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Net zero energy buildings: A consistent definition framework

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ABSTRACT

The term *Net ZEB*, Net Zero Energy Building, indicates a building connected to the energy grids. It is recognized that the sole satisfaction of an annual balance is not sufficient to fully characterize Net ZEBs and the interaction between buildings and energy grids need to be addressed. It is also recognized that different definitions are possible, in accordance with a country's political targets and specific conditions. This paper presents a consistent framework for setting Net ZEB definitions. Evaluation of the criteria in the definition framework and selection of the related options becomes a methodology to set Net ZEB definitions in a systematic way. The balance concept is central in the definition framework and two major types of balance are identified, namely the import/export balance and the load/generation balance. As compromise between the two a simplified monthly net balance is also described. Concerning the temporal energy match, two major characteristics are described to reflect a Net ZEB's ability to match its own load by on-site generation and to work beneficially with respect to the needs of the local grids. Possible indicators are presented and the concept of grid interaction flexibility is introduced as a desirable target in the building energy design.

1. Introduction

The topic of zero energy buildings (ZEBs) has received increasing attention in recent years, until becoming part of the energy policy in several countries. In the recast of the EU Directive on Energy Performance of Buildings (EPBD) it is specified that by the end of 2020 all new buildings shall be "nearly zero energy buildings" [1]. For the Building Technologies Program of the US Department of Energy (DOE), the strategic goal is to achieve "marketable zero energy homes in 2020 and commercial zero energy buildings in 2025" [2]. However, despite the emphasis on the goals the definitions remains in most cases generic and are not yet standardized. A more structured definition, even though limited in scope to new residential buildings, is the one of 'zero carbon homes' in the UK, where there is a political target to build all new homes as zero carbon by 2016. The zero carbon definition has undergone a lengthy process that started in 2006 and was still subject to revisions in 2011 [3,4]. Otherwise, the term ZEB is used commercially without a clear understanding and countries are enacting policies and national targets based on the concept without a clear definition in place. Commercial definitions may be partial or biased in their scope, for example including only thermal or only electrical needs in the balance, or allowing for energy inefficient buildings to achieve the status of ZEB thanks to oversized PV systems, but without applying relevant energy saving measures. For these reasons such definitions are not suitable as a basis for regulations and national policies.

Relevant work can be found in literature on existing and proposed definitions [5–13] and survey and comparison of existing case studies [14,15]. Furthermore, an international effort on the subject is ongoing in the International Energy Agency (IEA) joint Solar Heating and Cooling (SHC) Task40 and Energy Conservation in Buildings and Community systems (ECBCS) Annex52 titled "Towards Net Zero Energy Solar Buildings" [16]. It emerges from these analyses that little agreement exists on a common definition that is based on scientific analysis. There is a conceptual understanding of a ZEB as an energy efficient building able to generate electricity, or other energy carriers, from renewable sources in order to compensate for its energy demand. Therefore, it is implicit that there is a focus on buildings that are connected to an energy infrastructure and not on autonomous buildings. To this respect the term *Net ZEB* can be used to refer to buildings that are connected to the energy infrastructure, while the term ZEB is more general and may as well include autonomous buildings. The wording 'Net' underlines the fact that there is a balance between energy taken from and supplied back to the energy grids over a period of time, nominally a year.

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As discussed in [15] the Net ZEB approach is one strategy towards climate neutral buildings, in addition to others based on energy efficient buildings combined with almost carbon neutral grid supply. Net ZEBs are designed to overcome the limitation given by a non 100% ‘green’ grid infrastructure. Exploiting local renewable energy sources (RES) on-site and exporting surplus energy from on-site generation to utility grids is part of the strategy to increase the share of renewable energy within the grids, thereby reducing resource consumption and associated carbon emissions. On the other hand, especially for the power grid, wide diffusion of distributed generation may give rise to some problems such as power stability and quality in today’s grid structures, mainly at local distribution grid level. Development of “smart grids” is ongoing to fully benefit from distributed generation with respect to reducing the grids primary energy and carbon emission factors, as well as operation costs. Within a least-cost planning approach, on-site options have to be compared with measures at the grid level, which take advantage of the economy of scale and equalization of local peaks. However, it is clear that the mere satisfaction of an annual balance is not in itself a guarantee that the building is designed in a way that minimizes its (energy use related) environmental impact. In particular, Net ZEBs should be designed – to the extent that is in the control of the designers – to work in synergy with the grids and not to put additional stress on their functioning.

Considering the interaction between buildings and energy grids also leads to consider that every country, or regional area, has different challenges to face with respect to the energy infrastructure, on top of different climate and building traditions. Therefore every country has the need to adapt the Net ZEB definition to its own specific conditions, e.g. defining the primary energy or carbon emission conversion factors for the various energy carriers, establishing requirements on energy efficiency or prioritizing certain supply technologies.

What is missing is a formal, comprehensive and consistent framework that considers all the relevant aspects characterising Net ZEBs and allow each country to define a consistent (and comparable with others) Net ZEB definition in accordance with the country’s political targets and specific conditions. The framework described in this paper builds upon concepts found literature and further developed in the context of the joint IEA (International Energy Agency) SHC (Solar Heating and Cooling programme) Task40 and ECBCS (Energy Conservation in Buildings and Community Systems) Annex52: *Towards Net Zero Energy Solar Buildings* [16].

Table 1 shows a list of nomenclature used in this paper.

2. Terminology and Net ZEB balance concept

The sketch shown in Fig. 1 gives an overview of relevant terminology addressing the energy use in buildings and the connection between buildings and energy grids.

2.1. Building system boundary

The boundary at which to compare energy flows flowing in and out the system. It includes:

- Physical boundary: can encompass a single building or a group of buildings; determines whether renewable resources are ‘on-site’ or ‘off-site’.
- Balance boundary: determines which energy uses (e.g. heating, cooling, ventilation, hot water, lighting, appliances) are included in the balance.

Table 1
Nomenclature.

CHP	Combined heat and power
COP	Coefficient of performance
DHW	Domestic hot water
DSM	Demand side management
HVAC	Heating, ventilation and air conditioning
Net ZEB(s)	Net zero energy building(s)
RES	Renewable energy sources
STD	Standard deviation
d, D	Delivered, delivered weighted
e, E	Exported, exported weighted
f_{grid}	Grid interaction index
f_{load}	Load match index
g, G	Generation, generation weighted
g_m	Net monthly generation, annual total
G_m	Net monthly generation weighted
i	Energy carrier
l, L	Load, load weighted
l_m	Net monthly load, annual total
L_m	Net monthly load weighted
m	Month
max	Maximum
min	Minimum
t	Time interval
w	Weighting factor

2.2. Energy grids (or simply ‘grids’)

The supply system of energy carriers such as electricity, natural gas, thermal networks for district heating/cooling, biomass and other fuels. A grid may be a two-way grid, delivering energy to a building and occasionally receiving energy back from it. This is normally the case for electricity grid and thermal networks.

2.3. Delivered energy

Energy flowing from the grids to buildings, specified per each energy carrier in (kWh/y) or (kWh/m^{2}y). This is the energy imported by the building. However, it is established praxis in many countries to name this quantity ‘delivered energy’, see for example [17].

2.4. Exported energy

Energy flowing from buildings to the grids, specified per each energy carrier in (kWh/y) or (kWh/m^{2}y).

2.5. Load

Building’s energy demand, specified per each energy carrier in (kWh/y) or (kWh/m^{2}y). The load may not coincide with delivered energy due to self-consumption of energy generated on-site.

2.6. Generation

Building’s energy generation, specified per each energy carrier in (kWh/y) or (kWh/m^{2}y). The generation may not coincide with exported energy due to self-consumption of energy generated on-site.

N.B. Design calculations to convert building energy needs, such as for heating, cooling, ventilation, hot water, lighting, appliances, into the demand for certain energy carriers (here ‘loads’), accounting for system efficiencies and interactions are not covered in this paper; nor are calculations to determine on-site generation or possible self-consumption patterns. Readers are encouraged to refer to their relevant national methodologies and regulations for guidance.

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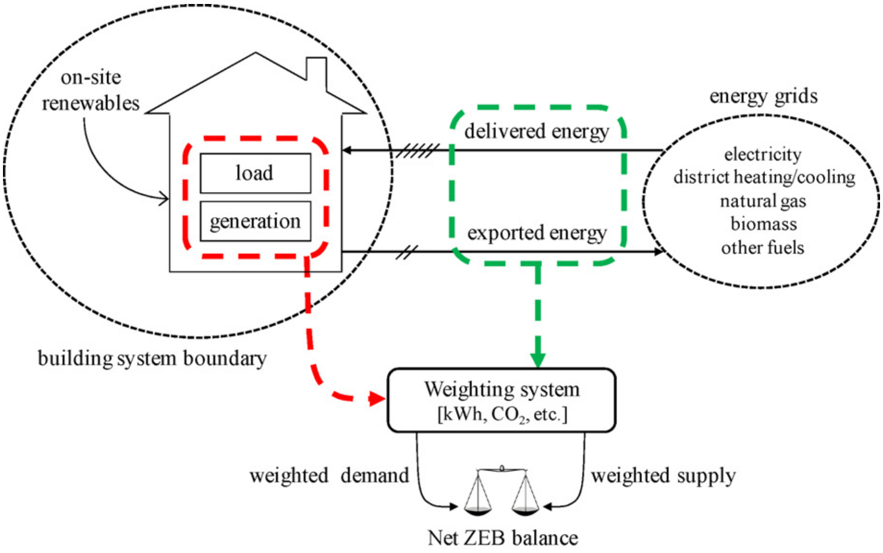

Fig. 1. Sketch of connection between buildings and energy grids showing relevant terminology.

2.7. *Weighting system*

A weighting system converts the physical units into other metrics, for example accounting for the energy used (or emissions released) to extract, generate, and deliver the energy. Weighting factors may also reflect political preferences rather than purely scientific or engineering considerations.

2.8. *Weighted demand*

The sum of all delivered energy (or load), obtained summing all energy carriers each multiplied by its respective weighting factor.

2.9. *Weighted supply*

The sum of all exported energy (or generation), obtained summing all energy carriers each multiplied by its respective weighting factor.

2.10. *Net ZEB balance*

A condition that is satisfied when weighted supply meets or exceeds weighted demand over a period of time, nominally a year. The net zero energy balance can be determined either from the balance between delivered and exported energy or between load and generation. The former choice is named *import/export balance* and the latter *load/generation balance*. A third option is possible, using monthly net values of load and generation and it is named *monthly net balance*.

The Net ZEB balance is calculated as in Eq. (1):

$$\text{Net ZEB balance}: |\text{weighted supply}| - |\text{weighted demand}| = 0 \quad (1)$$

where absolute values are used simply to avoid confusion on whether supply or demand is consider as positive. The Net ZEB balance can be represented graphically as in Fig. 2, plotting the weighted demand on the x-axis and the weighted supply on the y-axis.

The reference building may represent the performance of a new building built according to the minimum requirements of the national building code or the performance of an existing building prior to renovation work. Starting from such reference case, the pathway to a Net ZEB is given by the balance of two actions:

(1) reduce energy demand (x-axis) by means of energy efficiency measures;
(2) generate electricity as well as thermal energy carriers by means of energy supply options to get enough credits (y-axis) to achieve the balance.

In most circumstances major energy efficiency measures are needed as on-site energy generation options are limited, e.g. by suitable surface areas for solar systems, especially in high-rise buildings.

3. Framework for Net ZEB definitions

The balance of Eq. 1 represents the core concept of a Net ZEB definition. In order to use such formula in practice several aspects have to be evaluated and some explicit choice made, e.g. the metrics adopted for weighting and comparing the different energy carriers. Additionally, other features than the mere balance over a period of time may be desirable in characterizing Net ZEBs. These aspects are described and analyzed in a series of five criteria and sub-criteria, and for each criterion different options are available. Evaluation of the criteria and selection of the related options becomes a methodology for elaborating Net ZEB definitions in a systematic, comprehensive and consistent way. The Net ZEB definition framework is organized in the following criteria and sub-criteria (addressed with the symbol § in the following of the paper):

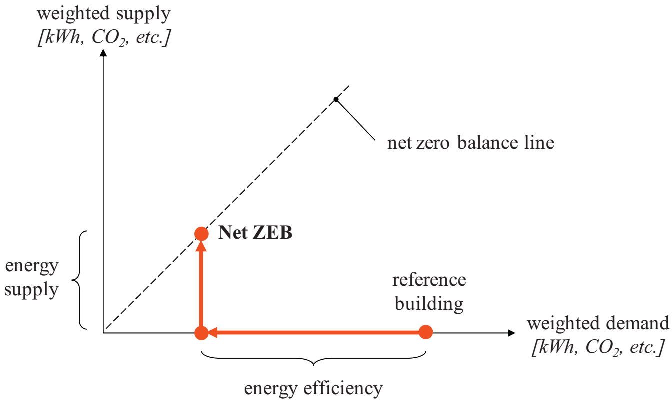

Fig. 2. Graph representing the net ZEB balance concept.

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1 Building system boundary
  1.1 Physical boundary
  1.2 Balance boundary
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2 Weighting system
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3 Net ZEB balance
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  3.3 Energy efficiency
  3.4 Energy supply
4 Temporal energy match characteristics
  4.1 Load matching
  4.2 Grid interaction
5 Measurement and verification

§1 Building system boundary

Defining the building system boundary is necessary to identify what energy flows cross the boundary. The building system boundary can be seen as a combination of a physical and a balance boundary. Only energy flows that cross the system boundary, i.e. both physical and balance boundaries, are considered for the Net ZEB balance. This means, for example, that if a definition excludes plug-loads from the balance boundary, the electricity used for plug-loads is not to be counted. With design data this is not a problem. With monitoring data though, it represents a complication because the power meter normally does not discern between the different power uses. A Net ZEB definition that does not include all operational energy services poses a challenge on building performance verification because it requires a more sophisticated measurement system, see criterion §5: Measurement and verification.

§1.1 Physical boundary

The physical boundary may be on a single building or on a cluster of buildings. In this paper the focus is mainly on single buildings, but the same framework would apply equally well to clusters of building. It is important to note though that a cluster of buildings implies a synergy between several buildings which are not necessarily Net ZEB as singles but as a whole.

The physical boundary is useful to identify so called 'on-site' generation systems; so that if a system is within the boundary it is considered on-site, otherwise it is 'off-site'. As analyzed later in criterion §3.4: Net ZEB balance – Energy supply, off-site supply options may or may not be accepted for calculating the balance, or may be given different priorities. As an example, one may think of a PV system installed on the parking lot, detached from the main building. If the boundary is taken on the building's physical footprint such system would then be regarded as off-site. If the boundary instead is set on the building's property or if the power meter is taken as the physical boundary, then the PV system would be on-site.

Furthermore, the physical boundary can be used to address the property issue of RES installations. On one hand RES installations or investments not on the building site may be accountable in the balance if financed by the building owner/constructor, as in the UK zero carbon home definition, see [18,19] and further discussion on allowable solutions in criterion §3.4: Net ZEB balance – Energy supply. On the other hand, a RES installation on the building site may not be considered accountable for the building balance if it is property of a third party, e.g. if the roof space has been rented to an investor (utility company, ESCO, etc.) who owns the PV system and runs it independently.

It has to be specified which two-way grids are available at the physical boundary. A two-way grid is a grid that can deliver energy to and also receive energy back from the building(s). Without a two-way grid it is not possible to define a Net ZEB. The power grid is normally available as two-way grid. Other two-way grids may be local thermal networks, such as district heating/cooling networks. Specific conditions are normally required by the grid operators in order to accept exported energy, such as on frequency and voltage tolerances (power grid) or temperature levels (thermal network).

§1.2 Balance boundary

The balance boundary defines which energy uses are considered for the Net ZEB balance. Operational energy uses typically include heating, cooling, ventilation, domestic hot water, fixed lighting and plug-loads. National and commercial standards on energy performance may consider different combinations of them. Other energy uses may be included in the balance, even though they are typically not considered in building energy performance codes and standards. This may include treatment of rain water or charging of electric vehicles. Electric vehicles are not a building related energy use but charging their batteries may be used as a way to optimize the interaction with the grid (see criterion §4.2: Temporal energy match characteristics – Grid interaction).

Other energy uses that do not occur in the operational phase, but in the life cycle of a building may be considered, such as embodied energy/emissions in materials and technical installations. More energy efficient and energy producing buildings are likely to deploy more materials (e.g. insulation) and technical installations (e.g. PV system) including materials whose manufacturing is energy intensive. Consequently, the importance of embodied energy/emissions increases and including it into the balance broadens the scope of Net ZEBs as environmental friendly and sustainable buildings. Embodied energy/emissions should be annualized for proper accounting in addition to operational energy use; this implies making assumption on the life time of the building and its components. Likewise, also energy used for erection and demolition of the building could be considered, even though their relative importance is generally low and it may be justifiable to neglect it [20].

§1.3 Boundary conditions

A consistent Net ZEB definition should allow a meaningful comparison between similar buildings in similar climates, as well as between the expected performance of a building from its design data and the measured performance revealed by monitoring data, see criterion §5: Measurement and verification. It is important to understand if any deviation from expected values is attributable to technical operating or design mistakes, or if it is simply due to different conditions of use. For this purpose it is necessary to explicitly specify a set of boundary conditions: functionality, space effectiveness, climate and comfort.

The functionality describes what type of uses the building is designed for, such as residential, office, school or hospital. In case of multi-functional buildings it is necessary to specify how the floor area is distributed between the different functions. The space effectiveness can be expressed in terms of people/m^2 or, consequently, of energy use per person. Variations from expected functionality and/or space effectiveness are important and should be taken into consideration before comparing the expected performance with the monitored one. For example, higher/lower people density causes different energy demand.

The reference climate and the comfort standards used in design also need to be specified. Variations from expected outdoor climate and/or indoor comfort conditions are important and should be taken into consideration before comparing the expected performance with the monitored one. For example, hotter/colder

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years or different temperature settings cause different energy demand.

§2 Weighting system

The weighting system converts the physical units of different energy carriers into a uniform metrics, hence allowing the evaluation of the entire energy chain, including the properties of natural energy sources, conversion processes, transmission and distribution grids. Choosing a common balance metrics also allows taking into account the so-called fuel switching effect, e.g. when export of PV electricity during summer compensates for imported biomass or fossil fuels in winter.

§2.1 Metrics

In [5] four types of metrics are considered: site energy, source energy, energy cost, and carbon emissions related to energy use. Advantages and disadvantages of each choice are discussed and it is shown how the choice would affect the required PV installed capacity. Other possible metrics are the non-renewable part of primary energy, exergy [6], environmental credits and politically/strategically decided factors. The choice of the metrics, especially with political factors, will affect the relative value of energy carriers, hence favouring the choice of certain carriers over others and influencing the required (electricity) generation capacity. For an analysis of the details and the implications for design of each choice reference is made to the mentioned literature [5–13].

Quantification of proper conversion factors is not an easy task, especially for electricity and thermal networks as it depends on several considerations, e.g. the mix of energy sources within certain geographical boundaries (international, national, regional or local), average or marginal production, present or expected future values and so on. A sample of conversion factors for primary energy and carbon equivalent emissions as applied in current building design practise is shown in Appendix A: conversion factors. There are no correct conversion factors in absolute terms. Rather, different conversion factors are possible, depending on the scope and the assumptions of the analysis. This leads to the fact that ‘politically corrected’ weighting factors may be adopted in order to find a compromise agreement.

Furthermore, ‘political factors’ (or ‘strategic factors’) may be used in order to include considerations not directly connected with the conversion of primary sources into energy carriers. Political factors can be used to promote or discourage the adoption of certain technologies and energy carriers. For example biomass and biofuels, in case of carbon emissions as the metrics, would have a very low conversion factor making it an attractive solution. However, availability of biomass is not infinite and it needs to be used also for other non-energy purposes such as food production. Hence, even in regions of abundant local availability it may be desirable to ‘politically’ increase the conversion factor in order to reduce the attractiveness of biomass and favour other solutions, e.g. solar systems.

§2.2 Symmetry

Each two-way energy carrier (e.g. electricity) can be weighted symmetrically, using the same weighting factors for both delivered and exported quantities, or asymmetrically, using different factors.

The rationale behind symmetric weighting is that the energy exported to the grids will avoid an equivalent generation somewhere else in the grid. Hence the exported energy has a substitution value, which is equal to the average weighting factor for that grid. This is a valid approach as long as the energy generated on-site does not have any negative effect on the balance or if that effect is accounted for somewhere else. First example: with on-site cogeneration the negative effect is the increase of purchased fuel because of the reduced thermal efficiency. The delivered energy entering the physical boundary is increased, therefore accounting for the negative effect and the exported electricity can be fully credited for its substitution value. Second example: with on-site PV generation the negative effect is the increase in embodied energy. If the balance boundary does include embodied energy of the PV system, then the total demand to be balanced off is increased, accounting for the negative effect and the exported electricity can be fully credited for its substitution value.

Asymmetric weighting may be used to account for the negative effect of on-site generation if that is not accounted for somewhere else in the balance. For example, in the above case with PV system, if embodied energy is not part of the boundary balance then each kWh of exported electricity should not be fully credited because it did cost something – in energetic terms – to produce it. Rather than omitting this aspect, it is possible to associate a negative value to the kWh generated (in terms of the adopted metrics, such as primary energy or emissions) and credit the exported kWh net of it, i.e. the substitution value minus the negative effect value. This way it is possible to give different weighting factors to different generation technologies generating the same carrier, e.g. PV and cogeneration in the same building, hence valuing their different properties, possibly in combination with political factors as discussed in criterion §2.1: Weighting system – Metrics. The drawback is that each system should then be equipped with a separate meter, at least in theory. Similarly, also delivered energy may have different weighting factors for the same carrier, as for example in the case of a portion of purchased electricity being covered by green certificates.

However, the main rationale behind asymmetric weighting is that energy demand and supply do not have the same value, hence delivered and exported energy should be weighted differently in order to reflect this principle. Two situations are possible:

(a) Delivered energy is weighted higher:
This takes into account the cost and losses on the grids side associated with transportation and storage of exported energy (and in case of electricity also possible earthing of feed-in power) as in the German tariff system since 2009, see [21]. This option may serve the purpose of reducing exchange with the grids–hence promoting self-consumption of on-site generation–in a scenario of wide diffusion of energy consuming and producing buildings;

(b) Exported energy is weighted higher:
This option may serve the purpose of promoting technology diffusion in a scenario of early technology adoption, e.g. the early PV feed-in tariffs adopted in Germany, Italy, Spain and other countries, where feed-in electricity is paid two to three times higher than what delivered electricity is charged for (here the asymmetric metrics is the energy cost).

§2.3 Time dependent accounting

Due to the complexity of the energy infrastructure, it is often feasible to estimate the weighting factors only as average values for a period of time. This is a static accounting, and it typically applies to primary energy and carbon emission factors. For an overview of static (and symmetric) conversion factors used in several countries see Appendix A: conversion factors.

Weighting factors will vary over time and space. Electricity, for example, may be evaluated for large regions while district heating/cooling or biomass may be evaluated at local scale, according to the actual availability of resources in the area. In any case the evaluation of weighting factors should be updated at regular

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intervals to reflect the development of the grids. To this respect it is possible to consider different scenarios on the possible evolution of weighting factors, as for example in [22] where the European electricity grid is analyzed towards 2050. In the evaluation of electricity and district heating/cooling weighting factors it is also important to distinguish between average and marginal production and specify which choice is made.

It is also possible to evaluate weighting factors on hourly basis, therefore leading to a dynamic accounting. As an intermediate option a quasi-static accounting would have seasonal/monthly average values and/or daily bands for base/peak load. For energy prices it is already quite common to have seasonal or hourly fluctuating prices, while for other metrics such as primary energy and carbon emissions this is not the standard praxis today but it may become more common in future. Examples of this are given by the hourly energy emission factors for electricity generation in the US [23] and the power demand tracking in real time of the power grid in Spain [24].

Dynamic and quasi-static accounting would help, at least in theory, the design of buildings that optimize their interaction with the grids. The Time-Dependent Valuation of saving [25] is such an example. However, including dynamic accounting in the Net ZEB balance would considerably increase the complexity of calculations and the assumptions on future time dependent patterns. It is rather preferable, in the authors' opinion, to calculate the Net ZEB balance with static or quasi-static values and then use, in addition, dynamic values to address the temporal energy match characteristics, see criterion §4: Temporal energy match characteristics.

§3 *Net ZEB Balance*

The balance of Eq. (1) may be calculated in different ways, depending for example on the quantities that are of interest or available and the period over which to calculate the balance. Furthermore, policy makers must decide whether or not to enforce minimum energy efficiency requirements and/or a hierarchy of renewable energy supply options.

§3.1 *Balancing period*

A proper time span for calculating the balance is assumed, often implicitly, to be a year. An yearly balance is suitable to cover all the operation settings with respect to the meteorological conditions, succession of the seasons in particular. Selection of shorter time spans, such as seasonal or monthly balance, could be highly demanding from the design point of view, in terms of energy efficiency measures and supply systems, in order to reach the target in critical time, such as winter time. On the other hand, a much wider time span, on the order of decades, could be selected to assess the balance along the entire building's life cycle including embodied energy. Nevertheless, as noted in criterion §1.2: Building system boundary – Balance boundary, embodied energy can be annualized and counted in addition to operational energy uses. It is therefore held that the balance is calculated on a yearly basis.

§3.2 *Type of balance*

The core principle for Net ZEBs is the balance between weighted demand and weighted supply, generically described in Eq. (1). Delivered and exported energy quantities can be used to calculate the balance when monitoring a building. Alternatively, estimates of delivered and exported energy may be available in design phase, depending on the ability to estimate self-consumption of energy carriers generated on-site. In these cases an *import/export balance* is calculated as in Eq. (2)[1]:

$$\sum_i e_i \times w_{e,i} - \sum_i d_i \times w_{d,i} = E - D \geq 0 \tag{2}$$

where *e* and *d* stands for exported and delivered, respectively; *w* stands for weighting factor and *i* for energy carrier. *E* and *D* stands for weighted exported and delivered energy, respectively; see also Table 1 on nomenclature.

However, most building codes do not require design calculations to estimate self-consumption, consequently lacking the estimations of delivered and exported amounts [10]. Such approaches perform like generation and load systems did not interact, basically because missing normative data on end users temporal consumption patterns (e.g. for lighting, electrical appliances, cooking, hot water use). Thereby, in most common cases only generation and load values are available and a *load/generation balance* is calculated as in Eq. (3):

$$\sum_i g_i \times w_{e,i} - \sum_i l_i \times w_{d,i} = G - L \geq 0 \tag{3}$$

where *g* and *l* stands for generation and load, respectively; *w* stands for weighting factor and *i* for energy carrier. *G* and *L* stands for weighted generation and load, respectively; see also Table 1 on nomenclature. It is worth noting that overlooking the interactions between generation systems and loads as in the generation balance is equivalent to assume that, per each carrier, the load is entirely satisfied by delivered energy while the generation is entirely fed into the grid.

Alternatively, a balance may be calculated based on monthly net values. For each energy carrier, generation and load occurring in the same month are assumed to balance each other off; only the monthly residuals are summed up to form the annual totals. This can be seen either as a load/generation balance performed on monthly values or, equivalently, as a special case of import/export balance where a "virtual monthly self-consumption" pattern is assumed. Such procedure has been proposed in the framework of the German building energy code, see [12,14], where it is thought with focus on electricity; the same procedure though may be applied also to thermal carriers. This approach may be regarded as *monthly net balance*, calculated as in Eq. (6), substituting Eqs. (4) and (5):

$$g_{m,i} = \sum_m \max[0, g_i(m) - l_i(m)] \tag{4}$$

$$l_{m,i} = \sum_m \max[0, l_i(m) - g_i(m)] \tag{5}$$

$$\sum_i g_{m,i} \times w_{e,i} - \sum_i l_{m,i} \times w_{d,i} = G_m - L_m \geq 0 \tag{6}$$

where *g* and *l* stands for generation and load, respectively, and *m* stands for the month; *w* stands for weighting factor and *i* for energy carrier. G_m and L_m stands for the total weighted monthly net generation and load, respectively; see also Table 1 on nomenclature.

The three balances are coherent with each other[2] but differ by the amount of on-site energy generation which is self-consumed,

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[1] For simplicity, the weighting factors are the same in Eqs. (2), (3) and (6), and are implicitly assumed as static yearly values, see §2.3: Weighting system - Time dependent accounting.

[2] Applied to the same case would give the same net balance: the three points lying on a 45° line (not necessarily passing through the origin if the net balance is not zero).

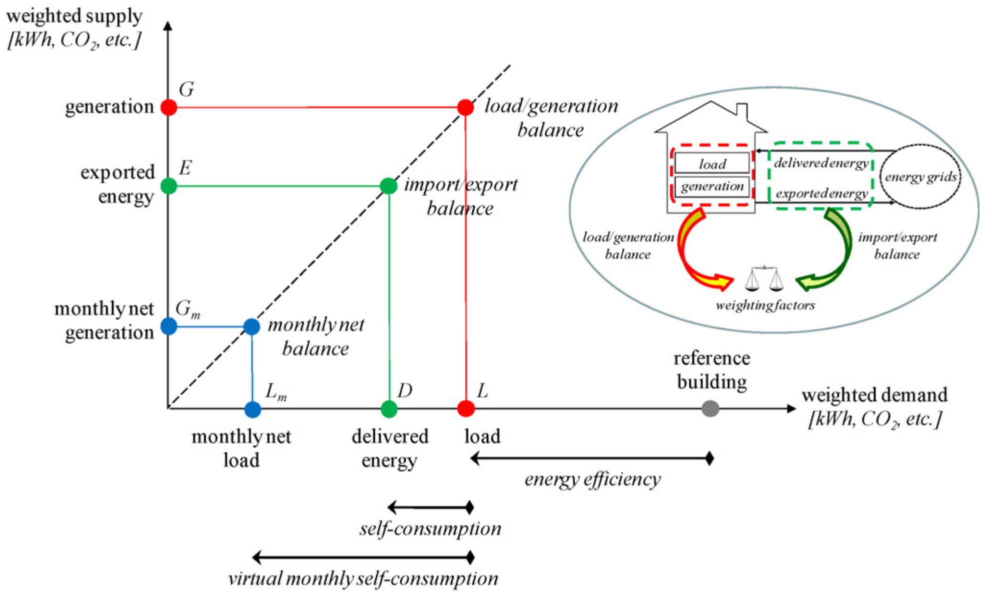

Fig. 3. Graphical representation of the three types of balance: *import/export balance* between weighted exported and delivered energy, *load/generation balance* between weighted generation and load, and *monthly net balance* between weighted monthly net values of generation and load.

or 'virtually' assumed as self-consumed, as shown in Fig. 3. Graphically, the load/generation balance gives the points for weighted demand and supply most far away from the origin; while with import/export balance and monthly net balance the points get closer to the origin as a consequence of the self-consumption and virtual monthly self-consumption, respectively. The import/export balance is expected to be always in between the two other, due to the fact that there usually is some amount of self-consumption but hardly more than the virtual monthly self-consumption, which can be regarded as an upper limit as long as seasonal energy storage is not considered.

It is worth noting that self-consumption of energy generated on-site can be seen as either an efficiency measure or as a supply measure depending on the type of balance adopted. In case of load/generation balance self-consumption is seen as part of the overall generation and is visualized in the graph as moving the weighted supply point up along the y-axis. However, in case of import/export balance self-consumption is seen as a reduction of the load, visualized in the balance graph by moving the weighted demand point closer to the origin, along the x-axis[3]. This is consistent with the implicit viewpoint of the two balances. In the load/generation balance the building is seen independently, so that energy generated, whether self-consumed or not, does not affect the efficiency of the building as such. In the import/export balance the building is seen in connection with the grids, so that self-consumption does reduce the amount of energy exchanged, in this sense improving the efficiency of the system building-grids.

Each type of balance has pros and cons. The import/export balance gives the most complete information, showing the interaction with the grids but it is the most difficult to obtain in design phase because it requires estimates of self-consumption patterns and detailed simulation (preferably with hourly or sub-hourly resolution). The load/generation balance is the most suit to be seamlessly integrated in existing building codes that are only oriented at calculating the loads. In facts, it is only necessary to add one step: calculation of the generation. The drawback is that it completely overlooks the interaction with the grids. The monthly net balance has the advantage of being simple to implement while not completely overlooking the interaction with the grids. On one hand it only needs monthly values of generation and load and does not require either detailed simulations or self-consumption estimates. On the other hand while the virtual monthly self-consumption is a coarse approximation, it still provides some information on the seasonal interaction with the grids. The higher the monthly net generation (or load), the higher the seasonal unbalance of energy exchanged with the grids.

§3.3 *Energy efficiency*

A Net ZEB definition may set mandatory minimum requirements on energy efficiency. Such requirements may be either prescriptive or performance requirements, or a combination of the two. Prescriptive requirements apply to properties of envelope components (e.g. U-values of walls and windows, air-tightness in pressurization test) and of HVAC systems (e.g. specific fan power, COP of heat pumps), while performance requirements apply to energy needs (e.g. for heating, cooling, lighting) or total (weighted) primary energy demand. See [26] for an overview of prescriptive and performance based energy efficiency requirements adopted in existing national or commercial certification systems.

Mandatory requirements on energy efficiency may be determined on the basis of cost-optimality considerations as in the plans of the EPBD [1]; such methodology is still under development for the time being, see [27–29]. Alternatively, mandatory efficiency targets could simply require a demand reduction (e.g. 50%) compared to a reference building of the same category (e.g. detached house, office, school).

In absence of explicit requirements on energy efficiency it is left to the designers to find the cost-optimal balance between energy efficiency measures and supply options, eventually considering embodied energy too, if in the balance boundary. However, the analysis of a large number of already existing Net ZEBs underlines the priority of energy efficiency as the path to success [15].

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[3] Also valid for monthly net generation balance and virtual monthly self-consumption.

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Restrictions on the use of some energy carriers, such as oil, can be a direct requirement of a Net ZEB definition or a consequence of the assigned weighting factor, e.g. assigning a ‘politically’ or ‘strategically’ high value to oil would reduce its attractiveness.

§3.4 *Energy supply*

A Net ZEB definition may set mandatory requirements on energy supply. A straightforward requirement is proposed in [30] by setting a threshold for the minimum share of renewable energy that has to be used for covering the building’s energy demand.

Alternatively, energy supply options may be categorized in different ways and a Net ZEB definition may set a mandatory hierarchy of renewable energy supply options. This prioritization is meant to add an additional dimension to the energy balance itself. Typically, distinction is made at least between ‘on-site’ and ‘off-site’; see [5,10,18,19]. For using a hierarchy of options a clear and unambiguous definition of what is on-site and off-site (and any further distinction) has to be stated in criterion §1: Building system boundary – Physical boundary.

In [5] the renewable energy supply options are prioritized on the basis of three principles: (1) emissions-free and reduced transportation, transmission, and conversion losses; (2) availability over the lifetime of the building; (3) highly scalable, widely available, and have high replication potential for future Net ZEBs. These principles lead to a hierarchy of supply options where resources within the building footprint or on-site (e.g. PV and CHP) are given priority over off-site supply options, (e.g. import of biofuel for cogeneration or purchase of green electricity). Reasons for supporting such a hierarchy are extensively discussed in the report. In [10] a similar categorization of supply options is given according to their distance from the building, even though no hierarchy of preferences is expressed. However, it is worth mentioning that the meaning of off-site varies depending on whether the focus is on the origin of the fuel [5] or on the location of the actual generation system [10].

Another example of classification and hierarchy is given by the “Zero Carbon Home” policy under development in the UK (only for new residential buildings), see [18,19]. In the Zero Carbon Home approach offsetting carbon emissions is achieved in two steps, named: “carbon compliance” and “allowable solutions”. Carbon compliance is a mix of mandatory energy efficiency measures and a selection of on-site options (e.g. PV and connection to thermal grids) to be implemented as first priority. Allowable solutions is a set of further supply options, including extended on-site options, near-site and off-site options; where the meaning of such words is again different than in [5,10].

One of the more contentious topics is likely be how to account for ‘soft’ renewable generation options (‘soft’ as opposed to ‘hard’ = physical generation of energy carriers). For example, the allowable solutions in the Zero Carbon Home definition in the UK include investment (through a national investment fund) in low- and zero-carbon energy projects off-site. These include investments in the local energy infrastructure and financing energy efficient renovation of buildings in the area.

Another area that requires further thought by policy makers, if renewable energy supply is to be prioritized, is defining ‘supply-side’ renewable generation separately from ‘demand-side’ generation. As defined in [5], supply-side renewable energy can be commoditized, exported, and sold like electricity or hot water for district systems, while demand-side renewable are only available in connection with reducing building energy demand on-site. Examples of demand-side generation include CHP systems, ground source heat pumps, and passive solar systems.

Restrictions on the use of some supply option, such crediting of electricity from gas fired CHP, can be a direct requirement of a Net ZEB definition or a consequence of the assigned weighting factor. For example, assigning a ‘politically’ or ‘strategically’ low value to electricity generated by gas fired CHP would reduce the attractiveness of such a choice[4]. However, it should be considered that in areas with poor performance of the grid (high share of fossil fuels and high carbon emission in the generation mix) it may be reasonable to allow solutions that make a very efficient use of natural gas, such as gas fired CHP, especially if the gas grid is already in place.

§4 *Temporal energy match characteristics*

Beside an annual energy or emission balance Net ZEBs are characterized by their different ability to match the load and to work beneficially with respect to the needs of the local grid infrastructure. Suitable indicators can be used to express characteristics of a Net ZEB such as the temporal match between a building’s load and its energy generation, *load matching*, and the temporal match of import/export of energy with respect to the grid needs, *grid interaction* [31,32]. Such indicators are useful to show differences and similarities between alternative design solutions. The indicators are intended as assessment tools only: there is no inherent positive or negative value associated with them, e.g. increasing the load match may or may not be appropriate depending on the circumstances on the grid side.

Load matching and grid interaction calculation have to be performed for each energy carrier separately. The calculation of such indicators needs energy data in a time resolution of months for studying the seasonal effects, and hourly or sub-hourly resolution for studying peak load effects. Target groups for this form of Net ZEB characterization are the building owners and designers, community and urban planners as well as the local grid operators in the context of “smart buildings” and “smart grids”.

§4.1 *Load matching*

The temporal match between load and generation for an energy carrier gives a first insight on a building’s ability to work in synergy with the grid. When there is a poor correlation between load and generation, e.g. load mainly in winter and generation mainly in summer, the building will more heavily rely on the grid. If load and generation are more correlated, the building will most likely have higher chances for fine tuning self-consumption, storage and export of energy in response to signals from the grid, see criterion §4.2: Grid interaction. Load matching can be addressed in design by separate calculations or simulations on load and generation, without need to know or estimate self-consumption. For this reason indicators of load matching fit well for being used in combination with a load/generation balance, see criterion §3.2: Net ZEB balance – Type of balance.

Suitable indicators for load matching are proposed under different wordings and summarized with a review in [32]. The most common wording for solar systems applied to buildings is the so-called “solar fraction”. Generalizing the term to any form of generation leads to the *load match index* [31] in the form of Eq. (7):

$$f_{\mathrm{load},i} = \frac{1}{N} \times \sum_{\mathrm{year}} \min\left[1, \frac{g_i(t)}{l_i(t)}\right] \tag{7}$$

where g and l stands for generation and load, respectively; i stands for energy carrier and t is the time interval used, e.g. hour, day or month. N stands for the number of data samples, i.e. 12 for monthly

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[4] This means adopting an asymmetric weighting system, see §2.2: Weighting system - Symmetry.

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Table 2
Effect of time resolution on the indicator values, data from [31].

Indicator	Time resolution		
	Monthly (%)	Daily (%)	Hourly (%)
Load match index	79	76	36
Grid interaction index	43	35	25

time interval and 8760 for hourly time interval, respectively. See also Table 1 on nomenclature.

Load match calculation is sensitive to the time resolution considered, as investigated in [31] for three existing buildings in Portugal, USA and Germany respectively, and in [33] by simulations for dwellings in high latitude climates. In that study, based on 10 min data resolution not more than 28% of the annual load can be matched although the annual yield fully balances the annual demand. Analyzing the load match at the monthly level, instead, gives a matching of 67%. Also the load considered, naturally, affects load match calculations. Simulations of a Belgian dwelling [34] report that considering 1 min data resolution 42% of the household electrical demand was instantaneously matched, while the fraction decreases to 29% when including the demand for space heating and DHW via heat pump. The reason is that the (electrically driven) heat pump increases the electric load in times with low solar power availability.

When calculated on monthly values the load match index provides basically the same kind of information as the monthly net balance, see criterion §3.2: Net ZEB balance – Type of balance. In this case though, the higher the load match index, the lower the seasonal unbalance of energy exchanged with the grid. The load match index is, however, a finer indicator than the monthly net balance because it looks at one energy carrier at a time and is not distorted by the weighting.

§4.2 Grid interaction

To assess the exchange of energy between a Net ZEB and a grid versus the grid's needs one must know at least the import/export profile from the building. The other half information must come from the grid's side, e.g. in terms of base/peak load, hourly price or carbon emission factor; but this is beyond the scope of this paper.

The grid interaction can be addressed based on metering or simulation data of delivered and exported quantities. Therefore, indicators of grid interaction fit well for being used in combination with an import/export balance, see criterion 0-Net ZEB balance-Type of balance. Such data have to consider the entire load, including user related loads such as plug loads even if excluded from the balance boundary, as the grid stress can only be addressed by a full balance approach, see criterion §1.2: Building system boundary – Balance boundary.

Several indicators have been proposed to analyze the interaction between buildings and grids, with a viewpoint from either the building or the grid perspective [32]. As an example, an index from the viewpoint of the building is considered here: the *grid interaction index* [31]. The grid interaction index represents the variability (standard deviation) of the energy flow (net export) within a year, normalized on the highest absolute value. The net export from the building is defined as the difference between exported and delivered energy within a given time interval. The grid interaction index is calculated as in Eq. (8):

$$f_{\text{grid},i} = \text{STD}\left[\frac{e_i(t) - d_i(t)}{|\max[e_i(t) - d_i(t)]|}\right] \tag{8}$$

where e and d stands for exported and delivered, respectively; i stands for energy carrier and t is the time interval used, e.g. hour, day or month. See also Table 1 on nomenclature. As for load matching, also the grid interaction index is sensitive to the time resolution considered. Table 2 shows the load match and the grid interaction index calculated for three different time resolutions based on a small all-electric solar home designed for the Solar Decathlon Europe competition in 2010, data presented in [31].

An important characteristic from the viewpoint of the grids is the *grid interaction flexibility* [32] of a Net ZEB, understood as the ability to respond to signals from the grid (smart grids), e.g. price signals, and consequently adjust load (DSM), generation (e.g. CHP) and storage control strategies in order to serve the grid needs together with the building needs, and/or adjust to favourable market prices for energy exports or imports. Therefore, to be meaningful the grid interaction flexibility has to be evaluated with a time resolution of an hour or preferably even lower.

What is actually in the hands of designers is to design the building and its energy systems to enhance grid interaction flexibility. The flexibility could be quantified using suitable indicator(s) evaluated in two opposite extreme situations. An extreme situation is an export priority strategy (maximum energy export): the generation system export energy to the grids regardless of the building's load or storage possibilities. The opposite extreme situation is a load matching priority strategy (maximum load match): control strategies for storage system, load shifting and generation modulation, where possible, provide maximized self-consumption of the generated energy. The difference between the two values tells how flexible a building is in terms of grid interaction. One important design strategy may be to enhance the grid interaction flexibility: the higher the flexibility, the better the building will be able to adapt to signals from the grid.

It is worth noting that for building designer to design Net ZEBs with high grid interaction flexibility, it is necessary to have data on end users temporal consumption patterns, e.g. for lighting, electrical appliances, cooking, hot water use. Such data should be statistically representative for the type of building in analysis (i.e. residential, office, school, etc.) or better such data should be even normative. In the same way as weather data are standardized to provide designers with a reference climate, user profile data may be standardized to offer designers a reference temporal consumption pattern (with hourly and seasonal variations) for each type of building. Furthermore, evaluation of different strategies for the control of load, generation and storage need the support of advanced dynamic simulations tools.

§5 Measurement and verification

The establishment of building performance targets at policy level necessarily leads to the development of energy rating systems, i.e. methodologies for the evaluation of the building energy performance. Ratings can be calculated ratings when based on calculations, or measured (or operational) ratings when based on actual metering [35]. Within this perspective, it is questioned whether the Net ZEB target should be a calculated or a measured rating. A measured rating would enable the verification of claimed Net ZEBs, the effectiveness and robustness of the design solutions applied, and at last the actual achievement of the energy policy targets.

To check that a building is in compliance with the Net ZEB definition applied, a proper measurement and verification (M&V) process is required [36]. Such process is strictly dependent on the options selected for each criteria of the definition and on the features of the building to be assessed. As a minimum, an M&V protocol for Net ZEBs should enable the assessment of the import/export balance, as this is the core of the Net ZEB concept. Eventually, an M&V process could aim at evaluating also the temporal match characteristics, such as the load match or grid interaction indices. This requires setting the time resolution and selecting the duration of measurements, sampling and recording time.

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As comfort is a mandatory requirement in buildings, an M&V protocol should also check the indoor environmental quality (IEQ). The complexity can then increase significantly due to the large number of sensors likely required in several locations within a building. Nevertheless, to warrantee indoor comfort is always the first priority in building design and the risk of designing Net ZEBs with poor IEQ shall be avoided; IEQ measurements would help to this respect. Furthermore it would help explaining possible deviations from the expected energy performance – in relation to the expected operating conditions criterion §1.3: Building system boundary – Boundary conditions – and point out relevant optimization measures.

Clearly, the completeness and complexity of a Net ZEB definition is reflected in the M&V process in terms of feasibility and affordability. It is worth noting that only the energy uses included in the balance boundary, see criterion §1.2: Building system boundary – Balance boundary, contribute to define the Net ZEB balance. As a consequence, the exclusion of an energy use from the balance boundary, e.g. the electricity use for plug-loads, would require the installations of a separate meter–or possibly several–in addition those located at the interface with the grids (on the physical boundaries). This means moving from a whole building monitoring approach to sub-metering [37–39], increasing the complexity of the monitoring system and jeopardizing the verifiability of the definition. For an easily verifiable definition, hence, it would be preferable to have all the energy carriers crossing the physical boundary included in the balance boundary as well.

Furthermore, in order to implement a measured rating for Net ZEBs it is necessary to specify the required validity over time and over variable boundary conditions. How long a claimed Net ZEB shall comply with the definition? What happens if in the selected time span, changes in boundary conditions occur, such as variation in the climate, occupancy, building uses? It is therefore necessary to define:

- The time span over which the measured rating shall satisfy the Net ZEB balance;
- Tolerances on the balance and required comfort conditions;
- Parametric analysis approaches to show the relationship between the balance and influencing variables, such as comfort, climate, building use, occupancy, user behavior.

4. Conclusions

While the concept of zero energy buildings is generally understood, an internationally agreed definition is still lacking. It is recognized that different definitions are possible, in order to be consistent with the purposes and political targets that lay behind the promotion of Net ZEBs. A framework for describing the relevant characteristics of Net ZEBs in a series of five criteria and relative subcriteria has been presented. For each criterion different options are available on how to deal with that specific characteristic. Evaluation of the criteria and selection of the related options becomes a methodology for elaborating Net ZEB definitions in a systematic, comprehensive and consistent way. This can create the basis for legislations and action plans to effectively achieve the political targets.

The common denominator for the different possible Net ZEB definitions in the presented framework is the balance between weighted demand and supply. The balance may be calculated in different ways, depending on the quantities that are of interest and available. An *import/export balance* focuses on the energy flows exchanged between the building and the grids; it applies in monitoring or in design when estimates of self-consumption are available. A simpler *load/generation balance* focuses on the gross load and generation quantities disregarding their interplay; it applies in design when estimates of self-consumption are not available. A third type of balance is the *monthly net balance* that can be seen as a combination of the other two; monthly generation and load (for each energy carrier) are assumed to balance each other off and only the monthly residuals are summed up to form the annual totals.

The choice of a proper balance metrics and weighting system should depend on targets in the political agenda and not being driven solely by feasibility of Net ZEB projects or minimization of investment cost; even though this may be a major target itself. However, it is important that authorities and competent national bodies and legislators are fully aware of the effect of the weighting factors when deciding upon the metrics to adopt for the Net ZEB definition they want to set in place.

Important aspects in the framework are the criteria on energy efficiency and energy supply. While the pathway to a Net ZEB is given by the balance of the two actions–energy efficiency and energy supply–experience from a large number of already existing Net ZEBs underlines the priority of energy efficiency as the path to success [15]. Minimum energy efficiency requirements may be enforced in a Net ZEB definition. Likewise, a hierarchy of energy supply options may also be enforced.

Net ZEBs are characterized by more than the mere weighted balance over a period of time. In this paper the authors propose a characterization based on two aspects of temporal energy match: *load matching*, the ability to match the building's own load, and *grid interaction*, the ability to work beneficially with respect to the needs of the local grid infrastructure. These aspects are evaluated separately per each energy carrier exchanged with the grids, no weighting is applied. For the load matching an indicator is proposed, the load match index, able to express the seasonal unbalance of energy exchanged with a grid. For the grid interaction the concept of grid interaction flexibility is introduced, which may be estimated in design phase by simulating different strategies for the control of load, generation and storage systems. The indicators presented address the topics but need to be further developed. However, there is a need to work with a time resolution of hours or even lower in order to address issues such as energy price fluctuation and grids' peak load. To this respect building designers need information on end users temporal consumption patterns, better if from normative data, and the support of advanced dynamic simulations tools.

Finally, it is argued that only a measured rating would enable the verification of claimed Net ZEBs, the effectiveness and robustness of the design solutions applied, and at last the actual achievement of the energy policy targets. Therefore, a measurement and verification (M&V) process is required and its completeness and complexity will dependent on the options selected for the definition criteria. It is stressed that for an easily verifiable Net ZEB definition it is preferable to include all operational energy uses in the balance boundary. Specification of other boundary conditions, such as reference climate, comfort, functionality and space effectiveness, are also necessary in order assess possible deviations from the calculated to the measured balance.

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Appendix A. Conversion factors

		Europe		Austria	Denmark	Finland		Germany		Italy	Norway		Spain		Sweden		Switzerland	
Energy carrier	Metrics	EN 15603 2008	PHPP 2007	Gemis Vers. 4.5	BR 2010 2010	BC 2012 2011	Gemis 2011	DIN V 18599/1 2007	GEMIS Vers. 4.5	UNI-TS-11300/4 draft 9/2009	NS 3700 2009	ZEB centre* 2010-2060	I.D.A.E. 2010	CALENER 2009	average* 2008	pol. factors 2008	SIA 2031 2009	EnDK 2009
Electricity	PEI, n.r.	3,14*	2.70	1,3*		1.70		2.60	2.61	2.18*							2.53	2.00
	PEI, total	3,31*		1.91	2,50*	1.70		3.00	2.96				2.28	2.60	1.50	2.50	2.97	
	$CO_{2\,\text{equiv.}}$	617,00*	680.00	389.00		329.62	331.00		633.00	531**	395	132	350*	649			154.00	
Natural gas	PEI, n.r.	1.36	1.10	1.12		1.00		1.10	1.12	1.00							1.10	1.00
	PEI, total	1.36		1.12	1.00	1.00		1.10	1.12				1.07	1.10			1.15	
	$CO_{2\,\text{equiv..}}$	277.00	250.00	268.00		202*	315.00		244.00		211		251*	204.00			241.00	-
Oil	PEI, n.r.	1.35	1.10	1.11		1.00		1.10	1.11	1.00							1.15	1.00
	PEI, total	1.35		1.13	1.00	1.00		1.10	1.11				1.12	1.08	1.20	1.20	1.24	
	$CO_{2\,\text{equiv..}}$	330.00	310.00	302.00		279*	381.00		302.00		284		342*	287.00			295.00	
Wood, pieces	PEI, n.r.	0,09**	0.20	0.01		0.50		0.20	0.01	0.00							0.05	0.70
	PEI, total	1,09**		1.01	1.00	0.50		1.20	1.01				1.25		1.20	1.20	1.06	
	$CO_{2\,\text{equiv..}}$	14**	50.00	6.00		32.40	17.00		6.00		14		0.00	0.00			11.00	
Wood, pellets	PEI, n.r.			0.14		0.50		0.20	0.14	0.00							0.30	0.70
	PEI, total			1.16	1.00	0.50		1.20	1.16					0.00	1.20	1.20	1.22	
	$CO_{2\,\text{equiv..}}$			41.00			19.00		41.00		14						36.00	
Disctrict heat 70% CHP (fossil)	PEI, n.r.		0.80	0.76				0.70	0.76	System specific							0,81*	0.60
	PEI, total			0.77	1,00*	0.70		0.70	0.77						0.90	1.00	0,8*	
	$CO_{2\,\text{equiv..}}$		240.00	219.00			230.00		219.00		231						162*	

PEI: primary energy indicator ($kWh_{primary}/kWh_{delivered}$); n.r.: non renewable part ($kWh_{primary}/kWh_{delivered}$); $CO_{2\,\text{equiv.}}$: equivalent CO_2 emissions ($g/kWh_{delivered}$). * See comments for each country.

Country	Comments	Sources
Europe	*Power according to UCTE mix **Wood in general	EN 15603 [17] Energy Performance of Buildings – Overall energy use and definition of energy rationgs – Annex E Factors and coefficients, CEN. PHPP (2007) Passive House Planning Package, *The Passive House Institute*, Darmstadt, DE.
Austria	*According to the Austrian Environment Agency	Database of GEMIS, Global Emission Model for Integrated Systems, Internet page of the program: http://www.oeko.de/service/gemis/en/
Denmark	*2015 requirements use 0,8; 2020 requirements use 0,6 for district heating and 1,8 for electricity	The Danish Building Code 2010, BR 2010
Finland	*Based on Motiva report, 2004	National Building Code of Finland. Part D3 Energy-Efficiency. Ministry of Environment 2011 Database of GEMIS, Global Emission Model for Integrated Systems, Internet page of the program: http://www.oeko.de/service/gemis/en/ Motiva report, 2004, emission factors and calculation of emission factors. Available at: http://www.motiva.fi/files/209/Laskentaohje_CO2_kohde_040622.pdf Motiva report, 2004, emission factors and calculation of emission factors. Available at: http://www.motiva.fi/files/209/Laskentaohje_CO2_kohde_040622.pdf
Germany	The normative primary energy factors for the national building code are given with DIN V 18599, emission date are not listet; if emission data are applied the most common source is GEMIS	DIN V 18599:2007-02, part 10, Beuth-Verlag, Berlin, 2009 Database of GEMIS, Global Emission Model for Integrated Systems, Internet page of the program: http://www.oeko.de/service/gemis/en/
Italy	*EEN3/08 resolution by AEEG - GU n. 100, 29.4.08 - SO n.107 - www.http://www.autorita.energia.it/it/docs/08/003-08een.htm www.minambiente.it/home_it/menu.html?mp=/menu/menu_attivita/&m=argomenti.html|Fonti_rinnovabili.html|Fotovoltaico.html|Costi__Vantaggi__e_Mercato.html	UNI-TS 11300 Part IV,under review (last draft 2009)-LA NORMATIVA TECNICA DI RIFERIMENTO SUL RISPARMIO ENERGETICO E LA CERTIFICAZIONE ENERGETICA DEGLI EDIFICI

Country	Comments	Sources
Norway	*EU mix scenario for nearly carbon-free grid towards 2050 (in line with IPCC 450 ppm scenario); average 2010–2060	NS 3700 (2010) Criteria for passive houses and low energy buildings – residential buildings, *Standards Norway*. SINTEF Energy Research (2011) CO_2 emissions in different scnarios of electricity generation in Europa, *Report for the Zero Emission Building research centre*, TR A7058.
Spain	*Carbon emissions only	I.D.A.E., Institute for Energy Diversification and Saving, http://www.idae.es/index.php/lang.uk CALENER, software for certification of energy efficiency in buildings, http://www.mityc.es/energia/desarrollo/EficienciaEnergetica/CertificacionEnergetica/ProgramaCalener/Paginas/DocumentosReconocidos.asp
Sweden	*Calcualted according to EN15316. For electricity, calculations are based on Nordic electricity	http://www.sweden.gov.se/content/1/c6/10/01/76/9e6cf104.pdf, download, 27 July 2011
Switzerland	*Based on waste combustion	SIA 2031 "Energieausweis für Gebäude", SIA 2040 "Effizienzpfad Energie", Schweizer Ingenieur-und Architektenverein, 2009 Gebäudeenergieausweise der Kantone – Nationale Gewichtungsfaktoren, EnDK, Bundesamt für Energie, 2009

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