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Technical systems' share of embodied energy in Danish building LCA cases

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Abstract
The aim of this study is to investigate embodied energy from certified sustainable buildings in Denmark and to analyse the technical systems' share of this embodied energy. Furthermore, the aim is to identify possible deficiencies and improvements of the method descriptions applied for the building LCA in order to properly include the technical systems and their share of the embodied energy of a building's life cycle. A more comprehensive analysis of five building cases was performed in order to investigate which technical systems were in fact included in the building LCA and to identify which technical systems were omitted in the building LCA. The study showed large variation in technical systems' share of embodied energy, or from 1 to 40%. The review also showed a large variation in how thoroughly technical systems were included in the LCA studies. On the basis of this study it is recommended that a more detailed description is provided on how technical equipment should be included in building LCA, and that improvement of the data availability for technical equipment is prioritised. Furthermore, better descriptions of design choices are needed to supplement the LCA calculations in order to improve the conformity check of performed LCAs.

Keywords – building life cycle, life cycle assessment, embodied energy, technical systems

1. Introduction

The construction and use of buildings in the EU account for about half of all extracted materials and half of the energy consumption [1]. Today there is a focus on the importance of sustainable development of the building sector. For the environmental sustainability it is known that there is a need for comprehensive understanding of the environmental impacts during the whole life cycle of buildings. The European Commission concluded in its Communication on Integrated Product Policy that Life Cycle Assessment (LCA) provides the best framework for assessing the potential environmental impacts of products [2].

Previously, the focus of environmentally improved building design has predominately been on limiting the operational energy use. However, with newer concepts of low-energy or zero-energy buildings etc., more attention is directed at the embodied impacts of building materials, i.e. the impacts from producing, maintaining and discarding materials from the building's full life cycle. As an example of on-going research within this field, participants from nearly 20 countries world-wide are working within the International Energy Agency Annex 57 on gathering information and understanding of embodied impacts and developing guidelines for evaluation of embodied energy and greenhouse gas emissions for building construction [3].

The knowledge on how to perform building LCAs is gradually expanding within the field of building design. Voluntary European standards for LCA of buildings have been developed [4], LCAs play an important role in building certification schemes and specific tools for building LCAs are constantly being developed. However, some areas of the building scale LCA are still not fully developed, one of these being a harmonisation of the scope of the building inventory, i.e. how much of the installed materials and components are actually included in the calculations of environmental impact. A notable of these underrepresented branches of the inventory is the technical systems. Thus, knowledge about the share that the technical systems actually represent in the environmental performance of the buildings is currently lacking [5]. The underrepresentation of technical systems in LCA is partly due to the fact that focus has been on quantifying the traditional building materials of greater volumes, e.g. concrete, and partly because data for the environmental impacts of technical systems has been lacking. With the increasing numbers of low energy and self-sufficient buildings, technical systems and installations become of great importance to the operational energy performance of the building, hence a better understanding of the embodied impacts related to these technical systems becomes equally more relevant.

The aim of this study is to investigate the reported embodied energy from certified sustainable buildings in Denmark and to analyse the technical systems' share of this embodied energy. Furthermore, the aim is to identify possible deficiencies and improvements of the method descriptions applied for the building LCA in order to properly include the technical systems and their share of the embodied energy of a building's life cycle.

2. Methods

Eighteen office and residential building LCAs were reviewed in terms of the embodied energy in building and the share of the technical systems in the calculated embodied energy. A more comprehensive analysis of five building cases was performed in order to investigate which technical systems were in fact included in the building LCA and to identify which technical systems were omitted in the building LCA.

2.1 European standards for building LCA

CEN/TC350 is responsible for the development of European horizontal standardized methods for the assessment of the sustainability aspects of new and existing construction works [6]. EN 15978:2011 *Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method* is an important standard for performing a building LCA [4]. The standard specifies the calculation method, including important aspects such as the system boundary and the life cycle stages included in the assessment of a building. Table 1 shows the life cycle stages of buildings as defined in the standard.

A building LCA normally involves evaluation of the whole life cycle as defined as stage A-D in the figure. According to EN15978:2011, the results from the final stage D, which concerns the potential benefits of recycling of building waste, must be reported as separate part of the calculation results.

Table 1. Life cycle stages as defined in the European standard EN15978:2011. The modules written with underscore are the modules included in the current Danish DGNB building LCA method [4].

	Life cycle stage	Module	
Building life cycle information	Product stage	**A1**	**Raw material supply**
		A2	**Transport**
		A3	**Manufacturing**
	Construction process stage	A4	Transport
		A5	Construction, installation process
	Use stage	B1	Use
		B2	Maintenance
		B3	Repair
		B4	**Replacement**
		B5	Refurbishment
		B6	**Operational energy use**
		B7	Operational water use
	End of life stage	C1	Deconstruction, demolition
		C2	Transport
		C3	**Waste processing**
		C4	**Disposal**
Supplementary information	Benefits and loads beyond the system boundary	**D**	**Reuse-, recovery-, and/or recycling potentials**

2.2 The building LCA methodology applied in case studies

The buildings analysed are all projects certified according to the Danish version of the DGNB method [7, 8]. It means that the projects are required to follow a method description for the building LCA according to the adapted Danish DGNB method and to use the Danish DGNB LCA tool. Furthermore, all projects have undergone third party conformity check.

The DGNB method description for the building LCA largely follows EN 15978:2011, but includes some simplifications of the modules included. The simplifications are motivated for different reasons, e.g. modules' expected minor importance for the overall results, limited data availability, complexity and time consumption of the detailed approach etc. The modules included in the current version of the DGNB building LCA methodology are written with underscore in table 1.

The DGNB LCA method description includes specifications of the inventory, i.e. the building elements that shall be included in the LCA. The technical systems to be included in the building LCA are:

- Central heating, cooling and ventilation units are included in the overall calculation. Pipes and systems for heat delivery are to be excluded from the calculation.
- Other building technical systems (such as solar energy collectors and photovoltaics/solar cells), as long as data is available.
- User equipment that have considerable high energy consumption in the use phase (such as refrigerators in supermarkets and cooling systems in datacentres), as long as data is available.

The reference study period for the building is defined as 50 years in the DGNB LCA assessment. The required service lives of materials and components shall be taken from a provided list with generic values.

One important exception from the EN 15978:2011 standard applied in the current DGNB building LCA methodology is that the impacts related to module D are not separated from the overall results of the building LCA. This is due to the structure of the applied database Ökobau 2011 [9], where end-of-life data impacts are not separated in modules C and D impacts.

2.3 *The review of the case study buildings*

LCA results of 18 DGNB certified office and residential buildings were reviewed. The buildings are all located in Denmark, built in the period 2010-2015. The buildings are of different sizes, from less than 1,000 m^2 GFA to over 40,000 m^2 GFA. The LCAs are performed by different experts following the DGNB LCA methodology, and all projects have undergone third party conformity check to ensure methodological consistency.

Five buildings were selected for a detailed review of the embodied energy of the technical systems. Table 2 gives an overview of selected important information about these five buildings.

Table 2. Selected parameters of the five buildings reviewed in detail.

Building no.	1	4	13	15	18
Building type	Office	Office	Office	Residential	Residential
Building completed	jan-15	apr-13	dec-11	sep-14	Not completed
Gross floor area (m^2)	15,800	775	46,500	1,630	4,000
Heated area	15,800	775	39,100	1,630	4,000
Heating system	District heating	Self-sufficient energy concept	District heating	District heating	District heating
Geothermal	No	Yes	No	No	No
Photovoltaics	Yes 340 m^2	Yes 140 m^2	No	Yes	Yes up to 1500m^2
Solar energy collector	No	Yes 10 m^2	No	No	No

2.4 Calculation of environmental performance

The LCA impact categories assessed in present study are limited to the total primary energy consumption (PEtot). For the embodied primary energy use, factors from the building material database Ökobau 2011 [9] and ESUCO [10] are used.

3. Results

3.1 Total primary energy demand and technical systems share in building embodied energy

The total primary energy demand (PEtot) in the eighteen buildings is shown in figure 1, diveded into building materials, technical systems and operational primary energy demand. The review of the eighteen building LCAs showed a large variation in all three parameters (operational primary energy demand, building materials and technical systems). The buildings' total embodied energy varies from 62 to 195 MJ/m^2/year. The technical systems only contribute with a very low share for most building LCAs, or less than 1% in 10 case studies. There are however three case studies where technical systems are noteworthy, between 5-6% for two building cases and more than 40% for one building which in contradiction is energy self-sufficient.

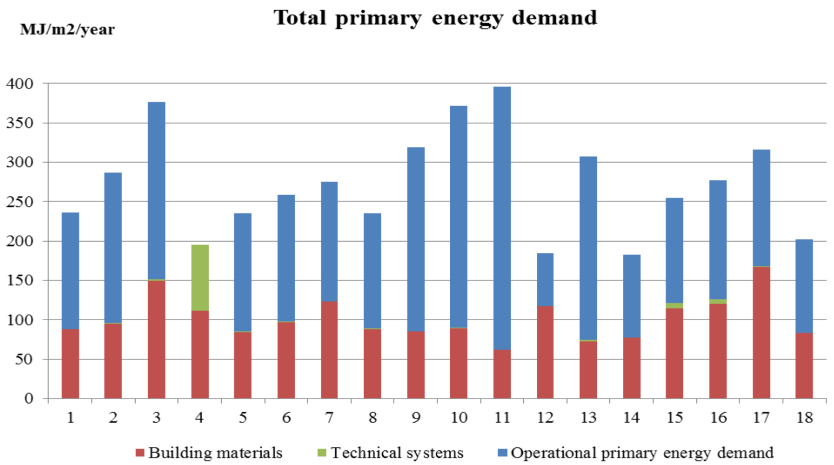

Fig. 1. Total primary energy demand (PEtot) for reference study period of 50 years, diveded into building materials, technical systems and operational primary energy demand.

3.2 Embodied energy of technical systems divided into life cycle stages

Figure 2 shows in more details the embodied energy of technical systems divided into the three following life cycle stages:

- **A1-A3:** Production of technical systems.
- **B4:** Replacements of technical systems during use stage of 50 years.
- **C-D:** End of life treatment and recycling potential for replaced materials.

The total embodied energy of the technical systems of the eighteen building LCAs varies from around 0 to 83 MJ/m^2/year. Building 4 alters from the remaining buildings with embodied energy in technical systems of more than 80 MJ/m^2/year, which is higher than the total building embodied energy for several building cases. In many cases the use stage (or B4 replacements) contributes with an important part of the embodied energy of technical systems due to their relatively short expected service life.

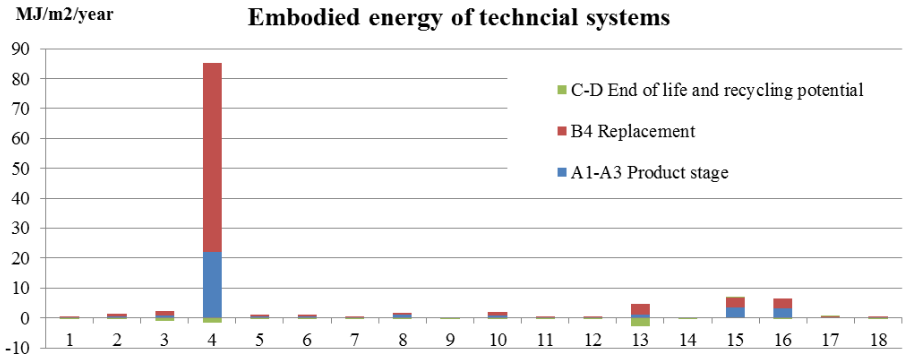

Fig. 2. Embodied energy (PEtot) of technical systems for reference study period of 50 years, divided into life cycle stages.

3.3 Technical systems included in building LCAs and embodied energy

Table 3 gives an overview of the review of the technical systems as included in LCAs of the five selected building cases. It shows a difference in the amount of technical equipment included in the building LCAs. The reasons can perhaps to some extent be explained by the different need for technical systems in particular building type or design approach applied (e.g. natural ventilation vs. mechanical ventilation). The cause can in many cases be due to lack of environmental datasets for specific technical equipment, such as photovoltaics, that are used in four of five building cases but not included in any building LCA. It also shows some mistakes in how data is inserted in the LCA, e.g. in one example where the amount of radiators is registered in meters but linked to a dataset that is given for kg radiators. In addition, the amount registered, regardless if it is meant to be in meters or kg seems to be underestimated compared to the building area.

Figure 3 shows the embodied energy of different types of technical systems divided into the three life cycle stages. Building 4 is the only building with geothermal heat pump installed, which has embodied energy in a totally different order of magnitude than the remaining types of technical equipment. The initial embodied energy (in A1-A3) is considerably higher than for the other types of technical systems included in all building LCAs reviewed, and with a relativeley low service life (of 15 years) resulting in 3 replacements (in B4) during the reference study period, the heat pump dominates the embodied energy of technical systems.

Table 3. Technical systems as included in the building LCAs for five selected building cases.

	Amount	Unit	Service life (year)
Building 1 – Office 15800 m^2			
Transfer station district heating	1	pcs	30
Circulating pump (250-1000W)	2	pcs	30
Storage tank, steel PEHD (double wall tank, 1000 l)	1	pcs	30
Ventilation system (central 30000 m3/h)	7	pcs	25
Air conditioner (direct heat exchanger, per 1 kW)	4*20	pcs*kW	20
Building 4 – Office 775 m2			
Circulating pump (50-250W)	4	pcs	25
Buffer storage (stainless steel)	210	kg	25
Radiator	147	kg	50
Air conditioner (direct heat exchanger)	5.4	pcs	15
Ventilation system central with heat recovery (1000 m3/h)	2	pcs	25
Flat plate solar collector	10	m^2	20
Electrical heat pump, brine-water, geothermal collector (20 kW)	2	pcs	15
Building 13 – Office 46500 m^2			
Transfer station district heating (per kW)	1700	kW	30
Ventilation system (central with heat recovery 10000 m3/h)	19	pcs	12
Ventilation system (central 30000 m3/h)	20	pcs	12
Air conditioner (direct heat exchanger, per 1 kW)	2725	kW	15
Building 15 – Residential 1630 m^2 – care home with 16 apartments and common areas			
Circulating pump (50W)	8	pcs	15
Buffer storage (steel)	19	pcs	25
Radiator	35.8	m*	50
Ventilation system central with heat recovery (1000 m3/h)	1	pcs	25
Ventilation system central with heat recovery (5000 m3/h)	1	pcs	25
Ventilation system decentralized with heat recovery (wall and ceiling, 60m3/h)	16	pcs	25
Building 18 – Residential 4000 m^2 – 40 apartments of different sizes and common area			
Circulating pump (50-250W)	40	pcs	25
Ventilation system central with heat recovery (200 m3/h)	40	pcs	25

** The amount registered in the LCA is given in m radiator but the dataset used is for kg radiator*

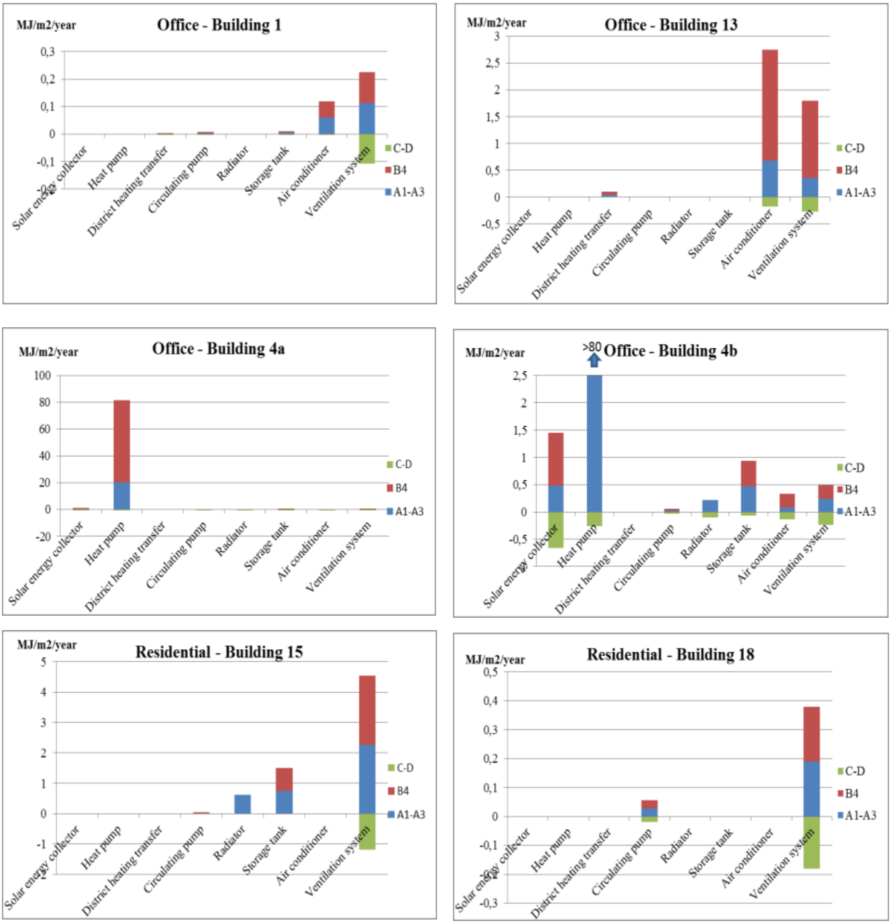

Fig. 3. The embodied energy (PEtot) of technical systems given in MJ/m^2/year diveded into life cycle stages. There is one figure for each building, except for building no. 4, where there are two figures. Note that the scale of the figures for each building differ.

If we ignore the impacts from the heat pump, no clear trend can be seen in the embodied energy of technical systems in the three office buildings. The embodied energy of air conditioner and ventilation systems is more than ten times larger in office building 13 than in office building 1. The expected service life of air conditioner differs betweem the building cases, resulting in more replacements during the reference study period in building 13 compared to building 1.

Comparison of the two residential building projects shows the same trend. There is an order of magnitude difference between the results of the two projects. The impacts are in both projects dominated by the impacts from the ventilation system, but the impacts per m^2/year are very different.

It has not been possible to analyse in more details if the difference can be explained by different design strategies for ventilation and air conditioner or if it can be explained by misleading use of datasets or calculation mistakes, but that is an object for further analysis.

4. Discussion and recommendations

This study shows a large variation in the embodied energy of the eighteen buildings reviewed. The share of technical equipment in the embodied energy was typically low, less than 1% for 10 building cases. However, in two residential building cases technical system corresponded to 5% of embodied energy and above 40% in one office building case. The review of the extent of technical equipment included in the building LCAs for the five selected buildings both showed a large variation in how thoroughly technical systems were included in the LCA studies and in the resulting embodied energy in technical systems per m^2/year. Some inaccuracies were found between the studies, such as inconsistency in service life used for technical equipment. This review indicates that in order to ensure consistency, better descriptions of how technical systems should be included in building LCA is needed.

Technical systems have often been assumed to be of minor importance for the environmental impacts of buildings and many cases been left out from building LCAs, often due to lack of data for technical equipment [5]. The study by Passer et al. on five Austrian residential building projects showed considerably higher share of the technical equipment of the total embodied energy compared to the Danish building LCAs (except building 4). The share of the technical systems in the Austrian cases was between 11-19% of the embodied energy [5]. Due to lack of information, it is difficult to explain in details the reasons behind the differences between the Austrian and the Danish cases on the basis of the trivial study that has been carried out here. However, it is assumed that the Austrian case studies both had more technical systems installed in the buildings and more detailed information about technical equipment included in the building LCAs compared to the Danish building LCAs reviewed.

Building 4 with the highest embodied energy due to the investment in geothermal heat pump is a self-sufficient energy building and is the only building of the 18 buildings reviewed that is not connected to central energy supply system. It should be noted that when the total life cycle primary energy consumption (embodied energy and operational energy) is taken into account, this building has far the lowest total primary energy demand of all buildings.

Continuous development towards lower use of operational energy in buildings together with focus on partly or totally self-sufficient energy buildings calls for improved knowledge of technical equipment share in embodied impacts. Four of the five Danish building cases reviewed had photovoltaics installed, which were not included in the building LCA, due to lack of datasets for photovoltaics. A Norwegian study on a wooden detached, single-family house by Inman and Wiberg (2015) showed the importance of including photovoltaics in a building LCA. Improvement of the availability of data on technical equipment is needed [11].

The reviewed case studies have all gone through third party conformity check, which the authors of this paper have experience with. Buildings are complex and even with ambitious quality check in building certification it is quite difficult to keep an overview of different building design strategies, such as light-weight concept, wooden structures, natural ventilation, self-sufficient energy buildings etc. In order to improve the third party conformity check, even better description of different design choices are needed together with the LCA calculations inserted in an LCA tool. It would benefit both LCA practitioners as well as the quality assurance, and it applies to technical systems as well as many other building elements.

Following recommendations are given on the basis of this study:

- More detailed description on how technical equipment should be included in building LCA is needed.
- Improvement of the data availability for technical equipment.
- Better descriptions of design choices together with the LCA calculations in order to improve the conformity check of performed LCAs.

Acknowledgment

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