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Design strategies for low embodied energy and greenhouse gases in buildings: analyses of the IEA Annex 57 case studies

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Abstract:
This paper introduces the IEA Annex 57 case study method, consisting of a format for describing individual case studies and an evaluation matrix covering all case studies. Sample case studies are used to illustrate the method and the evaluation matrix through a first preliminary analysis. In compiling and evaluation existing, transparent case studies we have taken a stakeholder perspective. By so doing it is intended to identify fordecision makers the key issues affecting EE/EC in buildings. Analysis in this paper focuses on one of the six case study themes, building design strategies for EE/EC mitigation and references cases covering e.g. material selection, building shape, construction stage strategies and strategies to handle the trade-off between embodied and operational impacts in net-zero emission building design.

Design strategies, embodied energy, embodied greenhouse gases, case studies, IEA Annex 57, LCA, buildings

Introduction

Participants from nearly 20 countries world-wide are working on IEA Annex 57 '*Evaluation of Embodied Energy and Carbon Dioxide Emissions for Building Construction*. The annex aims to provide stakeholders with detailed information as well as guidelines on calculation methodologies, databases and methods for design and construction of buildings with low embodied energy (EE) and embodied greenhouse gas emissions (EC).

So far, environmental strategies and policies for the built environment have mainly focused on energy use and environmental impact from the use of buildings. However, the interest in other building life cycle stages has recently increased substantially. The development of passive or net-zero energy/emissions buildings, amongst others, imply a trend-shift in overall life cycle impacts from operational energy to impacts embodied in building material and construction, see e.g. [1, 2]. A growing share of embodied impacts calls for a new focus in energy and climate change mitigation.

One of the methods used by Annex 57 is the compilation and evaluation of case studies, with the aim of pointing decision makers at the key issues which influence the reduction of EE/EC in buildings. This paper introduces the Annex 57 case study method, consisting of a format for describing individual case studies and an evaluation matrix covering all case studies. Example case studies are used to illustrate the method and the evaluation matrix, through a first preliminary analysis. The analysis focus on a few specific measures falling within one of the themes of the case studies, *strategies for reduced EE/EC* in buildings.

Definitions and clarifications

The term *embodied* has been used in different ways in literature and with varying system boundaries in LCA case studies. Chosen boundaries may include only the product stage A1-3, both the product and construction stage A1-5 or even including end-of-life stage C1-4 with reference to the modules in EN 15978 [3]. In a forthcoming report, Annex 57 will provide recommendations on the definition of EE and EC in terms of included life-cycle stages. In the meantime, sample case studies discussed in this paper also use slightly different system boundaries in terms covered life-cycle stages.

Case study method

To provide a comprehensive and transparent analysis, a case study matrix was set up consisting of six themes and a number of stakeholder-types , Table 1. The themes allow a thorough analysis of different perspectives regarding EE/EC of buildings. Partners of Annex 57 and external partners were invited to submit case studies targeting one or more themes and stakeholders. The division of case studies by stakeholder interest was to contribute to development of practice by addressing issues of concern to different groups of actors.

Table 1. Themes and targeted stakeholders of the Annex 57 case study matrix, showing case studies analysed in this paper.

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Targeted stakeholders Themes	National gov./policy	Local gov./planning	Designers/ consultants	Developers/ contractors	Clients/owners	Manufacturers
1. Strategies for reduced EE/EC	UK2, 9	UK2,4, 9 SE1	DK1-2 NO1 SE1-2 UK2- 5,7,9 CH1-2 KO3 AT1-2	UK2-5, 9	SE1- 2 UK4	DK1 NO1 K3
2. Significance of different factors over the full life cycle						
3. Impacts of calculation method and system boundaries						
4. Reduction strategies, significant factors and calculation of EE/EC for building components and construction materials						
5. Reduction strategies, significant factors and calculation of EE/EC for building sector at national level						
6. Integration of EE/EC calculations in decision making processes						

The six themes are as follows:

1. Strategies for reduced EE/EC. The theme involves in particular calculations case studies showing the potential for reducing the embodied impact of buildings through different design strategies, such as the selection of construction materials, flexibility and design for recyclability.

2. Significance of different factors over the full life cycle. Case studies typically including full life cycle impact calculations of buildings, displaying for example the significance of different life cycle stages/processes or significance of different building elements with regard to contributions to the whole life cycle impact.

3. Impacts of calculation method and system boundaries. This theme also typically include LCA case studies of buildings. However, the perspective is rather how methodological choices may affect calculation results and conclusions regarding significant contributors, such as the ones discussed under theme 2. Examples of important methodological choices in relation to EE/EC include length of the reference study period, completeness of building data, future energy scenarios, and source of data.

4. Reduction strategies, significant factors and calculation of EE/EC for building components and construction materials. Case studies with the building component and/or material as the object of study. This is to enable a discussion concerning EE/EC reduction strategies at building component level such as traditional materials vs. emerging state of the art materials or improved production processes for concrete products etc.

5. Reduction strategies, significant factors and calculation of EE/EC for building sector at national level. Case studies illustrating implications regarding EE/EC at the national level and

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may concern national strategies for reduction of EE/EC or calculations of EE/EC at national level, etc.

6. Integration of EE/EC calculations in decision making processes. Case studies which mainly address decision making processes to provide examples of how EE/EC calculations were integrated into the building design process or e.g. to provide real-life examples of ways to promote life cycle considerations by different stakeholders.

A case study template, incorporating a structure for details of calculation procedures, data used, system boundaries, etc. was designed to be used for all case studies, to promote better documentation and transparency. A case study call was launched in June 2013 and to date we have received 20 completed templates and an additional 50 offers of case studies to be analysed and included in the case study report of the Annex 57.

Case study evaluation matrix
The case studies are organised into an *evaluation matrix* based on themes and stakeholders as in Table 1, but also on additional detailed information, such as building type, location and key issues. Table 2 shows the more detailed (preliminary) evaluation matrix focusing on theme 1 case studies studied in this paper. The evaluation matrix facilitates for interested stakeholders to find relevant case studies for specific questions of interest to them. Most of the cases found in Table 2 include new buildings complying with energy standards in national building Codes or to passive house standard. However, to find examples of refurbishment and very high energy standard projects, like plusenergy or NZEB concepts, may also be of interest to stakeholders (see separate columns in Table 2).

Table 2. Preliminary case study evaluation matrix –exemplified by Theme 1 case studies studied in this paper.

Project type Strategies / measures	Residential – multifamliy	Residential – single family	Office	School		Refurbished building	NZEB
Choice of materials for load bearing structure	SE1-2 UK7,UK9 AT2 CH1-2	NO1 UK5	DK1	UK4		AT1 UK2	NO1
Use of recycled materials	SE2	DK2	KO3				
Choice of material type in facades	AT2	UK5		UK4		AT1	
Building shape	SE2 CH2						
Use of local materials	CH1			UK7			
Construction process	UK3	UK5		UK4			
On-site energy production	AT2	UK2				AT1 UK2	NO1

Table 3. Brief description of case studies included in the paper. NO=Norway, DK=Denmark, SE=Sweden, UK=United Kingdom, AT=Austria, CH=Switzerland, KO=South Korea. References in bracket.

No	Description

NO1 [4]	Zero emission (GHGs) concept single family building
DK1 [5]	LCA of a new headquarter office building with loadbearing structure in concrete
DK2 [6]	Exploratory comparative LCA of single family building with load bearing structure of shipping containers compared with a standard masonry building
SE1 [7]	LCA in early design of new, quite typical, multifamily building with load bearing structure in timber compared with concrete
SE2 [8]	LCA in early design of a new multifamily building complying with Nordic passive house standard comparing load-bearing structure (2 timber alternatives and one concrete), building form (square and rectangular) and use of recycled aluminium in roof
UK2 [9]	Simple renovation of terraced single family buildings
UK3 [10]	Investigation of energy use and carbon emissions, water and waste during the construction stage of 11 housing developments
UK4 [11]	New build near-passivhaus standard school building in the UK, constructed of timber and low carbon materials
UK5 [12]	EC and EE analyses up to end of construction of new build social housing, comparing a timber clad timber framed house with a brick clad timber-framed and a standard UK brick and block construction.
UK7 [13]	A comparison of two alternative structural designs for a school sports hall – steel framed with blockwork walls, and cross-laminated timber.
UK 9 [14]	A simplified analysis of EC/EE for a cross-laminated timber eight-storey residential building in London produced by the developers in order to demonstrate the potential carbón savings
KO3 [15]	LCA study of four-storey concrete/steel office building using slag-based concrete, re-used steel and a high proportion of renewable energy for operation. Compared with a reference building.
AT1 [16]	Plusenergy, refurbishment of multifamily building; Optimisation strategies for reaching plus-energy standard by the use of prefabricated wood elements for refurbishment
AT2	Passive house with plus-energy concept, new multi-family residential building; Prefabrication technology of wood housing (cross laminated timber) for wall- and floor elements.
CH1[17]	Multifamily building, hybrid construction (mainly made of wood, with concrete elements as thermal mass); utilization of local wood products.
CH2[17]	Multifamily building, massive construction (mainly made of reinforced concrete, masonry and steel); high insulation standard (25-35 cm).

Case study examples illustrating the use of the evaluation matrix

In this section, we illustrate how the evaluation matrix (as elaborated in general in Table 1 and in detail in Table 2) can be used to find cases providing information of interest to different stakeholders. In addition, results regarding design and construction strategies for low EE/EC are discussed based on an initial analysis of the cases in Table 3.

Cases illustrating individual design and construction strategies

As shown in Table 1, there are a considerable number of Theme 1 case studies that provide information of interest for *building designers and consultants*. As seen in Table 2, a majority of these consider the selection of load-bearing structure. Initial analysis of the case studies suggests that concrete is likely the most significant single material in terms of its contribution to EE/EC. This is understandably so for cases with concrete loadbearing structures, e.g. DK1. Meanwhile, since it is used in foundations even for timber buildings concrete also produces a significant impact also in timber alternatives like in UK5 and AT2. The case studies show therefore that mitigating EE/EC due to concrete is a major cross-cutting issue where design strategies may contribute. The choice of load-bearing structure is one key design strategy and Tables 2-3 provide five cases where the use of timber is compared with non-timber solutions. Initial analysis of these cases shows that four of the studies (SE1-2, UK5, UK9) demonstrate a clear advantage for timber structures in terms of EC and EE (where considered). The other study (UK7) shows a slight advantage for the steel structure in terms of EE and a slight advantage for timber in terms of EC. This latter study also considers impacts from end-of-life treatment (assuming combustion for wood and recycling for steel). Taking this into consideration timber is shown to be preferable over the lifetime for both EE and EC. However the assumptions made for end-of-life treatment may be contentious. The comparison presented here suggests that it is important to further analyse system boundaries and assumptions in the case studies to provide clearer advice to practitioners. For a variety of reasons, the use of timber is very rare in high-rise buildings. Therefore the case UK9 is particularly interesting since it presents the use of cross-laminated timber in an eight-storey building.

Use of recycled materials as mitigation strategy is for example dealt with in KO3, a standard high-rise steel/concrete office building where steel beams and plates were reused and slag was mixed with concrete. Data shows that these measures combined to reduce EC by 25 % compared with a reference case. Meanwhile, the case DK2 takes an exploratory approach with the very concept "Upcycle", where materials to the extent considered possible are recycled or reused. This approach reduced EC by over 80 % and EE by nearly 70 % compared to a reference masonry house. Though small in terms of mass, SE2 showed that using recycled as opposed to primary aluminium as a roofing material could reduce EC by as much as 9 %.

Meanwhile UK5 compares the use of a wooden vs. brick façade, finding EC and EE to be higher by as much as 30 % and 40 % respectively for the brick alternative. In CH1-2 it was observed that the material for the main construction in combination with the insulation materials cover a major part of the overall EC/EE for the building's whole lifetime.

Further building-level cases give examples of other strategies. For example SE2 considers two different floor plans for multifamily residential buildings. The findings show that the EC follows the ratio between floor area and building surface area fairly closely. This yields a reduction of around 5 % between a rectangular and square floor plan in this case.

Finally, the case studies UK3-5 in contrast to most other cases within Theme 1, include a focus on the construction stage and are thus of particular interest for contractors. UK3 presents the energy, carbon, water and waste of the construction stage of 11 housing developments in the UK, showing a large variation in the impact of these developments. One important variable affecting the carbon emissions is the type of energy used and whether

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construction takes place during the heating season. Other aspects that seem to contribute to the variation include building form and extent of off-site prefabrication of building elements (in particular UK5) since this, in turn, affects the construction waste volumes.

Net Zero Emission Building (NZEB) design strategies

As seen in Table 2, a few case studies target NZEB buildings. Again, these case studies target primarily designers who can get useful insights into key challenges regarding building design to reduce and balance the EE/EC with the energy produced on-site. The Norwegian case study NO1 presents the development of an NZEB conceptual design and investigates whether it was possible to achieve NZEB by counterbalancing emissions from the energy used for operation and EC from materials with those from on-site renewables in the cold climate conditions of Norway. The main result shows that the criteria for zero emissions in operation is easily met, however, it was found that the use of roof mounted PV production is critical to counterbalance emissions from both operation and materials. Firstly, it was found that the available roof area for PV is insufficient to generate enough electricity. Secondly, the PV panels were accountable for a significant part of the total EC in this case. Thus, the case study illustrates that the efficiency as well as production technology of the PV panels is a crucial challenge in achieving a NZEB building.

In this sense, this case study is also clearly relevant to the stakeholder manufacturers (as seen in Table 2). Other key challenges for manufacturers identified in the case study include mitigating impacts from main EC contributors which was the load-bearing structure and foundation (where concrete dominates) and insulating elements (where EPS and glass wool are used).

The Austrian AT1 case study is also focusing NZEB solutions but is instead an example of a refurbishment of an existing multifamily building to a plusenergy solution. Similarly, the goal of the project was to achieve an operational plus-energy solution without including the embodied energy and emissions to reach net plus-energy after refurbishment. Like in the Norwegian case study, an integrated energy concept with local energy production (HVAC, solar thermal panels, PV, etc.), has been essential to accomplish the plus-energy solution. Key contributors to EE/EC in the refurbishment include the new façade modules (despite the use of timber frame construction) and the installation of new HVAC system. Thus design solutions focussing on these systems need to be worked out to further reduce the total energy use and GWP.

Concluding remarks

Case studies are just what they are, case studies. Conclusions drawn from individual cases are not always relevant in other contexts. In addition, the calculation methodology, system boundaries and the data used have important impacts on the conclusions drawn from individual cases. The value of the compilation structure and presentation of Annex 57 is that heterogeneity of objects of study and methodological choices made between all of the gathered cases becomes transparent and accessible for a wide range of stakeholders and where

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cross-cutting themes can be identified and discussed. The case study catalogue can thus for instance be utilised by designers as a reference for and an overview of good design strategies with regard to reducing a building's environmental impact over its entire lifetime.

Issues developed in the forthcoming IEA Annex 57 case study report include case studies illustrating additional design strategies, for example design for recyclability, design for low maintenance need and design for a long life time. In addition, case studies will be provided from other parts of the world, thus highlighting contextual issues such as local construction practices, use of traditional materials, climatic contexts, etc. Using a systematic case study method as described in this paper will enable this compilation and analysis of case studies concerning EE/EC to provide a useful, comprehensive source for better understanding of different perspectives on EE/EC of use for a wide range of stakeholders.

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