Environmental sustainability building criteria for an Open Classification System

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Abstract. Existing classification systems linked to the environmental performance of buildings provide limited added value for practitioners. A survey among Swedish construction entrepreneurs showed that there is a real demand for better formulated criteria and clearer guidance. At the same time, critical investigation of requirements based on fixed average values for primary energy factors (such as in the EU Environmental Performance of Buildings Directive) shows that they are insufficient to provide guidance towards environmental sustainability building practices. They fail to take into account a number of methodological issues, including seasonal and hourly variability of energy supply and demand, and the future evolution of energy mixes. This is illustrated in the case of Sweden. The outline of an Open Classification System, currently under development, is then presented. This system focuses on methodological transparency and validity, as well as ease of use for practitioners. It addresses specifically issues where other existing systems were found to be lacking, and its methodology will be assessed to ensure that it provides optimal guidance towards environmentally sustainable practices. The system is based on three criteria: the energy resource index and global warming potential, calculated with attributional and consequential life cycle approaches, and a heat loss factor to assess the building's energy performance independently from the supply side.

Keywords: Sustainable construction; Building certification; Heat losses; Primary energy; Global warming potential

1 Context and Objective

The newly-started project "Open classification system" aims at developing easy-to-use criteria for environmentally sustainable construction, refurbishment and energy use over a building's life cycle. These criteria could be used in certification schemes such as FEBY [1] or Miljöbyggnad [2], or as an inspiration for further development of regulated energy requirements from the National Board of Housing, Building and Planning (Boverket). They could also serve as a basis for much needed guidelines for

Green Public Procurement (GPP) related to construction, as Sweden has been formally notified by the European Commission for failing to implement EU rules on Public Procurement [3]. Project results will be delivered in spring 2018.

Assessment criteria in several certification systems for sustainable buildings are based on a Life Cycle Assessment (LCA) methodology, like in BREEAM [4], LEED [5] and Miljöbyggnad [2]. European standards on Construction Product Regulations (CPR) and Environmental Product Declarations (EPD) include guidance on assessing environmental impacts from construction and operation in a LCA perspective [6, 7]. They are based on attributional LCA (ALCA), meaning that the inputs and outputs of all processes of a system are inventoried as they occur and add up to the global result. An alternative approach is consequential LCA (CLCA), describing all processes happening in the background system in consequence of decisions made in the foreground system, e.g. "how does the energy supply change if demand increases by 1% ?" [8]. Requirements in the EU Energy Performance of Buildings Directive (EPBD) [9] and the Swedish building code [10] are based on ALCA using fixed average values for primary energy factors (PEF). Our working hypothesis is that this method provides unclear guidance and does not steer towards environmentally sustainable practices.

The challenge is therefore to develop scientifically based criteria to describe and quantify desirable building properties that guide practitioners towards environmentally sustainable solutions. The method must be valid, verifiable, and relate to common practices by developers and constructors. These properties should be expressed in a classification system giving clear guidance and creating a communicative platform where technical requirements are translated into market values and used to benchmark environmental performance. To ensure these criteria are developed in a way suitable for the target audience, a survey among practitioners was carried out (see section 3.1).

This paper will first highlight the current regulation and methodological issues in LCA of buildings. The outline of a classification system to answer these issues is then presented, as well as how it will be assessed to ensure it reached its objectives.

2 Background

Performing an understandable and scientifically valid LCA of a building raises several methodological issues. Before assessing operational energy use, at least three background parameters must be set: the geographical scope of the energy supply, the composition of the energy mix, and impact factors per kWh for fuels and other energy carriers. At each step, assumptions must be made and the uncertainty increases.

The assessment of operational energy demand could be based on a Swedish, Nordic or European electricity mix. Transmission capacity is high on the Nordic electricity market, and is likely to increase further in the future, both between Nordic countries and with the rest of Europe, as a result of European policies [11, 12]. It is already common to use a Nordic mix [13], but an European mix might be suitable in the long term. On the other hand, a local or regional scale can be relevant for district heating.

Once the scope of the grid has been decided, the composition of the energy mix can be set. In an ALCA, the energy mix includes all production within the scope of the grid. In a CLCA, the so-called marginal mix corresponds to the generation displaced by a small change in demand. It can be set by selecting the most expensive plants in operation at any given time, but there are disagreements on how “wide” the margin should be (e.g. should it be the 10% most expensive plants or 5%?) [14, 15]. Historical production data for all plants can also be used [16], but assessing future energy use requires predicting future production with a high time resolution.

Once the composition of the energy mix is set, the impact of energy use may be calculated using impact factors per kWh for all energy carriers. The impact of energy use on energy resources can be assessed using primary energy factors (PEFs), in kWh primary energy used per kWh final energy used. The Energy Performance of Buildings Directive [9] and the Swedish building code [10] use fixed average values for PEFs and a yearly time resolution. However, the method they use is problematic for several reasons:

- PEFs are set currently in a manner that is opaque and out of reach for practitioners.
- PEFs do not take into account the variability of electricity and heat production depending on season and time of day. The energy mix varies greatly between peak times and periods of low demand, and the necessity of using hourly data to increase the validity of assessments of energy use is well documented [17–19].
- PEFs do not consider the future evolution of the energy supply: a building will use energy for several decades, but the way this energy will be supplied in the future might be very different from what it is today.

For all these reasons, fixed PEFs as per the EPBD might encourage unsustainable practices. For example, bioenergy is considered to have a PEF of 0 kWh/kWh in the EPBD[1]. Most multi-family dwellings in Sweden are heated by district heating, where the share of bioenergy is already large and will keep increasing. Large- and middle-size producers also produce electricity from biomass in combined heat and power plants (CHP). If an energy requirement based on a PEF of zero for bioenergy is to be used, the calculated impact of energy use would be so low that it would allow unconstrained energy wasting. Poorly insulated buildings shouldn’t be prioritized just because a simplified assessment drives down the PEF of the energy mix.

One way to provide a more suitable assessment would be to consider variable impact factors instead. The assessment could be performed with hourly values instead of yearly ones, to consider that peak hour electricity and heat production in winter is both more expensive and more environmentally damaging. The assessment should also consider the future evolution of the energy supply. However, integrating future scenarios with intermittent electricity production from renewable power plants and interconnected European grids is a complex task, yielding an uncertain result.

Another solution is using an additional quality factor at the building level, independent from the supply side, which remains robust regardless on assumptions about the energy grid. One such factor, used in the Swedish FEBY passive house criteria for

[1] It is considered to have a PEF of 1 kWh/kWh in the current Swedish building code.

about ten years, is the Heat Loss Factor (HLF) [1]. Reducing heat losses is a strategic priority, as it decreases the burden on the supply side, especially during peak hours.

The aforementioned solutions do not directly address environmental issues. Primary energy use doesn't consider which and how resources are used. More direct indicators of environmental impact seem needed to address environmental issues. An energy resource index (ERI) has been previously developed that moves beyond primary energy use to also consider the characteristics of energy resources in terms of scarcity and carrying capacity [20]. Global Warming Potential (GWP) is also a common indicator in LCA. Recent developments in LCA literature suggest that GWP from construction can be of the same magnitude as GWP in the operational phase [21–23].

A combination of three criteria based on heat losses, energy resources use and GWP would comply with European directives, provide a robust indication of a building's inherent thermal properties, and inform about its environmental impact.

3 Preliminary results

3.1 Survey among practitioners

To help set an initial direction for the design of environmental sustainability criteria, a survey was carried out amongst developers and entrepreneurs with previous experience in energy-efficient buildings and certification schemes. 26 answers were gathered. Relevant results are presented below:

- *Why work with classification systems?* Practitioners want to show that they actively work towards sustainability targets. Criteria also provide a structured procedure.
- *What important areas should be covered by such a system?* Buildings heat demand/losses, electricity use, and climate impact from operation rank the highest. Costs related to energy use, cooling demand, distribution losses and climate impact from construction materials are also considered important. Hot water and energy use for construction processes are considered the least important.
- *What are important areas related to indoor environment?* Almost all answers were rated high. This could mean that construction legislations are too lax, or that clients have high requirements that should be considered in classification systems.
- *How should a classification system be structured?* Practitioners tend to prefer systems where several subsystems can be chosen, and where better results in one subsystem can compensate for lacks in other subsystems.
- *How should certification results be communicated?* Criteria are more impactful when expressed as "grades" (gold, silver or bronze) than when expressed as concepts (passive house, low-energy house or standard house).
- *How should requirements be followed-up?* Third-party control is suggested for air tightness, energy signature and energy use. Self-monitoring is suggested for other aspects such as thermal transmittance or documentation of moisture.
- *Is it economically profitable to use certification schemes?* Lower costs appear to be desirable, and so do better formulations of the requirements and a better guidance to help apply criteria and measurements.

3.2 Outline of the classification system

Sustainable construction can be defined as addressing environmental, social and economic sustainability aspects. However, the present project focuses on developing a tool to assess environmental sustainability only. This encompasses both a building's properties and external conditions that impact its performance (energy supply, local transport infrastructure, etc.). It is however necessary to set boundaries to distinguish between different domains of responsibility, as the developer often has little control over the surrounding infrastructure. The classification method developed in this project addresses three subsystems, as illustrated in Figure 1:

1. Building properties, independent from the supply side
2. Use of energy resources from construction works and operational energy demand
3. Global warming potential from construction works and operational energy demand

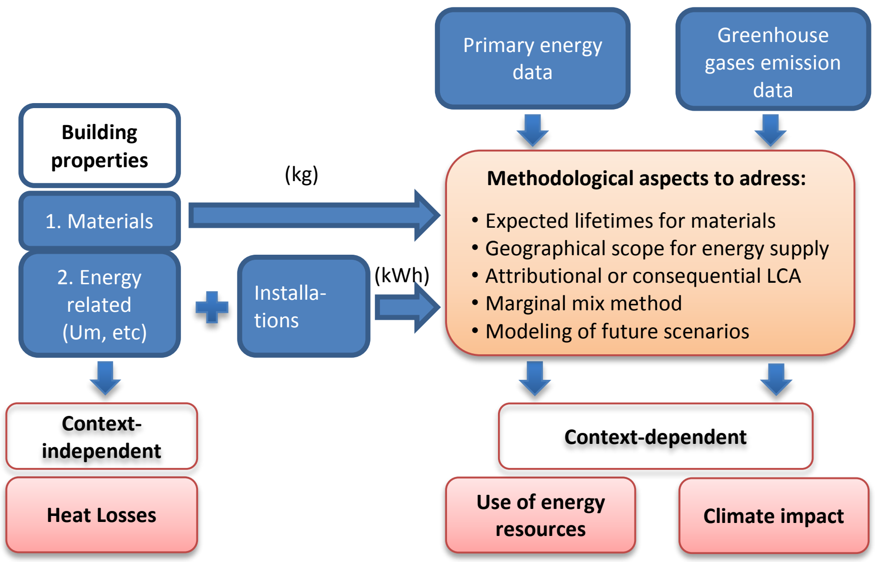

Fig. 1. Methodology and subsystems in the Open Classification System

Properties of buildings and materials can be used as a starting point to develop criteria related to each of the 3 subsystems. The Heat Loss Factor (HLF) represents the inherent quality of a building's climate shell. Climate impact is expressed as a Global Warming Potential (GWP) in kgCO2e. To indicate whether energy-intensive systems lead to a sustainable use of energy resources, primary energy is linked to indicators of sustainability, scarcity and carrying capacity in an Energy Resource Index (ERI).

Criteria can be formulated in two different ways:

- As mandatory minimum levels of performance, required to apply for a construction permit or in architectural competitions.

- As a voluntary complementary indicator to be communicated to the consumer (such as a color scale to represent environmental performance).

The latter is more suitable when the methods or data assessment are less robust. Figure 2 illustrates an example: a building could have to reach a minimum thermal performance (maximum value of HLF) to be granted a construction permit, while the ERI and GWP are rated on a A to F scale to be communicated to the consumer.

The Open Classification System will include both ALCA and CLCA perspectives, as the two approaches answer different questions, and two different time horizons:

- ALCA as per EN 15804 [7], using current average data for the energy supply
- ALCA with a high time resolution inventory linking the building's energy performance and the total energy supply, with inventory data based on future scenarios
- CLCA with a high time resolution inventory that links the building's energy performance and the marginal energy supply, including future scenarios

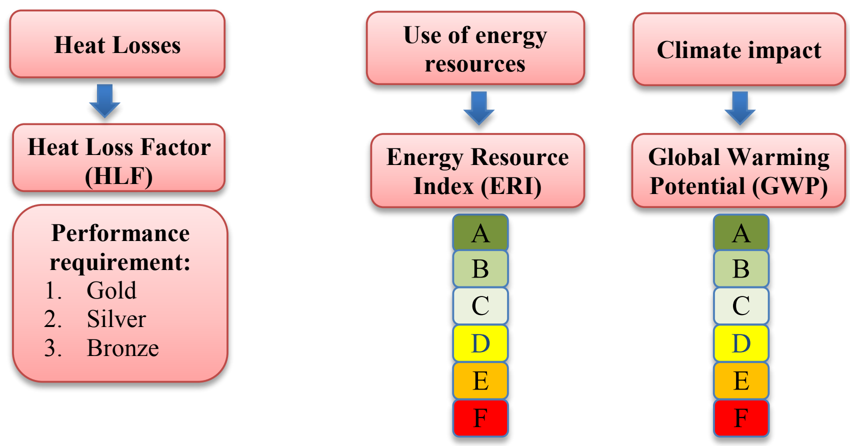

Fig. 2. Criteria used and expression of results in the classification system

3.3 Building Level: The Heat Loss Factor to Assess Energy-Related Properties

Definition and Measure of the HLF. The HLF is the sum of heat losses by transmission, ventilation and infiltration per square meter (in W/m^2) with an outside temperature equal to the design winter outside temperature (DWOT):

$$HLF_{DWOT} = H_T \cdot (21 - DWOT) / A_{temp} \quad (W/m2) \tag{1}$$

where H_T is the building's heat loss coefficient (W/K) and DWOT is the design winter outside temperature. For buildings with significant heat losses through the ground, it can be necessary to use a separate heat loss coefficient for these losses:

$$HLF_{DWOT} = H_T' \cdot (21 - DWOT) / A_{temp} + H_T'' \cdot (21 - T_{ground}) / A_{temp} \tag{2}$$

where H_T' is the heat loss coefficient without losses to the ground and H_T'' the heat loss coefficient to the ground. A HLF criterion can use hourly, weekly or monthly data, and compensate for small buildings and temperature differences in cold regions.

Relevance of the Heat Loss Factor. Heat losses are directly related to winter peak demand, when delivering energy is the most expensive and environmentally damaging. The HLF is therefore strategically and environmentally relevant.

The HLF is easily calculated and only relates to aspects the developer has influence over (the building's climate shell, air tightness, and ventilation). European standards exist for HLF calculation, and no additional data beyond what is used in yearly energy calculations is required. Calculations can be performed in a spreadsheet with an easy-to-review template. The HLF is therefore easy for practitioners to adopt.

Net heat, the final energy used for heating, is another alternative that could be considered, but it entails a more complicated calculation of energy balance, based on more uncertain behavior-related data. The Swedish building code also includes a complementary requirement on the average energy transfer coefficient (Um), which is linked to heat losses. In practice, this requirement only impacts buildings with a low form factor (relation between enclosing area and heated area). It has virtually no effect on smaller buildings with a high form factor, and doesn't limit losses from ventilation and infiltration, which makes it too rough to provide good guidance.

3.4 Assessment of Climate Impact and Resource Use

A well-established methodology already exists to calculate the HLF. The process is more complicated for the ERI and GWP indicators. Various methodological choices (scope, future scenarios, etc.) affect the results, and the sensitivity of criteria to these choices will be assessed and will be in itself a result of the project.

ALCA based on the current energy mix will use a Nordic electricity mix and hourly data. When including future scenarios, differences between a Swedish, Nordic or European electricity mix and how they impact the assessment results will be investigated. Only the most relevant mix will be used in the final classification system.

Hourly data is required, and such a high time resolution can't be found in reports for future energy scenarios. Two solutions are currently being explored. Ideally, authors of the three scenarios could provide either more detailed results, or a list of parameters they used so that we can run the model ourselves with a higher time resolution. Otherwise, hourly and seasonal variations will be extrapolated from current production data and applied to future yearly mixes found in the reports (assuming similar variations in 2050 and today).

Several approaches are possible to select the marginal mix in a CLCA. It can for instance be considered that the most expensive operated plants at a given time constitute the operational margin. The model for future energy mixes can also be run twice, with and without the additional demand from the building. The influence of this choice on the results will be assessed.

4 Evaluation of the method and use of the results

4.1 Evaluation of suggested methods for the classification system

Methodological choices that impact the classification results must be evaluated. Results must be accurate, robust and give unequivocal guidance, but the method must also be straightforward and cheap to carry out. Simplifications are needed but must be justified. This will be done by running the classification system with different methods on a range of test measures and comparing the results along the following criteria:

- Will the Open Classification System guide practitioners towards investing in measures that reduce impact on primary energy use and GWP?
- Will the method lead to suboptimal investments like overproduction of renewable energy at the building site?
- Will the method encourage measures that store energy from periods of overproduction from renewable power plants to use during demand peaks (winter)?
- How will peak hour demand be affected?
- How will the method address flexibility issues (ease of adapting, switching to new energy carriers, opening/closing plants, etc). Energy systems have shorter life times than buildings, so they will need to change during the building's lifetime.
- Are the methods transparent and easy to control (even by non-experts)? This is especially important if they are to be integrated in a national building code. Workshops with building contractors will provide feedback on these subjects.

4.2 Using the classification system to assess construction measures

Changing building and installation properties affects the HLF, ERI and GWP indicators. This will allow the constructor to easily assess the impact of any measure, and choose the optimal solution. Four types of measures linked to energy use can be distinguished, depending on whether they affect:

1. Heat losses (insulation, heat exchanger, etc) and the HLF
2. Electricity demand, and possibly heat load
3. Heat load from electrical installations that aren't coupled to outdoor temperature (fans, elevator), which changes the balance temperature when heating season starts
4. Hot water demand and heat recovery from hot water use

Other types of measures concern conversion or production:

5. Electricity production (for internal use or exported to the grid), usually PV panels
6. Heat pump solutions for heat and/or hot water
7. Solar heat recuperation and storage

These measures will change the energy demand of the building, which is reflected in the indicators. The benefits provided are then easily compared to each measure's cost.

5 Conclusion

The foremost objective of a classification system for environmental performance should be to guide practitioners towards adopting sustainable practices. As such, the system should be user-friendly and provide added value. Furthermore, its criteria should be scientifically valid, robust, and steer only towards sustainable practices. Existing criteria have been found to be somewhat opaque for practitioners and invalid due to oversimplifications (using a single indicator ignoring seasonal and hourly variations and future evolutions of the energy supply). The Open Classification System is currently being developed specifically to address these issues. Using a heat loss factor provides a robust indicator to assess energy performance that can be used to set minimum performance levels. The calculated energy resource index and global warming potential provide useful additional information directly related to resource use and environmental impact, which could be used to inform consumers. A number of methodological issues remain, but choices will be assessed using test measures to ensure the system provides correct guidance. Consultations with practitioners will ensure ease of use and transparency. Further, it should be noted that additional aspects of social and economic sustainability could be part of such a classification but have been excluded here. Seinre [24] points out that indoor environmental quality (IEQ) affects productivity, which in turn has a significant effect on economic sustainability, while Brown [25] showed that environmentally certified buildings are perceived as having a better IEQ but no significant impact on productivity.

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