing were parameterized as a function of the building floor area and height. The impact from the use phase is handled using the appropriate building life time and energy consumptions (considering minimal heating and lighting requirements).

This reference building defined so far is intended as a basic prefabricated building prototype, already including all the five LCA phases, and characterized by minimum insulation thickness and foundations depth. The incidence of extra insulation and special foundation is also included.

Table 1. Characteristic features of the four surveyed buildings

Building	Floor area (approx.)	Roof-top height	Indoor clearance	Roof-top window area	Side-wall window area
	m^2	m	m	m^2	m^2
A	1,000	8.4	7.3	132	14
B	3,000	9.7	8.5	0	220
C	12,500	9.5	8	2,170	670
D	22,000	8.6	7.2	836	310

3. Results and conclusions

The carbon and energy footprint of prefabricated industrial buildings as a function of the floor area is presented in Figure 1 and 2, respectively. The buildings were modeled using basic insulation (class B) and foundations. The roof-top height is 10 m, the indoors clearance is 8.65 m.

Both the CF and the EF results show that the main impact arises from the use phase. The relative incidence is 62% for the CF and 67% for the EF. In this case the use phase is computed considering a 20-year life-time, and it includes only the minimum energy need for heating (class A building located in Perugia, Italy) and lighting (300 lux with metal-halide lamps). Any other energy consumption derived from the specific usage of the building is not included. Table 2 summarize the analysis outputs.

Building insulation has a major impact on the building environmental footprint. The comparison between the low- (class B) and high-insulation (class A+) cases is shown in Figure 2. In this case the CF of the plant production phase, which include the insulting foam footprint production and processing, increases by 57% (80% for the EF), while both the CF and the EF of the use phase decrease by 28%. Since the use phase is the most impacting one, the net effect is an overall reduction of 11% (CF) and 9% (EF). As an example, a 5,000 m^2, 10-m high building (8.65 m clearance) with low insulation is characterized by a CF of 90.5 kgCO2eq/m^3, while the same building with high insulation has a CF of 81.8 kgCO2eq/m^3.

The parameterized approach is able to produce a full and detailed LCA analysis of CF and EF associated to a large variety of prefabricated buildings, both in design phase or already in use, and hence to provide a flexible tool to assess the environmental performance of different design choices.

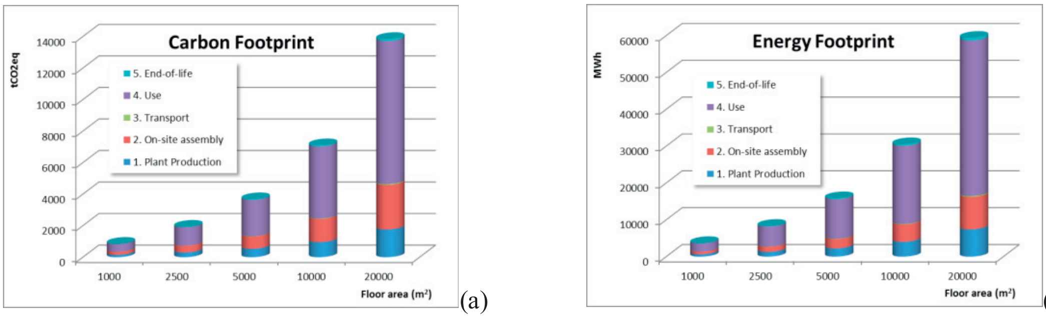

Figure 1. Carbon Footprint (a) and Energy Footprint (b) of the basic reference building as a function of the floor area.

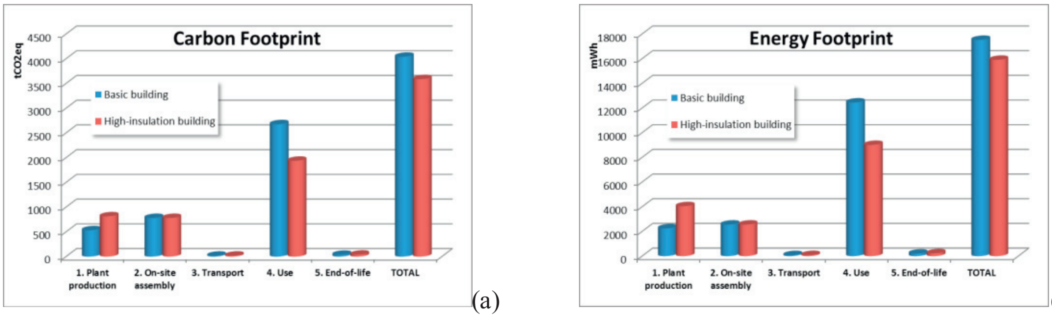

Figure 2. CF (a) and EF (b) of the basic reference building (in blue) versus the highly insulated building (in red).

Table 2. CF and EF for the reference basic building type.

Floor area		Total CF			Total EF	
m^2	$tCO2eq$	$kgCO2eq/m^2$	$kgCO2eq/m^3$	MWh	kWh/m^2	kWh/m^3
1,000	895	895	103.5	3,900	3,900	451
2,500	2,050	821	94.9	8,900	3,560	412
5,000	3,920	783	90.5	16,900	3,390	392
10,000	7,570	757	87.5	30,500	3,270	378
20,000	14,800	738	85.3	63,700	3,180	368

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Biography

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