INFLUENCE OF THERMAL INSULATION IN A BUILDING REFURBISHMENT FROM THE PERSPECTIVE OF A RATING SYSTEM, LCA AND THERMAL ANALYSIS

MASSIMILIANO BAGAGLI[1], GIUSEPPE IIRITANO[2],
GIOVANNA PETRUNGARO[2] & COSTANZO DI PERNA[3]
[1]ITACA, Italy
[2]Calabria Region, Italy
[3]Università Politecnica delle Marche, Italy

ABSTRACT

Environmental challenges seem to be increasingly on the agenda. The predicted climate changes, although still uncertain in their magnitude, appear to be getting closer and closer and some effects already seem to be manifesting themselves. The challenge for the future in the field of construction is a design that, with the help of increasingly effective tools, succeeds in meeting the new environmental goals. Bringing such considerations into the field of design means not stopping at what has been done so far, which is mainly based on the analysis of energy flows. New perspectives require a holistic and strategic approach that considers all environmentally relevant aspects of building activity at the individual building level. The research goal was to verify how three different analysis tools used in the building sector, namely, thermal analysis, a rating system and life cycle assessment (LCA), detect changes in the design phase. The three tools have been applied to a real case consisting in the refurbishment of an existing industrial building converted to a residential building. Once the three evaluations have been completed, some variations related to insulation have been applied to the design to see how the three tools react to changes. The different sensitivity of the tools is an element of choice for the designer who can thus select the method of analysis that best meets their needs.

Keywords: LCA, rating system, thermal analysis, building, insulation, ITACA Protocol.

1 INTRODUCTION

Over the past decade, the international community has become conscious that the planet will face various impacts of climate change due to both natural and human causes. While there is no broad consensus on how fast and how our climate is changing, in the scientific and public debate the growing awareness is evident that some degree of climate change seems to be inevitable. Considering that global temperatures will rise to a certain extent in the near future, the challenge is to adapt lifestyles in terms of a greater degree of resilience to the changes. With specific regard to the building sector, an approach closely linked to the analysis of energy flows seems to be no longer sufficient to deal with predictions for the future. New perspectives require a holistic and strategic approach that considers all environmentally relevant aspects of building activity at the individual building level. The present work comes from the general consideration that, in the construction sector, the main tools used for design analyse the behaviour of the building during the operational phase. Therefore, most of the knowledge is dedicated to the energy consumption of the operational phase and little or nothing is known about the environmental impacts due to the materials used in their production, the processing undergone by them, their transport to the site, the building's construction processes, its maintenance and its decommissioning. Also, equally little is known about the building's relationship with its surroundings and therefore with the external appurtenances and the urbanized area in which it is located.

To analyse how different tools are able to provide different information on the same building and to verify how sensitive those tools are when changes in the design are

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implemented, a real case of refurbishment of an existing building has been taken as case study. On the chosen building a thermal analysis, an evaluation through a rating system and a life cycle assessment (LCA) have been carried out. Once the three assessments have been completed some variations of the main parameters of the building, and specifically on insulation, have been applied and recorded by the three analysis tools. The objective is to study the same building in three different ways and to see how the different analysis tools react to changes in some building parameters; the results can provide useful information on the best tool to use according to the design purposes and give the designer a wider range of choices.

The three selected tools are: **a thermal software**, which can be considered as the basic tool, since such tools are the main tools for the design, but they focus exclusively on energy flows; a rating system, and specifically one of the most widely used rating systems in Italy, **the ITACA Protocol**, which allows to extend the view to aspects other than energy flows, taking account of the relationship between the building and the environment; and finally, on a longer timeframe, **a life cycle assessment**, which is a tool able to estimate the environmental impact of the building throughout its life [1]–[5].

The energy modelling employed is a specific software complying with the technical standards in force, Termo by Namirial.

For the sustainability assessment, the most recent version of the ITACA Protocol was used and specifically the UNI 13:2019 Reference Practice since UNI is the national standardisation and control body and therefore the ITACA Protocol is a national standard.

Finally, for the LCA evaluation the software used is SimaPro by Pré.

After applying the three tools and examining the results, some variations were made and new analyses were carried out, leading to new results. The variations applied concern one of the most controversial aspects of building design: insulation [6]. Starting from the real case, called Case Study A, two different case studies were defined, each with different insulation. The real case has only non-renewable insulation, while Case Study C has only wood fibre; Case Study B was designed with both renewable and non-renewable insulation.

The changes in insulation allow the evaluation of whether and how the three tools mentioned above are able to detect changes. The aim was not to judge which type and use of insulation is preferable, nor to optimise the renovation work using the three tools, but to reach some consideration about the different impacts of the materials used.

2 CASE STUDY A

The real case used as Case Study A regards the conversion of an existing industrial building into a social housing building. In Fig. 1, an image of the building before renovation is provided. The building was constructed using a precast reinforced concrete system both for the structure and the cladding. It has two floors with a flat roof for a total area of 6,130 m^2. The aim of the intervention was to remodel the previous building to a block of 46 residential units. The final appearance of the building is shown in Fig. 2.

The load-bearing structure remained unchanged, except for specific interventions such as cutting through the original floors to create patios and terraces. Rock wool insulation has been added to the floors in different sizes between the roof and the floors of the residential units. This difference is also due to the fact that the units now have floor heating. The outer shell originally consisted of 20 cm thick prefabricated reinforced concrete panels, which were lightened and pre-finished with polystyrene, to which a 10 cm thick layer of rock wool was added. The original panels had a washed gravel finish and were interspersed with a series of identical large double-height openings which, on the first floor, became arcades forming

Figure 1: Building before renovation.

Figure 2: Building after renovation.

loggias with recessed niches and small projections. This system of openings characterises all the elevations, interrupted only on the main façade by two reinforced concrete towers containing the stair lift system. Terraces have also been added and the arches on the first floor have been transformed. Besides, two sides of the external walls had to be replaced completely. The floors were cut to create internal courtyards with a system of walkways and stairs connecting the floors and the internal parts of the courtyards. The walls facing the inner courtyards were built from scratch and are either balloon frame panels with rock wool or metro-therm insulation and concrete panels with expanded polystyrene (EPS) insulation.

Furthermore, the building has been equipped with a centralized heating plant with hybrid system for each staircase, metering system for each apartment, heating system with radiant floor and solar thermal system for domestic hot water.

3 TOOLS APPLIED

3.1 ITACA Protocol

Buildings have a certain degree of complexity that is simplified by modelling. Environmental assessment tools called rating systems allow the building to be broken down into different environmental aspects that are easier to deal with individually. Moreover, unlike the other tools, rating systems often also study the link between building and its surroundings and between building and environs.

The ITACA Protocol was chosen over a wide range of other rating systems because it is one of the most widely used tools at national level for assessing the level of energy and environmental sustainability of buildings. Furthermore, it is linked to legislation on energy sustainability in buildings and to national technical standards. The criteria that make up the ITACA Protocol, when dealing with environmental issues that are regulated by the legislator, i.e. where there is a legal limit or where a technical standard plays an important role, take these references as a minimum level of fulfilment of the criteria [7]–[9]. This attention to standards is one of the strengths of the ITACA Protocol and distinguishes it from almost all other rating systems.

ITACA Protocol is a multicriteria building environmental sustainability assessment framework and, as other rating systems, it allows verifying the environmental performance of a building from different points of view: human health, expenditure of energy, water and other resources; it also promotes the construction of increasingly innovative buildings and the use of sustainable materials produced with low energy consumption and able to guarantee high levels of comfort. One of the key points in the entire procedure of assessment is the determination of the score for each criterion and of the overall score. For each criterion, a score is assigned from −1 to +5. Score 0 represent the benchmark (law limits if available or typical acceptable practice) and positive score correspond to better practice. A negative score means that the building is of poor quality in a particular aspect, below the benchmark. The total score is calculated by multiplying the score of each criterion by its appropriate weight and then adding the scores of all criteria. More criteria related to similar aspects are included in a category, more categories are included in an area. Areas include all criteria and categories related to general environmental impact assessments such as resource consumption or environmental loads caused by the building. Areas and categories have different weights and the procedure for obtaining a final overall score for a building involves scoring each individual criterion, then weighting the score for each criterion by reference to the importance of that criterion in the category, then summing the weighted scores of the criteria in an individual category. Once a score has been obtained for all categories, the procedure involves weighting the score for each category by reference to the importance of that category in the area, then summing the weighted scores of the categories in an individual area, and finally summing the weighted scores of all areas.

In Table 1 an overview of the weights of categories and areas is given. The determination of the total final score of the building is given with the following equation:

$$Stot = 0.1\,A.1 + 0.9\,(0.05\,A.3 + 0.45\,B + 0.2\,C + 0.2\,D + 0.1\,E).$$

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Table 1: Overview of the weights of categories and areas.

Categories and areas	Weight	Weight in the final equation
Category A.1 Site selection	10%	10%
Category A.3 Project infrastructure and services	5%	90%
Area B: Energy and resource consumption	45%	
Area C: Environmental loadings	20%	
Area D: Indoor environmental quality	20%	
Area E: Service quality	10%	

3.2 Life cycle assessment

Life cycle assessment (LCA) is a method, characterised by quantitative and therefore objective results. LCA has an iterative nature, which allows for subsequent improvements [10], the quantification and qualification of impacts and their distribution over the different phases of the life cycle, and, last but not least, the possibility of comparing different solutions. LCA definition is included in the standard ISO 14040, which states that 'LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)'. The analysis phases are those decoded in the UNI EN ISO 14040 and 14044 standards, which provide a goal and scope definition, a definition of the field of application, a definition of the data quality requirements [11] and an inventory analysis and are summarized in Fig. 3.

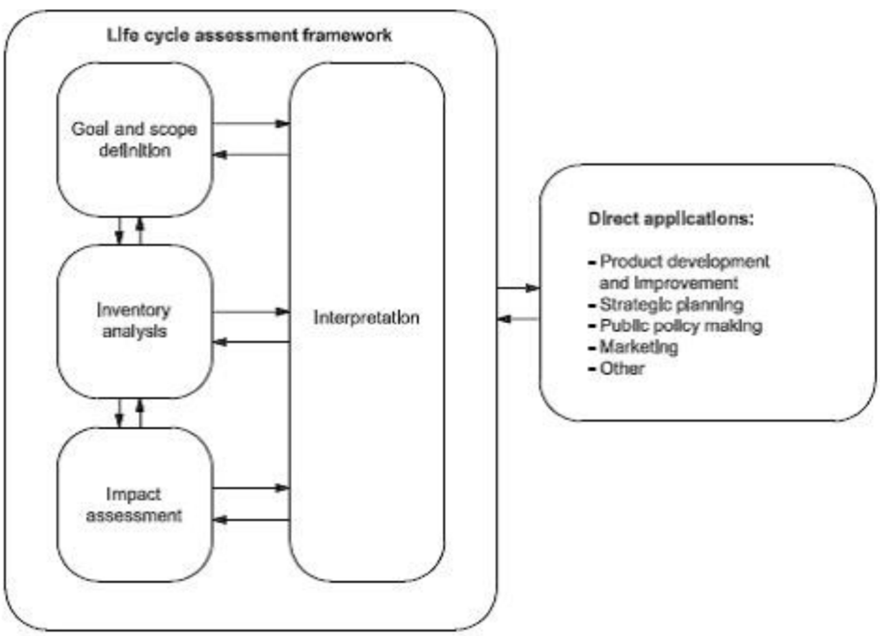

Figure 3: LCA phases.

The application of the LCA methodology to the building has involved all the life stages as described in Fig. 4.

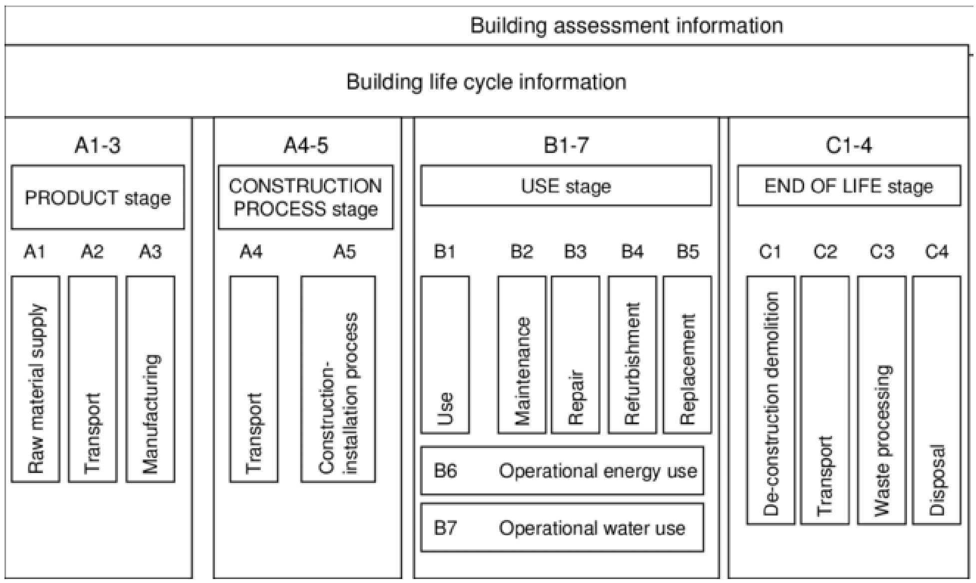

Figure 4: Life stages for a building.

The software used in this case study is SimaPro. Version 8.4, developed by Pré Consultants; it is one of the most widely used and established LCA software packages in the world.

3.2.1 Goal and scope, field of application and functional unit

The goal was the LCA of the building refurbishment previously described through the application of the methodology standardized by UNI EN ISO 14040 and 14044 and following steps foreseen by the same and the field of application was an industrial building which has become residential after redevelopment; a lifespan of 50 years was assumed with some replacements after 25 years. The functional unit chosen is the entire building, i.e. material and energy input and output flows are quantified in relation to the building as a whole. This makes it possible to compare results for different phases of the building's life cycle or to compare different solutions, e.g. in the use of materials or components, for the same building.

3.2.2 System boundaries

Defining system boundaries first means determining which process units to include in the life cycle analysis. The building system is broken down into process units, i.e. all those elements, materials and components, that make up the building and that are affected by material and energy flows during their life, i.e. during production, transport, installation and assembly, use and disposal.

The national standard UNI 8290:1981 'Classification of the technological system' was used to break down the building and identify its functional units. While it is a rather old standard, it is still a very effective tool for breaking down the building into its constituent parts to a very advanced level of detail and is still used as such.

The UNI 8290 Standard identifies a criterion for the classification and articulation of the building system into several levels according to a vision based on rationality and homogeneity. The characteristics of the building system are examined by the standard according to a detailed scheme set out on three levels, where the lower level arises from the decomposition of the upper aggregate level, and all this according to the approach proper to top-down analysis. This scheme is divided into the following first three groups but for the study the decomposition continued up to the sixth level:

- Classes of technology units
- Technological units
- Classes of technical elements
- Subsystems
- Components
- Subcomponents.

The first level (Classes of technology units) includes eight classes and three of them have been considered which are reported in the following:

1. Support structures
2. Enclosures
3. Internal partition.

For this study, reference was made to all the databases loaded in the software used, including Ecoinvent, Agri-footprint, ELCD, USLCI, Swiss Input Output Database and EU and DK Input Output Database; in addition, for some specific materials, Environmental Product Declarations (EPDs) have been used.

Establishing the system boundaries means not only defining the process units, but also the life cycle phases to be included in the study and the three main stages used are as follows:

- Phase I: Materials placement. In this phase the production of materials has been considered, then the extraction of the raw materials, transport to the related industries for treatment and processing; but also the installation phase which includes transport from the production company to the construction site and the assembly of the components.
- Phase II: Operational phase. The building is used by users. The energy consumptions assumed for this phase include consumption for heating, the production of domestic hot water production and cooling. In this phase, which has been assumed to last 50 years, maintenance is planned for some elements of the building.
- Phase III: Disposal. Demolition of components, transport from building to landfill. No recyclable materials were assumed as the analysis of the cross sections showed that recycling possibilities are limited.

Ultimately, the boundaries of the system are also defined by the inputs and outputs of matter and energy. In deciding which fluxes to study, the mass criterion was first of all taken into account, i.e. those fluxes whose weight with respect to the total was considered negligible were excluded, making sure that they were not of such environmental importance that they could not be excluded.

As a final step in defining the system boundaries, it is necessary to determine which releases into the environment need to be assessed. These are grouped by impact categories, which vary according to the method used for assessment. The following methods were used in the present study:

- Cumulative energy demand (CED) assessing MJ of primary energy from different energy sources as impact, so primary energy consumption is the object of the evaluation.
- IPCC GWP 20 assessing kg of CO_2 equivalent as impact, therefore the assessment refers to climate change. The present method has been preferred to the similar IPCC GWP 100 which is doing similar evaluations but in a time scale of 100 years instead of 20 because a shorter horizon, such as 20 years, would much better reflect the true effects of gases with a short atmospheric lifetime on the climate such as refrigerants and methane.
- Eco-indicator 99 (H) has eleven impact categories, which in turn are grouped into three damage categories: damage to human health, damage to ecosystem quality, damage to resources. The damage assessments in relation to the three safeguard areas, are comparable and therefore can be summarized up into a single score, the Eco-indicator expressed in Point (Pt) or MilliPoint (MPt), which represents the overall performance of the investigated system in terms of energy-environmental.

3.2.3 Data quality requirements and inventory analysis

The employed data are of various kinds, primarily those provided by the project documentation. Secondly, reference was made to the software databases, which include life cycle assessments of many materials used in the construction industry. Where data were not available in sufficient detail, EPDs were requested. Energy simulation data was used to determine energy consumption during the operational phase.

Finally, in the assessment according to the chosen rating system, the materials were all considered to be of non-local origin and therefore a distance of at least 300 km was also assumed between the production site and the construction site for the assessment of the impact of transport.

Unfortunately, the scarcity of systems-specific data in the different sources consulted led to the exclusion of systems from the present study. This is the big simplification that needed to be done. Another assumption made was the assessment of only the materials used in the refurbishment, so all existing materials were not included in the simulations. Also including what was produced, assembled and used in the previous industrial function of the building would have changed the considerations of impacts due to the refurbishment materials.

In the inventory analysis phase, all the building disassembly operations were carried out according to the scheme UNI 8290. The decomposition led to the calculation of the quantities of material used. Each identified material was then searched in the mentioned databases and was associated with a reference material drawn from these sources. For processing, assembly, transport, maintenance, decommissioning and landfill, energy and material consumption were associated. For each process included in the life cycle, materials and processes were then associated to make up the overall picture.

During the inventory phase some additional assumptions were made:

- Transport: All transports for all phases take place with diesel trucks with a capacity of 16 t.
- First assembly and assembly of materials for maintenance: Electrical consumption estimated as $1.8 \div 2\%$ of the ‘total embodied energy’.

During the disposal phase, it has been assumed that all materials are taken to landfill without recycling: this is a choice that is made for materials that cannot be recycled due to lack of quality (mixed and inseparable materials), lack of time or space for disassembly or lack of market for the recycled product. In the case study, the cross sections analysis showed that the materials used are not separable.

3.3 Thermal analysis

The assessment of the building's energy performance was performed under both winter and summer conditions. The evaluation is based on the energy performance index (EP), which expresses the primary energy requirement (PED) referring to the useful surface, expressed respectively in kWh/m^2 year) and which is calculated according to the provisions of the current national legislation on the subject.

The EP is a standardized performance indicator whose value may vary according to the technical and technological solutions adopted. For this reason, when choosing the energy production system and/or the envelope components, it is important to weigh the different solutions that can be adopted. The objective should be to assess the energy feasibility of each possible solution, with the aim of maximizing energy efficiency in compliance with the regulatory constraints imposed by law.

The PED is associated with regulated use of energy during the operational phase of the building life cycle and must be calculated ex-ante according to the national methodologies for asset design assessment and expressed as kWh/m^2 per year.

In Italy, PED does not have an absolute threshold as it varies for each building. To calculate the PED and other requirements, the 'reference building' is used. The 'reference building' is defined as a virtual building that has the same location and is geometrically equivalent to the one considered in the project, but with thermo-physical characteristics that comply with the minimum energy requirements in force.

To demonstrate that the designed building complies with the regulation, two different calculations are performed: one for the designed building with its own thermo-physical characteristics and the other for the reference building. The reference building represents a threshold, a limit that must not be exceeded. Its thermo-physical characteristics are a sort of maximum tolerance. If the calculation gives better values of the requirements for the designed building than those calculated for the reference building, then the project complies with the legislation, otherwise the designer has to change something to get back within the threshold set by the legislation.

It should be remembered that legislation and regulations identify the building's services as a single block: however, in the evaluation of the energy performance, it is advisable to distinguish the energy needs for: cooling, heating, domestic hot water, lighting, ventilation and transport. This characterization makes it possible to carry out an energy audit in a more understandable way, in order to evaluate possible inefficiencies in the energy conversion processes.

The total PED value for a building is given by some elements (PED for heating, domestic hot water, ventilation, cooling, lighting and transport) and it is expressed as follows in terms of non-renewable energy:

$$EPgl{,}nren = EPH{,}nren + EPW{,}nren + EPV{,}nren + EPC{,}nren + EPL{,}nren + EPT{,}nren.$$

Only the PED for heating, hot water and cooling were taken into consideration, as the building has no ventilation system and the consumption for lighting and transport was considered to be very low.

Another parameter to be taken into consideration is H′T, which represents the average total coefficient of heat transfer by transmission per unit of dispersing surface, and must be compared with H′T,limit, which is the regulatory minimum of the total average heat transfer coefficient of transmission per unit of dispersing surface; H′T must be lower than H′T,limit in order to comply with the regulations. The above parameters are used to calculate the building's Energy Performance Certificate (EPC). Once the calculations have been made, the building's EPC is issued.

4 RESULTS OF THE TOOLS APPLICATION

The ITACA Protocol, LCA analysis and thermal analysis were applied to Case Study A, which represents the real case. To verify the three tools in detecting variations in the design of the building, some modifications in the insulation have been introduced to specify Case Study B and Case Study C. Under these modified conditions, the thermal software, ITACA Protocol and LCA analysis were applied again. The results were compared with those obtained for the first case study. Case Study B involves the replacement of the rock wool insulation with wood fibre in the external walls and in some internal walls. The replacement was designed to maintain the same thermal resistance for three of the four external walls, while the internal walls and the fourth external wall maintained their overall width. It was not possible to change the width of the above-mentioned elements as this would have required the modification of the internal partition. In Case Study C, in addition to the changes made in Case Study B, all the insulation was replaced with wood fibre. No changes were made to the systems.

4.1 Results of the application of thermal analysis

In terms of thermal analysis, the modifications introduced in Case Study B improve the H′T index, as can also be seen from the EP,H,nd index, while the EP,C,nd index gets worse. On the other hand, the modifications made in Case Study C bring H′T to values very similar to those of Case Study A, as confirmed by the EP,H,nd parameter. Instead, they improve the EP,C,nd parameter. On the basis of the case studies presented and limited to them, the deviations in the values of the various parameters are modest and the thermal analysis, while capable of capturing the differences in the various case studies, cannot give unequivocal indications [12]. Thermal indexes and changes in the parameters are shown in Table 2.

Table 2: Thermal indexes and changes in the parameters for Case Study A, B and C.

Thermal indexes	**Case Study A**	**Case Study B**	**Case Study C**
H′T W/m^{2}K	0.31	0.25	0.32
H′T,limit W/m^{2}K	0.58	0.58	0.58
EPH,nd kWh/m^2 year	9.31	5.24	9.24
EPH,nd,limit kWh/m^2 year	19.37	18.86	18.93
EPC,nd kWh/m^2 year	29.25	32.76	29.3
EPC,nd,limit kWh/m^2 year	24.21	24.35	24.36

4.2 Results of the application of ITACA Protocol

As regards the analysis conducted with ITACA Protocol on the two new case studies, the changes made in Case Study B bring the overall rating of the building to 2.41 from 2.39, in particular Rating Area B from 1.12 to 1.14 while the changes made in Case Study C increase the building's overall rating to 2.44 from 2.39; specifically Area B Rating grows from 1.12 to 1.16 and Area C Rating from 0.71 to 0.76. Table 3 summarizes the three evaluations.

A closer comparison of case studies A and B or C shows that only in some cases there are differences in the score for a single criterion, while in other cases, although the performance

Table 3: Scores by categories, areas and total final scores for Case Study A, B and C.

Categories and areas	**Case Study A**	**Case Study B**	**Case Study C**
Category A.1 Site selection	0.26	0.26	0.27
Category A.3 Project infrastructure and services	0.12	0.12	0.12
Area B: Energy and resource consumption	1.13	1.14	1.16
Area C: Environmental loadings	0.71	0.71	0.76
Area D: Indoor environmental quality	0.03	0.03	0.03
Area E: Service quality	0.28	0.28	0.28
Total final score	2.39	2.41	2.44

indicator is changed, the criterion score does not change, as the changes do not yet allow the minimum score to be exceeded. Certainly, the ITACA Protocol shows some response in recording the changes proposed in Case Studies B and C. The changes have particularly affected the criteria relating to energy indexes, materials and thermal impact, and this was to be expected given the design changes foreseen in Case Studies B and C. Although the changes in the score are modest, the changes are noticed and result in changes in the assessment area and in the overall scores [13], [14]. The ITACA Protocol is a tool that aims to provide a broader building assessment than the thermal analysis, and this capability is also evident in the proposed modifications, which are more limited in terms of the whole building, but still detectable.

4.3 Results of the application of LCA

LCA analysis was performed for the three case studies. For each case study, the Cumulative Energy Demand (CED), the IPCC GWP 20 and the Eco-indicator 99 (H) methods were applied on each phase (material placement, operational, disposal and overall) but particular attention has been given to the full life cycle phase. The results show that LCA appears to be the tool most directly affected by changes. Basically, the materials considered have a constant mass in all case studies and mass is the key aspect in LCA analysis due to its influence on impact indicators. The only exception is the weight of the insulators, whose total mass increases even though they represent a small fraction of the total weight of the building and their variation represents at most 5% of the total weight. Therefore, for the same quantity of non-insulating materials, their impact is constant for each case study and for each calculation method. This means that the LCA analysis should only see the absolute impact of changing insulation from one case study to the other, and then the tool should show this in absolute and percentage terms. Calculations show that this is exactly what happens. It is different for insulation: the polystyrene does not change its mass between Case Study A and B, as it is the rock wool that is replaced by the wood fibre, and in fact the tool does not change its rating for each calculation method used.

Between Case Study B and Case Study C, on the other hand, the mass of the wood fibre increases significantly. Moreover, in Case Study B and Case Study C, the only increase in mass of the materials used in the renovation of the building is that of wood fibre, while polystyrene almost disappears, going from 12,000 to 350 kg and becoming in fact negligible. Table 4 shows the variations in mass for each insulation from Case A to B and C.

Table 4: Variations in mass for each insulation and percentage on total weight of the materials used, concrete and steel excluded, for Case Study A, B and C.

Insulation	Case Study A (kg)	Case Study B (kg)	Case Study C (kg)	Case Study A (%)	Case Study B (%)	Case Study C (%)
Polystyrene extruded	12,000	12,000	350	0.8	0.8	0
Rock wool	113,500	0	0	8.7	–	–
Wood fibre	0	188,800	261,300	–	13.7	18.7

Therefore, in the described situation, the rating of wood fibre was expected to increase and indeed the changes in impact rating show an increase. To complete the analysis, the impacts of the main materials per kg of material are provided and a focus has been made on insulation, although this was not the main intention of the present study.

From the calculations and under the hypothesis formulated, for the impacts of the CED method, polystyrene and wood fibre appear to be more energy consuming in their life cycle than rock wool as drawn in the present study. For the IPPC GWP 20 method, polystyrene appears to generate much more emissions than rock wool and wood fibre. Finally, for the Eco-indicator 99 (H), polystyrene seems to have a greater impact, but the differences are smaller than for the other methods. Table 5 summarises the situation.

Table 5: Impact per kg of material for insulations for each case study and for each method, full life cycle.

	Case Study A	**Case Study B**	**Case Study C**
	CED MJ/kg	**CED MJ/kg**	**CED MJ/kg**
Rock wool	16.81		
Polystyrene extruded	102.66	102.66	
Wood fibre		104.87	107.16
	IPPC kgCO$_2$/kg	**IPPC kgCO$_2$/kg**	**IPPC kgCO$_2$/kg**
Rock wool	1.610		
Polystyrene extruded	23.450	23.450	
Wood fibre		0.535	0.547
	Mpts/kg	**Mpts/kg**	**Mpts/kg**
Rock wool	0.132		
Polystyrene extruded	0.567	0.567	
Wood fibre		0.091	0.093

What is clear, however, is that LCA appears to be extremely sensitive to the amount of material used and is a very sensitive tool for capturing the changes that occur when materials are changed. Finally, it is important to consider the assumptions made for this study, which certainly have a major impact on the final results.

5 CONCLUSIONS

The final consideration that can be drawn from the example represented by this study is that LCA analysis proves to be a tool that can more accurately capture changes in materials and, in particular, in insulation compared to thermal analysis and evaluation using a rating system. Besides design, an LCA approach could also be of great help in the refurbishment of buildings, as its iterative nature and thoroughness of the analysis appear to be highly suitable for an optimization process. In this regard, a possible development of this study could be an ex-post evaluation of the refurbishment carried out, trying to verify which are the best choices analysed by this tool. However, it is important not to overlook the shortcomings of the tool, which are mainly related to the quantity and quality of the data. For some materials or installations, the database is very poor or inappropriate for national use. It would be appropriate to set up a survey and research system that addresses a product sector in its entirety and not with isolated experiences that are only valid in that specific context. Given the importance of the construction sector, it would be important to have a series of analyses on the different types of materials. Integration with other tools, e.g. those that can also analyse the context in which a building is located or verify other aspects related to building equipment or indoor comfort, can also improve the analytical capacity of LCA. In this sense, coupling with a rating system is certainly a valid solution, as they tend to compensate for some aspects.

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