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Energy in Buildings and Communities Programme

International Energy Agency

EBC Annex 57: Evaluation of Embodied Energy and CO_2 Equivalent Emissions for Building Construction

Project Summary Report

Technology Collaboration Programme

by iea

EBC

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Project Summary Report

Edited by

Alexander Passer, Alice Moncaster, Aoife Houlihan Wiberg, Chang-U Chae, Freja Nygaard Rasmussen, Harpa Birgisdottir, Julie Zelezna, Keizo Yokoyama, Maria Balouktsi, Marina Mistretta, Petr Hajek, Noriyoshi Yokoo, Seongwon Seo, Tatsuo Oka, Thomas Luetzkendorf, and Tove Malmqvist

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Participating countries in EBC: Australia, Austria, Belgium, Brazil, Canada, P.R. China, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Republic of Korea, the Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, Türkiye, United Kingdom and the United States of America

This edition published in 2024 by the EBC Executive Committee Support and Services Unit.

Additional copies of this report may be obtained from:
EBC Executive Committee Support and Services Unit (ESSU)
C/o AECOM Ltd
The Colmore Building
Colmore Circus Queensway
Birmingham B4 6AT
United Kingdom
www.iea-ebc.org
essu@iea-ebc.org

Cover picture: EBC Annex 57 project case studies
Source: Utsunomiya University

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Project Summary

The international research project 'EBC Annex 57: Evaluation of Embodied Energy and CO2 Equivalent Emissions for Building Construction' was launched under the International Energy Agency (IEA) Energy in Buildings and Communities (EBC) programme's Strategic Plan for 2007 to 2012. At that time, it was considered that life cycle analysis methods still needed a great amount of research that would benefit from international collaboration. Since then, the evaluation of energy consumption and related greenhouse gas (GHG) emissions resulting from the use of buildings has become more accurate and is now commonly applied in developed countries in the design of more energy efficient building envelopes, services systems, typically within the framework of building energy codes and regulations. This is helping to reduce energy and GHG emissions during building use, which means that the fractions of energy consumption attributed to life cycle stages other than during building use are increasing, as are the associated GHG emissions due to carbon dioxide (CO2), methane, fluorocarbon gases and other greenhouse gases. Therefore the evaluation and reduction of such 'embodied' energy and GHG emissions has now taken on greater importance. So, it is clearly appropriate to further progress the scientific basis of evaluating ssembodied energy and GHG emissions for building construction, and this was the justification for establishing this project.

Embodied energy and GHG emissions originating from construction of buildings and infrastructure account for about 20% of global energy consumption and GHG emissions. The embodied GHG emissions due to construction industries are approximately 5% to 10% of the entire energy consumption in developed countries and 10% to 30% in developing countries. Though the rates greatly vary depending on the country and region, the reduction of embodied energy and GHG emissions may have a tremendous effect on the reduction of global energy consumption and GHG emissions.

The research completed in this project has revealed the actual situation of embodied energy and GHG emissions in its participating counties, referred to in this document collectively as 'embodied impacts', and has also produced surveys of their calculation methods and documented their theoretical backgrounds. The calculation methods and effects of reducing embodied energy and GHG emissions have been explained using case studies.

The importance of embodied energy and GHG emissions has been gradually recognized. However, the situation at the project outset was that calculation conditions (prerequisites, boundary conditions, and so on) and calculation methods varied greatly depending on the country and researcher, and results also differed widely. Further, there were very few documents or guidelines covering methods for reducing embodied energy and GHG emissions. To address this and to contribute to the reduction of embodied energy and GHG emissions, the project participants, supported by their respective national teams, developed various calculation methods and provided guidelines for practitioners. To find solutions for these research issues, the project focused on the following objectives:

- 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;
- collect existing research results concerning embodied energy and GHG emissions due to building construction, analyze and summarize them to explain the state-of-the-art;
- develop methods for evaluating embodied energy and GHG emissions resulting from building construction;
- use collected case studies of buildings to develop measures for the design and construction of buildings with reduced embodied energy and GHG emissions;
- disseminate the results of the research and guidelines arising from the project.

Project duration
2011 - 2016 (completed)

Operating Agent
Prof Tatsuo Oka
Energy and Environmental Science
Graduate School of Engineering
Utsunomiya University
7-1-2 Yoto Utsunomiya
Tochigi 321-8585
JAPAN
+81 28 689 6188
okatatsuo@e-mail.jp

Participating countries
Australia, Austria, Czech Republic, P.R. China, Denmark, Germany, Italy, Japan, R. Korea, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, UK, USA
Observers: Brazil and Finland

Further information
www.iea-ebc.org

Project Outcomes

1. General context

The importance of embodied energy and related greenhouse gas (GHG) emissions is increasingly recognised. However, the situation is that calculation conditions and calculation methods vary greatly depending on the country or researcher, as do the results. Further, there are very few documents or guidelines covering methods for reducing embodied energy and greenhouse gas emissions.

The participants in the international project 'EBC Annex 57: Evaluation of Embodied Energy and CO2 Equivalent Emissions for Building Construction', supported by their respective national teams, have reviewed various calculation methods, and have provided guidelines for practitioners to contribute to the reduction of embodied energy and GHG emissions.

In general, the buildings sector is responsible for more than 40% of global energy use and contributes approximately 30% of the total global GHG emissions (References 2 and 3). Reductions in energy consumption and GHG emissions in this sector would make a significant contribution to the efforts of reduction of resource depletion and global warming (United Nations Environment Programme, 2009). Also, Given the high construction rates in rapidly developing nations and emerging economies coupled with the inefficiencies of the existing building stock worldwide, if nothing is done the fraction of these contributions will likely continue to rise in the future. Under these circumstances, intensifying the efforts for conserving resources and reducing the adverse effects on the environment becomes increasingly important in the buildings sector and decision makers are called to take much more vigorous actions towards this direction than they have done to date.

The work of this project was divided into four main activities, each of which was responsible for a specific aspect, and each of which has authored a discrete report. The overview of these activity reports is given in the sections below.

2. Basics, actors and concepts

This report emerged from the results of activity 1 to identify and clarify the methodological issues related to the definitions and fundamental concepts of ‘embodied energy and embodied greenhouse gas emissions’ (EEG). This activity presented a comprehensive framework and transparent reporting format that can be used by design professionals and consultants for the determination, assessment and reporting of EEG at the building level. The intent is to ensure the appropriate interpretation and application of the embodied impacts assessment results.

Another objective of this activity was 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 and recommendations for selected groups of actors.

3. A Literature Review

In the past, environmental impacts from building operations were only an issue when evaluating the environmental performance of buildings. In recent times however, awareness relating to EEG has been increasing among environmental professionals, companies and other stakeholders as parameters to evaluate environmental impacts from building construction activities, especially since the 1990s. The activity 2 report communicates the results of the literature review to identify relations between subjects and calculation methods, providing a reliable basis for the development of this project's guidelines.

In the reviewed papers, different ranges of the system boundaries and periods of assessment were defined, as well as for the calculation parameters depending on the purpose of the study. Considering that all methodologies revealed their advantages and limitations, this project did not consider it to be appropriate to suggest a single recommended, superior and suitable methodology for the assessment of EEG. Therefore, the activity 1, 3 and 4 guidelines provide a clear framework for EEG assessments of the building's lifecycle to compare and understand various results by different stakeholders and environmental professionals.

4. Scope of the assessment of energy and carbon emissions related building renovation measures

The purpose of activity 3 was to present the different types of data sources and calculation methodologies to evaluate the 'embodied energy' (EE) and 'embodied greenhouse gas emissions' (EG) of a building, based on a common framework and a transparent reporting format. The activity was mainly constituted by three parts: quantification methods, databases, EEG evaluation.

For quantification methods, the activity presented existing quantification methods of the assessment of 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 presented the technical elements, basis and procedure for calculating EEG impacts using these methods.

In the database section, this activity showed the content related aspects of creating EE and EG databases. Six minimum requirements for embodied impact database were identified and discussed: materiality, consistency, transparency, timeliness, reliability and quality control. These requirements demand professional operation and maintenance of LCA databases. In relation to this, several international and European standards are available for EEG for buildings and construction, which include: ISO 21930, ISO/TS 14067, ISO 21931, EN 15804, EN 15978, product environmental footprint, and so on. These standards differ in their requirements for modelling, in particular in the multifunctional allocation and recycling. This issue is discussed in detail in the database section of the activity 3 report.

Activity 3 implemented a preliminary survey for EEG databases from the participants in this project. The survey identified that an EEG database exists in most of this project's participating countries, but only as 'life cycle inventory' (LCI) data for building products. Thus, there is a need to convert the LCI data into embodied impact using impact assessments (global warming potential, total energy usage, and so on). Process based 'life cycle assessment' (LCA) was found as the dominant methodology to quantify the EEG data. EEG databases did not cover emerging products, but were 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 an IO-based methodology in the official EEG data, and for Switzerland, where capital equipment is part of the process based LCIs.

For the EEG evaluation of buildings, activity 3 showed the calculation of EE and EG emissions in the building design stage. As demonstrated in the illustrative example in the activity 3 report (Chapter 5.2.2), the building structure and HVAC system greatly contribute to the total embodied impacts, being responsible for 85% of the total EEG. This example shows the importance of the materials selection in a building structure. Additionally, fluorocarbons from the cooling system can also 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 were compared.

Activity 3 also identified other important issues (transportation, on-site emissions, waste management, imported products, and so on), which may have a high influence though often ignored in the quantification of the building EEG.

Lastly, activity 3 showed a macro (country-level) approach to quantify the EEG emissions for the building construction industry using the World IO table. This could help policymakers to identify the key industries affecting building construction in their country in line with their own country's intended contribution to the international treaty agreed at the United Nations Climate Change Conference (COP21) held in Paris in 2015, the 'Paris Agreement'.

5. Recommendations for the reduction of embodied greenhouse gases and embodied energy from buildings

The activity 4 report describes the research conducted by activity 4 of the project. This activity collected a large number of case studies from the wider project group, the majority of these quantitative, but with the addition of some providing qualitative information. These have been documented using a specially designed template format conceived to enable transparency and accurate comparisons between cases. The full collection of these case studies is included in the accompanying activity 3 report. Supplementary data were collected through surveys and discussions with the project participants, and discrete literature reviews. The methodology was first used to develop the template, and then to collect the case studies, and for the surveys and discussions, as described briefly in chapter 1 of the activity 4 report with more detail given in Malmqvist et al (2014).

Chapters 2 to 5 of the report each present a different focus, based on the analyses of the data. The first analysis in chapter 2 considers the impact of the 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 EEG. 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 activity 4 report have shown the wide range of numerical results emanating from current academic calculations of EEG. The data have been analysed to demonstrate the impacts of the chosen methodology, the data accuracy, the boundaries, and the assumptions made in the calculations; these impacts explain the reasons behind many of the numerical differences. Using this knowledge, the case studies were then used to propose specific design strategies that 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.

To the best knowledge of the project team, the use of the case study template was 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 analyses 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 they can be reduced.

There is one appendix report to the activity 4:

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

5. Summary of guidelines

A series of guidelines were produced by the project targeted to specific groups of actors working within the construction industry (construction product manufacturers, design professionals and consultants, and policymakers), and the education sector (educators). These guidelines are summarised below.

2.1 Guideline for Designers and Consultants – part 1

Unfortunately, there is still no consensus on exactly how EEG 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 straightforward 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 of the assessment of embodied impacts at the building level for participants in the building industry is established, particularly targeting design professionals and consultants. The group of design professionals and consultants includes architects, engineers and quantity surveyors among others.

While detailed information on the basics, as well as background information on system boundaries and indicators, is available in the activity 1 report 'Basics, Actors and Concepts', this guideline document aims 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 impact considerations into the design and decision-making processes;
- help them achieve this as early as possible in the design process and in the most transparent way possible.

In particular, this guideline document:

- explains the role of this stakeholder group in the information flow and supply chain;
- provides an understanding of 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.

2.2 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, this guideline aims to communicate and illustrate the key design strategies and illustrate their potential 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 embodied energy and embodied greenhouse gas emissions (EEG) can be integrated into the design process. This is illustrated in the second half of the guideline through selected examples from this project's 80 international case studies. The reader of the guideline can refer to the activity 4 report which includes detailed analyses of the 80 case studies. This guideline aims to translate those academic and technical results into an easy-to-understand series of illustrated recommendations for designers and consultants.

Four main design strategies are highlighted:

1 Substitution of materials:
- natural materials
- recycled and 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 EEG. 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 may have 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.

2.3 Guidelines for Construction Products Manufacturers

Over the life cycle of a building, embodied impacts can arise in all life cycle stages. Construction product manufacturers have a significant influence from raw material supply to the manufacturing process over the building use phase, and end-of-life and related recovery, reuse, and recycling potential respectively. In contrast to other aspects, the embodied impacts are directly linked to a particular building product, but may not explicitly be recognized as such, and therefore the construction product manufacturers need to pay special attention to them.

This guideline is targeted at construction product manufacturers. Its purpose is to improve the understanding and management of embodied impacts of construction products and related primary raw materials across the construction product manufacturing sector. The aim is to raise awareness on the subject of embodied impacts concerning construction products, and 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) in the construction products industry seeking to improve their market competitiveness usually hindered by lack of resources and limited access to information. To assist SMEs, this guideline document provides:

– methodological guidance for simplified calculation and assessment of embodied impacts;
– recommendations to improve production and procurement processes, as well as related environmental product information;

- options for the declaration of environmental product information, and in addition it is indicated which relationships exist between investigating embodied impacts and creating an environmental claim, such as an Environmental Product Declaration for example.

In this guideline, the essential results from this project are summarized and specific recommendations are presented, accompanied 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.

2.4 Guidelines for Policy Makers

This document is the deliverable 'Guidelines for policymakers', developed within activity 1 of this project 'Evaluation of Embodied Energy and Greenhouse Gas Emissions for Building Construction'. It also includes guidelines for including embodied energy (EE) and embodied greenhouse gas emissions (EG) considerations in the procurement process.

The main goal of activity 1 is to clarify the connections between actors and targets related to EE and EG for building construction. The EE and EG of a building 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 policymakers are intended to inform about EE and EG in the buildings sector, give recommendations about standardization of methodological principles and technical data requirements, as well as available guidance and tools to support planning.

These guidelines can provide insight to policymakers on the main issues related to EE and EG in building construction, with the final aim as 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, as opposed to the use of the same building), concerning energy consumed in building operation, considering them in the context of the life-cycle environmental impacts;
- inform and support the planning, design and assessment of policy instruments and schemes;
- provide insights to policymakers 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 the art of EE and EG in buildings;
- examines the importance of measuring and managing EE and EG

in the buildings sector as allowable solutions to reduce 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. Policymakers can confirm their policies by tracing items in suitable checklists.

There is a role for every stakeholder in the reduction of EE and EG of buildings. National and international policymakers should include EE and EG in compulsory regulations and codes for buildings, to involve significant targets on the behaviour of different actors in the buildings sector.

Finally, the whole discussion reported in these guidelines is summarised in the following synthesis table, including the most relevant facts highlighted in the document and the most relevant challenges policymakers would need to face when dealing with the topics of EE and EG (shown as Eceq) in buildings. Operational energy (OE) and related operational greenhouse gas emissions (OC) are also briefly included.

2.5 Guidelines for Educators

This guideline is targeted especially to educators, teachers at different levels of education (primary schools, secondary schools, universities, and so on) and to all other specialists involved in the education and dissemination area. The aim is to bring

KEY MESSAGES

1.	The consistency of measuring EE and Ec_{eq} must improve.	**2.**	Calculation should focus on major structural elements with the notion that granularity can be adressed at a later date.	**3.**	Design teams must be challenged to come up with innovative solutions that adress Embobied Carbon.
4.	Closed loop systems should be promoted so to maximise resource efficiency and lower EE and Ec_{eq} (i.e. new build should be designed for re-use).	**5.**	It is unlikely that legislation will address embodied carbon in a sufficient manner in the near future. In light of this industry should lead.	**6.**	The focus for reducing embodied carbon should be on every day builds rather than iconic ones.
7.	OE and OC should be maintained as priority. Embodied and operational energy and carbon are not conflicting issues, but they should be dealt with in tandem.	**8.**	Data should be trasparent and openly available across the industry.	**9.**	Better benchmarking and data sources are required.
10.	A business case for reducing EE and Ec_{eq} is needed.	**11.**	EE and Ec_{eq} modelling does not have to be overly complicated to be useful.	**12.**	Stronger links between researchers and practitioners should be forged.
13.	EE and Ec_{eq} savings made now are important and will help to offset climate change.	**14.**	Architectural approaches exist that can reduce both embodied and operational energy and carbon.		

basic information on the importance of consideration of embodied impacts (EEG) and to provide ideas and basic principles for education at different levels and different types of education processes.

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. The school building itself should serve as a good example of sustainable building (within all life cycles) with visible solutions focused especially on energy and greenhouse gas emissions 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. (Organisation for Economic Co-operation and Development, 2010)

Development of new school buildings should be targeted for zero carbon concept solutions 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. (Department for Children, 2009)

c) School procurement
Procurement of goods and services represents a large proportion of schools' carbon footprint. The impact can be lowered with 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; and so on.

d) Student involvement = behavioral change
Students 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, students can influence other members of their families (parents, grandparents and other relatives and friends) to change their pattern of life.

e) Inter-school collaboration
f) Involvement of local authority professionals

Conclusions

Various actors in the buildings and construction industry have recently recognised the growing importance of embodied energy and embodied greenhouse gas (GHG) emissions. However, a significant, and still considerably untapped, opportunity remains to limit these impacts along with the operational impacts of buildings. 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.

Towards this direction, this project 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, this project investigated how to achieve stronger integration of embodied impacts into diverse decision-making processes. As a result, actor-specific guidelines were developed.

Besides that, this project investigated the transition of the existing experiences of dealing with embodied energy to the newer concept of embodied GHG emissions, and made a clear distinction between the latter and stored carbon. In 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 these should be combined to form an overall approach that would have, among others, consequences for the further development of the Energy Performance of Buildings Directive in Europe, and similar initiatives elsewhere. It is recommended that 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 a building. Finally, EEG targets and benchmarks should be defined to assist the design process.

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Project Participants

Country	Organisation
Australia	CSIRO Ecosystem Sciences
Austria	Graz University of Technology
P.R. China	Tsinghua University IKE Environmental Technology
Czech Republic	Czech Technical University in Prague
Denmark	SBi – Danish Building Research Institute
Germany	Universitat Karlsruhe
Italy	IUAV University of Venice Università degli Studi Mediterranea di Reggio Calabria
Japan	Kogakuin University Utsunomiya University
R.Korea	Korea Institute of Construction Technology
Netherlands	Zuyd University
Norway	Nowegian University of Science and Technology
Portugal	University of Minho
Spain	Spanish National Research Council CSIC
Sweden	KTH (Royal Institute of Technology) Luleå University
Switzerland	treeze Ltd. University of Applied Sciences of Western Switzerland ETH Zurich
UK	University of Cambridge
USA	Texas A&M University
Brazil (observer)	Federal University of Esprito Santo University of Campinas
Finland (observer)	VTT Technical Research Centre of Finland

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EBC and the IEA

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 31 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes. The mission of the IEA Energy in Buildings and Communities (IEA EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)

The R&D strategies of the IEA EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. These R&D strategies aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five areas of focus for R&D activities:

– Integrated planning and building design
– Building energy systems
– Building envelope
– Community scale methods
– Real building energy use

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*):

Annex 1:	Load Energy Determination of Buildings (*)
Annex 2:	Ekistics and Advanced Community Energy Systems (*)
Annex 3:	Energy Conservation in Residential Buildings (*)
Annex 4:	Glasgow Commercial Building Monitoring (*)
Annex 5:	Air Infiltration and Ventilation Centre
Annex 6:	Energy Systems and Design of Communities (*)
Annex 7:	Local Government Energy Planning (*)
Annex 8:	Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9:	Minimum Ventilation Rates (*)
Annex 10:	Building HVAC System Simulation (*)
Annex 11:	Energy Auditing (*)
Annex 12:	Windows and Fenestration (*)
Annex 13:	Energy Management in Hospitals (*)
Annex 14:	Condensation and Energy (*)
Annex 15:	Energy Efficiency in Schools (*)
Annex 16:	BEMS 1- User Interfaces and System Integration (*)
Annex 17:	BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18:	Demand Controlled Ventilation Systems (*)
Annex 19:	Low Slope Roof Systems (*)
Annex 20:	Air Flow Patterns within Buildings (*)
Annex 21:	Thermal Modelling (*)
Annex 22:	Energy Efficient Communities (*)
Annex 23:	Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24:	Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25:	Real time HVAC Simulation (*)
Annex 26:	Energy Efficient Ventilation of Large Enclosures (*)
Annex 27:	Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28:	Low Energy Cooling Systems (*)
Annex 29:	Daylight in Buildings (*)
Annex 30:	Bringing Simulation to Application (*)
Annex 31:	Energy-Related Environmental Impact of Buildings (*)

Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO_2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO_2 Equivalent Emissions for Building Construction (*)
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building and Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
Annex 62: Ventilative Cooling (*)
Annex 63: Implementation of Energy Strategies in Communities
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles (*)
Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems (*)
Annex 66: Definition and Simulation of Occupant Behavior in Buildings (*)
Annex 67: Energy Flexible Buildings (*)
Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings (*)
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings (*)
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale (*)
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements (*)
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings (*)
Annex 73: Towards Net Zero Resilient Energy Public Communities (*)
Annex 74: Competition and Living Lab Platform (*)
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables (*)
Annex 76: Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions (*)
Annex 77: Integrated Solutions for Daylight and Electric Lighting (*)
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications

Annex 79:	Occupant-centric Building Design and Operation
Annex 80:	Resilient Cooling
Annex 81:	Data-Driven Smart Buildings
Annex 82:	Energy Flexible Buildings towards Resilient Low Carbon Energy Systems
Annex 83:	Positive Energy Districts
Annex 84:	Demand Management of Buildings in Thermal Networks
Annex 85:	Indirect Evaporative Cooling
Annex 86:	Energy Efficient Indoor Air Quality Management in Residential Buildings
Annex 87:	Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems
Annex 88:	Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings
Annex 89:	Ways to Implement Net-zero Whole Life Carbon Buildings
Annex 90:	Low Carbon, High Comfort Integrated Lighting
Annex 91:	Open BIM for Energy Efficient Buildings
Annex 92:	Smart Materials for Energy-efficient Heating, Cooling and IAQ Control in Residential Buildings

Working Group -	Energy Efficiency in Educational Buildings (*)
Working Group -	Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group -	Annex 36 Extension: The Energy Concept Adviser (*)
Working Group -	HVAC Energy Calculation Methodologies for Non-residential Buildings (*)
Working Group -	Cities and Communities (*)
Working Group -	Building Energy Codes

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