

Determining the environmental influence of energy generating components for façade integration within existing high-rise buildings by means of LCA

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Abstract The EU funded project “Cost-Effective” addresses indirectly energetic, environmental and economic related issues, raised by the amendment of the Energy Performances of Buildings Directive (EPBD) from 2010, with focus on the existing European high-rise building stock. Five new developed energy generating façade components shall be assessed from an environmental point of view by means of Life Cycle Assessment (LCA). The basic principles for the assessment will be presented, taking into account the component as well as respective potential target buildings for application. As the components are expected to have a significant influence within the operation phase of the building, the assessment focuses on the special use of the components for e.g. heating purpose.

1 Introduction and background

1.1 The European project "Cost-Effective"

The amendment of the Energy Performances of Buildings Directive (EPBD) [1] from 2010 stipulates the use of renewable energies for improving the overall energy efficiency of new and existing buildings within the European Union. In this way, the Directive encourages the reduced use of fossil resources from an environmental point of view. Furthermore, economic considerations like the determination of cost optimum levels for defining minimum requirements for the overall energy efficiency are implemented as new aspects. The EU funded project “Cost-Effective” [2] addresses such aspects of the Directive. It focuses on the

existing European high-rise building stock for non-residential use. Five new energy generating components for façade integration are developed to supply such buildings with thermal energy or electricity which is produced from renewable sources. Apart from showing the potential of a reduced use of fossil energy for building services, the project aims also at setting up cost-effective and environmental beneficial solutions for the integration of the components. The environmental influence of the new developed components is determined by means of Life Cycle Assessment (LCA). The assessment includes their whole life cycle as well as respective potential target buildings for application [Tab.1].

Tab.1: Overview on predominant building categories and their characteristics (existing high-rise buildings in Europe)

Building Category	Time line	Main materials for construction	Total floor space in EU [mill. m ²]	Typical annual primary energy consumption [kWh/m ² * a]
1	1945-1965	Reinforced concrete structure; Massive brick façade with cavity	119	400
2	1960-1980	Reinforced concrete with perforated façade; Brick, natural stone, stucco, ceramic tiles, glass cladding	53	420
3	1975-1990	Skeleton construction with precast concrete; Concrete, metal cladding	119	410
4	1975-1995	Skeleton construction with curtain-wall façade; Metal profiles, metal cladding	16.3	380
5	1980-2005	Tall buildings in skeleton construction with curtain-wall façade and air-conditioning; Metal profiles, metal cladding	11.6	350

As the components are expected to have a significant influence on the environmental building performance especially within the operation phase of the building, the assessment focuses on the special use of the component for e.g.

heating, cooling and ventilation purpose. The basic principles for conducting the LCA of the newly developed components will be described with regard to the components environmental influence while building operation.

In a first step, building categories, which are potentially of high interest for applying the new developed components, are classified. Table 1 gives an overview on pre-dominant building categories identified and their characteristics. In a second step technical concepts are set up, which combine retrofit measures for improving the building skin on the one side and the suitable usage as well as the integration of the new developed components within the building on the other side. They are intended as a solution for improving the energy efficiency within buildings of the classified building categories as shown in table 1.

1.2 Life cycle assessment (LCA)

Life Cycle Assessment (LCA) is a useful tool to describe life cycle characteristics of products, services or entire systems from an environmental point of view. It is standardized within ISO 14040 [3] and 14044 [4] and comprises the following phases: goal and scope definition, inventory analysis, impact assessment and interpretation. All relevant life cycle stages are accounted for, starting with the resource extraction, the manufacturing of materials and the product itself, the use and maintenance, as further relevant stages, and closing with the consideration of an End-of-Life. With regard to the goal and scope of the analysis, the considered life cycle stages are divided into single process steps, e.g. “manufacturing of glass tubes” or “collector assembly”. For each step, a list of input and output data of used materials, consumed energy and associated emissions are quantified. According to this information a LCA model for the considered product is set up within respective LCA software. By relating the process input and output data to impact categories by means of characterization models, an impact assessment is conducted. Results of such an impact assessment provide information on the potential environmental impacts which the considered product might have, e.g. the potential contribution to climate change or the consumption of resources.

1.3 European standards for LCA within the construction sector

The working group CEN TC 350 “Sustainability of construction works” [5] is working on standards concerning the sustainability assessment of buildings and building products, regarding environmental, social and economic aspects. With

regard to environmental standards, it is currently working on a harmonized, horizontal (e.g. applicable to all products/building types) approach to e.g. the measurement of operational environmental impacts of construction products and whole buildings. The standards to be produced are to be in line with ISO 14040, 14044 and ISO 14025[6]. They are based on a modular approach and address the entire life cycle.

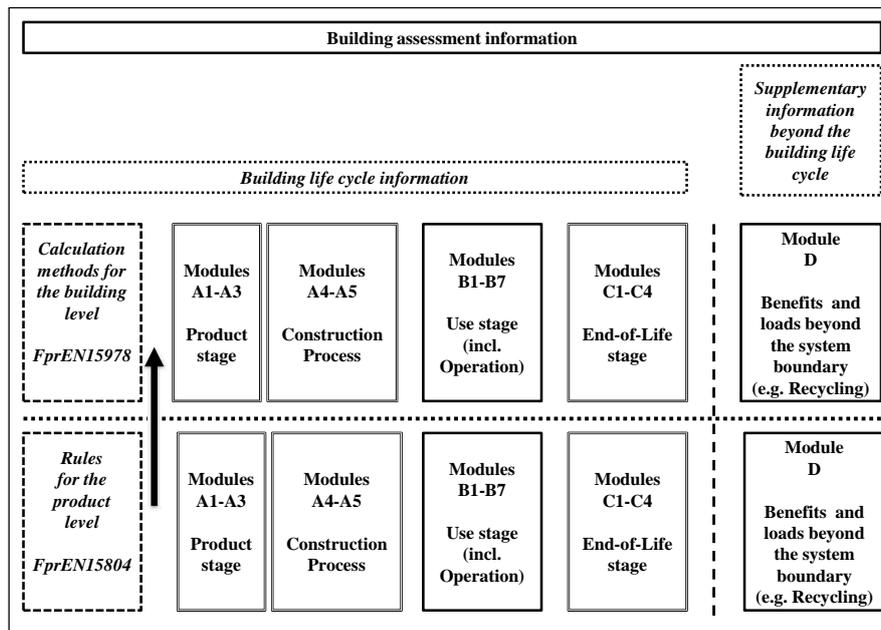


Fig.1: Schematic modular structure of building and product life cycle stages according to CEN TC 350.

Important standards developed by TC 350 are FprEN 15978 [7] and FprEN 15804 [8]. The document FprEN 15804 can be considered a document of product category rules (PCR) for building products by giving advice for the compilation of Environmental Product Declarations (EPDs). Results of a LCA, reviewed by external experts, for the respective building product are part of an EPD. The information given within this type of declaration is therefore suitable for the use within the environmental building assessment according to FprEN15978 [Fig.1].

2 Approach, system definition and boundary conditions

Each multifunctional component of the project “Cost-Effective” can be defined as a “building product”. As the characteristic “multifunctional” indicates, the component is developed to fulfil several functions after building integration. Some of these functions which might be considered are:

- the generation or saving of thermal or electrical energy,
- the reduction of energy produced from fossil resources,
- the increased buildings' independency from the public grid,
- the contribution to glare protection and prevention from overheating or
- the support of the buildings' energy efficiency.

Only after the synthesis of component and building, the component is able to serve for e.g. heating or cooling purpose, as it is constructed to be placed into the building façade. A building independent assessment would disregard a main advantage which the components provide, the provision of thermal or electrical energy. As the potential target building for application is an already existing building, it is furthermore advisable to combine technical building service innovations with retrofit measures for the building skin. As table 1 indicates, the classified buildings could have an age between 5 to 65 years and partly do not comply with current legislation on energetic requirements. Furthermore, users of the identified building categories are faced with overheating, draughts near windows or thermally uncomfortable offices. Therefore, the LCA is carried out on the basis of the modular approach for calculating environmental impacts according to European standardization activities (see 1.3). The assessment will be divided into one part focusing on the product “multifunctional component” and a second part focusing on the building with a “technical concept composed of the component integration and modernization activities”. The second part of the assessment will serve as basis for determining the environmental influence of the component for e.g. heating and cooling purpose on the overall environmental performance of a potential target building.

2.1 Description of product system, function and functional unit

In terms of the building product the following multifunctional components are analysed:

- a transparent solar thermal collector for window integration,
- an air heating vacuum tube collector for general façade integration,
- an building integrated photovoltaic element (BIPV),

- a natural ventilation system with de-centralized heat recovery for façade integration and
- an unglazed solar thermal collector combined with a new heat pump for heating and cooling purpose.

Due to the variety of functionality that the components offer, the functional unit will be determined for each component separately, e.g. for the BIPV element it is set to “generated electricity in [kWh] per glazing unit area in [m²] for 1 BIPV element.

The building part of the assessment focuses on the interaction between a potential target building and a tailored technical concept. These technical concepts have been set up within the course of the project and combine retrofit measures for improving the building skin on the one side and the suitable usage as well as the integration of the new developed components within the building on the other side. They address issues such as:

- improving the building energy efficiency,
- reducing the buildings’ energy demand,
- covering the buildings’ energy demand with thermal or electrical energy from renewable resources and in that way
- making the building more independent from fossil resources or the public grid while building operation.

Since the technical concepts partly combine several multifunctional components, there is the need for defining a profound functional unit for assessment. Each concept is therefore regarded separately. The potential environmental impacts are calculated for the entire building life cycle with a pre-defined building reference service life. A comparison between concepts is not foreseen yet, as this would require the definition of a common functional unit for assessment and an independent critical review according to ISO 14040 and ISO 14044.

2.2 System boundaries

The LCA follows a “Cradle to Grave” approach for both parts, following the life cycle stages of product stage and construction processes (Module A), use stage (Module B), End-of-life stage (Module C) according to prEN15978.

Thereby, the results of the component LCA will be used as input for conducting the LCA of the technical concepts on building level. In addition, parameterized LCA models for the components are set up within the GaBi software [9]. Furthermore, a parameterized and generic LCA building model is designed, being flexible to include the component model for later assessment. The models are

based on e.g. bill of materials or simulation data for the operation phase. Parameters used within the LCA models provide for interdependencies, e.g. varying collector surface area or different construction materials used within different building categories. The parameterisation of the LCA models allows for flexibility within the assessment. Whenever possible, processes or datasets representing European averages or reflecting best available technologies (BAT) are preferred for modelling.

The LCA model for the product part covers manufacturing processes for single elements of each component, e.g. the manufacturing of glass tubes, assembly processes, e.g. fixing and connecting as well as the connected material and energy consumption. Maintenance activities incorporate End-of-Life processes of exchanged elements after reaching a defined reference service life as well as the production of the element to be replaced. The End-of-life stage is reflected by material specific and pre-defined End-of-Life routes. The operation stage so far only comprises real expenditures connected to auxiliary energy, necessary for operating the component. Such expenditures are accounted for e.g. auxiliary electricity for driving pumps or buffers. Therefore, a parameterized LCA model is set up within the GaBi software. The analysis of the technical concepts on building level includes technical and energetic aspects as shown in Figure 2.

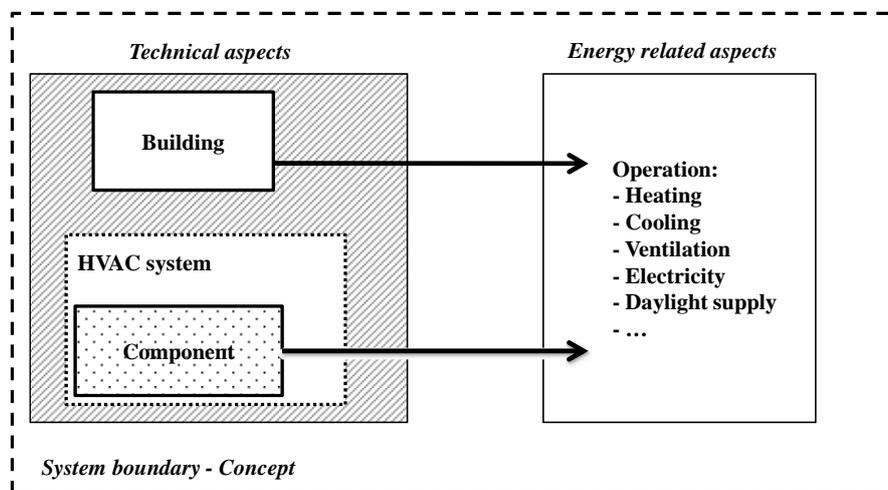


Fig.2 System boundary for the assessed technical concepts on building level

On the technical side, the component is part of the heating, ventilation and air-conditioning system (HVAC), integrated within the building. HVAC technologies and building construction are main constituent parts of a building and have to be accounted for LCA for this reason. Energetic aspects concern the necessary resulting energy demand for building operation which is influenced by e.g.

building layout or building skin and which has to be covered by the applied HVAC system.

3 Consideration of the operation phase by means of "technical concepts"

The significant environmental influence of the component on the overall building performance is expected to be highest while building operation. Therefore, the approach of assessing technical concepts is chosen. Coincidental, this approach represents a possibility to include the component operation by not only focusing on the energy demand that is necessary for operating the components. Nevertheless, energy gains or the potential reduction of thermal energy and electricity produced from fossil resources can be displayed. As also retrofit measures will lead to a decrease in energy consumption, two references for the assessment of the technical concepts are established. "Reference 1" equals the existing building without any retrofit measures and without having installed a multifunctional component. "Reference 2" displays the existing building after modernization/retrofit activities, but without having applied multifunctional components [Fig.3].

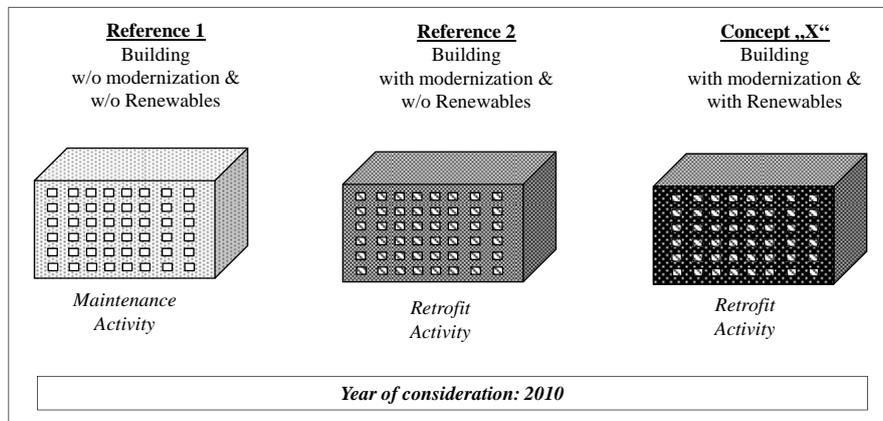


Fig.3 Overview on the two different types of references and the building with applied technical concept, including activities taken into account for the 1st year (2010) of assessment.

The first year of assessment is defined as year 2010 for all three buildings. The general reference service life for a building is assumed with 100 years. The age of the classified buildings in 2010 is calculated depending on their year of construction. The time period of consideration for each building class is

determined by subtracting the building age from the general reference service life. In this way, a building class dependent residual building service life between 35 to 95 years is determined. The residual building service life serves for accounting of the operation stage and maintenance activities. For the consideration of maintenance activities an exchange rate is calculated as ratio between the residual building service life and the single building elements reference service lives, like e.g. walls or HVAC technologies. Maintenance activities incorporate the End-of-Life of exchanged elements as well as the production of the element to be replaced. All construction elements and HVAC technologies that remain within the building after its residual building service life are taken to material specific End-of-Life routes. Main End-of-Life processes applied are:

- thermal incineration processes for materials with calorific/heating value,
- recycling processes for metals,
- construction waste recovery processes for mineral materials or
- landfill processes for all other materials, which cannot be incinerated, recovered or recycled.

The operation phase comprises real expenditures connected to auxiliary energy, necessary for operating the component. Such expenditures are accounted for e.g. auxiliary electricity for driving pumps or buffers. The fact, that the component is generating energy which can be used to substitute energy produced from fossil resources, is derived from energetic simulations on the component itself and on the building energy demand. The resulting energy demands for e.g. heating, cooling or electricity consumption and the information how this demand is covered, are taken as input for the assessment of the operation phase.

For the assessment of the year 2010 the following approach is chosen: The building "Reference 1" is assumed to be maintained, to be able to compare obtained results with building "Reference 2" and the building with applied concept X, where at least modernisation activities for the façade are regarded. Maintenance activities during the residual building service life and the End-of-Life are considered similar for all three buildings.

4 Results

At present, first results are expected by June 2011. The paper therefore intends to give preliminary results and to especially derive conclusion for the influence of each component after building integration by the analysis of the "technical concepts". A general forecast on expected results for such a scenario analysis is given within the following.

4.1 Presentation of results

Figure 4 gives an overview on how the results for the LCA of the technical concepts can be illustrated. The figure shows two reference buildings and a building with applied tailored technical concept for 1 pre-defined building category and 1 pre-defined environmental indicator or impact category. The potential environmental impacts for the whole building life cycle for a pre-defined residual building life are assigned relative. The potential range for the obtained results is also included, as assumptions for the modelling have to be made, which could influence the final results.

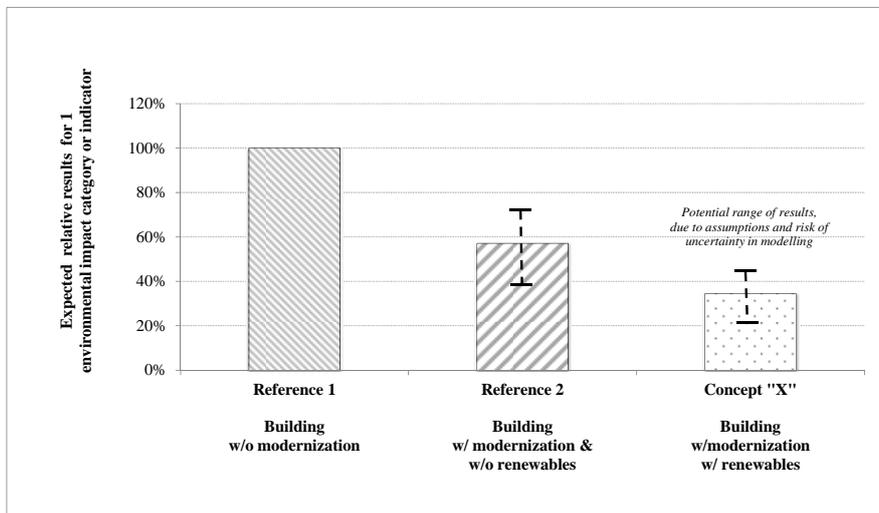


Fig.4 Overview on expected results for 1 building category and 1 concept applied, for a pre-defined residual building service life (incl. maintenance and retrofit activities, building operation and End-of-Life).

By comparing the buildings “Reference 1” and “Reference 2”, it is expected that the environmental impacts over the entire building life cycle will be reduced due to the improvement of the building skin according to today’s legislation. The main reduction will result from a reduced final building energy demand which is supposed to be cut down to 40-50% of the already existing building. Construction aspects or maintenance activities will have minor relevance.

The integration of the multifunctional components (Concept “X”) will further lower environmental impacts, as the energy generated is assumed to be used within the building. Conversely, fossil energy consumption can be reduced, leading to further reduced environmental impacts.

5 Summary and conclusion

An approach has been presented for assessing the environmental influence of energy generating components within existing European high-rise buildings by means of LCA. By taking into account a potential target building and a tailored technical concept, energy gains or the reduced use of fossil energy, arising from using the components, were addressed especially for the operation phase. Furthermore references for the technical concepts have been determined which equal the unmodified existing building, a modernized building without component and a modernized one with multifunctional component.

According to European standards, such as FprEN 15978 future research should be carried out for defining if and how new multifunctional HVAC components can be treated with regard to the influence on the original buildings' function. Furthermore, it would be advisable to divide between considerations for active, energy generating components (e.g. the BIPV element) and passive, loss avoiding components (e.g. the natural ventilation system with heat recovery, to be able to distinguish both systems. Consequentially, questions arise with this approach such as:

- what function does the component fulfil within the building and how can this influence the buildings' function;
- how shall system boundaries be drawn;
- shall the component be treated as energy generation unit or be accounted for HVAC technologies;
- could "credits" be accounted for the avoided primary production of thermal and electrical energy? And could they be easily assigned by "net credits" even if auxiliary energy is needed for operating the components?

Providing an answer to these questions is of importance as with increasing energetic building requirements and with the insistent European postulation of "Zero-Energy-Buildings", buildings will move in future towards fulfilling an augmented energy generation function.

Furthermore, it is also conceivable to draw European conclusion on the environmental reduction potential of the existing, non-residential, high-rise building stock by applying the multifunctional components. Oriented on already existing studies, such as IMPRO – Environmental improvement potentials of residential buildings [10], a total European reduction potential could be derived by means of e.g. information on available total European floor space and general assumptions on the buildings' energy balance.

6 Acknowledgement

The research leading to these results has received funding from the European Union's Seventh Framework Programme FP7-NMP-2007-LARGE under grant agreement n° 212206. This contribution is highly appreciated. The information given in this publication does not necessarily represent the view of the European Commission (EC).

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