 

# Towards a low-carbon strategy guided by the integration of renewable energy in building. The case of tourist complex in guelma.

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## Abstract

*Due to global climate change, reducing carbon emissions has become a crucial issue. Since the signing of the Paris Agreement in 2015, global attention to countermeasures against global warming has intensified, given that climate change poses major threats to human societies, and is fundamentally linked to energy consumption as well as Greenhouse Gas (GHG) emissions. Construction is one of the most energy-intensive activities in urban areas and is responsible for a significant amount of greenhouse gas emissions worldwide. Given its enormous environmental impact, changes need to be made towards a low-carbon strategy based on the use of renewable energy such as solar power. In this respect, the main objective of this study was to evaluate, analyze, and propose a scenario for a low-carbon building.*

*A Life Cycle Assessment (LCA) of a room located in a tourist complex in Guelma (Algeria) was carried out over 80 years during its four life cycle phases (construction, operation, demolition, and end of life) using Pleiades software. Its Equer tool was used to evaluate the 12 environmental indicators.*

*The results show that the addition of the photovoltaic panels has led to a 21.05% improvement in environmental performance over the entire life cycle of the room, and contributes to reducing the weight of its use phase by up to 24.05% via reducing all emissions emitted. All 12 environmental indicators showed significant reductions following the integration of this sustainable solution. It was concluded that photovoltaic panels are an important means of steering buildings towards a low-carbon future.*

Keywords: *Energy consumption; Greenhouse Gas Emissions; environmental impact; low-carbon strategy; renewable energy; Life Cycle Assessment; photovoltaic panels.*

## 1. Introduction

Over the past two decades, climate change has called into question the viability of sustainable development (Seneviratne et al., 2016). It has become a matter of great concern for humanity (Ahmed Ali et al., 2020; KIRATI, 2020). Much effort has been devoted to managing CO2 emissions by many countries to address climate change, as CO2 emissions have been considered one of the main causes of global environmental disasters in recent years (Duan et al., 2019; Nataly Echevarria Huaman & Xiu Jun, 2014; Xi & Cao, 2022). According to the Kyoto Protocol of the United Nations Framework Convention on Climate Change, CO2 has been identified as the main contributor to global warming since 2005 (Kim et al., 2017). Consequently, the development of a global low-carbon economy has become a key new

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priority (Kamali Saraji & Streimikiene, 2023; Kyriakopoulos et al., 2022; Wada et al., 2012; L. Zhang et al., 2017; Y. Zhang et al., 2019).

Previous studies have shown that the building sector has become a major source of carbon emissions and energy consumption worldwide due to rapid population growth (Nematchoua et al., 2021). It accounts for up to 40% of total energy consumption and 36% of CO2 emissions within the European Union (Pal et al., 2017). Algeria is no exception, as for many years the building sector has been one of the most energy-intensive sectors, but it is striving to reduce its carbon emissions. However, there is still a long way to go to meet international expectations. It is therefore necessary to steer society towards the adoption of low-carbon building (LCB).

The LCB concept originated in the low-carbon economy proposed by the UK government in 2003, and there is currently no clear definition in the academic community. In the Low Carbon Building Assessment Standard, adopted by the Chongqing Municipal Urban and Rural Development Commission, it was described as a building designed and built to optimize carbon emissions performance by reducing the carbon source and increasing the carbon sink during planning, design, construction, operation, demolition and recycling (L. Zhang et al., 2017). British academic Phil Jones (Jones & Xiaoxiao, 2008) has emphasized that the creation of low-carbon buildings should be based on reducing the energy demand of building products and making full use of renewable and reusable energy. Basically, three elements common to the various definitions of low-carbon building can be summarized as follows: reducing CO2 emissions and improving energy efficiency, using low-carbon materials and techniques and renewable energies, considering the whole life cycle (Li & Ou, 2010; Sartori & Hestnes, 2007). Some researchers mention that the most effective measures for LCB include low-carbon technologies (Cuce et al., 2016). Among these technologies, the use of active renewable energies is considered an important means of improving energy efficiency (Suh & Kim, 2019). Indeed, the incorporation of these techniques can reduce carbon emissions via a reduction in fossil fuel consumption during the operational phase.

Among the many sources of renewable energy, research into the use of solar energy is being actively pursued because of its unlimited energy source, practical system installation and good maintainability (Choi, 2022). Several studies have shown the importance of integrating solar energy into buildings. According to (Kirati et al., 2023) it is essential to make changes towards a sustainable energy transition by promoting the integration of solar energy, with the aim of promoting the design of buildings with reduced energy consumption. The production of this type of energy presents itself as an ecological alternative for producing electricity in a non-polluting way (Couderc, 2018).

In this respect, this article aligns with this line of action.

## 2. Method and materials

We carried out an environmental analysis of a room in a bungalow located in a tourist complex in Guelma (Algeria) over an 80-year period during its four life-cycle phases, detailing 12 environmental indicators (Table 1). then we studied the impact of integrating photovoltaic panels, comparing these results with those of the initial case.

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This methodology is divided into four main parts:

A. Definition of life cycle assessment.
B. Case study description.
C. Simulation software and protocol.
D. Description of improvement scenario applied to the case study throughout its life cycle.

**Table 1:** list of environmental indicators evaluated (Source: author;2023).

| Environmental indicators | Units |
|---|---|
| Greenhouse effect | t CO2 éq |
| Acidification | kg SO2 éq |
| Cumulative energy demand | GJ |
| Water used | $m^3$ |
| Inert waste produced | t |
| Abiotic resources depletion | kg E-15 |
| Eutrophization | kg PO4 éq |
| Photochemical ozone production | kg éthylène éq |
| Aquatic ecotoxicity | $m^3$ |
| Radioactive waste | $dm^3$ |
| Human toxicity | kg |
| Odour | $Mm^3$ air |

### 2.1. Life cycle assessment

Life Cycle Assessment (LCA) is a scientifically recognized and standardized methodology used to evaluate the environmental impacts of a product or process, from the extraction of raw materials to its end-of-life treatment "from cradle to grave" (Dakhia & Zemmouri, 2021).

The concept of life cycle assessment has developed over the years. In the 1970s and 1980s, life-cycle studies focused on quantifying the energy and materials used, as well as the waste discharged into the environment throughout the life cycle. The methodological framework of LCA comprises four stages: goal and scope definition; life cycle inventory analysis; life cycle impact assessment; and life cycle interpretation as shown in Figure 1 (Sharma et al., 2011).

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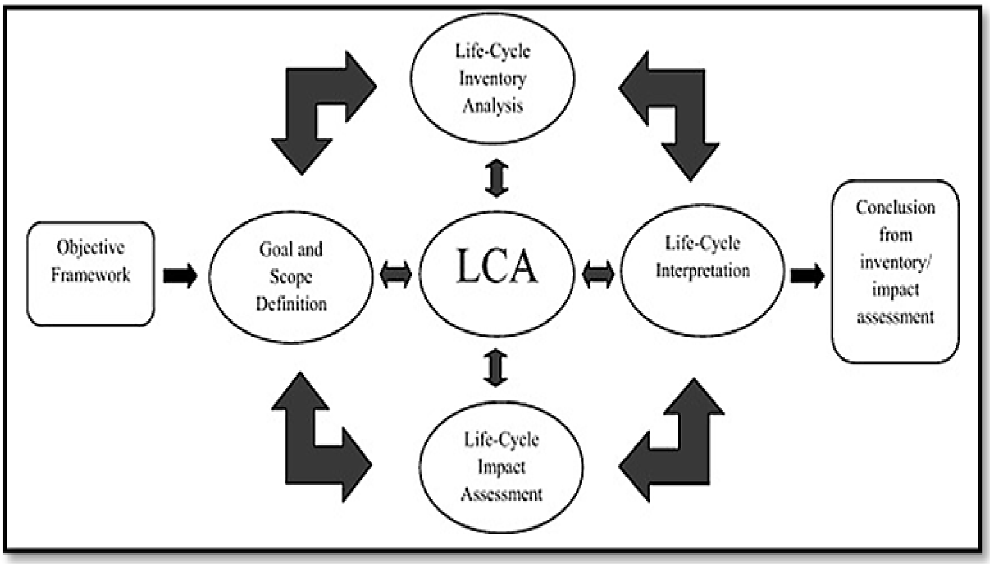


**Figure 1:** The LCA methodological framework (Sharma et al., 2011).

The definition of objectives and scope serves to establish the parameters of the functional unit, to delimit the boundaries of the system, and to specify the quality criteria for the inventory data. Life cycle inventory analysis consists of collecting and synthesizing information on the physical flows of materials and energy at different stages of the product life cycle. In life cycle impact assessment, these environmental impacts resulting from various material and energy flows are grouped into different environmental impact categories, where the characterization factor is used to calculate the contribution of each component to various environmental indicators (such as greenhouse gas emissions, resource depletion, etc.). Finally, life cycle interpretation deals with the interpretation of the results of life cycle inventory analysis and life cycle impact assessment (Sharma et al., 2011).

### 2.1.1. Building life cycle assessment

Worldwide, numerous efforts have been made to reduce the environmental impacts associated with the construction sector and the use of buildings. Among these, Life Cycle Assessment (LCA) has been accepted as one of the most reliable methods (Bahramian & Yetilmezsoy, 2020). It has been widely used in the building sector since 1990 (Khasreen et al., 2009), providing a sound methodological basis for calculating energy consumption and assessing resource depletion, GHG emissions and other environmental indicators over the entire life cycle of buildings (Buyle et al., 2013). Figure 2 shows the general structure and definition of building life-cycle stages according to the European standard for the sustainability of construction works, Assessment of the environmental performance of buildings (EN 15978) (Röck et al., 2020).

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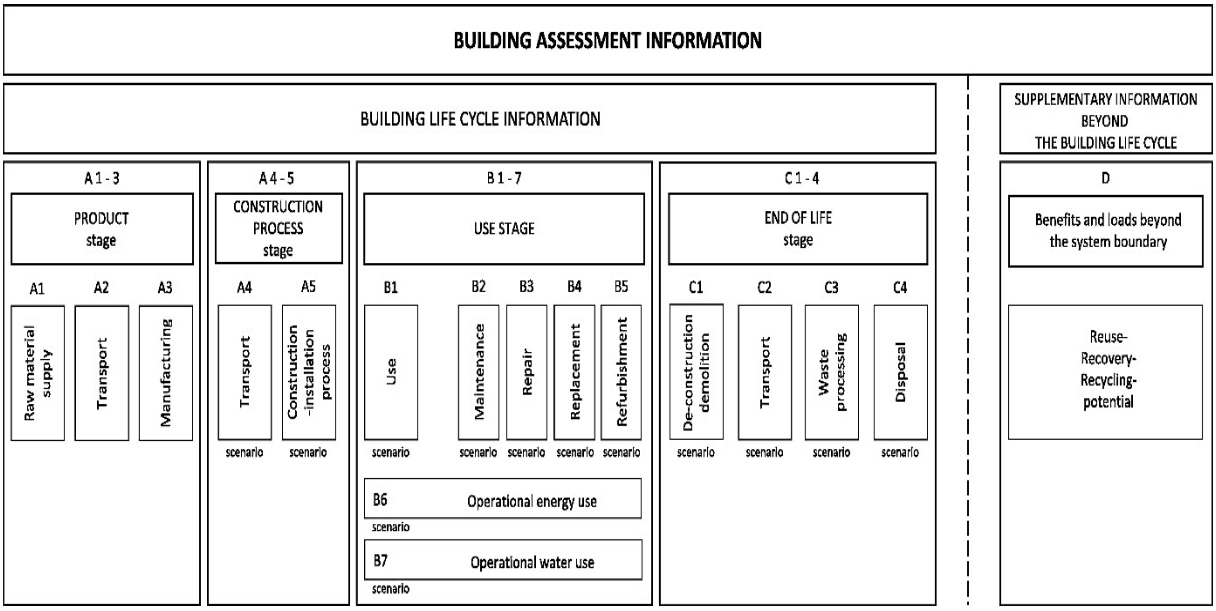


**Figure 2:** Phase and module breakdown of a building's life cycle in accordance with NF EN15978 (Röck et al., 2020).

Numerous life cycle assessment (LCA) databases, whether academic, commercial or public, are widely used in the building sector. Key databases include BEE, the DBRI4 database, Ecoinvent (which is used in this study), ECO-it, ECO methods, Eco-Quantum, Gabi, IO-database, IVAM, KCL-ECO, LCAiT, Simapro, and Spin. These LCA databases are often regional due to variations in energy production conditions at each site, resulting in differences in environmental impact related to energy supply (Fokaides et al., 2020).

### 2.2.Case study description

The building under study is located in the "El Baraka" tourist complex in the commune of Heliopolis, geographically north-east of the town of Guelma, which is located in northeastern Algeria (Figure 3).

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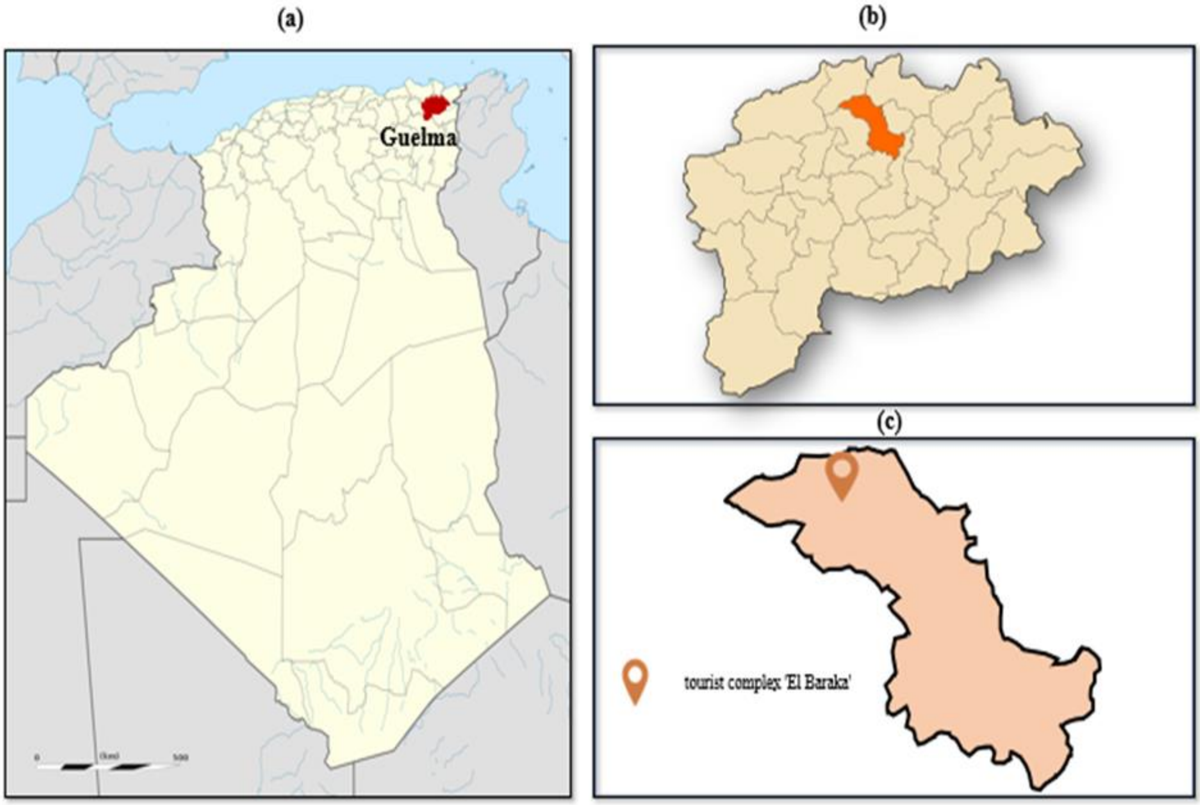


**Figure 3:** (a) location of the town of Guelma on the map of Algeria; (b) location of the commune of Heliopolis on the map of the town of Guelma; (c) location of the tourist complex on the map of the commune of Heliopolis (Source: Author; 2023).

The architectural composition of the overall plan (figure 4-a) shows the hotel in the foreground, with the entrance to the hammam in cabins, which benefits from a green space for relaxation. Set back from this is the entrance to the bungalows, which maintain the intimate character of the hotel.

We chose a 74.17 m² bungalow. It comprises a central space that acts as an entrance hall opening onto the kitchen and living room. This space leads to the bedrooms, bathroom and shower facilities, as well as the hammam cabin. The presence of a terrace and a small garden right at the entrance to the dwelling offers guests a corner of peace and contemplation. Figure 4-b shows a model of the bungalow, while figure 4-c shows the room under study.

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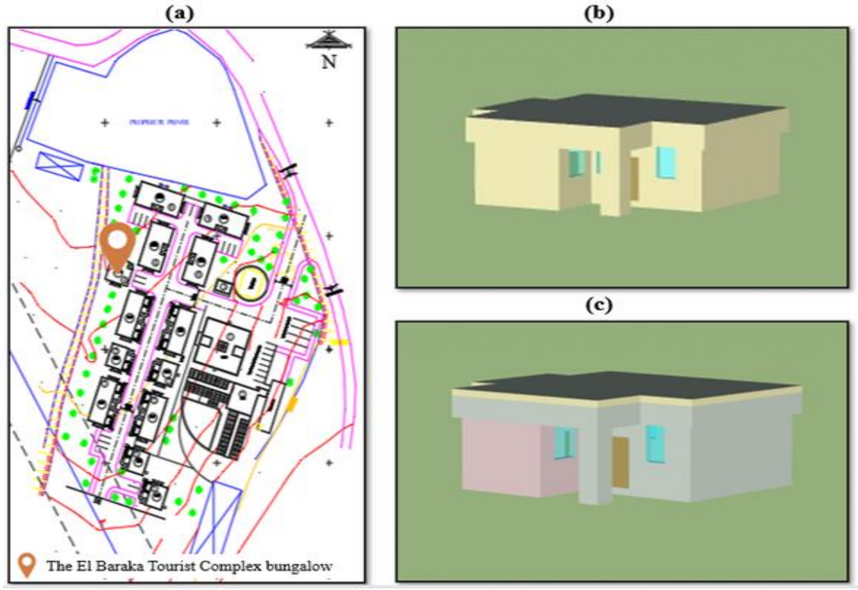


**Figure 4:** (a) location of the bungalow on the tourist complex; (b) the study bungalow;(c) the study room (Source: Author;2023).

### 2.3.Software and simulation protocol

In this study, we have exploited a combination of all the new IZUBA energy software features. The Pleiades software interface version 5.23.4.4 consists of six separate modules: Library, Modeler (formerly called ALCYONE in previous versions of the software), BIM, Editor (formerly known as COMFIE-PLEIADES), Results, and LCA Equer (nova EQUER). Each module fulfills a specific function (figure 5-a) and is regularly used by many research laboratories around the world, benefiting from a clearly established validation within the scientific community. The Pleiades simulation software is a reliable tool for analyzing the life cycle of buildings and neighborhoods (Salomon et al., 2005).

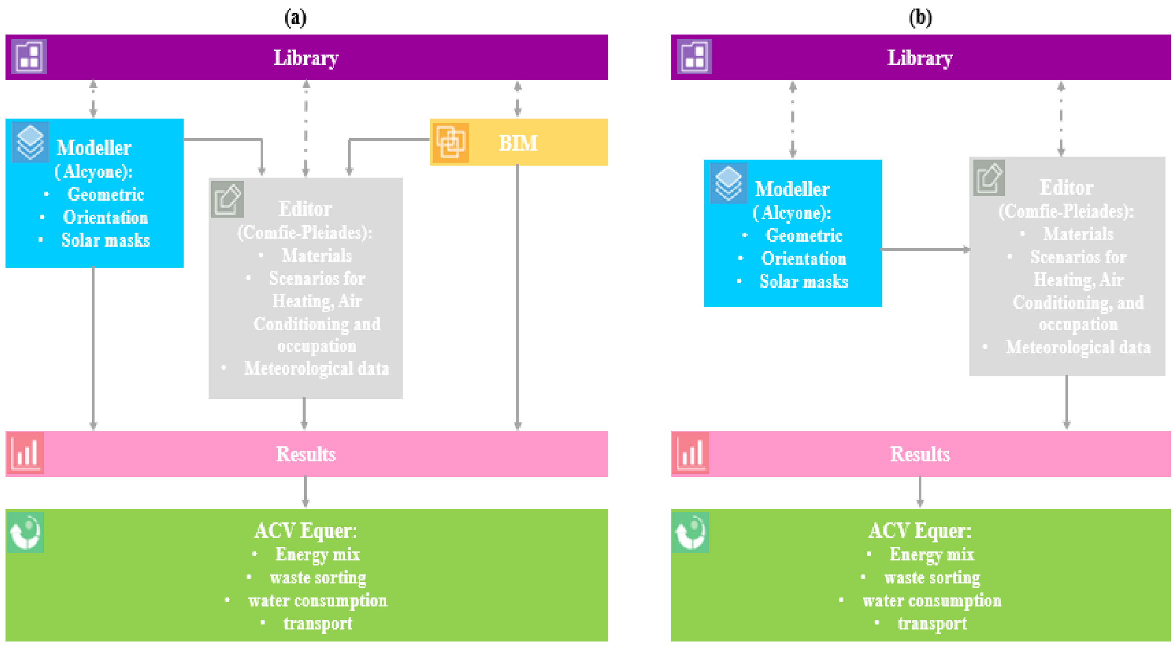


**Figure 5:** (a) Presentation of the Pleiades structure with its components and modules on the IZUBA energies website. (b) The analysis chain used in this study (Source: author;2023).

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Kaoula (Kaoula & Bouchair, 2018) clearly explained the function of its main modules as follows:

- The modeler (ALCYONE) is a graphical interface that allows you to quickly input building characteristics, including thermal properties, masks, systems, and usage data. It is used for both dynamic thermal simulation and regulatory calculations. In addition, it performs daylighting calculations for every hour of the year, as well as daylight factor calculations, and assesses compliance with the requirements of the High Environmental Quality (HEQ) and BREEAM labels in this respect.
- The editor (COMFIE-PLEIADES) is an energy simulation tool developed by the Energy Centre at the School of Mines in Paris. It enables for the dynamic multizone thermal simulation of a building. It performs hourly building simulation, providing energy engineers and architects with precise estimates of a building's energy requirements and temperature profiles.
- ACV Equer (Nova EQUER) is a tool specially designed to evaluate quantifiable aspects of environmental quality, and is integrated into Pleiades. Its exclusive use in this context is for life cycle assessment applied to buildings. The software was developed jointly by two research centers: the Energy Center of the School of Mines in Paris and the Institut National de l'Environnement Industriel et des Risques (INERIS). The software evaluates 12 environmental indicators for all phases in the life of a building or at the district level (construction, use, renovation, demolition), taking into account the fundamental environmental impacts based on data supplied by Ecoinvent.

The analysis chain followed in this research was as shown in figure 5-b.

The meteorological station in Algeria and its data are not included in Pleiades, so we have to enter them ourselves. To this end, the Pleiades STD COMFIE module integrates the MeteoCalc utility, which allows us to create and import our own meteorological data created by the Meteonorm software we use.

The main dynamic thermal simulation scenarios are grouped as follows: heating scenario, cooling scenario, dissipated power scenario and room occupancy rate. While the data required for building life-cycle analysis is structured into four main themes:

i. Energy
ii. Water
iii. Waste
iv. Transport

Structural and insulation materials are assumed to have a lifespan equal to that of the building, i.e., 80 years, coating 10 years, specific equipment 20 years and doors and windows 30 years.

### 2.4.Improvement scenario: integration of photovoltaic panels.

Integrating photovoltaic panels into a building reduces energy consumption and emissions. The installation of these panels on the roof of a building is widespread due to its large surface area. However, the orientation and inclination of the panels greatly affect their performance.

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Determining the optimum configuration requires careful consideration of factors such as solar irradiation, building orientation, shading and local climatic conditions.

In this variant, monocrystalline panels are installed on a small part of the roof (4 m²), facing south and inclined at 30°. No waterproofing elements need to be removed for assembly. The photovoltaic panels are fixed directly above the roof using special brackets. This installation creates an air gap beneath the panels, which can be beneficial for panel performance. The air gap generally allows better air circulation, which helps keep the panels at a lower temperature and improves their efficiency.

Monocrystalline panels generally have a higher efficiency, which means they produce more energy per unit area. For this reason, the panels selected in this variant have a peak power of 571.43 W. They tend to be more durable and perform better over the long term.

## 3. Results and discussion

This section presents the detailed results of the initial study case, including comparisons with the addition of photovoltaic panels throughout the room's lifecycle, as well as comparative results between the improved case and the initial case during the use phase.

### 3.1.Case of the actual scenario

The environmental impact is the result of the calculated rate of energy consumption and degree of thermal performance. After a thermal and energy analysis, the results are exported to ACV Equer (NOVA Equer) for an environmental assessment of the room studied. Figure 6 shows the results for 12 environmental indicators by life-cycle phase. Looking specifically at GHG emissions, the sum of emissions during construction (3.96 tons of CO2 equivalent), end-of-life (0.07 t), and the operating phase (59.68 t) totals 63.71 tons of CO2 equivalent over an 80-year period and for a surface area of 10.29 m2, equivalent to 77.39 kilograms of CO2 equivalent per year and per square meter. Such a figure is considered relatively high. It means that this room generates a significant amount of carbon dioxide every year, particularly during its use phase, which is responsible for 93.67% of its total (figure 7), contributing to climate change through its negative impact on the environment.

Of the four phases in the room's life cycle, the operating phase has the greatest impact. Analysis of the results in the table presented in Figure 6 shows that 86.28% of the room's environmental impact came from its "use phase". These results are also confirmed by several other studies (Dakhia & Zemmouri, 2021; Nematchoua et al., 2022; Sharma et al., 2011). According to the analysis of the results of this phase, among its main contributors to environmental impacts are electricity consumption, heating and air conditioning. This state of affairs leads us to reflect on how to reduce the environmental footprint of buildings and foster a low-carbon future, by improving energy efficiency through the use of cleaner energy sources with more environmentally-friendly technologies.

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Etapes

Export spreadsheet

| Impact | Construction | Utilisation | Renovation | Deconstruction | Total |
|---|---|---|---|---|---|
| Greenhouse effect (t CO2 eq.) | 3.96 | 59.68 | 0.00 | 0.07 | 63.71 |
| Acidification (kg SO2 eq.) | 18.04 | 125.50 | 1.09 | 0.85 | 145.49 |
| Cumulative energy demand (GJ) | 70.21 | 2 371.55 | 6.19 | 1.22 | 2 449.17 |
| Water used ($m^3$) | 38.57 | 10 117.60 | 4.46 | 0.57 | 10 161.20 |
| Inert waste produced (t) | 7 774.62 | 6.32 | 0.58 | 14.61 | 7 796.13 |
| Abiotic resources depletion (kg E-15) | 0.00 | 1.04 | 0.00 | 0.00 | 1.04 |
| Eutrophization (kg PO4 eq.) | 1.80 | 490.49 | 0.08 | 0.13 | 492.49 |
| Photochemical ozone production (kg ethyl | 12.86 | 70.22 | 0.50 | 0.93 | 84.51 |
| Aquatic ecotoxicity ($m^3$) | 83 296.85 | 602 535.82 | 4 305.31 | 2 451.27 | 692 589.24 |
| Radioactive waste ($dm^3$) | 0.43 | 4.58 | 0.01 | 0.00 | 5.03 |
| Human toxicity (kg) | 24.98 | 167.07 | 4.03 | 1.03 | 197.10 |
| Odour ($Mm^3$ air) | 15.13 | 960.04 | 0.38 | 0.08 | 975.64 |

**Figure 6:** Table showing the results of the various environmental indicators by life-cycle phase (Source: author;2023).

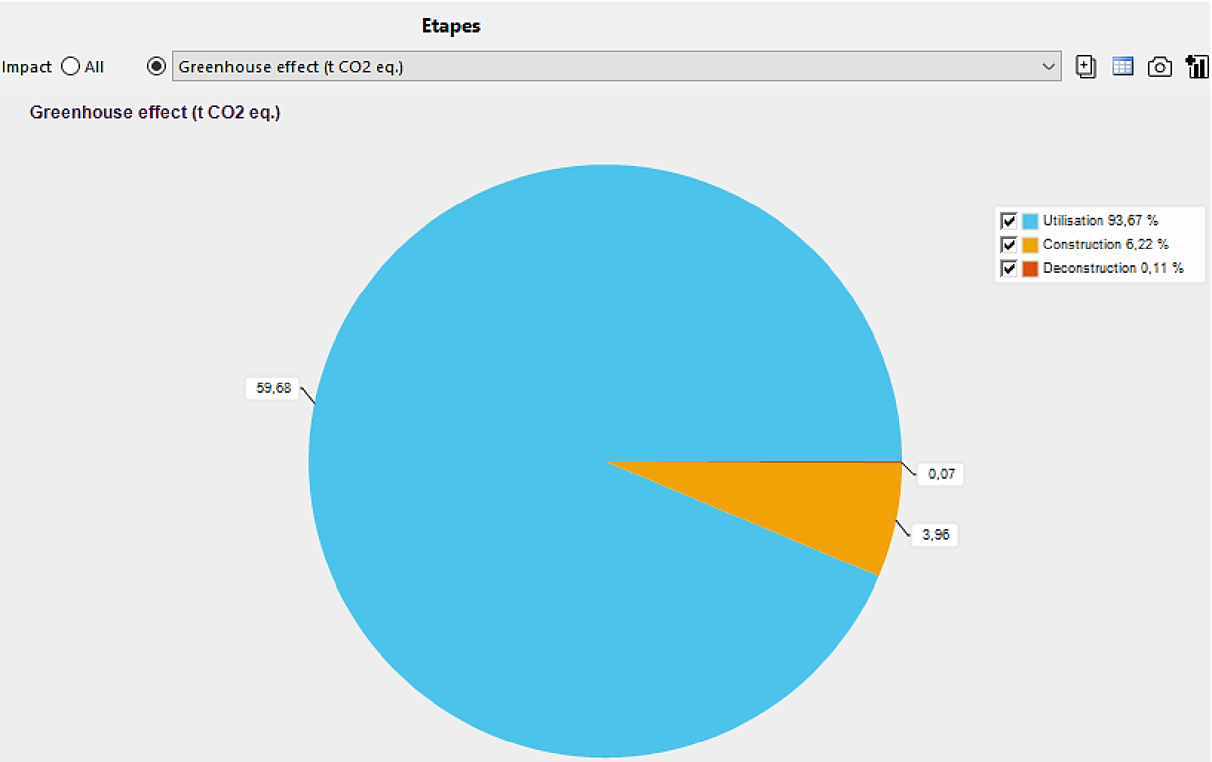


**Figure 7:** Percentage of Greenhouse Effect during the building life cycle (Source: author;2023).

### 3.2.Case study improvement scenario

When we compare the initial scenario and the 12 environmental impacts when adding monocrystalline panels, all indicators show decreasing results, as shown on the radar diagram in figure 8. They contribute to the reduction of several environmental indicators thanks to their ability to generate clean electricity from sunlight. According to figure 9, this addition brought an environmental improvement of 21.05%. The three indicators with the greatest

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variations are depletion of abiotic resources (-65.64%), radioactive waste (-65.21%), and cumulative energy demand (-44.67%).

Since monocrystalline panels produce electricity without direct GHG emissions, helping to reduce carbon dioxide emissions (CO2), this explains the remarkable reduction in GHGs in figure 9. They also minimize emissions of acid pollutants that contribute to environmental acidification, which justifies their 14.07% reduction.

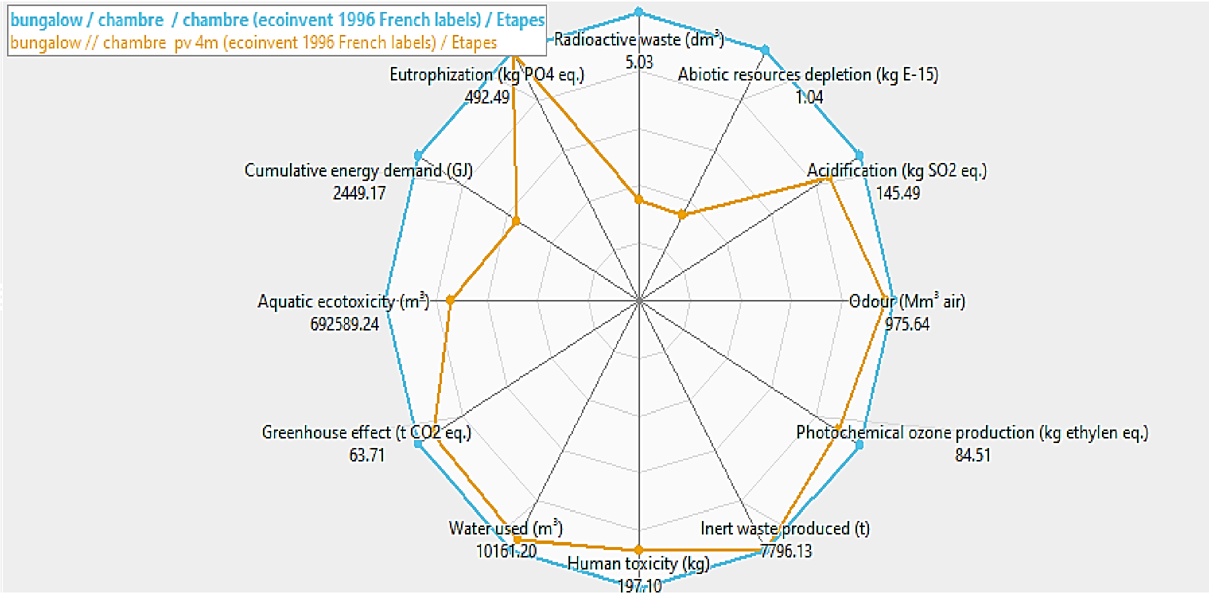


**Figure 8:** Radar diagram of two variants throughout the room life cycle (Source: author;2023).

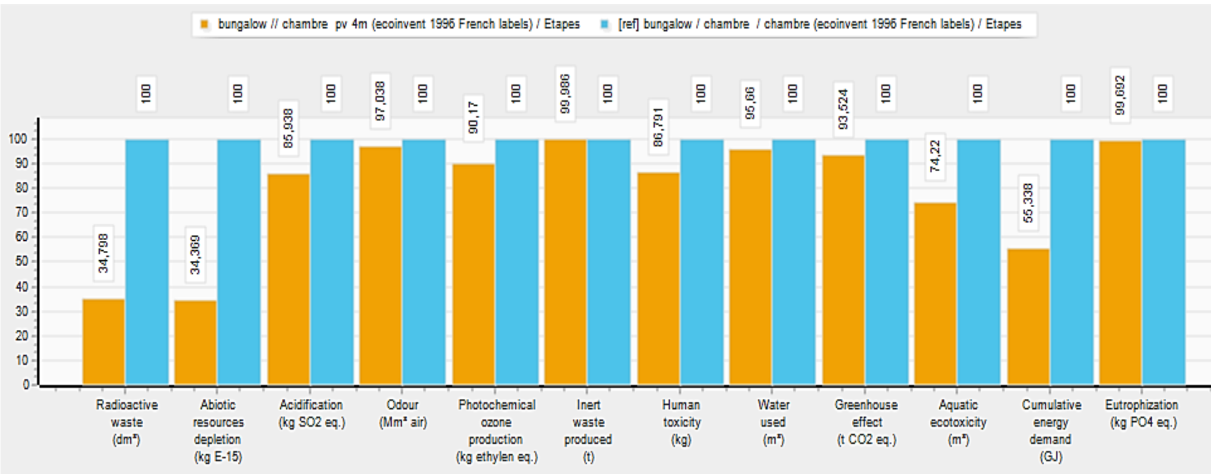


**Figure 9:** Comparative results (with percentage) of two variants throughout the room's lifecycle (Source: author;2023).

Figure 10 illustrates the results for each of the operating phases of the Life Cycle Assessment for the two cases studied. It shows that the addition of monocrystalline panels reduces the weight of the use phase by up to 24.05%. As already mentioned, the main contributors to environmental impacts during the operating phase are often related to electricity consumption, heating and cooling of the room. The installation of these panels makes a major contribution to reducing cumulative energy demand and consequently electricity consumption, as it

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produces a large proportion of the electricity from a renewable source. This type of production is the main reason for the significant reduction in other environmental indicators, particularly during this phase of the life cycle.

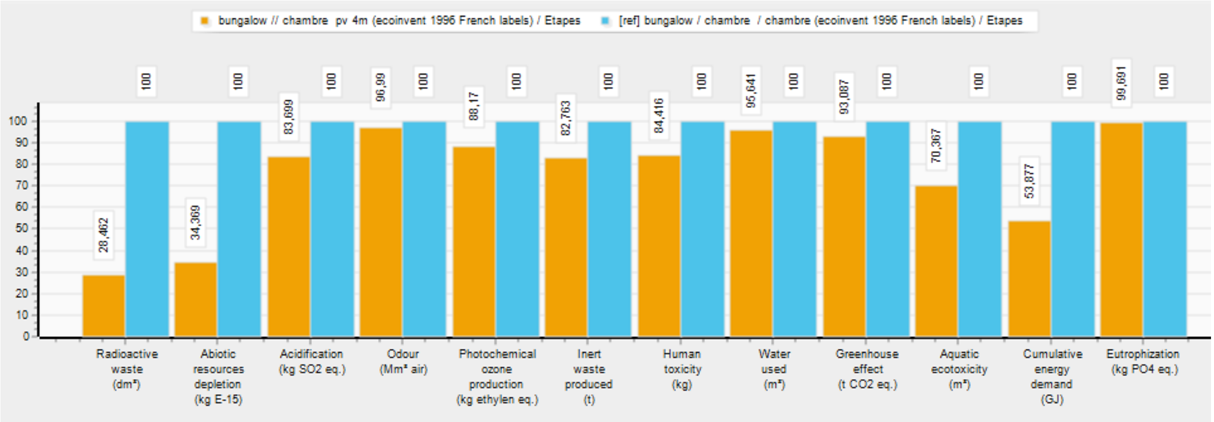


**Figure 10:** Comparative results for each usage phase in the life cycle analysis for both cases. (Source: author;2023).

## 4. Conclusion

Research and development to improve the environment of buildings and mitigate their negative effects on the environment over the long term is increasing as standards related to energy efficiency and the reduction of environmental impacts rise. Buildings play a major role in the energy consumption of the total energy available, contributing to the consumption of fossil fuels and the emission of various hazardous gases, resulting in global damage such as the greenhouse effect and acidification.

There are many different alternatives for reducing these effects. This study presents an approach for assessing the environmental impacts of a room located in a tourist complex in Guelma (Algeria) in its initial case throughout its life cycle. Subsequently, an improvement scenario representing the integration of photovoltaic panels was considered to enhance the room's environmental performance and steer the building towards a low-carbon strategy.

Although all phases of the life cycle present significant environmental aspects, the operational phase presents the highest percentage (86.28%) of environmental impact during the room’s life cycle. The optimization case study shows that significant improvements over the initial case could be achieved. The addition of monocrystalline panels has resulted in a 21.05% improvement in environmental performance over the entire life cycle of the room, and contributes to reducing the weight of its use phase by up to 24.05% by reducing all emissions emitted by the room. All 12 environmental indicators showed significant reductions following the integration of this sustainable solution.

In light of the initial case study results, it is important to integrate photovoltaic panels into buildings. They are an important means of improving their environmental performance by reducing emissions of greenhouse gases and other atmospheric pollutants, and increasing energy efficiency. They represent a crucial step towards low-carbon buildings.


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