TAKING THE STEP TOWARDS NET ZERO ENERGY BUILDINGS – HOW WILL THAT AFFECT THE ENERGY USE FROM A LIFE CYCLE PERSPECTIVE?

Björn Berggren[1]; Monika Hall[2]; Maria Wall[1]

[1]Lund University, Department of Architecture and Built Environment, Division of Energy and Building Design, Box 118, 221 00 Lund, Sweden.

[2]University of Applied Sciences and Arts Northwestern Switzerland, School of Architecture, Civil Engineering and Geomatics, Institute of Energy in Building, St. Jakobs-Strasse 84, CH-4132 Muttenz, Switzerland.

ABSTRACT

An important measure for climate change mitigation is reduction of energy use in buildings worldwide. There are today a growing number of buildings for which the design principle has been to achieve a Zero Energy Building (ZEB) or Net Zero Energy Building (Net ZEB).

It is today generally assumed, when the energy use of a building is discussed from a lifecycle perspective, that energy use in the operational phase of buildings accounts for 70-90% of energy used during its life cycle. However, a natural consequence is that for Net ZEBs the relative share of energy use related to building operation will decrease. Some might argue that the energy savings achieved related to building operation of a Net ZEB is lower compared to the increased energy use for production, maintenance and demolition.

This study analyzes the change of embodied energy compared to the decrease of the energy use related to building operation; by literature review and detailed analysis of eleven case studies, taking the step from a low energy building to a Net ZEB.

The study shows that taking the step towards Net ZEB is not counterproductive from an LCE perspective. The embodied energy will increase slightly when taking the step from a low-energy building towards Net ZEB balance. However, the energy savings achieved related to building operation exceeds, with great margin, the increased embodied energy.

Based on the literature review; embodied energy exceeds 50% of life cycle energy use when the annual operating energy use, primary energy exceeds 33 kWh/(m^2a) and 45 kWh/(m^2a) for residential and non-residential buildings respectively.

Within the detailed analysis; a rough breakdown of energy demand may be made: 35% embodied energy, 45% plug loads and lighting and 20% for heating, hot water and HVAC.

As embodied energy as a relative share of the total cycle energy use increases, embodied energy should be given more attention in the design of buildings.

Keywords: Life Cycle Energy, Net zero energy building, Embodied energy, Primary energy

INTRODUCTION

Reduced energy consumption is an important strategy for climate change mitigation. Buildings, worldwide, accounts for 40 % of the primary energy use and 24 % of greenhouse gas emissions [1]. As the population of the world grows, the need for buildings increases. Hence, reduced energy consumptions in buildings and increased use of renewable energy are important measures to reduce our energy dependency and generation of greenhouse gases.

Today; a number of buildings exist for which the design principle has been to achieve a Zero Energy Building (ZEB) or Net Zero Energy Building (Net ZEB) [2-6].

There are many different definitions and approaches of the two concepts. In general, the ZEB concept may be described as an autonomous building which does not interact with any external energy supply system (grid) such as district heating network, gas pipe network, electricity grid or likewise. The Net ZEB concept is a building where the weighted supply of energy from the building meets or exceeds the weighted demand and interacts with an energy supply system (grid). Such a building can export energy when the building's system generates a surplus and import energy when the building's system is insufficient to generate the energy required. The scope of the energy balance for the Net ZEB may vary for different concepts but is usually based on an annual balance of primary energy [7].

It is today generally assumed, when the energy use of a building is discussed from a lifecycle perspective, that energy use in the operational phase of buildings accounts for 70-90% of energy used during its life cycle. There are a number of substantiated and extensive studies with results supporting that allegation [8-11]. The studies differ in regard to calculation methodology used to account for the total energy use, Life Cycle Energy (LCE), but they reach similar conclusions which support the statement above. However, a natural consequence is that for Net ZEBs the relative share of energy use related to building operation will decrease.

Sceptics to the Net ZEB concept might argue that the energy savings achieved related to building operation of a Net ZEB is lower compared to the increased energy use for production, maintenance and demolition. A German study [12] concluded that life cycle energy use decreased for each step taken from a building; built according to building regulations, towards the Passive House standard. Taking the step to the ZEB, the life cycle energy use increased.

It may be argued that the German study is inconsistent since the life cycle energy use for the ZEB includes all embodied energy for the building's on-site generation and energy storage systems, whereas the embodied energy of the grid supplying the Passive House with energy is not included in the life cycle energy balance comparison.

The objective of this study is to analyze the change of embodied energy compared to the decrease of the energy use related to building operation; mainly by a literature review, but also by detailed analysis of eleven case studies; taking the step from a low energy building to a Net ZEB.

This paper presents a summary of research [13] which has been largely developed in the context of the joint IEA SHC Task40/ECBCS Annex52: "Towards Net Zero Energy Solar Buildings".

METHOD

The literature review was conducted by reviewing peer-reviewed papers and through a survey among participating researchers of the IEA SHC Task40/ECBCS Annex52 "Towards Net Zero Energy Solar Buildings", asking for case studies where LCE analyses were conducted and for information on country specific strategies for LCE analysis. All data were normalized into kWh/(m^2a). Only data based on primary energy were used, and where all energy use related to building operation was included.

The detailed analysis was conducted for eleven Minergie-A buildings. When this work was set out (July 2011), a total of 11 buildings had applied for Minergie-A certification. Data for the buildings were gathered from the database [14] managed by the Minergie® association.

RESULTS AND DISCUSSION

Within the literature review, a total of 143 case studies were collected [10, 11, 15-28]. Together with the eleven case studies from the Minergie database; a total of 154 cases are used in the analysis. In Figure 1 the relationship between operating energy and life cycle energy is presented for all cases. The relationship between operating energy and life cycle energy is almost linear. This data correspond well with the earlier, highlighted, linear relationship in [10, 11]. The negative values of operating energy occur if the energy supply exceeds the energy demand.

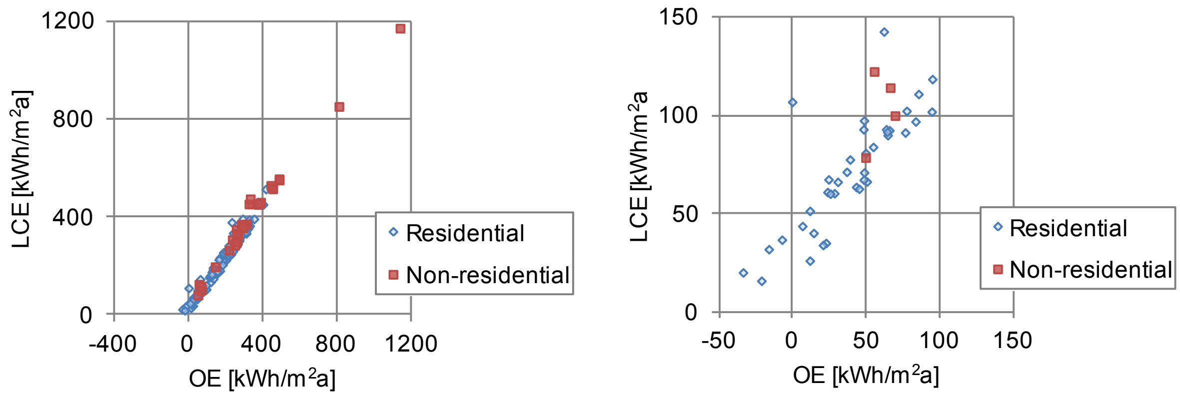

Figure 1: Relationship between operating energy (OE) and life cycle energy (LCE), primary energy. Right: All 154 case studies are included. Left: Case studies with OE < 100 kWh/(m^2a) are displayed.

Low energy buildings and Net ZEBs usually requires more material in form of insulation and installations (PV panels, solar thermal collectors, heat pumps etc.). Hence it could be logical to assume that the linear relationship between operating energy and life cycle energy would flatten out. However, the tendency is that the linear relationship is constant. This may be due to that design and construction of low energy buildings and Net ZEBs often has a focus on sustainable material management. It may also be partly due to that newer buildings show a tendency of a lower embodied energy compared to older buildings.

In Figure 2 the relationship between the operating energy and the embodied energy as percentage share of life cycle energy use is presented together with an exponential regression for residential buildings and non-residential buildings. As there are no case studies for non-residential buildings where operating energy≤0 kWh/(m^2a), data for a fictitious building have been incorporated.

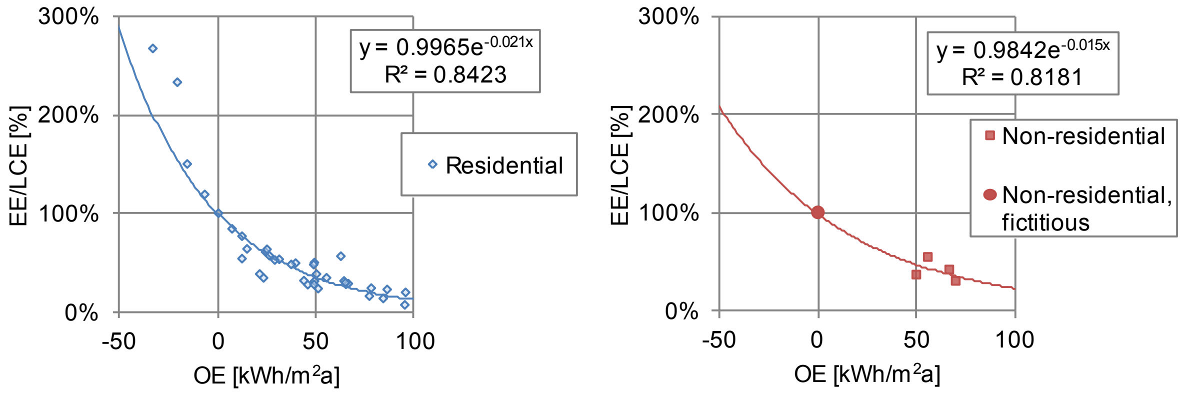

Figure 2: Relationship between operating energy (OE) and life cycle energy (LCE), primary energy. Right: All 154 case studies are included. Left: Case studies with OE < 100 kWh/(m^2a) are displayed.

Using the exponential regression formulas, the embodied energy exceeds 50% of life cycle energy use when the annual operating energy use is ≥33 kWh/(m^2a) and ≥45 kWh/(m^2a) for residential and non-residential buildings respectively. It may occur as strange that embodied energy as a share of life cycle energy exceeds 100% when the operating energy < 0 kWh/(m^2a). The effect is due to buildings that annually supply more energy than the annual energy demand, every year generating a surplus and thus reducing the total life cycle energy use.

The detailed distribution of embodied energy and operating energy of the detailed analysis of the eleven Minergie-A buildings is presented in figure 3. 10. For each project, demand and supply related to operating energy and embodied energy is presented. E.g. there is an energy demand to produce PV panels, presented as embodied energy on the demand side in Figure 10 (EE PVs). However, the PV panels also supply energy during building operation, presented as operating energy on the supply side (OE PVs).

Examining the demand for the different cases, the following rough division may be done: 35 % is embodied energy, 45 % is demand for plug loads and lighting and 20% is demand for heating, hot water and mechanical systems.

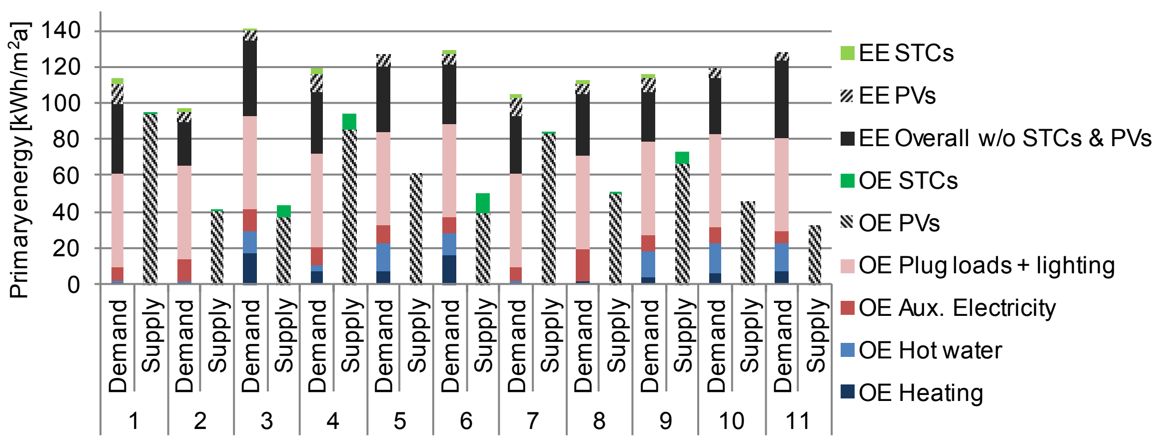

Figure 2: Distribution of operating energy (OE) and embodied energy (EE) by demand and supply in Minergie-A projects (non-renewable primary energy).

CONCLUSIONS

Taking the step towards Net ZEB is not counterproductive from an LCE perspective. The embodied energy will increase slightly when taking the step from a low-energy building towards Net ZEB balance. However, the energy savings achieved related to building operation OE exceeds, with great margin, the increased embodied energy.

Solar thermal collectors, PV panels and heat pumps reduce the operating energy use more than the increase of the embodied energy. Therefore, if a project only has resources to carry out a limited LCE analysis. They should focus on structural elements and building envelope.

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REFERENCES

1. International Energy Agency (IEA), *Towards Net Zero Energy Solar Buildings*, SHC Task 40/ECBCS Annex 52 IEA, Fact sheet pp. 2, 2011.
2. SHC Task40/ECBCS Annex52 IEA, *Net Zero energy Buildings database*, http://iea40.buildinggreen.com/index.cfm (accessed 10.09.11).
3. Musall, E., et al., Net Zero Energy Solar Buildings: An Overview and Analysis on Worldwide Building Projects, in Eurosun Conference 2010, Graz, 2010. pp. 9.
4. Lenoir, A., F. Garde, and E. Wurtz, *Zero Energy Buildings in France: Overview and Feedback* in ASHRAE Annual Conference 2011, Montreal, 2011. pp. 13.
5. Voss, K. and E. Musall, Net zero energy buildings - International projects of carbon neutrality in building, Birkhauser Verlag, Basel, 2011.
6. Fachinformationszentrum. *Net zero-energy buildings – Map of international projects*. http://www.enob.info/en/net-zero-energy-buildings/map/ (accessed 05.04.12).
7. Marszal, A.J., et al., Zero Energy Building – A review of definitions and calculation methodologies. Energy and Buildings, 2011. 43(4): p. 971-979.
8. Adalberth, K., *Energy use during the life cycle of single-unit dwellings: Examples.* Building and Environment, 1997. 32(4): p. 321-329.
9. Adalberth, K., Energy use in Multi-Family Dwellings during their Life Cycle, Doctoral Thesis, Lund University, 1999.
10. Sartori, I. and A.G. Hestnes, Energy use in the life cycle of conventional and low-energy buildings: A review article. Energy and Buildings, 2007. 39(3): p. 249-257.
11. Ramesh, T., R. Prakash, and K.K. Shukla, *Life cycle energy analysis of buildings: An overview*. Energy and Buildings, 2010. 42(10): p. 1592-1600.
12. Feist, W., Life-cycle energy balances compared: low-energy house, passive house, self-sufficient house, in International Symposium of CIB, 1997. pp. 13.
13. Berggren, B., M. Hall, and M. Wall, *LCE analysis of buildings – Taking the step towards Net Zero Energy Buildings.* Energy and Buildings, 2013. 62(0): p. 381-391.

14. MINERGIE®, *Minergie database*, 2011: Minergie Agentur, CH-4132 Muttenz.

15. Junnila, S., A. Horvath, and A.A. Guggemos, *Life-Cycle Assessment of Office Buildings in Europe and the United States* Journal of Infrastructure Systems, 2006. 12(10): pp. 7.

16. D Carls, Bewertung und Optimierung von ökonomischen und ökologischen Bauwerkslebenszyklen am Beispiel BOB - Balanced Office Building, in Fachbereich Architektur, Bergische Universität Wuppertal: Wuppertal, 2007.

17. D Kugel, Life cycle analyses as an economical and ecological savings potential in building planning and management, in Bauphysik und technische Gebäudeausrüstung, University Wuppertal: Wuppertal, 2007.

18. *CIRCE, ENSLIC BUILDING – energy saving through promotion of life cycle assessment in buildings* http://circe.cps.unizar.es/enslic/texto/d 4-2-circe.pdf (accessed 10.04.12).

19. Schweizer Solarpreis 2007, *Marché international support office*, http://www.solaragentur.ch/dokumente//M-07-10-16%20Marche%20International.pdf (accessed 10.04.12).

20. Swiss Federal Institute of Aquatic Science and Technology. *Forum Chriesbach - Energy*. http://www.eawag.ch/about/nachhaltig/fc/energie/index_EN (accessed 08.04.12).

21. Scheuer, C., G.A. Keoleian, and P. Reppe, Life cycle energy and environmental performance of a new university building: modeling challenges and design implications. Energy and Buildings, 2003. 35(10): p. 1049-1064.

22. Pullen, S.F., *Energy used in the Construction and Operation of Houses.* Architectural Science Review, 2000. 43(2): p. 87-94.

23. Victoria Building Commission, *Energy impacts of different house types in Victoria*, http://www.buildingcommission.com.au/resources/documents/EE_FactSheet_FINAL_18June06.pdf (accessed 12.09.11).

24. G. Beccali, et al., *Energy and environmental analysis of a mono-familiar Mediterranean house*, in World Sustainable Building Conference - SB08, Melbourne, 2008. pp. 8.

25. Plataforma Arquitectura, *LIMA house*, http://www.plataformaarquitectura.cl/2010/11/12/lima-low-impact-mediterranean-architecture-saas/ (accessed10.04.12).

26. Keoleian, G.A., S. Blanchard, and P. Reppe, *Life-Cycle Energy, Costs, and Strategies for Improving a Single-Family House.* Journal of Industrial Ecology, 2001. 4(2): p. 22.

27. Villa, N., et al., *Life Cycle Assessment (LCA) of buildings applied on an Italian context*, in CleanTech for Sustainable Buildings - From Nano to Urban Scale, Lausanne, 2011. pp. 6.

28. Leckner, M. and R. Zmeureanu, Life cycle cost and energy analysis of a Net Zero Energy House with solar combisystem. Applied Energy, 2011. 88(1): p. 232-241.