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Life Cycle Assessment of energy related building renovation: methodology and case study

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Abstract

Existing buildings are responsible for a major share of energy use and greenhouse gases emissions in the total environmental impacts of the construction sector. While renovating a building increases its energy performance, it also raises the investment costs or environmental impacts due to the materials and building integrated technical systems (BITS) added to improve its energy performance. To address these trade-offs, there is a need to consider a life cycle approach to avoid impacts' transfer between the operational and embodied impacts. In this paper, we present a scientifically sound, yet practical Life Cycle Assessment (LCA) methodology for building renovation developed in the framework of the IEA annex 56 "Cost effective energy and carbon emissions optimization in building renovation". The approach is consistent with the existing building LCA's state-of-the-art but goes into a more applicable methodology by focusing only on the significant life cycle stages for energy related building renovation i.e. the production, transportation, replacement and end of life of new materials for the thermal envelope and BITS and the operational energy demand before and after renovation. In this paper, the methodology is applied on a case study of a multi residential building built in 1965 in Western Switzerland which was renovated in 2010. The LCA results are presented using three indicators: the total and non-renewable cumulative energy demand (CED) and the global warming potential (GWP). While embodied impacts due to the new materials and BITS remain negligible in the renovated building compared to the energy savings, it is found that the overall impacts are reduced from a factor 4 for the GWP. This study should be connected to the other contributions of the IEA annex 56 including costs assessment in order to determine cost effective and low environmental impacts building renovation.

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1. Introduction

Existing buildings are responsible for a major share of energy use and greenhouse gases emissions in the total environmental impacts of the construction sector. While renovating a building increases its energy performance, it also raises the investment costs or environmental impacts due to the materials and building integrated technical systems (BITS) added to improve its energy performance. To address these trade-offs, there is a need to consider a life cycle approach to avoid impacts' transfer between the operational and embodied impacts. In this paper, we present a scientifically sound, yet practical Life Cycle Assessment (LCA) methodology for building renovation developed in the framework of the IEA annex 56 "Cost effective energy and carbon emissions optimization in building renovation". During the last decade, many LCA methodologies have been published at national and international levels in order to present solutions to perform building LCA. These include, for instance, generic approaches such as presented in ISO 14040 and followings [1] ILCD Handbook [2]. There are also more building oriented approaches such as the EN 15978 [3] or the EeBGuide operational guidance document for building LCA [4] published recently. Although these approaches tend to present a LCA methodology as complete as possible, it is generally not fully applicable in practice, due to the lack of information required or the time and resources needed to put it into practice. At national level, some methodologies have also been developed e.g. in Switzerland with the SIA 2032 technical report [5].

The aim of the following considerations is not to inventory and to compare all existing methodologies but to present the approach used in Annex 56 to perform the LCIA of existing buildings. The methodology used in Annex 56 is a compromise, taking into account several constrains such as:

- Coherence with existing approaches;
- Inclusion of the relevant sources of impacts in the case of building renovation;
- Availability of information (especially for existing building);
- Time and resources required to find the information.

In the framework of Annex 56, a pragmatic approach has been considered to perform the LCIA of a renovated building. The approach remain consistent with the existing building LCA's state-of-the-art but goes into a more applicable methodology by focusing only on the significant life cycle stages for energy related building renovation.

2. Methodology

To develop a scientifically sound yet practical methodology, the Life Cycle Assessment (LCA) only includes processes having a relevant contribution to the total environmental impacts of renovated buildings which can be put in practice with a reasonable effort. As a result the main focus is put on the integration of embodied energy and related carbon emissions in the assessments of operational energy use energy related building renovation. The life cycle impacts of renovation packages are determined by comparing them with the life cycle impacts of a corresponding "anyway" renovation solution which only aims at restoring full functionality of the building and not improving energy efficiency. Hence, only measures that affect the energy performance of the building are considered (thermal envelope, building integrated technical systems (BITS), energy use for the on-site production and delivered energy).

2.1. System boundaries

To define a LCA of renovation measures, it is mandatory to define the temporal (life cycle stages) and physical (elements and contributors) system boundaries. The temporal system boundary for the LCA comprises the different stages of the life cycle of building renovation measures. As an illustration, Figure 1 shows the life cycle stages of a building to take into account in the LCA of renovated measures. Only the stages in grey in Figure 1 are taken into

account for the case studies according to the IEA annex 56 methodology i.e., the production, transportation, replacement and end of life of new materials for the thermal envelope and BITS in addition to the operational energy consumption.

Concerning the physical system boundary of the LCA methodology, the embodied part (calculated over the life cycle) includes all the construction materials added for improving the thermal envelope and the BITS added for improving the efficiency of the heating system (e.g. boilers, heat pumps etc.). Each element (roof, façade etc.) is made of one or more layers, each layer corresponds to a material and all should be inventoried. For the LCA calculation rules, it is important to use appropriate service life for each materials and BITS. The service life is defined as the time during which a building component (construction material, BITS component) fulfil its function. At the end of its service life, the component must be replaced. Not all layers (materials) of a building element are replaced at the same time, some are never replaced (e.g., the bearing structure). Below are presented three different cases of replacement:

- Some heavy layers might be part of the element structure but might be replaced during the life cycle of the building. In case of a wall with concrete and bricks on each side of the insulation, the bricks might be replaced during a massive renovation while the bearing structure is not.
- A material placed between two layers of the envelope structure will have the same service life as the layer with shorter service life. Similarly, the insulation between two concrete layers will have the same service life as the two concrete layers.
- If a construction element is designed to ease the replacement of some internal parts, only the replaced parts are taken into account for the replacement.

Hence, the service life of materials depends on the type of construction element (wall, floor, roof), the situation of the element and the position of the material layer within the element.

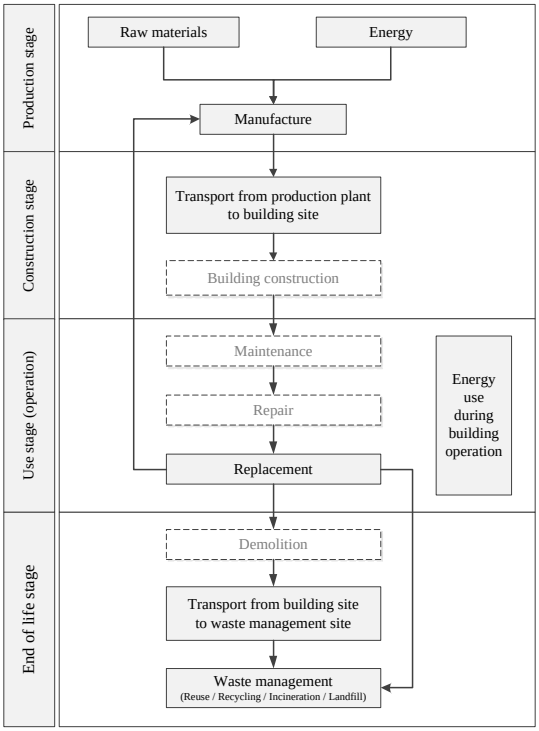

Fig. 1. System boundaries and life cycle stages considered.

In addition, these components use one or more energy vectors that need to be taken into account (e.g., electricity, oil, natural gas, pellets) to account for the energy consumption. The energy consumption of building operational phase comprises the building-related and the non-building related energy consumption. The non-building related energy refers to the occupant-related use e.g., through the use of home appliances. In the LCA methodology for energy related building renovation, the mandatory aspects are: the building-related end-uses such as heating, domestic hot water (DHW), the air conditioning, the ventilation, the lighting and the auxiliary (pumps, control devices). As the calculation of heating needs require to assume at least a default values for the energy use of appliances for internal heat sources, it is possible to include them in the methodology with a default value. It enables to account for their increasing share on the remaining energy use of buildings.

2.2. Life Cycle Inventory

The life cycle inventory consists in compiling all building related data and to associate them with life cycle inventory (LCI) data compiling all the input and output (air, water, soil emissions). Generally speaking, in the building sector, the LCI step is pre-defined i.e., the environmental data describing a material or an energy carrier being already calculated in terms of life cycle impact assessment (LCIA), see the next sub-section.

2.3. Life Cycle Impact Assessment

Many LCIA indicators have been developed in LCA, describing environmental impacts (such as global warming, ozone depletion, acidification etc.), resource use (energy and raw materials depletion etc.) or additional environmental information (hazardous waste, etc.). The EN 15978 recommends using a wide range of LCIA, resource use and waste indicators. On the other side, the Swiss system for LCA in the building sector recommends using only four indicators: global warming, non-renewable and total cumulative energy demand and the total environmental impacts based on ecofactors methodology [6]. However, from a practical point of view, comparing different renovation scenarios would become very tedious if more than a few indicators are used. A key point is to choose a limited number of indicators assuming they achieved a large consensus and acceptance, the building sector must have a significant share on the indicator, the data for building materials and energy carriers should be available for the indicator. According to these criteria and to be widely implemented in practice, the number of indicators in the Annex 56 LCA methodology has been limited to the three following indicators:

- CED: Cumulative Energy Demand. It represents total primary energy used, renewable or not. It includes the non-renewable part (fossil, nuclear, primary forests) as well as the renewable part (hydropower, solar, wind, biomass). CED is expressed in MJ.
- CED_{NRE}: Cumulative Energy Demand non-renewable. It represents the non-renewable part of the CED. It is also expressed in MJ.
- GWP: Global Warming Potential. The GWP is related to the emissions of greenhouse gases. All gases are converted in equivalent-CO2 using appropriate factors defined by the IPCC.

3. Case study

A building located in Morges (Switzerland) and built in the sixties is used as a case study to implement the LCA methodology. The building has 69 flats and a commercial centre in the ground floor. During the year 2010, a complete renovation was conducted for the residential part of the building [7]. The renovation enabled to reduce the final energy consumption of a factor five and the final energy consumption for heating of a factor ten. Figure 2 presents a view of the building before and after renovation.

a) 

b) 

The goal of the LCA is to compare the environmental impacts of the building before and after renovation. To that purpose, the LCA methodology of the Annex IEA 56 and presented in section 2 was implemented in Eco-bat 4.0, a Swiss LCA software for calculating the environmental impacts of building's designs [8]. First, the thermal balance of the building was conducted with Lesosai 7.4 [9] for both cases and validated with on-site energy consumption. Then, the building model after renovation was exported to Eco-bat. It uses as main data source the Swiss recommendation list KBOB of LCA data for the building sector [10]. The KBOB list gathers environmental impacts data based on LCA of building materials, building integrated technical systems (BITS), and different heating systems. The baseline reference study period chosen in the Annex 56 methodology is set at 60 years.

Fig. 2. View of the building (a) before renovation; (b) after renovation.

3.1. Results before and after renovation

Results of the comparative LCA of the building before and after renovation are presented in Figure 3 for three indicators: CED_{NRE}, CED_{TOT} and GWP.

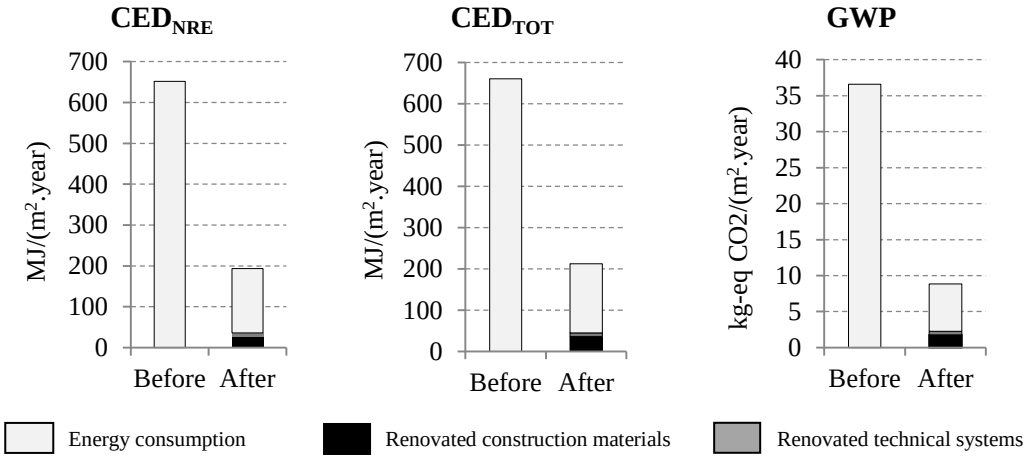

Fig. 3. Results before and after renovation for the CED_{NRE}, CED_{TOT} and GWP indicators.

Whatever the indicator, the renovation enables to reduce the environmental impact of a factor 3 to 4. This is mainly due to the drastic reduction of the impacts of the heating energy consumption. Even the high decrease of the energy consumption of the building, this aspect remains substantial with around 80% of the environmental impacts depending on the indicator. The impacts linked to the new technical systems for heating, DHW, ventilation represent between 4% and 6% of the total impacts. The UBP indicator developed for the Swiss context and aggregating air, water and soil emissions shows a similar trend with a higher contribution of the materials compared to the energy consumption after renovation (12% of the total impact) [11]. The materials added for the thermal envelope are responsible of 15% to 25% of the total impacts.

3.2. Comparison of the LCA results with the Swiss indicative values

It is also possible to compare the LCA results according to national targets in terms of greenhouse gases emissions and primary non-renewable energy consumption. As an illustration, Figure 4 presents the comparative for the GWP

The value of the project for the stage "Construction" is below the Swiss SIA 2040 indicative value [12] for both indicators. As a result, all the renovation choices for the envelope and the BITS seems relevant. However, it is important to highlight that the indicative values are calculated for a larger perimeter than the Annex 56 methodology by taking into account elements not playing a role in the thermal performance. The project's value for the "Operational" stage is below the indicative value for the CED_{NRE} indicator. However, it is above the indicative value for the GWP because of the use of natural gas as energy carrier for the heating and DHW. Generally speaking and without taking into account the mobility, the renovated building fulfils the national environmental targets according to the Annex 56 methodology. The higher GWP impact of the energy consumption is compensated by the lower GWP impact for construction materials and technical systems.

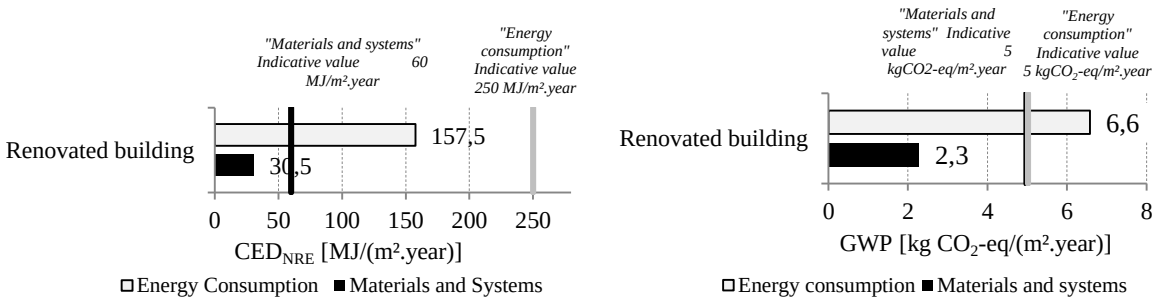

Fig. 4. Comparison of results with the Swiss indicative values for the 2000-Watt society.

4. Conclusions

The energy related building renovation developed in the framework of the annex IEA 56 enables to compare different renovation scenarios of a building before and after renovation. It can be used as a decision making aid to compare different renovation scenarios or as an assessment tool for a building before and after renovation as shown in the case study of this paper.

In the case study, the environmental impacts of the building were reduced despite the use of new materials and technical systems. The operational energy consumption remains the main impact source while the embodied impacts of the construction materials and BITS represent around one quarter of the total impacts. It is thus relevant for energy related building renovation to first reduce the energy consumption and then to choosing construction materials, with the same functionality but with the lowest impact. In the case study conducted in Switzerland, the results of GWP and CED_{NRE} were found below the national indicative values of embodied and operational impacts. These indicative values are part of the target values set by Switzerland to achieve the intermediate goals for 2050 of the 2000-Watt society.

The methodology for energy related building renovation is fully operational and can now be used in renovation case studies. However, when optimizing both financial costs and environmental impacts, it is important to link the LCA results with the Life Cycle Cost costs results as developed in the overall Annex IEA 56 methodology.

Acknowledgements

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