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Application of Energetic Life Cycle Assessment of Retrofit Interventions on the Historical Heritage: The Case of "Palazzo Del Sedile"

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ABSTRACT

In recent years the legislation in energetic certification of buildings oriented the construction sector towards an increasing restraint about energy requirements, associated with the different phases of life cycle of a building. For this purpose, the Life Cycle Assessment, internationally recognized for reliable valuation of energy and environmental performances, is still a useful tool to determine any impact in the life cycle of process. The first part of this paper focuses on LCA and its application to historical heritage. A reported analysis of literature and a description of the software and methods used in the case study are shown. In the second part of the paper, LCA analysis was performed using the software SimaPro by PRé Consultants v.8.5.2.0, based on the hypothesis aimed to the energy efficiency of "Palazzo del Sedile", an historical building located in Matera, a southern city of Italy. The data related to this building have been derived from previous energetic analyses carried out on the same building and from statistical data and other affine studies in the literature. The Cumulative Energy Demand, the Eco-indicator 99 and the EDIP2003 methods have been implemented. Finally, the differences between the outcomes of these assessment methods have been discussed.

1. INTRODUCTION

From centuries, the construction sector plays a prominent role in economic and social terms, but on the other hand is responsible for a high impact on the environment in terms of raw material consumption, energy consumption, emissions and wastes, not so much related to new constructions, but in a preeminent way related to historical and post-war constructions.

The European Directive [1] assigned to each UE member the task of identifying a long-term strategy to support the renovation of residential and non-residential buildings, both public and private, in order to achieve a decarbonized and energy efficient real estate stock by 2050, facilitating the cost-effective transformation of existing buildings into nearly zero energy buildings, which is interpreted into the need to implement solutions that reduce energy needs and wastes especially in the use phase [2].

Specifically, a first mention of the importance of the energy diagnosis relating to historical buildings was set up by the AiCARR (Italian association for air conditioning heating and refrigeration), which in February 2014 published a guide for the evaluation and improvement of the energy performance of historic buildings, in accordance to the recent legislation [3].

Energy efficiency became one of the prerogatives to the environmental sustainability; on this track the demand for reliable indicators easy to use for environmental assessment of buildings has led in recent years to the development of several tools with very different approaches.

The regulatory path, however, is based on a Life Cycle Thinking approach, i.e. the quantification of synthetic environmental indicators using the Life Cycle Assessment method, internationally recognized as a method to evaluate the environmental profile of products, encoded within international regulations and promoted by European environmental policies. This approach points to a strong sustainability in order to verify the reduction of all environmental impact at each stage of the life cycle of the building and its components [4].

In this spirit, the scoring systems are progressively integrating environmental criteria within the LCA.

The LCA (Life Cycle Assessment) method is the most internationally accredited assessment for the quantification of the damage and its outcomes can be immediately related to impacts on human health, ecosystem quality and consumption of natural resources [5-15].

The aim of this paper is to compare the results obtained from the implementation of different life cycle assessment methods on energetic retrofit interventions assumed for an historical building in Matera (Italy) named "Palazzo del Sedile". The LCA is carried out with the SimaPro Software v. 8.5.2.

In literature, few are the data related to the sustainability or to the energy performance of the buildings that belong to the historical patrimony of the city of Matera [16-18].

In fact, there are only studies related to the evolution history of the City [19] or related to the structural preservation of the "Sassi" [20-21], or simply manuals [22].

2. LIFE CYCLE ASSESSMENT

2.1 Brief synopsis of LCA and its regulations

The LCA is an objective and reliable methodology to get a comprehensive and holistic approach of assessing environmental damage related to the building even when it is used to support decision making for the definition of policies strategic in this sector.

The origin of the LCA can be traced back to the early sixties with the publication of studies related to energy loads associated with some industrial productions. In this period an approach that embraces the entire life cycle, the so-called "Environmental Life Cycle Thinking", began to make its way. In the following decade, the problem exhaustibility of raw materials and energy resources encouraged further studies, mainly focused on optimizing the management of energy resources.

Between the late sixties and early seventies, there was a gradual transition from analysis focused mostly on energy consumption to analysis which considered both the consumption of raw materials and energy resources.

Also, during this period was introduced the "from cradle to grave" approach, quantifying the use of resources and the release of pollutants into the environment throughout the product life cycle. The quantification of resources' consumption and environmental impacts of the products developed under the name of REPA (Resource and Environmental Profile Analysis) in the United States, while in Europe it was called eco-balance [23].

The strategic importance of adopting the LCA methodology as a basic and scientifically suitable tool for identifying significant environmental aspects is clearly expressed within the COM 2001/68/EC Green Paper and the COM 2003/302/EC on Integrated Product Policy, and is suggested, at least indirectly, also within the European EMAS (1221/2009) and Ecolabel (66/2010) regulations.

The national and international standard guidance for LCA studies is mostly represented by the ISO series:

- UNI EN ISO 14040 (2006) "Environmental Management-Life cycle assessment - Principles and framework";
- UNI EN ISO 14044 (now updated to 2018) "Environmental Management-Life cycle assessment-Requirements and guidelines";
- ISO 21931-1 (2010) "Sustainability in building construction-Framework for methods of assessment of the environmental performance of construction works Buildings";
- UNI EN 15978 (2011) "Sustainability of construction works-Assessment of environmental performance of buildings-Calculation method" [24].

2.2 Methodology

LCA is an environmental assessment methodology applicable in any industrial or service sector that provides a comprehensive and detailed view of the system in order to:

- highlight and detect opportunities for the reduction of environmental impacts linked to the life of products;
- support decision making on interventions on processes, products and activities and compare the effects of different environmental policies and resource management;
- establish the initial step for a possible environmental declaration of EPD product;
- support marketing and environmental communication;
- comparing products and their emission with the same function.

The modern structure of the LCA proposed by ISO 14040 series consists of four main phases [25]:

- Goal and scope definition (ISO 14041);
- Life Cycle Inventory analysis, LCI (ISO 14041);
- Life Cycle Impact Assessment, LCIA (ISO 14042);
- Life Cycle Interpretation (ISO 14043).

In These years there have been many tools of calculation, software and manuals based on the indications and procedures of the ISO standards and which have made LCA a standardized methodology and therefore usable widely, but it is not a completely defined methodology because research must go on, they serve reference databases, new methods for calculating environmental impacts and reference models for interpretation [26].

According to the requirements of UNI EN 15643 environmental assessment of a building over its life cycle should consider the phases of

-Production: raw materials, production processes, transport.

-Construction: construction site transportation, installation.

-Use: consumption energy, maintenance, repair, retraining.

-End of Life: building demolition or disassembly, disposal, recycling and transportation of waste other.

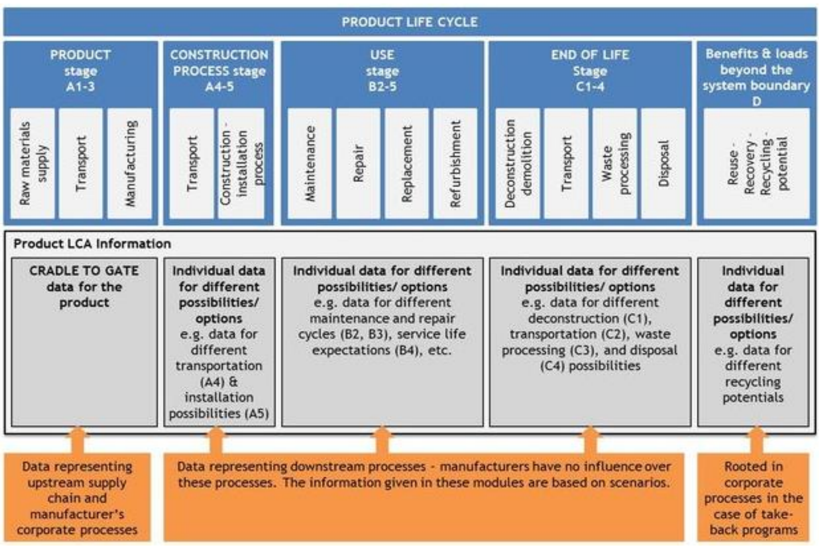

Figure 1. Stages of the life cycle of a building in accordance with EN 15978 [27], image from [28]

3. CASE STUDY

The aim of this paper is to discuss on the outcomes acquired from the implementation of various life cycle assessment approaches on energetic retrofit interventions assumed for an historical building in Matera named "Palazzo del Sedile". The LCA has been executed using the software SimaPro by PRé Consultants v.8.5.2.0.

The data on energetic performances, especially about the assembly phase and use phase of life cycle, have been gotten from past realistic and accurate investigations carried out on the same building that were necessary for the drafting of the PhD thesis of the doctoral student Negro E. cited in the articles [16-17, 29].

The information identified with the end of life phase were gotten from actual information and other relative investigations in literature [30-34].

3.1 Description and location of the building

The "Palazzo del Sedile" is an historical building located in the old town of Matera, a southern city of Italy. It was built in 1540 and now is owned by the Province of Matera.

In 1944 it has undergone to a change of use that made it a focal point for the city's musical heart becoming the main venue of the conservatory dedicated to the composer "Egidio Romualdo Duni".

From the early '80s, the underground levels of the building host a modern auditorium with a capacity of about 450 seats.

Figure 2. Entrance façade of Palazzo del Sedile in Sedile's Square

The mezzanine floor has a pentagon shape. An atrium connects the rooms on the ground floor to those on the first floor. The mezzanine floor presents seven rooms composed of Administration services and toilets.

The plant has an area of about 345m^2; the heights vary from 2.40 m up to 5.05 m (when there are vaults). Similar situation is found on the first floor made up of thirteen rooms divided into classrooms and toilets. About ninety people between students and staff attend the building. Its total area is about 590 m^2 and the heights flow from 2.60 m up to 6.70 m at the top of the vaults. The rooms with flat floors have a height of 3m.

The mezzanine floor facing west has different characteristics from the central body of the building: the two parts were constructed in different periods, with different styles of construction, and this makes the energy performance of these two parts of the building quite different.

The bearing structure of the building consists of thick masonry septa (net of plaster) with variable width between 80 cm and 100 cm for the external walls, and between 40 cm and 60 cm for the internal ones. The interior floors consist of blocks in limestone as well as the roof covering. The waterproofing is made with tar and bricks in walkable floors and tiles in the areas with pitched roof.

In Table 1. the general parameters recorded in the PhD thesis [35], and useful in order to implement the LCA, are given.

Table 1. General parameters of Palazzo del Sedile

Floors [n.]	**Total height [m]**	**Gross volume [m^3]**
3	13	5.550
Total area [m^2]	Floor area [m^2]	Opaque walls [m^2]
1.500	595	1.144
Transparent walls [m^2]	Dispersant surface [m^2]	A/V [m^2/m^3]
67	2.217	0,17

3.2 Implementation of LCA

The energetic retrofit on the building case of study consists in interventions on the envelope, air conditioning and heating systems and lighting, which complies with the minimum requirements imposed by Ministerial Decree June 26,2015 [36].

The retrofit interventions hypothesized on the building and the new energy consumptions savings are shown in Table 2.

Table 2. Retrofit interventions and energy consumption savings

Element	**Before interventions**	**After intervention**	**Savings [%]**
Opaque Walls	Limestone wall of 45 - 90 cm and inner plaster of 2 cm U = 0,63 - 1,12 W/m^{2}K	Covering wall insulation with inner coat of 5 cm Kenaf plate (λ = 0,038 W/mK). U = 0,31 W/m^{2}K	4
Roof slab	Limestone roof of 45 cm externally covered with tiles of 1 cm and internally covered with plaster of 2 cm U = 1,042 W/m^{2}K	Covering roof insulation with inner coat of 9cm Kenaf plate (λ = 0,038 W/mK). U = 0,25 W/m^{2}K	13
Windows	Wooden windows with double glass 4/6/4 or 6/12/4 U = 3,15 - 1,78 W/m^{2}K	PVC windows with low emissive double glass 4/8/4 with 8mm of argon interspace. U = 1,71 W/m^{2}K	20
Heating system	Boiler on the rooftop η_{nd} = 0,81	Stainless steel compression heat pump COP = 3,08 and P = 20 kW and installation of thermostatic valves	58
Lighting	Metal Iodide spotlights, Neon 1x36 W, Neon 2x36 W, Incandescent lamps	LED technology lamps	91

With the combination of these intervention, Negro E. estimated energy savings in kWh/year for about 70 % compared to current consumption. This estimate is very plausible because the analysis was carried out through data collection and investigation in situ, a modelling and dynamic simulation mode by Designbuilder software and EnergyPlus™.

(1) Goal and scope definition, system boundaries and functional unit

The definition of the boundaries of the system object of the study is an operation that depends on the goal of the study itself: the same system studied with different boundaries has different results

The approach used for the case of study is "from gate to cradle", also considered as the "downstream module", which is the module that contains the product scenarios from the moment it leaves the gate of the manufacturer company and ends its "life" in transportation, use and end of life. LCA was assessed only on the retrofit interventions. According to EN 15978, A2 to D stages are assessed: in the whole life cycle, it was not considered only the raw materials stock and their assembly.

As functional unit it was decided to use the m2 floor area.

This step is defined in SimaPro under the section "Goal and scope" recognizable in the left portion of software's GUI and includes: the description of LCA analysis that defines the author, developer, objective of the study, functional unit and the library (database) with its own specific field of application. The databases used for the case of study are Ecoinvent3, ELCD and Industry data 2.0 [37].

(2) Inventory Analysis (LCI)

The inventory analysis is usually the most delicate phase analysis of LCA and consists in the collection and quantification of incoming and outgoing flows for a given subsystem along the entire life cycle. The inventory analysis should provide a completer and more objective possible representation of reality and it is crucial the quality of data and information implemented in the model.

In the case study the system is divided into four subsystems corresponding to opaque walls, floors, windows, heating system. The lighting system is considered only as energy consumption in the use phase (see Table 2).

For the envelope it has been hypothesized a lifetime of 35 years, while for the heating system and lighting a duration of 15 years.

This decision has been made in relation to the fact that the retrofit interventions planned on Palazzo del Sedile are non-invasive and tend to just improve the energetic aspect of this historical building, which is outdated.

Not having studied in detail the thinkable incompatibility between old materials and new materials, it was decided to reduce the lifetime before the needing of further interventions [38].

For each material or element constituting the subsystem, there is a corresponding process and product stage to implement in SimaPro. These steps are included in SimaPro's GUI field "Inventory". The processes already implemented in software are grouped into categories and subcategories depending on the specific area to which they refer.

(3) Impact Assessment (LCIA) and interpretation

From the LCI results, the impact assessment phase of the life cycle aims to assess the extent of potential impacts on human health and the environment. In particular, the inventory data is associated with specific categories of environmental impacts and category indicators. Moreover, LCIA provides information for the next phase of interpretation that aims to propose useful recommendations in relation to the goals and objectives of the study. The interpretation stage may generate an iterative process of review and revision of the field of application of LCA, highlighting the limits and potential of the LCA methodology applied to the present case [25].

In this section of SimaPro were chosen the assessment methods provided by the library and the relative normalization and weighting.

As it was logical to expect from the behavior of an historical building like Palazzo del Sedile, the LCA evaluation of the case study in all three methods of evaluation highlighted how the phase of use is the most significant, as it is considered a duration in years definitely longer than assembly and subsequent disposal phases. It follows the disposal phase because a greater quantity of the retired materials is sent to landfill; it closes the list the transport and assembly of the elements because the interventions to be carried out are, as already said, non-invasive and aimed just at energy efficiency.

The assessment methods implemented in SimaPro for the case study are [39]:

Cumulative Energy Demand (CED): it considers five categories of impact: non-renewable energy, fossil; non-renewable energy, nuclear power; renewable energy, biomass; renewable energy, wind, solar and geothermal energy; renewable energy, hydropower.

In terms of primary energy to the assembly phase is associated an energy consumption amounted to 7,15 % of the total, the use phase energy consumption equal to 75,65 % and the disposal phase an energy consumption equal to 17,20 % of the total. The normalized characterization according to the Italian energy mix provided by Italian GSE for the year 2017 for impact categories is shown in Figure 3.

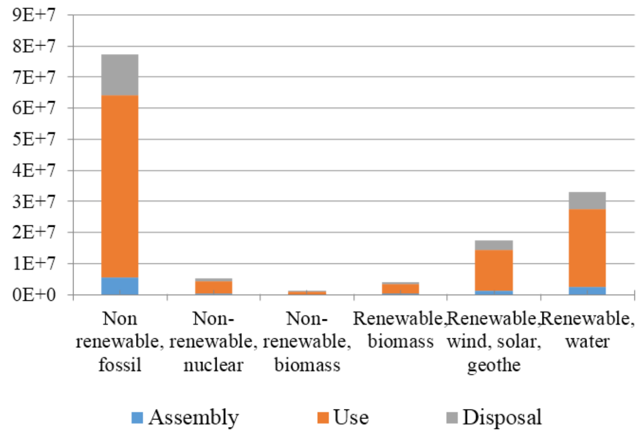

Figure 3. Normalization of impact categories of CED method

Eco-indicator 99: it evaluates three types of environmental damage: Human Health, Quality Ecosystem and Resources. Each category of damage is in turn divided into categories of impact.

The units of measurement associated with the categories of impact are respectively the DALY (number of disability-adjusted life years or the burden of illness due to disability or premature death attributable to each disease), the PDF m2yr (Potentially Disappeared Fraction) or PAF m2yr (Potentially Affected Fraction), and the MJ surplus (surplus energy that it will be necessary to extract 1 kg of material at a time when the consumption of such material will be five times that extracted by humanity before 1990).

In terms of primary energy to the assembly phase is associated an energy consumption amounted to 2,83 % of the total, the use phase energy consumption equal to 70,17 % and the disposal phase an energy consumption equal to 27 % of the total. These results are quite different than Cumulative Energy Demand method. The normalization for impact categories is shown in Figure 4.

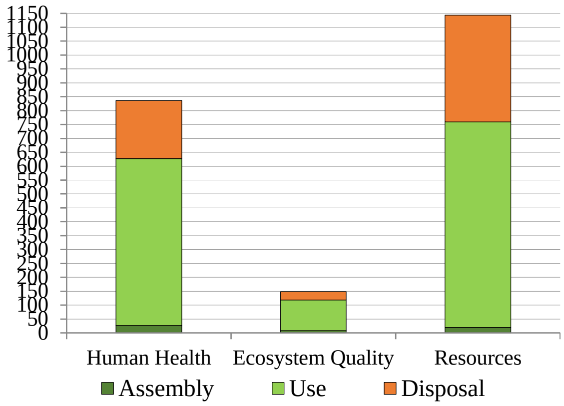

Figure 4. Normalization of impact categories of Eco-indicator 99 method

EDIP2003: it considers environmental impact, resource consumption and impacts in workplace as general damage categories and has 19 different impact categories each with its own unit of measurement. Its main innovation lies in the consistent attempt to include exposure in the characterization modelling of the main non-global impact categories. EDIP2003 can be used both with and without spatial differentiation.

In terms of primary energy to the assembly phase is associated an energy consumption amounted to 2,32E+3 Pt (9,75 % of the total), the use phase energy consumption equal to 1,7E+4 Pt (71,4 3 % of the total) and the disposal phase an energy consumption equal to 4,47E+3 Pt (18,78 % of the total). These results are quite similar to Cumulative Energy Demand method even if the impact categories are very different from each other with.

The normalization for the relevant impact categories is shown in Figure 5.

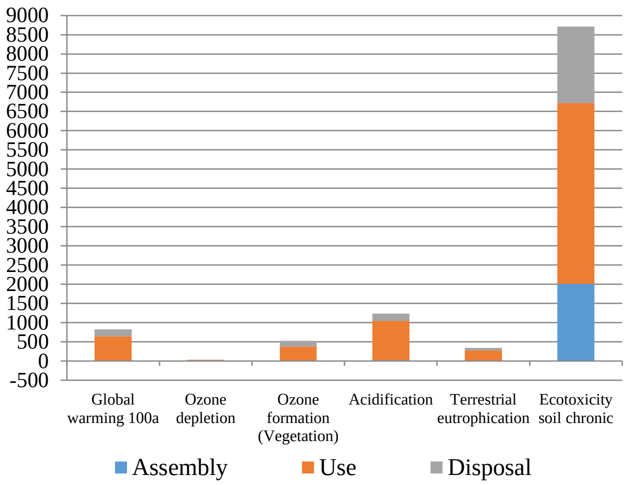

Figure 5. Normalization of impact categories of EDIP2003 method

Weighting also, like the normalization step, is considered as an optional step according to the ISO standards. Weighting is the process of converting the results of the normalized indicators of the different impact categories into other values using numerical factors (weighting factors) based on subjective valuations dependent on the incorporation of social, political and ethical factors [40]. The weighting process consists of multiplying the weighting factors by the result of the normalization for each impact category, but it has not been considered in this paper.

(4) Brief comparison between the three methods

These three methods are quite different, and it is very difficult to have a real numerical or statistical comparison. In general, depending on each methodology and the way by which the study is conducted (basic level, or an advanced level using software tools), when evaluating the impact assessment of a certain product and its corresponding components, the evaluation of each impact category and the calculation of the final impact score points is given by a common mathematical equation [41].

It is also true that the substantial difference between the methods implemented depends on the fact that within the LCIA step, two approaches of characterization can take place along the impact pathway of an impact indicator: midpoint approach and endpoint approach. Characterization at midpoint level models the impact using an indicator located somewhere along the methodology mechanism but before the endpoint categories; while characterization at the endpoint level requires modelling all the way until the endpoint categories described by the areas of protection (in most methodologies, the main areas of protection are eco system quality, human health and resources). EDIP 2003 is a midpoint-oriented method, Eco-indicator 99 is an endpoint-oriented method while Cumulative Energy Demand is categorized as “other based LCA methodology” because is focused just on energetic resources consumption.

Table 3. Comparison between the outcomes of the three implemented methods

	Cumulative Energy Demand	**Eco-Indicator 99**	**EDIP 2003**
Assembly	7,15 %	2,83 %	9,75 %
Use	75,65 %	70,1 %	71,43 %
Disposal	17,20 %	27 %	18,78 %

Looking to the percentages of energy impact allocate in the three main phases of the life cycle, there is a further demonstration of how much each method has a weighing system characterized by a quantitative factor, but also by a subjective one: they give space to some aspects rather than others going to affect the weighing system.

By comparing the percentage allocations of environmental impact for the three main phases, it is possible to easily realize that there is a common framework in the calculations, otherwise it would not have been expected that the use phase was the most expensive one. But on the other hand, there is no consistency in the allocation of the importance of impacts.

Indeed, the deviation is not excessive, but considering that upstream of those percentages are sometimes very high values of primary energy, to a small percentage variation corresponds a substantial energetic one.

3.3 System view

An interesting reflection that is worth highlighting is the relationship between the energy savings and the economic efforts that involves the retrofit interventions. The normalized results are given in Table 4 which represents the system view.

Table 4. System view

	Energetic savings [%]	Economic efforts [%]	η [%]
Opaque envelope	12,29 %	48,27 %	3,23 %
Windows	14,81 %	21,21 %	8,87 %
Heating system	43,18 %	24,78 %	22,13 %
Lighting system	29,72 %	5,74 %	65,77 %

The η rate which numerically expresses the system view, represents the percentage ratio between the economic effort to carry out the interventions described above and the energy savings that such interventions would bring.

The table shows that the most useful profit among all the interventions, is the lighting system as it represents a right compromise between energy savings and the estimated economic investment to be done in order to accomplish it. On the contrary, it is clear that the estimated investment to retrofit the opaque envelope is excessive compared to the energy saving that might entail.

This system view shows that even small measures to be studied at the design stage (just think of the type of insulation of HAVC system, or for example the conscious choice of the type of lighting system) can greatly influence the efficiency of an entire retrofit intervention both from a practical, energetic and economical point of view. It is important, therefore, to maintain the overall view of the system and its response in the short and long term on the timeline of the life cycle.

4. CONCLUSIONS

The general aim of this paper is to promote the sustainable use of energy resources, environmental, natural, as an integral part of the design process or retrofit process.

The proposed guidelines could enable the operator of the sustainable and energetic sector to provide an indication about the maximum savings percentages obtainable in functions of the retrofit intervention on the buildings and their impact to the environment.

The environmental assessment tools (regulations, databases and software), in addition to the dynamic simulations of the building itself, are an excellent companion for achieving a sustainable result at 360 degrees.

The LCA is confirmed a reliable tool; however, comparing more methods, it is perceived an important role to the subjectivity in the results, that is causes heterogeneity of the assessment that reduces the comparability of the LCA results and, therefore, causes a difficult univocal interpretation of the assessment [42].

The limits of LCA with SimaPro [43] are a prototypical character of the building sector, an increasing complexity of the process and its phases, highlighted by the interactions between the building and external factors, environment as well; also, the quantity of mini sub processes involved in a life cycle of a building and the difficulties in retrieving data compatible with the reality.

Finally, it is necessary to underline how the availability of an accessible and update database of materials and processes related to the Italian context, would increase the reliability and the significance of the results obtained. Moreover, an increasing number of case studies relating to historical buildings located in Italy, it would allow a better comparability of results and the definition of environmental sustainability benchmark at national level.

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Atti 7.

NOMENCLATURE

U	thermal transmittance, $W.m^{-2}.K^{-1}$
COP	dimensionless coefficient of performance
P	thermal power, kW
A	Area, m^2
V	Volume, m^3

Greek symbols

λ	thermal conductivity, $W.m^{-1}.K^{-1}$
η_{nd}	dimensionless average seasonal yield

Subscripts

nd	global