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Chapter

Viewpoints on Environmental Assessment of Building Certification Method – Miljöbyggnad

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Abstract

Production, management, use, and end-of-life of buildings has a large impact on climate change. Therefore, environmental targets are set to lower the greenhouse gas (GHG) emissions from the building sector. To reach these targets building regulation and voluntary environmental assessment methods (EAMs) that evaluate and certify the building's environmental impact are put forward as tools to push the building sector towards lower GHG emissions. In Sweden, building design is governed by building regulations and the dominant EAM is 'Miljöbyggnad' (MB) ("Environmental building"). Today, more than 1900 buildings have been certified by MB and it has influenced the building and property sector. In this chapter the potential impact MB and the linked Swedish building regulations have on building performance, energy use and GHG emissions, will be reviewed and discussed. The analysis investigates several of the MB's indicators, evaluate to what degree EAMs can influence the design of the building and the energy system to lower the energy use and GHG emissions based on material choices. The analysis presents important aspects that may influence the design of the building and its energy system and what challenges and possibilities the indicators, criteria and regulations can have on buildings and climate change. In addition, some modification and suggestion for improvements are presented.

Keywords: environmental assessment of buildings, GHG emissions, indoor environment, Miljöbyggnad, energy, environmental impacts

1. Introduction

Buildings are a major source of environmental impact, such as greenhouse gas (GHG) emissions, and use large amounts of energy and natural resources. Building construction and operation account for 36% of global final energy use and of 39% of energy related GHG emissions [1]. Awareness of the threat of a climate crisis and its recognition in global Sustainable Development Goals, and in European and national

political targets, has increased the pressure to do necessary measures to reduce anthropogenic GHG emissions. The importance of decreasing the impact from building and construction industry has also been highlighted. Apart from legislation, taxation and benefit packages, environmental assessment methods can be considered as a voluntary neoliberal way to work with environmental governance [2]. They may also influence legislation. For example, the Swedish EAM Miljöbyggnad (MB) has inspired a new legislation regarding mandatory climate declaration for all new buildings in Sweden which is mandatory from January 2021 [3]. It is therefore of great importance how the environmental assessment tools content, indicators and criteria guide building design and decision-making in the building sector.

In Sweden, the most commonly used system for environmental certification of buildings is Miljöbyggnad (MB), translated to English “Environmental building”. MB was developed as a joint project between Swedish government, companies in the building and construction sector, several municipalities, insurance companies and academia, as a voluntary environmental rating tool to assess all new buildings in Sweden [4]. This still influences its characteristics. More than 1900 buildings are certified with MB [5]. Environmental certification is a third-party verification that a building meets the environmental certification criteria that the system address. Sweden’s largest organization for sustainable community building, Sweden Green Building Council (SGBC) owns and develops the system, and performs certifications [5]. MB certifies both new and existing/renovated buildings of different kinds: such as detached and semi-detached houses, blocks of flats and most types of commercial and public buildings (here called non-residential buildings), encompassing hotels, offices, restaurants, healthcare buildings, schools, kindergartens, and sport centers. MB analyzes and evaluates fifteen different indicators for new buildings. The processes for MB certification include registration of the project, pre-notification, application, review, clarification, and certification and in addition, requires reporting and verification of results with follow up inspections within three years after completion and certification, and then reporting back on maintained performance every fifth year to prolong the gained certification grade.

Each indicator can achieve Bronze, Silver or Gold grade. To achieve Gold grade, the building should have enhanced environmental performance and measurements or questionnaires should be made to guarantee the enhanced building performance and indoor climate levels [5]. If any of the indicators are classified Bronze, there is no possibility to achieve the total grade Gold.

The 15 indicators (16 indicators for existing buildings) are clustered into the areas *Energy*, *Indoor Environment* and *Material*. The final building grade calculated by aggregating the 15 indicators into 12 aspects, and then into the 3 areas, and finally into the building grade. This is described in the manual for MB [5]. An example of the grading and aggregation of the MB 3.0-certified pre-school Almgården in Gävle is shown in **Table 1**.

The aim of this book chapter is to reflect some viewpoints about the MB’s potential impact on energy use, GHG emissions and effect on building performance. By analyzing and investigating nine of MB’s 15 indicators, it is studied to what degree MB may influence the design of buildings, the energy system and lower the GHG emissions. The analysis focuses on whether the certification system influences the design of the building and its energy system as intended and what challenges and possibilities the indicators, criteria and linked regulations can have on buildings and GHG emissions. The nine indicators that affect the GHG emissions the most in the areas Energy, Indoor environment and Material were identified and have been

			Indicator	Aspect	Area	Building
Energy	1	Heat power demand	SILVER	BRONZE	SILVER	SILVER
	2	Solar heat load	BRONZE			
	3	Energy use	GOLD	GOLD		
	4	Share of renewable energy	SILVER	SILVER		
Indoor Environment	5	Noise	SILVER	SILVER	SILVER	
	6	Radon	SILVER	SILVER		
	7	Ventilation	SILVER			
	8	Moisture safety	SILVER	SILVER		
	9	Thermal climate, winter	SILVER	BRONZE		
	10	Thermal climate, summer	BRONZE			
	11	Daylight	BRONZE	BRONZE		
	12	Legionella	SILVER	SILVER		
Material	13	Logbook of building material	SILVER	SILVER	SILVER	
	14	Phasing out the hazardous material	SILVER	SILVER		
	15	Building structure and the foundations climate impact	BRONZE	BRONZE		

Table 1.
Example of how indicator grades are valued and aggregated to a final building grade for a certified building, Almgården pre-school, Gävle, Sweden.

studied. Their potential impact on GHG emissions and building design will be presented and discussed.

The method used in the project is primarily a study of the MB manual and literature linked to the subject. The authors have had regular workshops to discuss the documents and literature and a reference group of five people from both building industry and academia with knowledge regarding MB, energy and environmental issues related to buildings have had input to the process. Some certified planned and built buildings have also been analyzed separately.

2. Energy aspects

2.1 Background regarding the aspect energy

In order to have an understanding for why four indicators are included in the Energy area, a brief overview of Sweden’s energy system, building stock energy performance and energy supply/distribution are presented below. The four indicators within the energy area are: Heat power demand, Solar thermal load, Energy use and Renewable energy.

Sweden’s use of energy is divided among the industry, the transportation, and the residential and tertiary sectors. The latter accounts for approximately 40% of Sweden’s energy use, namely 147 TWh in 2018. Shares that sum up to this number are residences 59%, public service 11% and service businesses 21%, the building construction sector 3% and remaining 6% owing to agriculture, forestry and fishing [6].

Building type	Share of total heat supply [%]	Share of DH supply [%]	Share of building type heated by DH [%]	Specific energy demand [kWh/(m ² •a)]	Specific energy demand (DH heated) [kWh/(m ² •a)]
Detached	40	12	17	107	138
Multi-family	33	52	90	140	143
Non-residential	27	36	77	127	149

Table 2.
Average final specific energy demand for space heat and domestic hot water preparation in 2016 [7].

More than half of this energy is used for space and domestic hot water (DHW) heating; 54% in 2018 [6]. For this reason, the building stock should confine energy use, the rate at which energy is used (power), from which sources and its quality. **Table 2** displays statistics on space and DHW heating for various buildings. A large share of multifamily and non-residential buildings is heated with district heating (DH) whereas detached buildings are predominantly heated with electricity (direct and/or various heat pump types). **Table 2** does not include facility electricity (electricity for pumps, fans, certain common lighting, elevators, etc.). Nor is household and office/business electricity, which by default are calculated as 30 kWh/(m²•a) [8] and 50 kWh/(m²•a) [9], respectively.

It is important to differentiate energy carriers, primarily electricity and DH in view of when the power demand of the building stock is high due to issues during cold weather. Even if Sweden per capita is an extreme electricity consumer, electricity is generated using energy sources with low or moderate GHG emissions. For example, 160 TWh electricity were produced in 2019, from hydropower 39%, nuclear 39%, wind 12%, and the remaining 9% from combined heat and power (CHP) plants serving electricity to industry and society [6]. There is a growing demand for cooling energy, especially for non-residential buildings.

Electricity involves problems with power or capacity shortage. *Power shortage* occurs when demand is higher than supply on a national level. Several combined factors contribute to power shortage [10]:

- It is cold in the whole country;
- Wind generates little power since cold weather seldom are windy;
- Nuclear power does not produce as predicted or is being phased out;
- Drought leaves hydropower dams with low water levels;
- Imported electricity is limited due to low overproduction in neighboring countries or grid links to those countries are not in operation;
- Reserve power sources do not deliver enough power;
- Grid shortage of capacity in Sweden (see below).

Shortage of capacity implies power shortage in local areas, especially in expanding cities. Distribution cables from northern regions with great hydropower production to

population-dense southern regions are today inadequate. Though supplied electricity has been constant since the 1980s, expanding urban and diminishing rural areas have changed the consumer landscape [6]. Transitions in society increase electricity use, for example from oil burner boilers to heat pumps [6], increased number of electric vehicles, establishment of data centers, etc. [10]. Main and local networks are reaching capacity limits.

DH can come from burning fuels, incineration and/or waste/residual heat from the industry with the purpose of heating buildings (or for industrial applications). DH can also come from a CHP plant, which produces thermal and electric power for the local community, with very high thermal efficiency. CHP delivers most power when outdoor temperatures plummet. Cold periods involve burning fuels with high energy content, such as costly renewable types (such as tall oil) or fossil fuels, which are being phased out due to high GHG emissions. In view of MB, every new building will increase the pressure on energy generation, grids and networks. Renovation of old buildings often reduce thermal energy requirement, but will in turn often imply increased use of electricity for this purpose. Therefore, power requirements, which are not explicitly expressed in Swedish Building Regulations (BBR), are important in MB and consequently reduce the increase of GHG emissions. From a future community development perspective, minimized electricity consumption should be rewarded.

2.2 Heat power demand

One of the indicators in MB assesses the heat power demand during winter. When outdoor temperatures drop, heat demand of the building stock increases, which implies that energy systems must use fossil and/or expensive renewable fuels. The purpose of this indicator is according to MB, translated to *Heat power demand*, to encourage buildings that have low space heating demand during the coldest winter period. The demand is seemingly set equivalent to heat losses by transmission, ventilation and air leakage at Design Winter Outdoor Temperature (DVUT) [11], divided by the building envelope area (unit W/m^2 , A_{env}), given no solar irradiation and internal heat gains in the building. DVUT is available for cities in Sweden and dependent on the thermal time constant of the building (time constants corresponding to 24 hours to 12 days) in accordance to SS-EN ISO 15927-5 [12]. **Table 3** shows score criteria. F_{geo} is a geographic factor stated in the building regulations [13], which is 1 for the Stockholm region, larger for Northern regions and lower in Southern regions.

These two calculation methods are suggested by MB:

- The building's heat loss coefficient (with unit W/K) and time constant are calculated to assess DVUT. The heat demand comes from multiplying the heat loss coefficient with the difference between design indoor temperature and DVUT, divided by the envelope area.

Building type	Bronze	Silver	Gold
Residential	$\leq 25 \cdot F_{geo}$	$\leq 20 \cdot F_{geo}$	$\leq 15 \cdot F_{geo}$
Non-residential	$\leq 30 \cdot F_{geo}$	$\leq 24 \cdot F_{geo}$	$\leq 18 \cdot F_{geo}$

Table 3.
Indicator 1, heat power demand limits, related to envelope area [W/m^2] [5].

- The heating demand can be simulated with a building energy simulation software, where solar and internal heat gains are set to zero, while the building is ventilated as if it were occupied. The climate file is that of a typical reference year for the location. Space heating demand is divided by the envelope area.

Verification is done in two ways: either with the energy signature of the building (measured supplied power versus outdoor temperature) or making a more exact calculation by using actual/measured values as input in the model used to predict the power demand.

The idea of limiting thermal power losses through transmission, ventilation and air leakage is encouraging, since this requirement is not explicitly stated in BBR, aside from criterion on maximum installed electricity power for space heating and an average area-weighted U-value of the envelope. It is also an aspect which is becoming increasingly important due to the energy systems problems with power and capacity shortage, and for limiting increased GHG emissions that new buildings entails. However, calculation procedures evaluation criterions can be doubted for several reasons, described below.

The definition of the indicator creates uncertainties. While it is called *Heat power demand*, the defining equation is based on heat losses. This may be true if all forms of heat gains are set to zero, but buildings usually have a base load which could be considered, especially when ventilations systems are on (i.e., has the presence of occupancy). Also, there is an erroneous definition when compressor energy of exhaust air heat pump is included as a form of heat recovery.

Another aspect is that the building's heat loss coefficient is normalized by division with the envelope area. The compactness of a building, measured with the Heat Loss Form Factor (HKFF is the ratio between envelope and heated floor area), affects heat losses. A compact building with low HKFF, reduces losses. Normalization with envelope area allows less energy-efficient buildings to fulfill the criteria, in contrast to reducing losses on basis of heated floor area. Moreover, envelope area can be complicated to calculate for buildings with complex facades. But this could perhaps be one way to avoid that the indicator drives building design towards buildings with low ceiling heights and low slab/intermediate floor thicknesses, such as made of wood instead of concrete.

The geographic factor F_{geo} is included in the criteria to consider the location of the building (see **Table 3**). The geographic factor comes from building regulations [13] for adjusting *energy* requirement depending on location varying between 0.8 in the south and up to 1.9 in the north. The reference value in which F_{geo} is equal to 1.0 is for Stockholm. However, energy and power demand for a location are not necessarily proportional. Kiruna in the north has the F_{geo} value of 1.9, meaning that a similar building situated in Kiruna or Stockholm will have an annual space heating requirement with the ratio of 1.9/1.0, implying that the building has the same heat loss coefficient at both sites. Now, if the space heat losses are calculated on basis of design indoor temperature 21°C and DVUT (assuming a time constant of 1 day) for Stockholm and Kiruna, -15.5 and - 30.0°C respectively, a ratio of 1.4 is obtained; Kiruna obviously has higher heat losses. So far, the heat loss coefficient ratio for the buildings is 1 (implying that the cost of building construction is the same), while noting that the ratios between energy and power demand are not the same.

If a heat demand criterion is set the same at the two sites, the heat loss coefficient ratio of 0.72 (= 1/1.4) is obtained, indicating that buildings in the north must primarily have increased insulation thicknesses (thus reducing energy losses, too). The introduction of F_{geo} (based on energy) in MB criteria for power demand changes these ratios. To fulfill the criterion, the heat loss coefficient ratio becomes 1.36 (= 1.9•0.72), indicating

that buildings in northern Sweden meet this indicator criterion easier than buildings in the south. This may seem unfair, but it is noteworthy that the south is much more densely populated and the north is the big producer of hydropower and bio mass, with larger access to primarily electricity power.

The relationship between DVUT and the time constant of the building comes from SS-EN ISO 15927-5 [12]. Yet, the theories behind the standards have not been documented in a scientific way: the authors have not been able to find reports, peer-reviewed articles etc. on the topic. Nor has research been carried out to test and validate these concepts. Same criticism has been forwarded in view of building simulation tools standards [14]. Some inconsistencies can be noted: In order for heat to be stored and retrieved from building components, the indoor temperature must be able to fluctuate. However, calculation routines prescribe the use of a design indoor temperature that should be no lower than 21°C. Meanwhile, the time constant of the building is related to the response of the building subjected to a constant cold outdoor temperature, if the heating system is shut off, and the indoor temperature drops to approximately 63% of the temperature difference between the indoor and outdoor temperatures. It is questionable if the design of buildings with different time constants, in the same location, exposed to the same weather, can be verified, for example by measuring power supply versus outdoor temperature. Neither DVUT nor the time constant are measurable entities. This poses problems for verification, where a proposed method is the so-called energy signature. DVUT also appears in the winter thermal comfort indicator assessment.

Another weakness is that the typical climate of a location used in the indicator criteria is the “average” weather that was measured between 1981 and 2010. This climate format has substituted normal reference climate, based on 1961–1990, owing to climate changes. These climate files are based on previous historical 30 years of data. Given that an energy simulation of the building must be done (see Section 2.4), the same building model can be used for thermal power assessment. Today, this can be performed with the typical climate year, given that the internal and solar gains are set to zero, but it is not clear if this typical climate file contains design outdoor temperatures. Yet, certified buildings will be exposed to a future climate. Accordingly, predictive simulations should consider future weather exposure; not mean values of historic climate. A proposal is that extreme winter and summer conditions be projected in a design reference climate for designing future building heating and cooling power demand. The importance of using different climate files for various purposes is discussed by Petersen [15].

2.3 Solar thermal load

The purpose is to reward buildings that are designed to limit excessive indoor temperatures and reduce space-cooling requirement during the summer (see **Table 4**). The solar thermal load (STL) is defined as the solar energy that is transmitted through the window and contributes to heating/overheating of the room, based on the unit W/m² (here, floor area of the considered room/zone).

Building type	Bronze	Silver	Gold
Residential	≤ 38	≤ 29	≤ 18
Non-residential	≤ 40	≤ 32	≤ 22

Table 4.
Indicator 2, solar thermal load limits based on zone floor area [W/m²] [5].

Calculations are performed on facades that are oriented to the east, west and/or south. Active/movable shading devices should be activated. An important part of the assessment is to estimate the solar heat gain factor g_{sys} for windows and shading devices, as well as occupant behavior (such as when using curtains). It is important to choose the most critical rooms where occupants stay more than temporarily. Analyzed rooms shall correspond to more than 20% of A_{temp} (total floor area in spaces heated to more than 10°C). Shading from surrounding buildings and vegetation must be considered.

A simplified method in MB is utilized unless more detailed simulation tools are available. STL is for rooms with window in one orientation, assuming solar irradiation 800 W/m² onto vertical surface, calculated according to Eq. (1):

$$STL = 800 \cdot g_{sys} \cdot \frac{A_{glass}}{A_{room}} \quad (1)$$

A_{glass} is glazed area and A_{room} is the floor area of the room. In the event that the room has windows in two orientations, Eq. (2) is used (supposing 560 W/m² solar intensity) where *S or E or W* depicts glazing area to the south, east or west:

$$STL = 560 \cdot g_{sys} \cdot \frac{A_{glass} \cdot S \text{ or } E \text{ or } W}{A_{room}} + 560 \cdot g_{sys} \cdot \frac{A_{glass} \cdot S \text{ or } E \text{ or } W}{A_{room}} \quad (2)$$

Depending on results from the two STL-equations, the highest value should be chosen for evaluation of reward according to **Table 4**.

This indicator has the aim of reducing solar loads primarily through passive means. It is closely linked to Indicator 10 *Thermal climate in summer*. Though this rating is quantified as heat load, it is only a part of space cooling demand. Yet, an annual building energy simulation must be performed (see Section 2.4), in which the space cooling energy demand is simulated. Internal heat gains are suggestively a larger problem when it comes to creating cooling demand and is not addressed in this indicator – thus questioning the weighting of this indicator in comparison to the other three within the energy area.

As previously mentioned, buildings should be designed in view of future climate projections. Though the solar intensity will probably remain unchanged in the future [15], the outdoor temperature will rise. This will significantly increase cooling requirement. The authors suggest that this indicator focus more on space cooling requirement, also considering internal heat gains, cool recovery from exhaust air, minimizing solar heat gains (as now) and have calculations based on projected future heat waves. Though energy implications are included in Indicator 3 *Energy use*, this indicator should combine attempts to reduce solar and internal heat gains. An option is to exclude it, or integrate it with Indicator 10 *Thermal climate in summer* addresses STL issues, see Section 3.3. As of today, this indicator has the same weighted importance as the other three energy indicators – and should probably not.

2.4 Energy use

Swedish regulations have historically understood that by decreasing energy losses, supply needs will be reduced. Requirements on building envelope component U-values and heat recovery from exhaust ventilation, rendered reduced supplied thermal power demand and thermal energy use. Building regulations have previously been

based on the concept of specific energy use (i.e., purchased energy). In being an EU member state, building regulations have harmonized with EU formats using the concept of primary energy. In essence, the basis for the primary energy number (EP_{pet}) is specific energy use entities, multiplied by a weight factor (not primary energy factor) for each energy carrier, according to the building regulations, see Eq. (3).

$$EP_{pet} = \frac{\sum_{i=1}^6 \left(\frac{E_{sh,i}}{F_{geo}} + E_{sc,i} + E_{DHW,i} + E_{fe,i} \right) \cdot WF_i}{A_{temp}} \tag{3}$$

where.

- $E_{sh,i}$ is space heating energy from energy carrier i [kWh/a];
- $E_{sc,i}$ is space cooling energy from energy carrier i [kWh/a];
- $E_{DHW,i}$ is domestic hot water heating from energy carrier i [kWh/a]
- $E_{fe,i}$ is facility energy from energy carrier i [kWh/a];
- WF_i is weight factor for energy carrier i [1].

The weighting factors are for building regulations imposed in 2020 as follows: electricity 1.8; DH 0.7; district cooling 0.6; solid, liquid or gaseous biofuels 0.6; fossil oil 1.8 and fossil gas 1.8 [13].

The upper limits for detached houses are 90–100 kWh/(m²•a) depending on size, 75 kWh/(m²•a) for multi-family buildings and 70 kWh/(m²•a) for non-residential buildings. The limits may be increased if the activities within the building require enhanced ventilation rates (for hygienic and health reasons). There are also limitations on maximum electricity power for heating purposes and mean envelope U-values (0.30, 0.40 and 0.5 W/(m²•K)), respectively for the building types. **Table 5** displays MB’s reward criterions.

Energy use of new buildings has to be predicted with a whole-building energy simulation software that calculates time step of one hour or less, using a typical year climate file for the location. The monitoring plan in **Table 5** requires sub-metering so that space heating, heating of ventilation air, DHW heating, space cooling, facility energy (electricity) and in non-residential buildings the business/service activity electricity can be determined. Monitored values must be normalized for comparison and verification with BBR requirements.

Building type	Bronze	Silver	Gold
Residential	≤ BBR’s requirement validated with measured energy use. A monitoring plan. Management routines for energy use follow-up.	Bronze + ≤ 80% of BBR’s requirement validated with measured energy use	Bronze + ≤ 70% of BBR’s requirement validated with measured energy use
Non-residential	≤ BBR’s requirement validated with measured energy use. A monitoring plan. Management routines for energy use follow-up.	Bronze + ≤ 70% of BBR’s requirement validated with measured energy use	Bronze + ≤ 60% of BBR’s requirement validated with measured energy use

Table 5.
Indicator 3, energy use requirements [kWh/(m² a)] [5].

In the process of harmonizing building regulations to EU formulations, Swedish regulations had to impose criteria in terms of primary energy and derive a definition of Nearly Zero Energy Buildings (nZEB). The weighting factors (see Eq. (3)) were introduced in BBR 25 in 2017 and have undergone changes until BBR 29 in 2020. These can be seen as partially politically determined as they do not fully reflect differences in primary energy of energy sources. This is partly due to disagreements on how to calculate primary energy factors in district heating and cooling, from bio energy from forest residuals, waste to energy and free cooling (also to discourage direct use of fossil energy, oil and fossil gas were assigned factors equal to electricity). A stated aim has also been to derive values which are more “technological neutral” and “cost optimal” [16].

The relationship between BBR’s weighting factors for electricity and district heating ($1.8/0.7 = 2.6$) “coincides” with Boverket’s outmoded experience of average seasonal coefficients of performance (SCOP) for heat pumps, though with the ambition to be technology neutral. However, this value is considerably lower than the design SCOPs of most modern heat pumps. Below, an example of a real building is presented to illustrate how the building regulations influences how much primary energy is potentially available for space heating, depending on choice of heating system.

For Strömsbro school in Gävle, BBR 29 [11] sets a nominal maximum value for EP_{pet} 70 kWh/(m²•a) (see Eq. 3), with adjustments for increased ventilation which are omitted in this case. The following energy use parameters are prescribed (note that a factor called MBN is introduced here, which quantifies the percentage of BBR value needed to get a reward, see **Table 5**):

- $E_{DHW,i}/A_{temp} = 6.0$ kWh/(m²•a) DHW heating requirement;
- $E_{fe,el}/A_{temp} = 11.1$ kWh/(m²•a) facility electricity;
- $E_{sc,il}/A_{temp} = 0$ kWh/(m²•a) space cooling (low summer activity);
- MBL MBs levels, 1 = Bronze, 0.7 = Silver and 0.6 = Gold;
- $F_{geo} = 1.1$ for Gävle.

Eq. (3) can be rewritten for DH (Eq. (4)) and heat pump (Eq. (5)) heated building. The heat pump efficiency is estimated by varying three SCOPs (set to 3, 4 or 5). The three values can reflect different company products, different technologies (for example ground source or ambient air source heat pumps). Since the heat pumps also heat DHW at higher temperatures, the value of SCOP has been reduced with 0.5 units. Eqs. (4) and (5) establish available space heating requirement that is left, given the prescribed values for other variables expressed above.

For DH, the maximum allowable space heating energy use is expressed as:

$$\frac{E_{sh,DH}}{A_{temp}} = \frac{\left(EP_{pet} \cdot MBL - \frac{E_{DHW,DH}}{A_{temp}} \cdot 0.7 - \frac{E_{fe,el}}{A_{temp}} \cdot 1.8 \right) \cdot 1.1}{0.7} \quad (4)$$

For heat pumps, the remaining energy use for fulfilling requirement is as follows:

$$\frac{E_{SH,HP}}{A_{temp}} = \frac{\left(EP_{pet} \cdot MBL - \frac{E_{DHW,HP}}{A_{temp} \cdot (SCOP - 0.5)} \cdot 1.8 - \frac{E_{fe,el}}{A_{temp}} \cdot 1.8 \right) \cdot 1.1 \cdot SCOP}{1.8} \quad (5)$$

Results in **Table 6** indicate that it is easier to fulfill energy requirement limits with an efficient heat pump than DH. This implies that heat pump heated buildings can

Energy carrier	BRONZE [kWh/(m ² •a)]	SILVER [kWh/(m ² •a)]	GOLD [kWh/(m ² •a)]
District heating	72.0	39.0	28.0
HP SCOP = 3	83.8	45.3	32.5
HP SCOP = 4	114.7	63.4	46.3
HP SCOP = 5	145.5	81.3	60.0

Table 6.
Available energy use for space heating for a kindergarten in Gävle, given that other energy entities are prescribed, heated by DH or heat pump (HP) with SCOP = 3, 4 and 5, respectively [5].

fulfill energy requirements with low insulation levels in the envelope and/or ventilation and air infiltration losses. However, this problem does not come from MB – this indicator is directly based on BBR’s calculation methods and weighing factors. As long as this bias exists in BBR, it will be reflected in MB, unless MB sets more stringent requirements than BBR. However, it should be noted that other limitations in BBR restrict supplied energy (such as the envelopes average U-value and electricity use for heating purposes).

2.5 Share of renewable energy

The purpose of Indicator 4 *Share of renewable energy* is to reward buildings that request and use energy from renewable sources. The share of renewable energy used during one year is evaluated and results from the energy use simulations (Indicator 3) are used as input. Analysis is performed on building energy use (heating, cooling and management/facility energy) and for non-residential buildings, the business/activity energy, too (electricity). Household energy/electricity may be included in the case of residential buildings. Climate compensation energy is excluded.

The provided tool categorizes energy source in three categories as follows:

- *Category 1*, renewable energy from flow resources: Solar energy from solar collectors or photovoltaic cells; wind and hydropower; residual heat which if unused would be lost and cannot be used within its own process or product.
- *Category 2*, renewables from fonds resources: biomass; fuels with organic origin.
- *Category 3*, non-renewable energy: Energy originating from natural gas, oil, peat, nuclear (uranium); fuels with fossil origins, such as fossil plastic in waste; energy of unknown origins.

Criteria for rewards are presented in **Table 7** and instructions state some definitions. These are, coarsely summed up, as follows:

Gold requires *locally* generated and *new* renewable energy from flow sources as in Category 1 and considers only the energy that is used within the building. The term *new* is not clearly defined, but could be interpreted as coming from newly or planned built renewable energy sources. For cooling energy, electricity or district cooling energy should be categorized according to origin.

The energies origin for electricity from the grid is classified according to Energimarknadsinspektionen’s (the Swedish Energy Market Inspectorate) guarantee of origin. Electricity originating from solar-, hydro- and wind power are renewable and flowing. The Nordic residual mix is the produced electricity that is not sold with

Building type	Bronze	Silver	Gold
Residential and non-residential	> 50% of used energy is renewable. Guarantee of origin of electricity and allocated DH is accepted.	Alternative 1: > 75% of used energy is renewable whereof >10% is from flow sources. Alternative 2: > 80% of used energy is renewable. For both alternatives: electricity has guarantee of origin and third-party review of allocated DH is accepted.	> 80% of used energy is renewable, whereof >5% is from local flow source and used in the building. Electricity has guarantee of origin and third-party review of allocated DH is accepted.

Table 7.
Indicator 4, requirements on shares of renewable energy [%] [5].

guaranteed renewable origin. The Swedish Energy Market Inspectorate provides annual information on its shares.

The origin of the energy that is supplied by the specific DH system is classified depending on fuel mix. Only the origin is assessed; not technical solutions or equipment in neither building nor DH system. Allocated DH shall be checked by an environmental auditor. The energy supplier shall guarantee that it will be available for at least three years. Consequences of the residual’s constituents are accounted, i.e., DH which is not sold with guaranteed origins. For Silver and Gold, allocation and residual must be reviewed by a third party. For heat pumps in the DH system, energy supplied to heat pumps, excluding electricity, will be allocated in Category 1. Electricity to heat pumps are allocated depending on origin. Energy with unknown origin is classified as non-renewable (category 3) and electricity as Nordic residual mix.

Origin-labeled or allocated energy is verified with contracts, invoices, etc. Solar collectors or photovoltaics can be verified with photo or as-built documents. The intentions of awarding the use of renewable energy and specifically to encourage establishment of new renewable production units, is appropriate, such that energy use of new buildings will not burden the existing energy production systems. If origins of electricity will result in expanding electricity from renewable sources can on the other hand be discussed. As long as not all the renewable electricity produced is bought with green certifications it will not have much influence over the energy production.

The three categories could also be discussed from an environmental point of view. Should a more differentiated categorization represent the actual environmental impact from different energy sources be more appropriate, transparent and meaningful? Both life cycle assessment data for different energy sources and the energy efficiency in the energy production process could be included. The differences between different systems can be very large. For example, the lifecycle estimates of GHG emissions from wind power and coal is 10 gCO₂e/kWh vs. 1050 gCO₂e/kWh [17]. Variations can also be large between the environmental loads from the same type of energy generator depending on the source. For example, photovoltaic panels (PV panels) can have very different GHG emission impact if produced with coal in China or with the Swedish energy mix in Sweden.

3. Indoor environment aspects

Eight indicators related to the indoor environment are included in MB; Noise, Radon, Ventilation, Moisture safety, Thermal climate in winter, Thermal climate in

summer, Daylight and Legionella [5]. The focus in this part is the ventilation, thermal comfort and daylight.

Several of the environmental indicators have a synergy and affect each other as well as energy indicators. For instance, ventilation can affect the indicators for energy (both the heating load and energy use), radon content inside the building, thermal comfort both in summer and winter, the noise level (due to the running fan and ducting networks in the ventilation system) and the logbook of the material (choice of environmentally friendly material for the ventilation system). Therefore, the ventilation system is a decisive indicator for the total grading of the MB assessment.

3.1 Ventilation

In a building, the ventilation system has the role of regulating and ensuring optimal indoor air quality and good thermal comfort. In terms of air quality, the uncertainty is greater when it comes to people's experience than for the thermal climate. However, there is no doubt that the quality of the indoor air is of great importance for comfort, health and performance. The balance between air quality and thermal comfort depends on a number of factors, which includes thermal regulation, control of internal and external sources of pollutants, air change rate, air distribution system, residents' activities and preferences, and reasonable operation and maintenance of the building system [18]. Guidelines for good indoor air quality have over the years often specified the highest acceptable levels of a wide range of airborne pollutants, such as dust content, CO₂, volatile organic compounds, microorganisms. However, very few unambiguous correlations have been found between pollution levels and symptom outcomes for the low-dose range to which people in non-industrial premises are usually exposed. For human-generating pollutants (so-called bio effluents), CO₂ content is often used as an indicator. Studies show that for larger populations, the number of dissatisfied users is 14% if all people are exposed to a CO₂ content of 800 ppm [19].

The ventilation indicator in MB assesses the building's ventilation solution and the purpose of the indicator is to reward buildings with good air quality. For ventilation, there are both minimum flow requirements as well as CO₂ level limits in MB. In residential buildings, the focus is on minimum flow rate and in non-residential buildings, both flow rate and air quality (CO₂ levels) are emphasized.

In new residential buildings, the minimum requirement is providing at least 0.35 l/sm² (A_{temp}) outdoor fresh air by the ventilation system. In non-residential buildings, 7 l/s per person should be added and to get higher grades. For Silver and Gold, CO₂ level should not exceed 1000 and 900 ppm respectively, except for temporary occasions. If the ceiling height in non-residential buildings is more than 3 m, smaller flow rates can be accepted if the CO₂ levels are within the accepted limits. In addition, the 1000 ppm CO₂ limits is per room and for the number of occupants the room is designed for [5]. The grading criteria for indicator of ventilation is shown in **Table 8**.

In addition, for the ventilation of wet rooms such as kitchen, bathroom, washroom and toilet, the minimum exhaust flow is 10 l/s. Moreover, for kitchens, there should be a minimum 10 l/s flow with at least 75% capture efficiency for the air pollutions and contaminants emitted during cooking and food preparation. The capture efficiency limits require efficient ventilation hoods equipped with carbon filters or other type of filters, which in turn may lead to larger fans with higher power and energy use. Thus, it will be more challenging to get a higher grade for the ventilation indicator and at the same time get higher grades for energy indicators.

Indicator 7	BRONZE	SILVER	GOLD
Residential building	Fresh outdoor flow rate $\geq 0.35 \text{ l/s}\cdot\text{m}^2$ A_{temp}	Bronze +	Silver +
	Building care-taking routines for control of air quality.	Exhaust flow in kitchen according to Table 3 .	Exhaust flow in kitchen according to Table 3
			Approved questionnaire or measurement.
Non-residential buildings	Fresh outdoor flow rate $\geq 7 \text{ l/s}$ and person $+0.35 \text{ l/s}\cdot\text{m}^2$ A_{temp} . Building care-taking routines for control of air quality.	Bronze + CO2 concentration in the room should not exceed 1000 ppm except in very temporarily occasions	Silver + Alternative 1: Approved questionnaire. Alternative 2: Locally measured ventilation index $\geq 90\%$ in the occupied room Alternative 3: CO2 concentration in the room should not exceed 900 ppm except in very temporarily occasions.

Table 8.
The grading criteria for Indicator 7 ventilation [5].

According to **Table 8**, in order to get Gold, the criteria for Silver must be fulfilled and a questionnaire should be provided among the building users or to have measurement of ventilation index. This additional criterion is important and well-suited since specifying required ventilation rates cannot guarantee an adequately low exposure to indoor pollutants. Guidelines by The Swedish Work Environment Authority address the important question of efficient air distribution. In addition, dissatisfaction with the quality of the indoor air cannot only be explained by incorrect ventilation, but also by the fact that the activities in the building/room could have changed after the design.

Ventilation index is a measure on how well the interior is ventilated and is defined according to Eq. 6 below:

$$\varepsilon_c = (C_e - C_i) / (C_{sp} - C_i) \cdot 100 \text{ (\%)} \tag{6}$$

C_{sp} = set-point value of the average pollutant concentration in the occupied zone, ppm or $\text{mg}\cdot\text{m}^{-3}$.

C_i = pollution concentration in the supply air, ppm or $\text{mg}\cdot\text{m}^{-3}$.

C_e = pollution concentration in the exhaust air, ppm or $\text{mg}\cdot\text{m}^{-3}$.

ε_c = the ventilation index or ventilation effectiveness for contaminant removal.

Ventilation index is 1.0 for perfect mixing condition because the concentration in the exhaust is the same as in the whole occupied zone. Ventilation index below 0.9 indicates ill-functioning air distribution in the room such as short-cuts and stagnation zones. To be able to get Gold for the ventilation indicator, the measured ventilation index should be more than 90% in the occupied zone. Alternatively, for the non-residential buildings, the measured CO₂ levels should be below 900 ppm. As many building energy simulation programs assume a well-mixed condition, which is not the case for stratified systems, it is suggested to prioritize measurements. Stratified

ventilation is a concept that often creates high ventilation effectiveness (ventilation index over 1.0) and good indoor air quality [20–23]. There are many different air distribution strategies creating stratified conditions, such as impinging jet ventilation, displacement ventilation and confluent jet ventilation. These systems have the potential to create better air quality than mixing ventilation or the same level of air quality as mixing ventilation but with lower air flow rates and hence energy use [24–26]. Personalized ventilation systems have even higher effectiveness with the possibility to achieve ventilation effectiveness above 3 [27].

The recommended/minimum air flow rates given in the European standard EN 16798.1 [28] and MB assume complete mixing in the room. For non-residential buildings ventilation rates could be adjusted by the ventilation effectiveness in accordance with the European Standard EN 16798–3 [29] if the air distribution differs from complete mixing. However, this is not allowed in MB, which is one weakness.

Ventilation unit or the air-handling unit affects the electricity load and the heating power demand (due to possible heating coils). The deciding parameters are the operation schedule, the specific fan power (SFP), flow rates and heat recovery. To guarantee an acceptable indoor air quality it is not possible to compromise on the ventilation requirements. However, a time-controlled ventilation system is more efficient and can save energy together with heat recovery from the exhaust airflow. Thus, effective and energy efficient ventilation systems (with low SFPs and higher heat exchanger efficiencies) are essential in order to get higher grades for MB indicators. To remove the contaminants and pollutants from the interior, it is also important to get the filters cleaned and have it instructed in the building care-taking schedule. Such routines and instructions can be implemented in the compulsory ventilation control protocol (OVK) of the building [30].

Uncontrolled ventilation through air leakages is not included in the indicator. Air leakage influences ventilation and stands for a part of transmission losses and affect the heating power indicator as well as the total energy use [31, 32]. Building air tightness is not directly defined in the Swedish building regulation codes and it is not specified in this indicator. It can also increase the heating power demand and building energy use. Thermal comfort especially during winter can be affected due to possible draft and unwanted cold airflow from outdoor connected leakage and openings to occupancy zone. Therefore, it is suggested to add airtightness as a separate indicator, expecting minimum air tightness for newly and modern building and rewarding airtight building. An airtight building can decrease the energy use throughout the year while maintaining the thermal comfort level. In addition, it is suggested to perform airtightness measurement during the building process so that the possible leakage can be detected and get fixed with the minimum costs. This should be implemented in the regulations and criteria so that it can be verified and followed later on. Air leakage does also affect the ventilation designed flow and pressures and there is not any guide or recommendations on that. An indicator for air tightness, which can be merged with the indicator for ventilation into one aspect for ventilation would therefore be appropriate.

In addition, possibilities of airing, i.e. opening external doors and windows is important to occasionally introduce extra fresh air. This is considered for ventilation of bathrooms. However, it can be also considered for the main occupancy rooms. Airing is used also as a cooling method to adjust the inside temperature and in this case, it saves cooling energy; however, in the heating season, airing will increase the energy use by at least 4 kWh/m² and year [8, 9].

3.2 Thermal climate in winter

Thermal climate in winter, indicator 9 in MB, is essential in cold climates like in Sweden, and linked to the indicator *Heat power demand*. The assessment in MB is based on the predicted percentage of dissatisfied (PPD) index with DVUT. PPD is an estimation of the occupants' dissatisfaction of the thermal climate. Generally, PPD should be kept below 20% and there is always a minimum 5% PPD, i.e. there are at least 5% of the occupants who feel dissatisfied in an occupied room ASHRAE 55 and ISO 7730 [33, 34]. In the thermal comfort calculation, the so-called operative temperature, is approximately an average between the room air and the internal surfaces temperatures in the room. For PPD calculation, the operative temperature should be calculated for a point in the occupied room that has the highest risk for thermal discomfort. Such position can be 1.0 m away from the largest window and between 0.6–1.7 m over the floor. Moreover, the occupants clothing insulation (clo) and the metabolic rate (metabolic equivalent of task, met) affect the PPD. It can be considered, as 1.0 clo (a person with T-shirt and trousers) and 1.2 met (for a sitting person) if not detailed information is available. Building energy simulation programs such as IDA-ICE, EnergyPlus and DesignBuilder can be used for PPD calculations.

To get the Bronze grade, the PPD should be less than 15% with DVUT, and building care-taking routines should be provided to control the thermal climate and thermal comfort in winters. The routine should include the function of the heating system, control measurement of the temperature, user questionnaire or manuals to fix the issues leading to possible complaints (regarding the thermal comfort). The PPD should be calculated for a critical room located on a top floor with steady occupants the PPD can be calculated for several rooms and the critical rooms with highest PPD numbers can be chosen to fulfill the criteria.

For Silver grade, the PPD should be less than 10% with DVUT and for Gold, a questionnaire or measurement should be provided. The questionnaire and measurement are done during a year with its specific weather, however, PPD is calculated within the design temperature, DVUT. The weather during the measurement year might be quite different from a normal year, and this would affect the thermal comfort results.

A building has the capacity to store heat and release it when it gets colder, thus it affects the choice the DVUT within the same climate, i.e., a heavier building can withstand more temperature variations than a building with less thermal mass. For calculation of DVUT the building thermal mass is considered as one day and night (24 hours) and without the heating gain from solar and the internal loads (occupants, devices and lighting). Thus, it has been considered a worst scenario, i.e., the building is considered light and one of the reasons is that the thermal comfort should be measured in individual rooms (with lower thermal mass in compare with the whole building) and not for the whole building.

Unwanted cold air movement is called downdraft and might worsen the thermal comfort especially during winter. Air speed is specified and measured in the occupancy zone, 0.5 m inside of wall/window. In the simulation models, it is considered as 0.15 m/s for air speeds in the occupied room, but temporarily, there might be higher air speeds for instance if the person is sitting too close to a window with downdraft especially during colder periods. This will also lead to an increase in PPD and thermal dissatisfaction, however, it is difficult to simulate draft and more detailed CFD simulations would be needed.

3.3 Thermal climate in summer

Thermal climate in summer is decided based on the PPD index in a critical warm and sunny day. The assessments can be based on indicator 2, solar heat load together with the building management routines. For Bronze, Silver and Gold grades, the PPD should be less than 20, 15 and 10% with the most critical conditions, respectively. To get Silver, the building should be equipped with openable windows and doors (in residential buildings) and to get Gold, questionnaire or measurement should be provided [5].

For building without cooling facilities, the grading for the thermal climate in summer is referred to indicator 2, which is about reducing solar heat loads during the summer. For buildings without cooling system, the critical room should have internal loads (occupants, appliances and lighting) below 20 W/m^2 . The PPD should be calculated for a critical room located on a top floor with steady occupancy; the PPD can be calculated for several rooms and the critical rooms with highest PPD numbers can be chosen to fulfill the criteria.

Having smaller windows would lead to less solar heat gain during summer and improve the grade for indicator 10. However, the smaller window size would also decrease the received daylight, which makes it more challenging to get enough daylight. In addition, it will decrease the building's purchased heating energy during winter and hence benefit indicator 3, the energy use. There might be a balance between the window size and the related indicators for solar heat gain, energy use, thermal climate and daylight. Research studies have shown that, the building equipped with modern windows (lower U-values and transmission losses as well as higher visible light transmittance) can have higher window areas and still fulfilling the criteria for both solar heat gain, thermal comfort and daylight requirements [35]. Also airing possibilities should be limited to the time when the indoor temperature is lower than the outdoor. For instance, in case of heat waves, it is better to have the windows closed during the daytime and instead, if possible, have them opened during the night, when it is cooler, i.e. night cooling ventilation [36].

One problem and weakness with the requirements for Gold is that the questionnaires and measurements are done during a specific summer with its specific weather, whereas, calculations are performed using historical weather data (normal year based on 1981–2010). This means that the fulfillment of Gold depends much on how warm the hottest day, in relation to the normal year, have been for the specific summer the measurements or questionnaires have been performed. Therefore, it is also suggested for the design and calculation of indicator Thermal climate in summer to use more extreme summer conditions than the typical year based on 1981–2010.

3.4 Daylight

The windows in the building, their location, size, light transmission factor and U-value, have a large impact on the daylight condition, the solar heat load, energy use and indoor comfort discussed earlier. They also influence the indoor light quality in the building, which affect the people using the building. Human eyes have evolved in sunlight and therefore responds much better to it than artificial light. In addition, it can be troublesome for people to work in a room without windows with no awareness of the weather and contact with the outdoors. We spend around 80–90% of our lives within buildings and numerous research studies have demonstrated and indicated that glazing has profound implications in terms of human health, happiness and

productivity [37–40], and in northern countries lack of daylight can lead to Seasonal Affective Disorder (SAD), a syndrome characterized by recurrent depressions that occur annually at the same time each year which is affected by access to daylight [41].

In MB, indicator *Daylight* demands that the interior of the building should be provided with acceptable access to daylight. The daylight access is assessed by calculation of window to floor ratio, simulation of the daylight factor (DF). For some buildings, sales halls and halls, daylight is assessed by calculation of the percentage of the outlook area. For non-residential buildings, building caretaking routines should be also provided. The requirements are minimum DF of 0.8% for Bronze, 1.0% for Silver and 1.3% for Gold. The DF, is a measure of the luminosity indoors in relation to the outdoors with a standard gray sky, according to CIE Overcast Sky in ISO 15469: 2004 [42]. For simulation, it is required to know the window's glass size, location, light transmittance, reflection, floor area and room geometry, distance and height of surrounding buildings, exterior shadings, fixed screens, etc. The surrounding buildings and planned buildings according to the municipality's detailed plan should be also considered in the simulation.

Percentage of outlook area (with view to the outside) can be applied for workplaces in sales halls and halls (rooms with high ceilings that are intended for, e.g. sports, warehouses, trade fairs, light industry and logistics) and associated facilities that are only used temporarily. Then the proportion of view area (outlook area) is defined as being able to look out with 5° or more indoors at a height of 1.5 m, both horizontally and vertically. Floor area where these conditions are met is defined as the view area or outlook area and is expressed as a proportion of the whole floor surface.

Daylight affects the total energy use in a building as the penetrated light into the building will turn into heat and increase the internal gain. This will lead to a decrease of heating demand in the heating season and increase in the cooling demand in the cooling season. The heated parts inside the building will get higher temperatures, and in addition, the air around the floor areas will be warmed up and create plumes which also affect the thermal comfort especially during the summer season. The same phenomena might improve the thermal comfort during the winter period.

Increased glazing area will lead to more daylight. However, the transmission losses through the windows will also be increased. Thus, there is a trade-off between the glazing area (which transmit the daylight) and the total energy use, thermal comfort and solar thermal load. The buildings equipped with new modern windowpanes with lower U-values and transmission losses as well as higher visible light transmittance, can have higher glazing areas, providing more daylight with acceptable thermal comfort during summer and at the same time keeping the energy use low [35]. Obviously, this comes with the penalty of higher initial cost of the windows.

The criteria in MB regarding daylight can be difficult to reach if designing and building a thick/deep building where the rooms are deeper than 6 m. Even though median DF can be used as indicator, it can be difficult to compensate the lack of daylight in the rooms with light areas closer to the windows. Getting enough daylight can also be a problem for tall buildings located in dense and highly populated city districts with narrow streets. Alternatively, if large balconies are blocking light from the sky. In addition, for residential building, some rooms such as bedrooms are protected so that the interior cannot be viewed from the neighbors and the privacy can be obtained. In such cases, if there are surrounding buildings, it will be challenging to receive enough daylight especially for rooms located in the lower floor levels.

It can therefore be discussed if it could be possible to adjust the indicator and focus on daylight demand in the rooms where there is less demand of privacy and accept lower DF in other rooms. Then rooms where people spend most of their awake time at home, like the dining or living rooms, would have to meet high DF criteria. A total median or medium DF in a whole apartment could also be another way to make the indicator more flexible. However, a risk could be that rooms with very poor DF conditions would be designed and built. The occupants view on the daylight could also be asked via questionnaires, especially in the rooms with low DF levels.

Internationally, there are examples that the limit values for sufficient amount of daylight are set differently depending on room and building function as opposed to the static approach, which is used in MB [43]. The indicator could also develop to use more dynamic daylight performance metrics that consider the quantity and character of daily and seasonal variations of daylight for a given building site [44]. Today the criteria are the same for a building independent if it is located in the northern and southern Sweden. Hence, one should consider implementing a more dynamic approach for daylight in MB.

4. Material aspects

In the material area, indicator 15 *The structure and foundations climate impact*, is a new indicator in MB added in v3.0 year 2017 [45], where the GHG emissions from main building structure is taken into consideration. Embodied GHG emissions is the amount of CO₂e emitted to produce a material, product, or building. As the embodied GHG emissions of buildings are responsible for a large proportion of the environmental impact from buildings with a relative importance of 20–50% of the life cycle GHG emissions [46], this indicator can be of great importance. It can help to shift the focus in the buildings sector from efficiency in operation towards a life cycle perspective, which is necessary according to several studies that have demonstrated the importance of the embodied GHG emission [47]. The aim of indicator 15 stated by SGBC is to increase the knowledge of the load bearing horizontal and vertical structures climate impact, increase demand and supply of EPDs, and reward measures that reduce the environmental impact of the load bearing structures [5]. Included in the indicator's calculation are the GHG emissions from the first life cycle stages of the building products (Stage A1-A4 according to EN 15978, **Figure 1**) [48] that are used in the main structure, (the loadbearing vertical and horizontal structures) and the foundation down to the drainage layer.

For the grade Silver and Gold, emissions from transports (Stage A4) are included as well as a requirement that a certain part of the life cycle analysis data comes from EPDs (Environmental Product Declarations). Gold rating requires proving of reduction of GHG emissions by at least 10% lower than the Silver level for the already chosen building design, frame and foundation. This can be done, for example, through changes of material choice, dimensions or quantities in the load-bearing structure.

4.1 No absolute criteria for embodied greenhouse gas emissions

When analyzing what impact the indicator has on greenhouse gas (GHG) emissions and energy use, there are a number of issues that can be discussed. To start with the indicator in general, it does not have absolute criteria with a specific absolute level

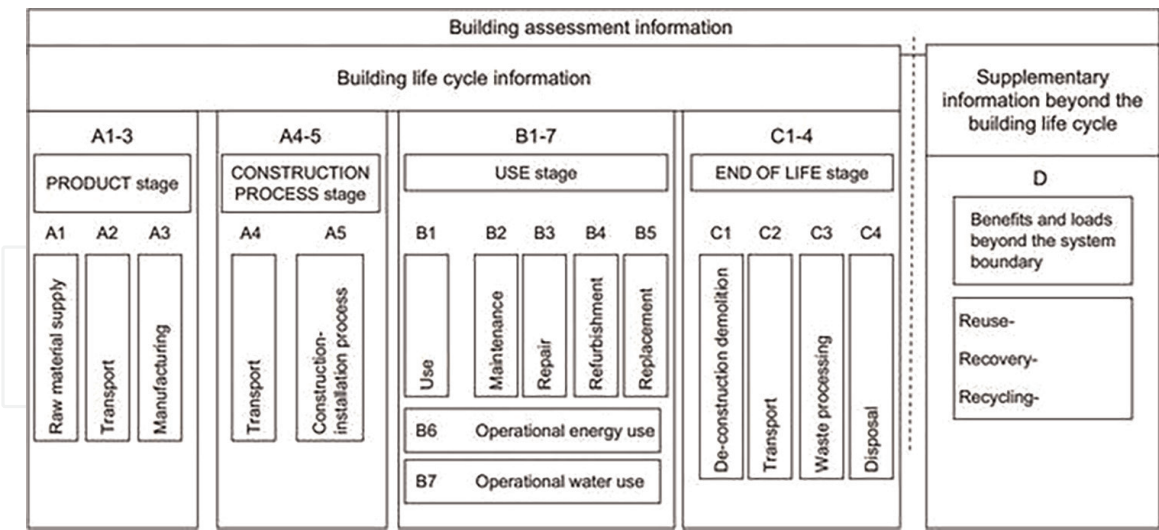


Figure 1.
Building's life cycle stages according to EN 15978 (2011) [48].

of emissions that the building has to meet. This makes it difficult to compare the environmental performance of different buildings. However, for the Gold level is a relative decrease of 10% required. This type of relative criteria that credit an improvement compared to a reference building, is similar to indicators used in the American EAM LEED (Leadership in Energy and Environmental Design) [49] and the British BREEAM (Building Research Establishment Environmental Assessment Method) [50]. Moreover, the decrease is calculated relative to an optional pre-design that can be designed as a worst case scenario with high levels of embodied GHG emissions. Other research show that the GHG emissions from buildings can vary a lot, between 165 and 665 kg CO₂e/m² for residential buildings and 355–580 kg CO₂e/m² for office buildings (first quartile and third quartile) [46]. Therefore, 10% lower GHG emissions than a building with high levels of embodied GHG emissions can still be much higher than the average levels of embodied GHG emissions. At the same time it is difficult to set more absolute targets or criteria as there are many aspects of the design of a building that influence the choice of material and the amount of material needed in the load-bearing structure. The same reason makes it difficult to have a reference building or reference GHG emissions to measure the buildings performance against.

Moreover, for Bronze, only generic data may be used which will not promote choosing materials with lower environmental impact within a product or material group. For Silver and Gold, it is different. Then at least 50% vs. 70% of the climate impact for the production of the building materials need to be based on product-specific EPDs. Then specific products or materials can be promoted. A variety of parameters and methodological choices influence LCA and EPDs. The embodied GHG levels in the generic data used in LCA tools used for the MB assessment is therefore of great importance. Values can vary a lot making the choice of used data important [51]. For example, the median of embodied carbon per kg concrete is equal to 0.19 kg CO₂e/kg, and has rather small variability of outcomes, (the interquartile range varies between 0.14 and 0.28 kg CO₂e/kg), and the interquartile range of structural steel can vary between 1.7 and 2.8 kg CO₂e/kg, with total variation ranging from 0.34 to 4.55 kg CO₂e/kg [52]. The chosen generic embodied GHG emission data for steel can thus

influence if the material is perceived as a more environmental material in comparison to another material with an EPD and what the buildings absolute calculated embodied GHG emissions will be.

4.2 The impact of the system boundary

As mentioned before, buildings embodied GHG emissions represent a large proportion of a buildings total life cycle emissions. In indicator 15, part of this embodied GHG emissions are included as only the load-bearing structure belonging to the frame is accounted for (here meaning load-bearing walls, pillars, beams, floors and foundation down to the drainage layer). Other parts of the building are not included, such as the building envelope or entire internal or external walls. Nor is technical equipment or finishing materials included.

Other studies indicate that variations regarding the embodied GHG for only the structure can be 200–350 kgCO₂e/m² and for the whole building 600–850 kg CO₂e/m² [53]. Thus, the embodied GHG in the structure can, according to this data, represent between 25 and 40% of the buildings total embodied GHG emissions. The embodied GHG emissions from a building can also be influenced by the building's geographical contexts, climate zones and building type [46].

Another system boundary aspect is that all life cycle stages are not included; only stages A1-A4. Other life cycle phases such as maintenance, replacements or end of life, which deals with an uncertain future, are excluded. This is in line with the Cradle-to-Gate approach which is one of the three different life cycle models for buildings system boundary that EN 15978 proposes [54], which is used in EPDs. The other ones are Cradle-to-Grave, which also include buildings use phase and end of life impacts, and Cradle-to-Cradle which include potential benefits of reuse, recovery and/or recycling potentials. One consequence of MBs limited life cycle perspective is that material aspects linked to the future that may influence the environmental impact of a material during the use phase from a 50 to 100 year perspective are not taken into consideration. The benefits with long lasting products with low maintenance and replacement rate are thus not getting any credits. There is therefore a risk that suboptimizations are made. On the other hand is it not possible to have exact data beforehand regarding future management, refurbishments, service and end of life procedures. If not including future lifecycle stages in some way, the indicator does not differentiate between materials that are recyclable and non-recyclable. It is not clear how the environmental impact of recycled and reused products, or the potential benefits with reusing, or recycling the material should be calculated. For the generic data in the tool, materials with recycled content is not an option.

Another issue very close to the system boundary aspect is the room for variations in results when calculating the amount of materials that are included in the load bearing structure. Variations can be based on how detailed the structure is dimensioned, and the marginal regarding loads that has been used, as well as the detailing in calculation, for example if it is based on a BIM model or if it is based on general data linked to square meters of slabs, walls, etc. Variations in how A_{temp} is measured can also influence the results. If a building has a large garage, storage in the attic, or installation/service room for ventilation equipment that is heated above 10°C, it will be included as part of the A_{temp} . The number of square meters in A_{temp} will then increase and lower the calculated GHG emissions from the structure per square meter. This is the effect even though the amount of

useable floor area in the building is the same as for a similar building without the same additional areas.

4.3 The environmental impact of using environmental product declarations

MB clearly states that it wants to promote the use of EPDs, which contain reliable and verifiable LCA-based information as a way to promote more specific and accurate LCA data for used materials. EPDs are in one way essential if wanting to compare and assess construction products environmental performance [55]. It is one way to get the building industry aware of the environmental impact from building products. However, there is no clear cause-effect relationship between environmental impact and use of EPD documented materials compared to materials lacking EPD. On one hand, companies doing EPDs will become aware of the GHG emissions and the EPD can also be an incentive motivating producers to develop and retailers to sell products with lower GHG emissions [56] which may promote development of products with lower embodied GHG emissions. On the other hand, local materials or reused materials produced by small and medium-sized enterprises (SMEs), local companies, or new startups might not have the economic power or see economic reasons for doing EPDs. They could then be outcompeted by other materials and larger companies who are able to put in the necessary investment in doing an EPD, which according to surveys are 13,000–41,000 USD and includes a workload of 22–44 person-days [56]. This can be a substantial cost for SMEs.

4.4 Inclusion of greenhouse gas emissions from transport

To achieve silver or gold Indicator 15 also demands documentation of transport of building material and products with generic information of GHG emissions from trucks, trains, boats and airplanes. This criteria has the potential to make building companies aware of the impact transportation distance and way of transport has on the GHG emissions. However, there are no criteria levels for total emissions from transport and there are no differentiation made between different fuels, even though there is a large difference in emissions from trucks with fossil fuels, bio-fuels or electricity as fuel and also between electric trains and trains using fossil fuels. These differences would be appropriate to include in such a calculation. If this is not included, the indicator will not push the industry towards using transportation methods with low emitting fuels.

4.5 Embodied greenhouse gas emissions benchmarks – next step

With the current situation, Indicator 15 has no direct measurable impact on the lowering the embodied GHG emissions from buildings. The 10% reduction criteria for Gold could give some effect. However, the impact is dependent on what construction material that is used for the optional pre-design building that is improved. Moreover, to understand if this 10% reduction is enough for lowering the GHG emissions from the building structure, one has to look at how much the GHG emission levels for buildings need to be decreased and set benchmarks for buildings. Creating benchmarks is difficult and could be one reason why MB at this stage not has any absolute criteria regarding embodied GHG emissions. Benchmarks can be set in different ways. These can be based on a relative improvement of conventional buildings average GHG emissions. As more and more LCA studies are conducted, this type of data will increase and become more

available, but there have already [57] been attempts to create benchmarks. The Swedish certification system NollCO₂ or the Swiss SIA 2040 [58] are established benchmarks, which could be used. For example NollCO₂ demands a reduction in energy use and GHG emissions from building materials (phase A1-A5) in comparison with calculated project specific reference building based on parameters for building materials and systems. Furthermore, measures to reach net zero through balancing the remaining GHG emissions are demanded [57]. Different types of reference buildings have different GHG emission criteria levels and the specific projects receives a project-specific limit value that is approximately 30% lower than the baseline, which is expressed in kgCO₂e/m² BTA. This varies between 140 and 312 kgCO₂e/m² depending on type of building, layout and design [59]. The Swiss SIA 2040 benchmark is based on the German Environment Agency goal of reducing GHG emissions to 1 t CO₂e per capita per year by the year 2050 [60] to be able to achieve the target of staying below a global temperature increase of “well below 2 °C”. Benchmarks for GHG emissions from buildings represent 36% of these GHG emissions, i.e. 360 kg CO₂e per capita per year. To follow the Swiss SIA with benchmarks with GHG emissions per capita the number of square meters per capita also needs to be decided upon. What would then be a reasonable level number of square meter per capita and for future GHG emission targets for buildings? As an example, four Swedish buildings that have been MB certified had embodied GHG emissions between 110 and 305 kg CO₂e/A_{temp}. It is forecasted that there is a need to build 592,000 new homes until 2029 in Sweden [61], i.e. 65,778 homes per year, for a population that was 10.3 million inhabitants 2020 and is estimated to reach 11 million in 2029 [61]. If each home is 50 m² this would result in 0.3 m² new housing per year per inhabitant and 35–97 kg CO₂e/ year per inhabitant in GHG emissions from the load bearing structure of these houses if built as the certified buildings. If compared to the Swiss SIA carbon benchmarks, GHG emissions from structure of new housing would represent 10–20% of the total GHG emission budget per inhabitant in Sweden. Working with lowering the embodied GHG emissions from building is thus an important issue. Especially in countries like Sweden where the GHG emissions from the average district heating and the Nordic electricity mix is comparably low (0.059 kg CO₂e/kWh [62] vs. 0.090 kg CO₂e/kWh [63], keeping in mind that MB and forthcoming mandatory climate declaration of buildings consider only phases A1-A5.

How and on what level the GHG benchmarks for buildings should be set has not been elaborated on more in this study. However, it can be concluded that to have ambitious and effective climate mitigation targets, it is necessary to develop clear targets that are transparent and consider both embodied GHG emissions and operational GHG emissions. This would be the next step for MB indicator 15 - to ensure that the impact influence building design to lower the buildings embodied GHG emissions. Despite the fact that indicator 15 does not have any benchmark levels at the moment, several certified buildings have only reached the Bronze level. The reason behind this is not clear. If they were searching for a total Gold score, they would have needed to have Silver on this indicator. If fixed benchmarks with GHG emission criteria would be welcomed or not by the buildings sector is difficult to know, but it is not promising when the indicators without benchmarks are not reached.

5. Concluding discussion

This study has scrutinized nine of the indicators with the strongest link to GHG emissions in the Swedish environmental assessment tool MB. It has highlighted a

number of things with the indicators that influence what aspects of building that are assessed and has a potential to also influence the GHG emissions, building design and choice of building systems. It clarifies the strong link MB has to the Swedish energy regulations and how both MBs' and BBRs' energy aspects are linked to the national energy system.

In general, MBs certification system is highly appreciated covering different aspects of the energy use, indoor environment as well as the material choice of the building. The follow-up inspection (within three years after the built/renovation) verify the gained certification grade and guarantee sustainable choices and good performance. Therefore, MB is an effective system with a comprehensive view on environmental assessment of buildings. However, a few limitations with the indicators and how the criteria drive sustainable building design have been identified. To improve the assessment criteria and make it even more handy and applicable the most important conclusions are here presented for the areas Energy, Indoor environment and Material:

Conclusions regarding energy-related indicators:

- The power demand of buildings addressed in MB is important to limit peak demand related emissions. Analysis of quantification methods and the criterions conclude that the unit for quantification, space heat losses divided by envelope area, may lead to less energy efficient building design; design outdoor temperatures or climate files for simulation should be based on future climate projections. The criterions set by MB involve energy factors, which do not reflect power demand.
- The solar thermal load assessment serves to reduce cooling demand. The major criticism is whether or not STL should be allocated in junction with the summer thermal comfort indicator instead of in the energy area. Introduction of a cooling demand indicator as a whole (considering solar thermal, internal heat loads and climate changes) is more justified.
- Energy use is completely based on BBR procedures, which is an advantage in the design and building permit processes. However, BBR criteria, hence MB's criteria, are dependent on weighting factors to assess primary energy use. These are not primary energy factors. Instead of leading to neutrality among heating systems types, results are biased and may lead to increased emissions since characteristics of local energy systems are not considered. The question is linked to the indicator *Share of renewable energy*. MB could suggest its own weight factors to avoid biases in BBR.

Conclusions regarding the indoor climate indicators:

- To guarantee an acceptable indoor air quality, it is not possible to compromise on the ventilation requirements in MB. Effective and energy efficient ventilation systems (with low SFPs and higher heat exchanger efficiencies and scheduled use based on the actual demand) are essential in order to get higher grades for MB indicators. For non-residential buildings, it is suggested that ventilation rates could be adjusted by the ventilation effectiveness in accordance with European Standard to incite energy-efficient air distribution systems.

- A separate indicator for air tightness is suggested. It affects draft, thermal comfort, heat power demand and energy use. Expecting minimum air tightness for newly and modern building and rewarding airtight buildings could be an indicator merged with the indicator for ventilation. Airtightness measurements during the building process and after completion could be demanded to detect and fix possible air leakages.
- To assure good thermal comfort, it is suggested that performed modeling and simulations are also made with representative weather for the specific location. The thermal comfort criteria in MB is based on PPD, calculated within the design temperature, DVUT, which is based on a 30-year period, available for 1981–2010. The weather during the measurement year might be quite different from a normal year, and this would affect the thermal comfort results. This yields in general for other indicators and for the calculation and simulation of the energy and thermal comfort.

The most important conclusions regarding the material indicator are:

- The actual effect of the indicator on building design, GHG emissions and the environment can be questioned when the indicator does not include absolute criteria that demand a measurable reduction of the embodied GHG emissions.
- There is a large part of the building that is not included in the LCA as it is not part of the load-bearing structure, and there are life cycle stages that not are considered. Therefore, the indicators lose the possibility to reduce GHG emissions from many building parts and do not encourage building with recyclable material or material with low environmental impact from a longer life cycle perspective.
- Next step to assure the indicator pushes buildings to lower embodied GHG emissions would be to set some type of benchmarks for maximum embodied GHG emissions.

Moreover, a clearer distinction between local environmental aspects, which mainly concern local environment, health, and quality aspects, versus global environmental aspect would be welcomed. It would make the existing conflict between environmental quality and environmental loads, which affect building design, environmental assessment tools, and environmental decision-making in general, more visible.

MB is a certification system that pushes building design and the building sector towards more environmental and high-quality buildings. However, the indicators and criteria seem to beset to improve conventional buildings. To reach the environmental targets in the building and property sector, especially regarding GHG emissions, and make the urban transition that is necessary the indicators and criteria levels need to be adopted more towards these environmental targets.

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Conflict of interest

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Abbreviations

A_{temp}	Floor area that is heated above 10°C
A_{env}	Building envelope area
BBR	Boverket's Building Regulations
BIM	Building information modeling
CFD	Computational fluid dynamics
CHP	Combined heat and power plant
CO ₂ e	Carbon dioxide equivalent
DF	Daylight factor
DH	District heating
DHW	Domestic hot water
DVUT	Design winter outdoor temperature
EPD	Environmental product declaration
EP_{pet}	Primary energy number
F_{geo}	Geographic factor according to BBR
GHG	Green house gases
g_{sys}	Solar heat gain coefficient for windows and shading devices
HLKK	Heat loss form factor
HP	Heat pump
LCA	Life cycle assessment
MB	Miljöbyggnad
PPD	Predicted percentage of dissatisfied
SAD	Seasonal Affective Disorder
SCOP	Seasonal coefficient of performance
SFP	Specific fan power
SGBC	Sweden Green Building Council
STL	Summer thermal load
USD	US Dollars


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