Final report

1.1 Project details

Project title	Evaluation of Embodied Energy and Carbon Dioxide for Building Construction
Project identification (program abbrev. and file)	EUDP 64012.0113 EUDP 13-1 64013.0176 Udvidelse
Name of the programme which has funded the project	Energieffektivitet
Project managing company/institution (name and address)	Danish Building Research Institute, Aalborg University Copenhagen, A.C. Meyers Vænge 15, 2450 Copenhagen SW
Project partners	Harpa Birgisdottir og Freja Nygaard Rasmussen SBi.
CVR (central business register)	29 10 23 84
Date for submission	31.01.2017

1.2 Short description of project objective and results

In English

The evaluation of energy consumption and related greenhouse gas (GHG) emissions resulting from the use of buildings is becoming more accurate and being applied in the design of more energy efficient building envelopes, systems and regulations. This means that the percentage of the energy consumption as well as GHG emissions, namely due to carbon dioxide, methane, fluorocarbon gases and other greenhouse gases, caused by stages other than the buildings use is increasing, and their evaluation and reduction will be more important in the future. It is clearly an appropriate time to further study the scientific basis of embodied energy and GHG emissions for building construction, and therefore the Annex 57 project was created and organized with an international team as part of IEA EBC.

To find solutions for the research issues related to embodied energy and GHG emissions, the following specific objectives are focused upon:

- Subtask 1 - Identify and clarify the methodological issues related to the definitions and fundamental concepts of embodied energy and GHG emissions, develop recommendations for tackling the identified methodological issues when it comes to the assessment of embodied energy and GHG emissions at the building level, as well as define the relationship between actors and targets related to embodied energy and GHG emissions for building construction
- Subtask 2 - Collect existing research results concerning embodied energy and GHG emissions owing to building construction, analyze and summarize them into the state of the art.
- Subtask 3 - Develop methods for evaluating embodied energy and GHG emissions resulting from building construction.
- Subtask 4 - Use collected building's case studies to develop measures for the design and construction of buildings with reduced embodied energy and GHG emissions.
- Subtask 5 - Develop a project summary report outlining the technical results of Annex 57 and disseminate research results and guidelines of Annex 57.

The project results were published in the following reports and stakeholder guidelines:

- Subtask 1 report; Basics, Actors and Concepts
- Subtask 2 report; A Literature Review
- Subtask 3 report; Evaluation Methods of Embodied Energy and Embodied GHG in Building and Construction
- Subtask 4 report; Recommendations for the reduction of embodied greenhouse gasses and embodied energy from buildings
- Subtask 4: Case study collection report
- Summary report of Annex 57
- Overview of Annex 57 results
- Guideline for designers and consultants-part 1
- Guideline for designers and consultants-part 2
- Guidelines for construction products manufacturers
- Guidelines for policy makers
- Guidelines for education

The Danish participation in the project has been very valuable in form of gathering comprehensive knowledge about the subject of embodied energy and GHG emissions related to buildings, which is believed to be brought in focus in the near future in Denmark as well as internationally. The Danish participants have had an important role in subtask 4, as one of subtask leaders and main contributors to the following three independent publications:

- Subtask 4 report; Recommendations for the reduction of embodied greenhouse gasses and embodied energy from buildings
- Subtask 4: Case study collection report
- Guideline for designers and consultants-part 2.

Furthermore, as being the chair of the editorial board of Annex 57, a comprehensive overview and knowledge to all subtasks and publications has been collected, which can be transferred to considerations related to possible future requirements towards embodied energy and embodied GHG emissions related to buildings in Denmark.

På dansk
Samtidig med at driftsenergiforbruget i bygninger nedbringes betydeligt bliver andelen af det indlejrede energi og de indlejrede drivhusgasemissioner, når bygninger evalueres over hele deres livscyklus, stigende og dermed evaluering og reduktion vil være vigtigere i fremtiden. Efterhånden som metoden for evaluering af indlejret energi og indlejrede drivhusgasemissioner relateret til bygninger er blevet mere præcis, kan den nu også anvendes i design og udførelse af mere miljømæssigt bæredygtige bygninger. Det var derfor et passende tidspunkt for ca. fem år siden at igangsætte internationalt forskningsprojekt som en del af IEA EBC til at studere det videnskabelige grundlag for indlejret energi og indlejrede drivhusgasemissioner for bygninger.

For at finde løsninger på nogle identificerede metodemæssige og videnskabelige spørgsmål vedrørende indlejret energi og indlejrede drivhusgasemissioner, blev følgende specifikke formål med projektet identificeret og opdelt i følgende subtask:

- Subtask 1 - Identificere og tydeliggøre de metodiske spørgsmål i forbindelse med de definitioner og grundlæggende begreber i forbindelse med indlejret energi og drivhusgasemissioner, udvikle anbefalinger til at håndtere de identificerede metodologiske spørgsmål, når det kommer til vurderingen af indlejret energi og drivhusgasemissioner på bygningsniveau, som samt definere forholdet mellem vigtige aktører og mål relateret til indlejret energi og drivhusgasemissioner for bygge og anlæg
- Subtask 2 - Samle eksisterende forskningsresultater vedrørende indlejret energi og drivhusgasemissioner for bygninger, analysere og opsummere dem.
- Subtask 3 - Udvikle metoder til evaluering indeholdt energi og drivhusgasemissioner resulting fra bygge og anlæg.
- Subtask 4 – Indsamle case studier og bruge de indsamlede casestudier for at samle viden om indlejret energi og indlejrede drivhusgasemissioner i relation til bygninger, samt udvikle retningslinjer for hvorledes indlejret energi og indlejrede drivhusgasemissioner kan blive reduceret i bygninger.
- Subtask 5 - Udvikle en oversigtsrapport over de samlede resultater fra Annex 57.

Projektets resultater blev offentliggjort i følgende rapporter og retningslinjer interessenter:

- Subtask 1 report; Basics, Actors and Concepts
- Subtask 2 report; A Literature Review
- Subtask 3 report; Evaluation Methods of Embodied Energy and Embodied GHG in Building and Construction
- Subtask 4 report; Recommendations for the reduction of embodied greenhouse gasses and embodied energy from buildings
- Subtask 4: Case study collection report
- Summary report of Annex 57
- Overview of Annex 57 results
- Guideline for designers and consultants-part 1
- Guideline for designers and consultants-part 2
- Guidelines for construction products manufacturers
- Guidelines for policy makers
- Guidelines for education

Den danske deltagelse i projektet har været yderst værdifuld i form af indsamling af omfattende viden om indlejret energi og indlejrede drivhusgasemissioner relateret til bygninger, et emne som menes at blive bragt i fokus i den nærmeste fremtid i Danmark såvel som internationalt. De danske deltagere har haft en vigtig rolle i subtask 4, både som en af subtask ledere og vigtige bidragsydere til følgende tre uafhængige publikationer:

- Subtask 4 report; Recommendations for the reduction of embodied greenhouse gasses and embodied energy from buildings
- Subtask 4: Case study collection report
- Guideline for designers and consultants-part 2.

Som formand for redaktionsgruppen for Annex 57, har den danske deltagelse også sikret et bredt indblik og viden til alle subtasks og publikationer fra Annex 57, en viden som kan overføres til overvejelser vedrørende mulige fremtidige krav for indlejret energi og indlejrede drivhusgasemissioner relateret til bygninger i Danmark.

1.3 Executive summary

Various actors in the building and construction industry have recently recognised the growing importance of embodied energy (EE) and embodied greenhouse gas emissions (EG). However, a significant, and still considerably untapped, opportunity to limit these impacts along with the operational impacts of buildings remains. However, the embodied impacts are important and indispensable aspects of the overall performance and sustainability of construction works and thus, their consideration and calculation should become the norm worldwide.

Annex 57 identified key actor/stakeholder groups influencing embodied impacts along the building supply chain and investigated whether and to what extent specific actions are required. Additionally, Annex 57 investigated how to achieve a stronger integration of embodied impacts into the diverse decision-making processes. As a result, actor-specific guidelines were developed.

Besides that, Annex 57 investigated the transition of the existing experiences of dealing with "embodied energy" to the newest concept of “embodied GHG emissions” and made a clear distinction between the latter and stored carbon. At the end, as a result of this analysis, recommendations for uniform definitions were developed and a basis for the description of system boundaries was provided. For the first time, such an analysis was used as a basis to declare and classify diverse case studies from different countries in an overall system. Finally, the necessity to improve the transparency and quality of data for construction products and assessment results for buildings was identified and analysed.

Operational and embodied impacts work hand in hand, and therefore they should be combined to form an overall approach that would have, among others, consequences for the further development of the EPBD in Europe. The relationships and interdependencies between operational and embodied impacts should be analysed in a future project. Additionally, extending the scope of GHG assessments to include embodied GHG in addition to operational GHG facilitates the determination and assessment of a carbon footprint for the building. Finally, more than ever targets and benchmarks for embodied energy and embodied GHG emissions should be defined to assist the design process.

In Denmark there has been a discussion about if requirements related to embodied energy and embodied GHG emissions should be the next step in relation to energy requirements of buildings. SBi has just recently published a report (in Danish) with the purpose to assess whether it currently makes sense that buildings embodied energy and environmental impacts is lifted in the building code and to come up with ideas on how such a requirement (possibly optional) can be formulated. The knowledge gathered in the Annex 57 five year project has been utilised in this particular Danish report about buildings embodied energy and GHG emissions and possibilities related to lifting those requirements into the building code.

1.4 Project objectives

The interest in issues related to the determination, assessment and influencing of embodied energy (EE) and embodied greenhouse gas emissions (EG) of construction products and buildings has grown significantly during the last years. Although the fundamentals in the form of terms, system boundaries, data bases and calculation rules have already been, to some extent, a subject of scientific discussion and international standardization, they are not yet in a form that facilitates their application and leads to clear and transparent results. This is where the contribution of IEA EBC Annex 57 comes in; it presents the fundamentals in such a way that they can be efficiently included in the decision-making of relevant actors.

The overall work is accomplished through the different subtasks (STs):

ST2 analyses the status of the scientific discussion on the basis of an evaluation of available literature. The identified misconceptions and gaps form the basis for the Annex 57 work.

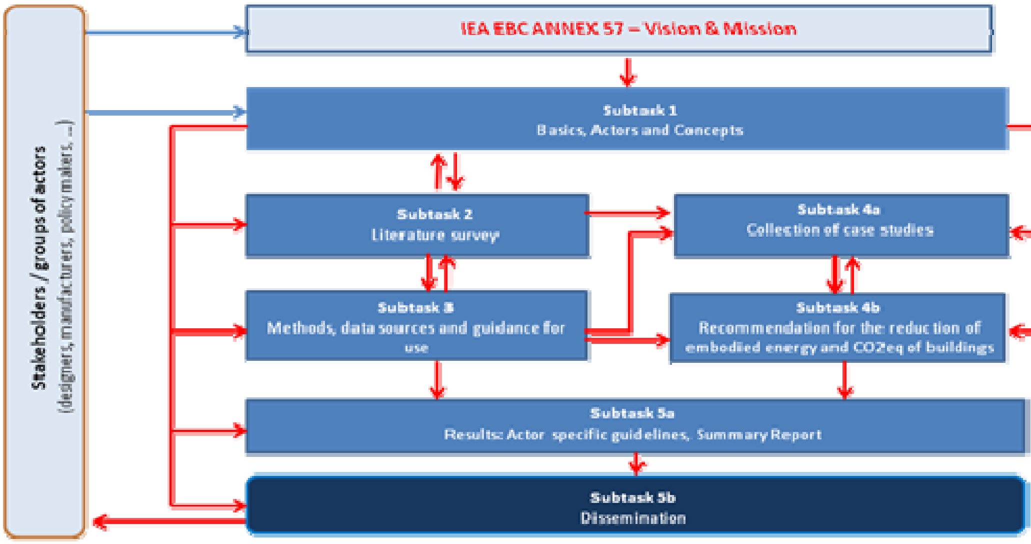
ST1 picks up on the results of ST2 and develops recommendations for indicators and system boundaries to ensure transparent and accountable results and allow for the classification of existing approaches in a unified system. Additionally, it explains how to describe the building and its life cycle and the data needs for calculations at the building level. Finally, it presents the relevant stakeholder groups and decision-making situations, including recommendations for action.

ST3 deals with issues related to the development and provision of data. Specifically, it describes specific methods for developing data for embodied energy and emissions and analyses available databases, while classifying them in an overall system.

ST4 deals with the collection, presentation, evaluation and classification of case studies using a typology developed on the basis of partial results of the other STs. As a result, design recommendations for achieving buildings with low embodied energy and GHG emissions are derived from the analysis of the extensive collection of case studies taking into account their interaction with the other design objectives and criteria.

ST5 presents the results in a way to appeal to politicians, scientists and practitioners. In this context, actor specific guidelines were developed that can be found available at the Annex 57 homepage.

The interrelationships between STs are illustrated below:



Subtask 4
The Danish participation in the project was within the five year period mainly focused within the work of subtask 4. The purpose of Subtask 4 (ST4) has been to collect relevant building case studies and use these to develop measures to design and construct buildings with less embodied energy and greenhouse gas emissions.

The IEA EBC Annex 57 ST4 report **Evaluation Methods of Embodied Energy and Embodied GHG in Building and Construction** was the final output from the Subtask 4 research work. It explains the work of ST4, analyses the case studies collected from Annex 57 members, and discusses approaches to reducing embodied energy (EE) and embodied greenhouse gas emissions (EG) from buildings. Four different levels of analysis were used to assess the impacts of methodology on the numerical results, the range and average values for impacts of different life cycle stages, components and building typologies, potential design and construction strategies for reducing EEG, and the influence of decision-making contexts on measuring and reducing EEG in buildings.

In addition, all Annex 57 case studies are compiled in an independent report: **IEA EBC Annex 57 ST4 Case study collection report** including 80 case studies from 11 countries.

The ST4 group has also produced a Guideline for designers with recommendations for reduction of embodied energy and greenhouse gas emissions based on the analysis developed in the ST4 report, **Guideline for designers and consultants – Part 2**. The goal of this guideline was to translate the academic results of the analysis performed in the ST4 report into more reader friendly communication form for designers and consultants.

1.5 Project results and dissemination of results

Participation, meetings and seminars
Participating countries in Annex 57: Australia, Austria, China, Czech Republic, Denmark, Finland, Germany, Japan, Korea, Portugal, Norway, Sweden, The Netherlands and United Kingdom. Observer country: Brazil

Two meetings were held annually in Annex 57 and seminars and workshops were held in relation to different conferences, such as World Sustainable building conference in Barcelona in 2014, Sustainable building conference in Prague in 2016 and Annex 57 conference in Tokyo in 2016.

Results of ST1 report
This report emerged from the results of Subtask 1 (ST1) with the purpose to identify and clarify the methodological issues related to the definitions and fundamental concepts of embodied energy and embodied GHG emissions. At the same time, ST1 aims at presenting a comprehensive framework and transparent reporting format that can be used by design professionals and consultants for the determination, assessment and reporting of embodied energy and embodied

GHG emissions at the building level. The intent is to ensure the appropriate interpretation and application of the embodied impacts assessment results.

Another objective of this subtask is to identify relevant actor/stakeholder groups and decision-making situations. There is a need for discussing and investigating whether and to what extent specific actions are required and how a stronger integration of embodied impacts into the decision-making processes can be achieved. In this sense, this report also analyses the tasks and roles of individual stakeholder groups, works out the peculiarities in connection with the demand for and supply of information related to embodied impacts and encourages the development of specific guidelines/recommendations for selected groups of actors**.**

Results of ST2 report

In the past, environmental impacts from building operation were the only issue to evaluate the environmental performance of building. In recent times however, more and more awareness relating embodied energy and GHGs has been increasing among environmental professionals, companies or other stakeholders as parameters to evaluate environmental impacts from building construction activities, especially since the 90s. The ST2 report communicates the results of literature review, aiming to find relations between subjects and calculation methods, giving support to a more concrete base for the development of Annex57's guidelines.

In the reviewed papers, researchers have set different range of system boundaries, the research period of assessment, and the calculation parameters depending on the purpose of the study. Considering that all methodologies revealed their own advantages and limitations, it's not appropriate to suggest one recommended, superior and suitable methodology for the assessment of embodied energy and GHGs (EEG). Therefore, the ST1, 3 and 4 guidelines will provide a clear framework for embodied energy and GHGs assessments of the building's lifecycle in order to compare and understand various results by different stakeholders and environmental professionals.

Results of ST3 report

The subtask 3 (ST3) purpose is to present the different types of data sources and calculation methodologies to evaluate the EE and EG of a building, based on a common framework and a transparent reporting format. The ST3 is mainly constituted by three parts; quantification methods, databases and embodied energy and GHG evaluation. For quantification methods, the ST3 presents existing quantification methods of the assessment of embodied energy and GHGs (EEG) for buildings. Depending on the purpose and scope of analysis or evaluation, the required level of detail, the acceptable level of uncertainty, and the available resources, the primary datasets (original EE and/or EG data) are calculated using one of the following methods: Process-based life cycle assessment, Input-output (IO) analysis, or Hybrid analysis, which combines the other two methods. This section presents the technical elements, basis and procedure for calculating EEG impacts using these methods.

In the database section, ST3 shows the content related aspects of creating EE and EG databases. Six minimum requirements for embodied impact database (LCI data) are identified and discussed; materiality, consistency, transparency, timeliness, reliability and quality control. These requirements demand a professional operation and maintenance of LCA databases. In relation to this, several international and European standards are available for EEG for building and construction, which include; ISO 21930, ISO/TS 14067, ISO 21931, EN 15804, EN 15978, Product environmental footprint (PEF) etc. These standards differ in their requirements on modelling, in particular in the multifunctional allocation and recycling. This issue is discussed in detail in the database section in ST3 report.

The ST3 implemented preliminarily survey for EEG databases from the participants in Annex 57. The survey identified that an EEG database exists in most of participants Annex 57 countries but only as LCI data for building products. Thus, there is a need to convert the LCI data into embodied impact using impact assessments (GWP or total energy usage etc.). Process based LCA was found as the dominate methodology to quantify the EEG data. EEG databases did not cover the emerging products but was rather more focused on general products. EEG impacts from capital equipment are not included in the EEG data except for Japan, where a hybrid process is used with IO based methodology in the official EEG data, and for Switzerland, where capital equipment are part of the process based LCIs.

For the EEG evaluation of buildings, the ST3 shows the calculation of EE and EG emissions in the building design stage. As demonstrated in the illustrative example in the ST3 report (Chapter 5.2.2), the building structure and HVAC system have greatly contributed to the total embodied impacts (energy and GHG emissions), being responsible by 85% of the total embodied energy and GHG emissions. This example shows the importance of the material selection in a building structure. Additionally, fluorocarbons from the cooling system also could highly affect the total EG. This study illustrates as well that it is possible to reduce energy and GHG emissions of buildings through the smart use/selection of building materials in the design stage. In this section, the embodied impacts of key building materials, for typical residential buildings (detached) in different countries are compared.

The ST3 also discusses other important issues (transportation, on site emissions, waste management, imported products, etc.), which may have a high influence though often are ignored in the quantification of the building EEG.

Lastly, the subtask 3 shows a macro (country-level) approach to quantify the EEG emissions for the building construction industry using the World IO table. This could help policy makers to identify the key industries affecting building construction in their country in line with their own country's intended contribution to the Paris Agreement.

Results of ST4 report

The Subtask 4 report describes the research conducted by Subtask 4 (ST4) of Annex 57 of the International Energy Agency implementing agreement. ST4 has collected a large number of case studies from the wider Annex 57 group, the majority quantitative but with the addition of some providing qualitative information. These have been inserted using a specially designed template format conceived to enable transparency and accurate comparisons between cases: the full collection of these completed templates is included in the accompanying Annex 57 ST4 Case Study Report. Supplementary data was collected through surveys and discussions with the Annex 57 participants, and through discrete literature reviews. The methodology used to first develop the template and then collect the case studies, and for the surveys and discussions, is described briefly in chapter 1 of the ST4 report, and in more detail in Malmqvist et al (2014).

Chapters 2 to 5 of the report then present a different focus, based on analyses of the data. The first analysis in chapter 2 considers the impact of methodology on the quantitative case studies collected, and explains how the different systems boundaries and calculation approaches affect the outcome. Chapter 3 uses the quantitative case study results to analyse the impact of different components and life cycle stages on the total embodied impacts. Chapter 4 further develops this to describe some strategies for the reduction of embodied energy and greenhouse gas emissions. Chapter 5 then considers the impact of different contexts on how and whether decisions to measure and reduce impacts might be practical.

The final chapter of the report summarises the conclusions from the previous four analysis chapters, and then makes some general recommendations.

The analyses of the case studies provided in the ST4 report have shown the wide range of numerical results emanating from current academic calculations of EEG. The numbers have been analysed to demonstrate the impacts of the chosen methodology, of the data accuracy, of the boundaries, and of the assumptions made in the calculations; these impacts explain the reasons behind many of the differences in these numbers. Using this knowledge, the case studies were then used to propose specific design strategies which can reduce the embodied impacts of buildings, the contexts in which the decisions to measure and reduce EEG of buildings may be taken, and the responsibilities of different stakeholders for reducing embodied impacts under different circumstances.

The use of the case study template was, to our knowledge, a unique approach to gathering diverse data from a wide number of academic participants. Each case study was based on a more extensive publication, including peer-reviewed journal and conference papers or postgraduate dissertations. The collection of the case studies, and their careful analysis through four different approaches, has produced an important body of work, as contained within this report and the accompanying case studies report. This will push forward the understanding of the extent of embodied impacts of buildings, and of the methods by which we can reduce them.

There is one appendix report to the ST4 report:

- Case study collection report with around 80 case studies from 11 countries.

Guideline for Designers and Consultants – part 1
Unfortunately, there is still no consensus on exactly how embodied energy and GHG emissions should be defined, calculated and assessed. Different assumptions and boundary conditions are used which leads to widely differing results. Undertaking such assessments is not as straight-forward as it may seem and without a standard methodology, agreed rules and available data, clients cannot be assured of consistent and evidenced results.

In this guideline, a basic understanding about the assessment of embodied impacts at the building level for participants in the building industry is established, targeting particularly design professionals and consultants. The group of design professional and consultants includes architects, engineers and quantity surveyors among others.

This publication is part of a series of guideline publications targeted to specific groups of actors working within the construction industry (construction product manufacturers and policy makers) and the education sector (educators).

While detailed information on basics, as well as background information on system boundaries and indicators is available in the ST1 report "Basics, Actors and Concepts", the aim of this guideline document is to translate those results into more comprehensive and easily digestible recommendations and supporting information for designers and consultants.

The main objectives of the guidelines are:

- to inform designers about the importance of integrating embodied impacts considerations into the design and decision-making processes
- to help them achieve this as early as possible in the design process and in the most transparent way as possible.

In particular, this guideline document:

- explains the role of this stakeholder group in the information flow and supply chain
- provides an understanding on how an assessment of embodied impacts can be integrated into the typical design process
- provides specific guidance on how to calculate, assess and report embodied impacts
- provides knowledge and recommendations on which standards, datasets and tools to use depending on the availability and transparency

Acquiring a complete understanding of both operational and embodied impacts allows design teams to create the best possible design solutions and specifications for a low energy and emissions building. This guideline document ensures a better understanding of the assessment of embodied impacts being part of an integrated design process.

Guideline for Designers and Consultants – part 2
This second part of the guideline is also targeted specifically to design professionals and consultants and should be seen as a supplement to Guideline for Designers and Consultants – part 1. However, the aim of this guideline is to communicate and illustrate the key design strategies and illustrate their potentials for reducing embodied energy and emissions through the use of case study examples.

The guideline gives a brief introduction to designers and consultants about how the life cycle approach and evaluation of EEG can be integrated in the design process. This is illustrated in the second half of the guideline through selected examples from the 80 international Annex 57 case studies. The reader of the guideline can refer to the ST4 report which includes detailed analyses of the 80 cases studies. The aim of this guideline is to translate those academic and technical results into a more easy to understand series of illustrated recommendations for designers and consultants.

Four main design strategies are highlighted:

1 Substitution of materials:
  - Natural materials
  - Recycled & reused materials and components
  - Innovative materials
2 Reduction of resource use
  - Light-weight constructions
  - Building form and design of layout plan
  - Design for flexibility and adaptability
  - Low maintenance need
  - Design for service life extension
  - Reuse of building structures
3 Reduction of construction impacts
  - Reduction of construction stage impacts
4 Design for low end-of-life impacts
  - Design for disassembly
  - Design for recyclability

To conclude, the guideline discusses and illustrates different design and construction strategies focusing on reducing the embodied energy and emissions. However, the relationship between operational energy and embodied energy also has to be taken into account. For example, a material with a low insulation value has low embodied energy, but can potentially result in high operational energy and vice versa. These relationships need to be taken into account at an early design stage, because decisions during this phase have the greatest potential for minimising the whole life cycle energy.

Guidelines for Construction Products Manufacturers

This guideline is targeted specifically to construction products manufactures. The aim is to raise awareness on the subject of embodied impacts in relation to construction products, to present the starting points for the integration of embodied impacts assessment into the continuous improvement of production-related processes and product-related characteristics and information. One additional goal is to provide access to related guidance, data, information sources and assessment tools respectively. This guideline is specifically intended for use by small and medium-sized manufacturing enterprises (SMEs) seeking to improve their market competitiveness usually hindered by lack of resources and limited access to information.

The purpose of this guideline is to improve the understanding and management of embodied impacts of construction products and related primary raw materials across the construction product-manufacturing sector. In assistance of the SMEs in the construction products industry this guideline document provides:

a. methodological guidance for a simplified calculation and assessment of embodied impacts
b. recommendations to improve the production and procurement processes as well as related environmental product information
c. options for the declaration of environmental product information, in addition, it is indicated which relationships exist between investigating embodied impacts and creating an environmental claim, such as e.g. an Environmental product declaration (EPD).

Since the first oil crises in the 1970’s operational energy efficiency has become an increasingly important aspect of the design of buildings, as well as a subject of legislation respectively. As a result, the operational energy and related operational impacts of new buildings have decreased considerably since that time. Figure 1 pictures schematically the ratio between the operational impacts and the embodied impacts due to the erection of a building till it´s end of life (EoL). It can be noted that embodied impacts are gaining more and more importance due to the additionally added building products.

Specifically, in this document, the term “embodied impacts” refers only to the primary energy consumption and the adverse effects on the climate resulting from greenhouse gas (GHG) emissions that arise in the life cycle of construction products due to their production, installation into the building or construction works, maintenance and end of life; the so called embodied energy and embodied GHG emissions. These have a great influence on the embodied impacts for building construction in connection with the use of resources (in this case energy resources) and the adverse effects on the environment (here global warming potential - GWP).

It can be seen that over the life cycle of building embodied impacts can arise in all life cycle stages. Construction product manufacturers have a significant influence from raw material supply to manufacturing process over the building use phase and end-of-life and related recovery, reuse, recycling potential respectively. In contrast to other aspects the embodied impacts are directly linked to a particular building product but cannot explicitly be recognized as such, wherefore the construction product manufacturers need to pay special attention to them.
In this guideline, essential results of the Annex 57 are summarized and specific recommendations are presented, accompanied also by supporting information. Specifically, construction product manufacturers are strongly advised to inform themselves concerning the applicable methodological guidance, the recommendations given to improve their production and procurement processes as well as related environmental product information.

Guidelines for Policy Makers
This document is the deliverable “Guidelines for policy makers”, developed within the Subtask 1 of IEA - EBC Annex 57 “Evaluation of EE and Greenhouse Gas Emissions for Building Construction”. It also includes guidelines for including EE and EG considerations into the procurement process.

The main goal of Subtask 1 is to clarify the connections between actors and targets related to EE and carbon for building construction. Building EE and EG are affected significantly not only by the construction methods adopted, but also by the energy efficiency of the material production processes and by the energy generation mix.

In such a context, the guidelines for policy makers aim towards informing about EE and EG in the building sector, give recommendations about standardization of methodological principles and technical data requirements, as well as guidance and tools to support planning.

These guidelines can provide an insight to policy makers on the main issues related to embodied energy (EE) and embodied GHG (EG) in building construction, having as final aim a wide integration of EE and EG assessment into local policies. The main objectives of the guidelines are:

- To inform about the importance of EE and EG (referring to all the contributions required during the production and end-of-life of a building, opposed to the “use” of the same building), in relation to energy consumed in building operation, considering them in the context of the life-cycle environmental impacts;
- To inform and support the planning, design and assessment of policy instruments and schemes;
- To provide insights to policy makers about the main tools aimed to push the market towards low EE and EG building design.

In particular, this report:

- provides definitions of energy use, EE and EG;
- assesses the state of art of EE and EG in buildings;
- examines the importance of measuring and managing EE and EG in building sector as allowable solution to reduce the GHG emissions;
- considers the importance of the life-cycle perspective in building energy efficiency;
- provides guidance for policy makers on EE and EG in buildings, in terms of elements to include in legislation. Policy makers can confirm their policies by tracing items in suitable checklists.

Clearly there is a role for every stakeholder in the reduction of EE and EG of buildings. National and international policy makers should include EE and EG in compulsory regulations for buildings, in order to involve significant targets on the behavior of different actors of the building sector.

Finally, the whole discussion reported in these guidelines is summarised in the following final synthesis table, including the most relevant facts highlighted in the document and the most relevant challenges policy makers would need to face when dealing with the topics of embodied energy and GHG in buildings.

Guidelines for Education

This guideline is targeted especially to educators, teachers at different levels of education (primary schools, secondary schools, universities etc.) and to all other specialists involved in the education and dissemination area. The aim is to bring basic information on the importance of consideration of embodied impacts (embodied GHG emission and embodied energy) and to provide ideas and basic principles for education at different levels and different types of education process.

This guideline is based on the work and results of IEA EBC ANNEX 57 “Evaluation of Embodied Energy & Embodied GHG Emissions for Building Construction”.

This publication is a part of a series of guideline publications targeted specific groups of actors working in the education system.

Several practical approaches on how to reduce the environmental impacts can be found:

a) Sustainable design

Sustainability should be a visible part of the educational environment. School building itself should serve as a good example of sustainable building (within all life cycles) with visible solutions focused especially to energy and CO2 footprint reduction. For instance, this can be achieved through the following:

- integration of living roofs;
- planting within the building;
- low-embodied energy and sustainable timber construction, and the
- use of renewable energy technologies. (OECD, 2010)

Development of new school buildings should be targeted for zero carbon concept solution of buildings.

b) Reduction of impacts from operation

Schools should encourage:

- reducing emissions from energy use in school buildings;
- reducing emissions from school procurement and waste;
- reducing emissions from school travel and transport. (Departement for children, 2009)

c) School procurement

Procurement of goods and services represents a large proportion of schools’ carbon footprint. The impact can be lowered by the help of a “Strategic framework” (Department for children, 2009), including

- strategic commitment;
- supply chain engagement;
- specifications of goods and services (available tools that allow to procure low carbon goods and services);
- product choice and labelling (e.g. source local food);
- accreditation of suppliers;
- product market development; etc.

d) Pupils involvement = behavioral change

Pupils and staff are involved in monitoring energy and waste around the school and regularly visit other schools, colleges and community groups to present their environmental work and encourage others to follow their example. (Department for children, 2009).

This approach includes:

- practical projects around the school;
- monitoring and reporting (energy, waste);
- setting targets for energy reduction.

As a consequence children can influence other members of their families (parents, grand-parents and other relatives and friends) to change their pattern of life.

e) Inter-school collaboration

f) Involvement of local authority professionals

1.6 Utilization of project results

The project involves participation in the IEA project, so there is no apparent technology added value for users. The project has generated some of the necessary knowledge to support the work of formulating potential future requirements related to embodied energy and greenhouse gas emissions related to buildings in Denmark. Thereby, Denmark can help meeting national and joint international requirements for reduction in the use of energy and release of greenhouse gas emissions related to buildings.

The project had the purpose of securing Danish participation in an IEA project and did not have the purpose to develop commercial products. However, it should not be excluded that the future methods developed during the project can be commercialized at a later stage. An example could be development of construction materials and products with lower embodied energy and embodied greenhouse gas emissions.

1.7 Project conclusion and perspective

The project had an international character so it was expected to encourage greater international cooperation in the development and research with regard to embodied energy and embodied GHG emissions related to buildings. At a Danish level this could lead to knowledge that could be used to work towards future requirements related to embodied impacts of buildings and building materials.

The project research and deliverables were very broad and therefore also the project conclusions. The project resulted in several reports and guidelines. The overall conclusions were gathered in the project overall report as follows:

1. Embodied energy and GHG emissions (EEG) as standard practice

The 'danger' of LCA calculations is that they can be used to produce discrete figures for EEG, which politicians and other decision-makers may then be tempted to take both as accurate and as universally applicable. The more complete explanation given in this report conversely runs the risk of assumptions that the approach is fundamentally flawed, or so inaccurate as to be meaningless. However this report has also demonstrated that as LCA methodology is becoming adopted more frequently, there are relevant conclusions and recommendations that can be drawn.

The availability of transparent data is currently scarce for innovative materials and for natural and bio-based materials produced at a small-scale. We strongly recommend that the development of these data is made a global priority.

The design of a building is based on a vast range of requirements and values, of which reducing whole life cycle EEG will only ever be part. However the potential to significantly reduce the EEG from buildings, through a wide range of different measures, has been clearly demonstrated through the work of the Annex 57.

We recommend that calculations of embodied energy and greenhouse gas emissions are conducted as standard for all buildings, just as in more recent years the operational impacts have been calculated. The development of policy instruments, possibly including regulation, to encourage this should be a priority for all Governments.

2. Practical measures to reduce EEG
The whole aspects of EEG are illustrated through IEA-EBC Annex57 work, impact of EEG in the world, state of art of existing research relating to EEG, calculation method of EEG and measures to reduce EEG, and so on. EEG is one of the indicators to design and build better building. The results of Annex57 suggest that long life buildings, recycle and natural materials, non-Freon materials and equipment are effective, but the practical measures to reduce EEG are not concluded. It needs further study on development of practical design and construction methods, building materials and equipment relating to reduce EEG for future challenges.

3. Technology transfer to developing countries
EEG in Asian countries is considered to be very large and it will further increase. It is expected to decrease elongation of EEG by spreading long-life buildings and reducing usage Freon. Transferring the results of Annex 57 work and technologies relating to EEG reduction into developing countries will contribute to reduce energy consumption and GHG emissions in the world.

4. Integrated into Building Assessment Tools
Many assessment methods and tools relating to operating energy and EEG of buildings have been developed and implemented in the world. It is expected to reflect Annex57 results in these methods and tools and improve them into practical ones.

5. EEG in Education
It is considered that the whole aspects of EEG are not fully recognized and grasped. It needs to spread the results of Annex 57 work to utilize building design and construction, and to accommodate society's demands of wholesome buildings. EG associated with buildings occupies 20% of total GHG emissions in the world, therefore it is important to cover EEG of building in education as well as industrial products and agricultural products.

6. Combining impacts of construction and operation of buildings
After focusing on the construction phase, building renovation as well as embodied impacts (energy and GHG emissions) it is time to merge the knowledge gained so far. Focusing on only one of the aspects may lead to severe sub-optimisation. Too much effort on reducing the energy demand for building constructions may lead to an inefficient use of energy during the use phase of a building and too much focus on reducing the energy demand during operation may lead to too much embodied energy.

The objectives of potential future Annex are the following

- Establish a common methodology guideline to assess the life cycle based primary energy demand, greenhouse gas emissions and environmental impacts caused by the energy use of buildings
- Apply this methodology on a sample set of building case studies to derive benchmarks
- Derive regionally differentiated guidelines and tools (eventually linked to BIM) for architects and planners to design buildings with a minimum life cycle based energy, carbon and environmental footprint
- 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

The scope of a potential future Annex may cover dwellings (single and multiple family housings), office buildings and possibly school buildings, both new and retrofit buildings. The life cycle should cover the stages product (production of construction materials including resource extraction), construction process (erection of the building), use (operational energy and water use, maintenance, repair and replacement), as well as end of life (de-construction, waste processing and disposal). The indicators addressed may comprise primary energy demand (non-renewable and renewable), greenhouse gas emissions as well as environmental impacts caused by energy use.

Now IEA EBC Annex 72 has been accepted as continuing the work of Annex 57 and the first meeting in the preparation phase of this Annex will be held in Copenhagen hosted by SBi in May 2017.