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IEA EBC Annex 72 - Assessing life cycle related environmental impacts caused by buildings – targets and tasks

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Abstract. Investment decisions for buildings made today largely determine their environmental impacts over many future decades due to their long lifetimes. Such decisions involve a trade-off between additional investments today and potential savings during use and at end of life - in terms of economic costs, primary energy consumption, greenhouse gas emissions and other environmental impacts. Life cycle assessment (LCA) is suited to identify measures and action to increase the resource efficiency and the environmental performance of buildings and construction. This paper gives an overview of an ongoing international research project within the IEA EBC with the overall aim to harmonise LCA approaches on buildings and foster life cycle thinking in the real estate and construction sectors. The objectives of the project are i) to establish a common methodology guideline to assess the life cycle based environmental impacts caused by buildings, ii) to establish methods for the development of specific environmental benchmarks for different types of buildings, iii) to derive regionally differentiated guidelines and tools for the use of LCA in building design and tools such as BIM, and iv) to improve data availability by developing national or regional databases with regionally differentiated LCA data tailored to the construction sector. To ensure practical solutions a number of case studies will be used to test and illustrate the consensus approaches and research issues.

1. Introduction

In response to concerns about climate change, energy security and social equity, countries around the world are either planning to substantially reduce energy demand and greenhouse gas emissions or in the case of emerging economies to develop in less energy intensive ways. The construction as well as heating and cooling of buildings is one major cause of primary energy demand, greenhouse gas emissions and environmental impacts of developed and emerging economies [1-4]. Buildings have a long lifetime of between some decades to more than 100 years. The replacement rates in Europe for instance suggest that the average lifetime of residential buildings is well above 60 years. Thus, investment decisions on buildings today determine by and large the environmental impacts during several future decades. Furthermore, such decisions can involve a trade-off between additional investments today and potential savings during use and end of life (both in terms of economic costs on one hand and primary energy demand, greenhouse gas emissions and environmental impacts on the other). Today, natural resources such as clean air, clean water, biodiversity or natural resources are free and their use as a sink is hardly charged to those polluting them. The current price system does not (systematically) account for such external environmental effects (market failure) which leads to an inefficient (over)use of natural resources. That is why, environmental assessments of human activities are necessary to highlight the inefficient use of natural resources and to take measures and action to increase the resource efficiency of buildings and construction by substantially reduce consumption and pollution of natural resources.

The life cycle assessment (LCA) approach as standardised by ISO 14040 and 14044 [5, 6] is suited to quantify the environmental impacts of buildings based on the principles of ISO 15392 [7]. The assessments performed using the LCA approach are very much in line with an economic assessment which follows a life cycle costing approach. Hence, LCA is suited to complement economic information on buildings with information on their environmental impacts (see also Figure 1). Important developments on the topic in recent years have been the many international (such as ISO 21930 [8] and ISO 21931 [9]) and European (such as EN15978 [10] and EN15804 [11]) standards for the development of environmental product declarations of building products and the environmental performance assessment of construction works as well as the recently published report by the European Commission on resource efficiency and resource consumption mitigation opportunities in the building sector [12].

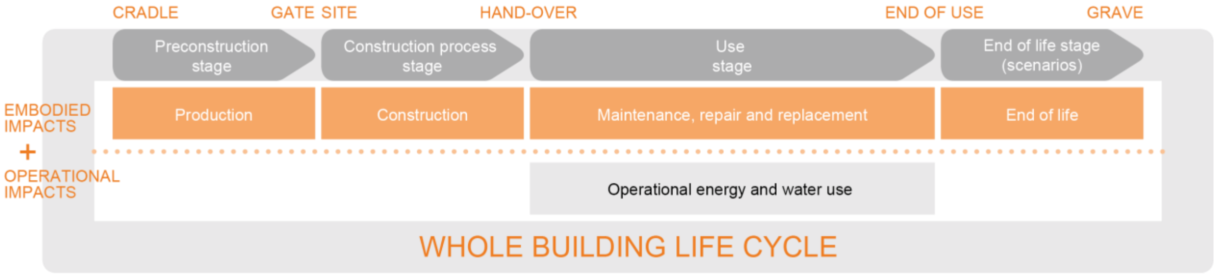

Figure 1. The different stages in the Life Cycle of buildings and the distinction between embodied and operational environmental impacts.

The environmental assessment of buildings using life cycle assessment approaches entails several research issues and issues which call for harmonisation and consensus, while respecting national and regional traditions. The following list of issues illustrates the kind of topics discussed in the international research project IEA EBC Annex 72, building on results of the former IEA EBC Annexes 31 [13] and 57 [14]:

- Environmental “optimisation”: When considering the entire life cycle of buildings, efforts can be either focused on reducing embodied or operational impacts. With current discounting practices, the use and end of life phases are economically less important. This situation gives rise to the following questions: Where is the environmental optimum between gross zero operational energy buildings on one hand and minimised embodied impacts buildings on the other? Is it sensible to try to reduce energy consumption for heating and cooling close to zero or do the environmental impacts of the additional material and equipment overcompensate the reduced environmental impacts during operation?
- Net zero energy buildings: More and more buildings integrate on-site renewable energy systems to compensate their operational energy demand e.g., for the heating, ventilation, lighting and appliances uses or even to additionally compensate their embodied energy. The energy produced onsite can either be self-consumed or fed into the grid depending on the level of production and the simultaneity between production and the building energy demand. Previous LCA studies (e.g. in IEA EBC Annex 56 project, see e.g. [15]) have used an annual balance for estimating the building energy demand and production. Other approaches have

assessed the life cycle related impacts based on an hourly balance. Is there one particular preferable approach and if so, which one should be recommended? How should life cycle net zero impact buildings be defined, including rules for balancing and communication?

- Integration of environmental assessment in design process using tools such as building information modelling (BIM): For the aforementioned goal of an environmental optimisation of buildings during their lifecycle it seems necessary to include the environmental assessment in the early design stages to have a higher influence on the final outcome (see "McLeamy effort curve" [16] and potential shift through BIM). Current digital design tools and especially BIM provide the potential to include various kinds of assessment information and simulations (embodied and operational energy, daylighting, et cetera) in early design stages. Issues related to this integration in digital design tools are the different levels of modelling within the tools as well as the accuracy and reliability of information during the different stages of the design process. As this information is only gradually defined, assessment tools need to use constantly refined values and presumptions throughout the planning process. Can approved level of detail (LOD) definitions in design tools such as BIM and defined stages within the building design process be used to mark steps in which to incrementally assess and optimise the environmental performance of the building design? Which values and presumptions should be taken for the assessment at the different design stages? Which variability and safety factors have to be considered to achieve significant and complete assessment results?
- Service life: Some standards prescribe or suggest service lifetimes of building components and technical systems. However, observed lifetimes can be significantly different from the lifetimes prescribed or suggested in national standards. Buildings are long-living investments but office and industrial buildings in particular may have relatively short service lives. Some experts claim that environmental impacts caused by construction (and material supply) today should be balanced within one to maximum two generations, i.e. 30 to 60 years. What service life or reference study period should be chosen with such long-living investments like buildings? Should the reference study period be defined based on observed or default lifetimes or based on an argumentation based on intergenerational equity?
- Technology development: Buildings are expected to be used during 50 to 100 years or even longer. During this period, economy and in particular building elements, building technologies and energy supply systems (fuel oil, natural gas, coal, electricity, wood, biogas) will develop (see e.g. [17]). The following questions related to future scenario will be discussed in the IEA EBC Annex 72: Should technology developments and changes in the mixes related to electricity, heating, cooling and waste management be considered when assessing the environmental impacts of the use and end of life phases? How to deal with new building products and with technology developments of existing ones? How to deal with potential change in type and pattern of use of buildings?
- Aggregation and assessment of current and future emissions: A substantial part of the energy use, greenhouse gas emissions and environmental impacts occur several decades in the future. This raises the question of how to aggregate emissions occurring today (during production and construction stages) and emissions occurring during the use stage and in particular during the end of life stage and whether or not to apply any discounting approach (see e.g. [18]).

2. Objectives of IEA EBC Annex 72

The work of the IEA EBC Annex 72 is organized in five Subtasks which are closely interlinked.

The research work of the IEA EBC Annex 72 aims to achieve the following objectives:

- Establish a harmonised methodology guideline to assess the life cycle based primary energy demand, greenhouse gas emissions and environmental impacts caused by buildings.
- Establish methods for the development of specific environmental benchmarks for different types of buildings to help designing buildings with a minimum life cycle based primary energy demand, greenhouse gas emissions and environmental impacts.

- Derive guidelines on tools (building design tools, BIM and others) and workflows for design decision makers.
- Establish a number of case studies, focused to allow for answering some of the research issues described above and for deriving empirical benchmarks.
- Develop national/regional databases with regionally differentiated life cycle assessment data tailored to the construction sector, covering material production, building technology manufacture, energy supply, transport services and waste management services; share experiences with the setup and update of such databases.

3. Methods

3.1. Surveys

Surveys for LCA experts and for designers were established to learn more about the current situation of LCA in the building sector: One part of the survey is on the methodologies applied to assess the environmental impacts of buildings with regard to modelling aspects, system boundaries and environmental indicators. In addition, the degree of dissemination of the applied methodologies, the frequency of use among designers and their demand for assessment results is investigated. A second part is on national practices of workflows and planning tools, methods, data formats etc. used by LCA experts and design decision makers in the participating countries. Lastly, the surveys include a section on national/regional LCA databases and are exploring the national needs (data gaps) and the driving forces for the demand on LCA data and databases.

3.2. Round robin test and harmonised methodology

A round robin test to assess the greenhouse gas emissions, primary energy demand and other environmental impacts of two reference buildings are performed to identify the differences in national building assessment approaches [19].

The insights gained from the surveys and the round robin test will be used to develop and extend the methodology guideline on LCA of buildings and benchmarks. The guidelines and approaches agreed within IEA EBC Annex 57 [14, 20] serve as starting point. The guidelines will be extended to the full life cycle of buildings and will include:

- operational impacts,
- modelling aspects such as allocation and recycling,
- modelling onsite electricity production,
- reference service life / reference study period,
- technology development (e.g. in the electricity mix supplied to the building during its use phase)
- recommendations on environmental indicators.

A clear distinction is made between modelling practices on one hand and data and databases on the other. In addition the areas of disagreement will also be highlighted by offering at least two alternative approaches in such cases. Regional and national traditions will be captured to the extent feasible and necessary.

3.3. Work flows and data interfaces

The results of the survey on national practices of workflows (see Section 3.1) and semi-structured interviews with selected experts help to identify the current state and potentials of implementing the assessment of life cycle related environmental impacts of buildings during the design process. Besides the survey a systematic literature review is performed to identify the requirements for the implementation of life cycle related aspects in different stages of the design process. As a result, implementation strategies in view of internationally compatible solutions of design tools and formats (e.g. BIM) of life cycle information (e.g. following existing structures of a cost calculation approach) are proposed.

Based on building case studies (see Section 3.4.) an analysis on how differences in building models (completeness and detailing) can be considered throughout the planning process (e.g. application of correction factors) is performed. The aim is to establish guidelines for measuring the completeness of a building model and to indicate how it can be used for life cycle assessment of buildings. Furthermore, guidelines for design decision makers on how to use available information to assess the life cycle-related environmental performance of buildings during the design process for their improvement will be developed.

3.4. Case Studies

A substantial set of building case studies are analysed for which the life cycle based environmental impacts are quantified using either national/regional assessment practice or the methodology agreed in IEA EBC Annex 72 (see Section 3.2.). The buildings selected should be representative to the country/region. The set of case studies include different building types and different decision-making situations. A harmonized documentation of these case studies is developed, including the information on the use (covering e.g. use profiles) of the buildings analysed as well as the climatic zone.

These case studies are helpful in establishing empirical benchmarks based on the methodology developed in the IEA EBC Annex 72 (see Section 3.2.). To develop these benchmarks different reference units (functional equivalence, i.e. impacts per m^2 and year basis, impacts per person etc.) are analysed. The benchmarks shall apply on the entire life cycle of buildings and be subdivided into embodied environmental impacts (production of materials and technical systems, construction, use and end of life) and operational impacts during the use phase. The established benchmarks related to the primary energy demand, greenhouse gas emissions and environmental impacts of buildings are regionally differentiated and tied to different building types such as residential, office, or school buildings. It is explored whether or not a typology of climatic regions can be established to allow empirically derived benchmarks being applied across the participating nations.

Furthermore the case studies will serve as basis to classify and characterize different approaches to optimizing life cycle primary energy demand and greenhouse gas emissions performance of new buildings and renovation projects. The potential to reduce environmental impacts of different types of optimization strategies are assessed in order to develop guidelines for building design and decision-making.

The planning and design workflow have an impact on the whole life primary energy demand/greenhouse gas emissions of the building. Many decisions are taken with no thought of primary energy demand nor greenhouse gas emissions – for instance the choice of structural frame may be based on architectural layout and on construction industry standards for that country, while facade material may depend on local planning requirements, etc. The aim is therefore to further analyse the case studies focusing on the decisions in the planning and design workflow. As a result of this analysis examples and in-depth knowledge on process aspects promoting or hindering a relevant application of environmental life cycle thinking in building design are given.

3.5. LCA databases for the construction sector

The results of the section on national LCA databases in the surveys are used to document national databases used in the construction sector and provide recommendations in view of further improving the situation regarding data availability and suitability. The documentation includes a standardised description of existing database contents. The information gained in the survey on existing national databases helps to develop guidelines and practical hints on how to establish a publicly available LCA database suited for the building sector. It mainly addresses countries with a current lack of a reliable, country specific LCA database. The guidelines include considerations and information related to:

- the need of national databases,
- the contents of such databases,

- organisational aspects (e.g., on how to organise data collection and funding, how to organise updates, etc.).

In a next step the developed guidelines are implemented in country case studies. The aim is to compile a default set of publicly available national environmental indicator results of construction materials, building technology, energy supply, transport services and waste management. The default set of results shall be suited to be used in the preliminary design stage or in case of lack of more specific information.

4. Planned working steps and intermediate Results

4.1. Methodology guidelines (Subtask 1)

Subtask 1 (ST1) takes up the methodological foundations developed in IEA EBC Annex 57 [21] for the determination, assessment and influencing of embodied impacts and further develops them into a complete life cycle approach. Currently, ST1 discusses the following topics (among others): (a) how to avoid physical discounting in the GWP [22] on the one hand, and, at the same time, make possible the consideration of the time factor through the inclusion of external costs (here the damage costs of greenhouse gas emissions - see, inter alia, [23]). In this case, according to the social discounting rate approach [24] the lowest possible interest rate should be selected; (b) the possibilities of considering technical progress for different use cases in a specific way. For the analysis of scenarios this topic may be considered, but for the deterministic models [25] in the context of a sustainability assessment this should be excluded; (c) that although when reusing an existing building structure in the next life cycle the already consumed energy and resulting GHG emissions for the old structure are accounted for as zero (since they can no longer be influenced), the further maintenance, later replacement and the EoL must be taken into account.

Additionally, ST1 deals with the development and use of environmental benchmarks on the basis of the current standardization activities [26]. This standard aims to develop a typology of reference levels, to improve the transparency and traceability of published benchmarks and to describe typical application cases. Some of the authors are directly involved in the latter standardization process. One example of alignment with the ongoing standardization activity is that also Annex 72 adopts the system of limit, reference and target values. Own contributions under the ST1 focus on the basic principles of developing benchmarks for specific types of buildings and uses in different climate zones. However, it is also discussed how, on the basis of scientifically recognized needs and politically formulated goals, target values for the maximum greenhouse gas emissions caused by a building can be defined in a top-down approach, which correspond to a budget and contribute to a uniform net-zero emission approach.

4.2. Work flows and data interfaces (Subtask 2)

Thus far, the activities of Subtask 2 (ST2) have been closely coordinated with ST1 with respect to the establishment and execution of the global survey amongst design professionals. The public survey has been translated by Annex experts in 9 languages and is currently conducted in more than 20 countries.

On ST2 specific topics of LCA workflows and design integration, the work has been structured according to the following tasks:

a) Definition of design phases and milestones,
b) Building decomposition and element method,
c) Strategies for handling design variability and LCA uncertainty,
d) Sample cases for digital building models,
e) Definition of LCA exchange requirements,
f) Options for communication of LCA results.

The ST2 experts have been in regular exchange and have already shown their contributions in various publications on these topics: Yang et al. [27] analysed the environmental impacts in the Chinese context, highlighting the potential to reduce impacts during the design process.

Röck et al. [28] discussed the general challenges of coupling LCA and BIM based on case study implementation. Lupíšek et al. [29] shared their specific findings on the potential for interconnection of tools for cost estimation and life cycle assessment in the Czech context. Peuportier et al. [30] presented building life cycle assessment tools developed for the French context. In the aim of mainstreaming LCA in the building design process, the research of Szalay et al. [31] contributes by showcasing a modular methodology for life cycle assessment of buildings and building stocks. Contributing to both ST1 and ST2 topics, García-Martínez et al. [32] presented their BIM-based LCA approach for obtaining environmental benchmarks for the life cycle of buildings.

The Annex specific research thus has shown the challenges as well as great potential for integrating LCA in the building design process. At this point, ST2 is aiming to coordinate efforts and identify the common requirements for integrating the environmental assessment in different design stages. For this matter, the ST2 experts are elaborating their activities focusing on several key topics in order to: i) identify a common understanding of building decomposition based on existing systems (e.g. for cost estimation); ii) map LCA databases used along the design process in order to identify requirements for both LCA datasets as well as digital building models, as well as; iii) develop common strategies for the handling of variability and uncertainty in design-integrated LCA workflows.

In order to advance the discussion on the ST2 topics, a special session on ‘Building assessment workflows’ will be held in the framework of the SBE19 DACH conference in Graz, Austria.

4.3. Case studies (Subtask 3)

Experience with analysing a bulk of building cases from different countries in the Annex 57 project demonstrated how building LCA show large variations in assumptions and methodological choices resulting in large variation of numerical results, and which makes them impossible to be compared [33]. Therefore, understanding of methodology and work on harmonisation has had first priority. The first part of the work with case studies, which is in its beginning phase, will focus on collection of case studies displaying and evaluating the consequences of different methodological choices, such as use of dynamic energy modeling, the length of the reference study period, the functional unit and circular economy strategies. Moreover, the work with case studies will focus on displaying different national benchmarks which are already in use based on different methodology and assumptions. The results of this evaluation work can contribute to the development of suggestions for harmonised methods. Later in the project, case studies applying a harmonised method will be collected.

For the subtask on workflows and data interfaces, focus has been on gathering information across countries before collecting case studies. Case studies can be used to analyse how differences in building models (completeness and detailing) can be taken into account throughout the planning process (e.g. application of correction factors).

4.4. LCA databases for the construction sector (Subtask 4)

A preliminary screening about the types of databases used among the IEA EBC Annex 72 participating countries was performed. The participating countries were asked whether an own national database was developed and is being used and if so, by whom the database is developed and maintained. Further, they were asked, what type of data (generic or product specific) is used within their database. Generic data is usually data gathered from different sources of information; whereas product specific data is gathered from one or several producers for a specific construction product. Specific producer data can as well be published in the form of an environmental product declaration.

In total 23 countries filled in the questionnaire. Among the IEA EBC Annex 72 participants, 9 countries have developed their own databases, 10 countries use adapted datasets from foreign databases for their purpose and three countries did not develop or adapt own datasets. In two countries, the national database is developed and maintained by a public organisation. Several entities develop the databases but the database is maintained by the public sector in three countries. In 4 countries any organization can develop and maintain a database. To perform a building LCA, in 7 countries mainly generic datasets are used. 15 countries use both generic and specific datasets. In one country generic datasets are used in an early design stage and specific data in detailed design.

5. Outlook / Deliverables

The results of IEA EBC Annex 72 will help fostering the use of environmental information in the design and decision making process of buildings and thus lead to more resource efficient, environmentally sustainable buildings in the future. The deliverables will promote the importance and best practices of environmental life cycle assessment of buildings and will include a series of reports and national datasets:

- Report on harmonised guidelines on the environmental performance assessment of buildings, based on results of LCA;
- Report on establishing environmental benchmarks for buildings, including case study examples;
- Report on national LCA databases used in the construction sector, including a standardised characterisation of LCA databases relevant to the construction sector;
- Report on design decision maker’s guidelines on optimization using building assessment workflows and tools, including case study examples;
- Report on building case studies (using a standardised template), including guidelines with good examples on the application of LCA in different stages of the design process;
- Report on how to establish national/regional LCA databases targeted to the construction sector, including recommendations for data exchange;
- Default publicly available, national data set(s) of LCA based environmental indicators.

The work of the IEA EBC Annex 72 will be finished by 2021 (http://annex72.iea-ebc.org/about).

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