INDUSTRY CORNER

FROM LOW-ENERGY TO NET ZERO-ENERGY BUILDINGS: STATUS AND PERSPECTIVES

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INTRODUCTION

"Net Zero-Energy Building" has become a popular catchphrase to describe the synergy between energy-efficient building and renewable energy utilisation to achieve a balanced energy budget over an annual cycle. Taking into account the energy exchange with a grid overcomes the limitations of energy-autonomous buildings with the need for seasonal energy storage on-site. Although the expression, "Net Zero-Energy Building," appears in many energy policy documents, a harmonised definition or a standardised balancing method is still lacking. This paper reports on the background and the various effects influencing the energy balance approach. After discussing the national energy code framework in Germany, a harmonised terminology and balancing procedure is proposed. The procedure takes not only the energy balance but also energy efficiency and load matching into account.

KEYWORDS

building energy codes, building energy balance, building integrated photovoltaic, combined heat & power generation, grid interaction

1 BACKGROUND

A completely balanced annual budget for the operating energy or carbon emissions has been the goal of various building and estate projects that have been initiated and implemented recently within Germany and in other countries. The project results are called zero-energy buildings, zero-carbon or carbon-neutral buildings, equilibrium buildings, ...

Politics has adopted these concepts to define energy-saving and climate-change goals within the building sector. The topic is addressed not only in the energy research programme [1] and the current energy concept of the German Federal Government [2] but also in the continuation of the *Energy Performance in Buildings Directive* of the EU (see Table 1) [3]. In North America, *"Zero-energy Building"* has become a general term covering efforts to improve the energy efficiency of buildings significantly [4].

In energy-autonomous buildings—those not connected to an external energy infrastructure—the on-site energy systems, usually solar energy systems, and the energy storage must be dimensioned to guarantee the energy supply *at all times* [5]. The goal for *net* zero-energy buildings is simply a neutral result for an energy or emission balance over the period of one year. Plus-energy buildings aim for a positive balance. "Net" as a modifier indicates that the goal refers to a calculated result over a defined period for the balance between demand or consumption values and electricity fed into the grid. It certainly does not mean buildings without any energy demand at all. Interaction with an existing energy infrastructure is decisive to balance the energy supply and demand, both in terms of quantity and also concerning the form of energy, in some cases. Under European climatic conditions, seasonal compensation plays the dominant role from the energy perspective, whereas short-term equilibrating processes are most important regarding power. Seasonal storage within the building is deliberately omitted from the concept for net zero-energy buildings. In particular, this could not be implemented rationally today for electricity, as batteries are not suitable and building-integrated hydrogen systems are far from technical maturity. However, the feature that net zero-energy buildings share with energy-autonomous buildings is the balanced energy budget, not just the low energy consumption as in the case of passive buildings, for example. Avoiding a fixed goal for energy efficiency, e.g., specified as an energy coefficient in kWh/m^2a, makes the concept internationally attractive, as there is no need for agreement on one energy coefficient for a building category that disregards differing climates, building traditions, and user behaviour: The common feature is the balanced annual budget!

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TABLE 1. Definition and targets of the 2010 Revision of the EU Energy in Buildings Performance Directive [3]

Article 2: Definitions *Nearly zero-energy building means a building that has very good energy performance. The nearly zero or very low amount of energy required should be supplied to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.*
Article 9: Nearly Zero-Energy Buildings *Member States shall ensure that:* *(a) by 31 December 2020, all new buildings are nearly zero-energy buildings; and* *(b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings.* *Member States shall draw up national plans for increasing the number of nearly zero-energy buildings. These national plans may include targets differentiated according to the category of building.*

2 NET ZERO-ENERGY BUILDING THEORY

Although the energy-balancing procedure for a net zero-energy building appears to be simple at first glance, the details quickly become complex and open questions are numerous. To date, no single balancing procedure has been recognised in Germany or internationally. A forum for this topic was established in 2008 on German initiative as a working group within the International Energy Agency entitled "Towards Net Zero-energy Solar Buildings" [6]. After a comprehensive literature review [7], initial boundary conditions for a harmonised definition [8] were formulated as part of its methodological work. The initial work is concentrating on concepts in which on-site demand for non-renewable energy is compensated by exporting electricity to a public grid (building energy balance). Special cases such as all-electric buildings with an external grid power supply based entirely on renewable energy,[1] or solutions on the scale of building quarters or towns, with their extended system boundaries and technical potential,[2] are generally beyond the scope of this group at present.

The basic approach at the individual building level is always a two-step concept, consisting of

1. reducing the energy demand
2. exporting energy optimally into external grids.

Furthermore, definitions are needed for

- a suitable metric (primary energy, carbon emission, etc.)
- an accounting procedure (conversion factors),
- the balance boundary
- the balancing period.

The investigated national approaches vary in these aspects, each one applying the calculation procedure already introduced nationally to determine energy demand (Fig. 1).

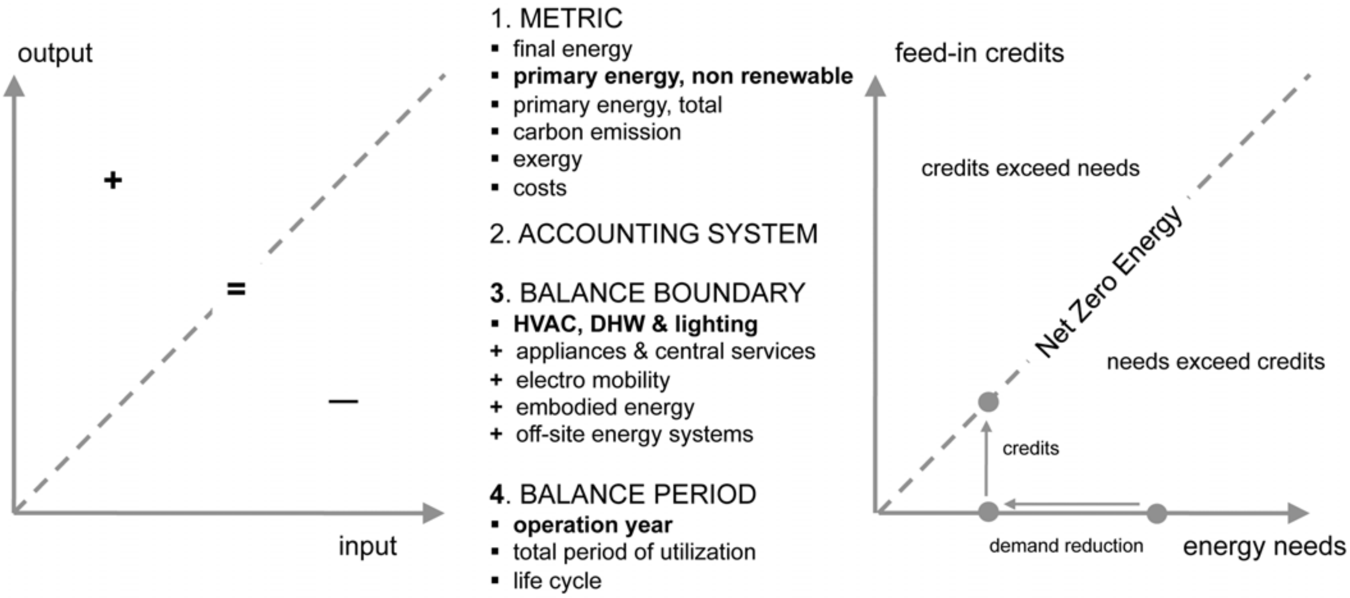
In 2007, a study on the non-residential building stock in the USA determined that an average reduction in consumption of 60% would be needed, simply to compensate theoretically for the electricity consumption of the buildings on an annual basis via electricity fed into the grid from photovoltaic systems mounted on the buildings themselves [9]. Savings of more than 90% would be needed for some building categories. These data illustrate how essential it is to increase energy efficiency drastically if net zero-energy buildings are to be achieved. After suitable evaluation, the remaining energy demand or consumption immediately describes the credit that is required from export to the grid. Based on the presently dominating concepts with photovoltaic generation on the building itself, the area and orientation of the available envelope surfaces directly determine the maximal allowable energy demand of a building at a given site. As the number of storeys increases, a zero balance cannot be achieved with solar energy technology alone, as the building energy demand increases more rapidly than the envelope area suited for solar energy conversion. Significant use of wind power directly at the building is limited to a few special cases. By contrast, building-integrated co-generation (combined heat and power – CHP) is promising, specifically when it is based on renewable energy sources [10].

Even when the balance according to Fig. 1 is zero and there is agreement concerning all four criteria for balance calculation, there are large differences in the energy performance among existing net zero-energy buildings. The differences mainly concern:

- the temporal match between energy supply and demand (load matching – degree of internal usage)
- the temporal match between exported electricity and the grid requirements (temporally variable value of the exported electricity)
- matching between the consumed and exported forms of energy (fuel switching, e.g., excess electricity exported during summer but natural gas consumed in winter)

An economic incentive for internal usage of the generated electricity, rather than export to the grid has been introduced in Germany since 2010, when the energy feed-in law was revised [11]. Within the German context using CHP-generated electricity within the building is also more economic than export [10]. With the planned introduction of so-called "smart grids" using electricity tariffs varying according to the time of day and year, the value of electricity drawn from or exported to the grid will affect the building operator financially and can thus be used as a steering mechanism. Net zero-energy concepts, which rely essentially on the storage capacity and power reserves of the grid, will become more expensive to operate than those that adapt the import and export of

FIGURE 1. The left-hand diagram illustrates the schematic input/output balance of a building project. The balance calculation needs the definition of a metric and an accounting system, the system boundary and the balancing period. As an example, the right-hand diagram uses primary energy (non-renewable fraction only), the system boundary of the German energy code EnEV and one year of operation. The diagonal within the diagram describes a net zero-energy building in this context. The primary energy demands are balanced by the primary energy equivalent of the electricity fed into the local grid. Net plus-energy buildings in that sense are represented in the upper left part of the diagram.



electricity to the building consumption profile and the tariff situation. Although the trend toward so-called *all-electric buildings* in the residential and non-residential sectors avoids winter consumption of natural gas, for example, it increases the seasonal imbalance between consumed electricity and the potential for exporting photovoltaic electricity due to the electricity consumption of the required heat pumps. The electricity consumption in winter and thus consumption of grid electricity increase. Solutions based on CHP are the only ones that usually lead to the summer electricity supply being lower than the building demand, as insufficient heat sinks are available then and CHP systems are usually operated in the heating-led mode. The combination with photovoltaic power generation and active load management means that the degree of internal usage can be more constant throughout the year.

3 PROJECTS

Within the framework of the IEA, data was acquired and analysed on more than 300 projects around the world that addressed the topic of net zero-energy buildings [12]. All types of building categories and sizes are represented. Most of the buildings are located in Europe. First examples of existing buildings that were renovated to meet the net zero-energy building criteria are also included. Table 2 presents a selection of projects and their features. The international university competition, "Solar Decathlon," regularly attracts public attention to the topic. Figure 2 shows the Wuppertal University entry from the 2010 competition in Madrid [13].

4 NET ZEBS IN BUILDING ENERGY CODES—THE GERMAN EXAMPLE

Until early 2011 no national energy code defines a Net ZEB explicitly. The basis for evaluating the energy balance of buildings in Germany is the energy-saving regulation (EnEV); the system boundary encloses all of the energy flows covered by DIN V 18599 [14]. This refers to the energy used for space heating, domestic water heating, cooling, ventilation, and lighting. It does not include the "miscellaneous" electricity consumption of user-specific equipment, appliances, and central services. The calculation procedure is based on monthly energy balances. Credits for electricity from renewable energy sources are explicitly mentioned for the first time in the 2009 EnEV revision (see Table 3) [15]. The German Institute for Building Technology has provided a more detailed explanation (see Table 4) [16].

Electricity generated for use within the building by building-integrated CHP systems is taken into account by the standard [14]. The central concept is to calculate a credit for the electricity generated in combination with heat provision, thus reducing the primary energy equivalent calculated for the fuel used in the CHP system (credit procedure). In the simplified version, the credit is calculated as part of the annual balance. In contrast to the procedure for PV power supply as described above, monthly surpluses in the electricity generated compared to the building's electricity consumption are not cut off. This procedure applies, regardless of whether the fuel used is renewable (e.g., rapeseed oil) or non-renewable. A negative value for primary energy is set to

TABLE 2. Selected net zero-energy buildings [12].

Typology			Project name	Country	Location	Date completed	Usable floor area in m^2	Web link	Energy supply features
residential buildings	new buildings	single house	Home for life	DK	Aarhus	2008	190	www.activehouse.info/cases/home-life	• all electric house • heat pump • solar collectors • PV system
		single house	Lighthouse	UK	Watford	2007	93	www.kingspanlighthouse.com	• woodchip-fuelled boiler • solar collectors • PV system
		single house	ÉcoTerra Alouette Home	CA	Eastman	2007	234	www.maisonalouette.com/english/ecoterra2/	• all electric house • heat pump • BIPV (building-integrated photovoltaic/thermal)
		apartment block	Kraftwerk-B	CH	Bennau	2009	1400	www.grabarchitekten.ch/	• wood-fuelled stoves • PV system • façade collectors • heat export
		apartment block	Kleehäuser	DE	Freiburg	2006	2519	www.kleehaeuser.de	• natural gas CHP • solar collectors • PV system • share in wind park
		Estate	Solarsiedlung	DE	Freiburg	2008	7890	www.solarsiedlung.de/	• CHP district heating • photovoltaic roofs
		Estate	BedZED	UK	Wellington	2002	7270	www.zedfactory.com/bedzed.html#	• biomass CHP • biomass-fuelled boiler • PV system • electric cars
		Estate	SunnyWatt	CH	Watt	2010	5900	www.kaempfen.com	• all-electric house • heat pump • solar collectors • PV system
	renovation	single house	Wohnhaus „Moschik"	AT	Arnoldstein	2010	240		• woodchip-fuelled boiler • wood gasifier and boiler • chimney stoves • solar collectors • PV system
		apartment block	Blaue Heimat	DE	Heidelberg	2006	3374	www.zero-haus.de/blaue-heimat.html	• natural gas CHP • PV system • share in wind park

(continued on next page)

TABLE 2. (continued)

Typology			Project name	Country	Location	Date completed	Usable floor area in m^2	Web link	Energy supply features
non-residential buildings	new buildings	school building	Primary school Lajon	IT	Lajon	2006	625		• heat pump • solar thermal collectors • PV-systems
		school building	Enerpos building	FR	St. Pierre, La Reunion	2008	1300	www.enerpos.univ-reunion.fr	• all electric building • PV-systems
		office building	Marché international support office	CH	Kempttahl	2008	1516	www.kaempfen.com	• all electric building • heat pump • PV system
		office building	JUWI-Haupt-quartier	DE	Wörrstadt	2009	8500	www.juwi.de/ueber_uns/standorte_weltweit/woerrstadt.html	• woodchip-fuelled boiler • solar collectors • PV system • battery bank • biogas export
		office building	Bürogebäude AEE	AT	Villach	2002	399	www.aee.or.at/index.php?menue3=31	• solar collectors • woodchip-fuelled boiler • PV system • heat export
		office building	Pixel	AU	Melbourne	2010	1000	www.pixelbuilding.com.au/	• micro on-site wind turbines • fixed and tracking PV systems • anerobic digestor with methane gas used as source for hot water
		office building, factory	Haupt-quartier Solon SE	DE	Berlin	2008	8300	www.solon.com/de/unternehmen/solon-auf-einen-blick/solon-corporate-headquarter/	• use of waste heat • regional heating with biogas • PV systems • battery bank • solar charging station
		office building, factory	Solvis	DE	Braun-schweig	2000	8215	www.solvis.de/sol_nullemissionsfabrik.php	• use of waste heat • solar collectors • rapeseed-oil CHP • PV system
		office building, factory	Solarfabrik	DE	Freiburg	1999	4260 (BGF)	www.solar-fabrik.de/unternehmen/firmenprofil/nullemissionsfabrik/	• rapeseed-oil CHP • rapeseed-oil-fuelled boiler • PV system
	renovation	office building	IDeAs Z2 Office	US	San Jose	2007	669	www.z2building.com/	• all-electric building • heat pump • PV system
		office building	WWF headquarters	NL	Zeist	2007	3770	www.rau.nl	• solar thermal collectors • PV system- rape oil CHP

FIGURE 2. The building entered by Wuppertal University in the Solar Decathlon Madrid, 2010. The energy supply is based on solar power generation and vacuum tube collectors combined with a heat pump. Photo: Peter Keil, Düsseldorf.

TABLE 3. Guidelines for taking electricity from renewable energy sources into account within the German energy-saving regulation EnEV 2009 [15].

If electricity from renewable energy sources is used in the buildings that are to be constructed, the electricity in the calculations … may be subtracted from the end energy demand, if it   *1. is generated in the immediate vicinity of the building and*   *2. is primarily consumed within the building itself and only the excess electricity is fed into a public grid.*   *The maximum amount of electricity as covered by Statement 1 that can be credited is the amount corresponding to the calculated electricity demand for the relevant usage.*

TABLE 4. Explanation of EnEV by the German Institute for Building Technology [16]

• *Electricity generation "in the immediate vicinity of the building" can be assumed when power lines of the public electricity grid are not used to conduct the electricity generated from the renewable energy sources to the building. By contrast, it is irrelevant whether the building owner or a third party is the operator of the generating system. If the initially stated condition applies (no transfer via the public grid), so-called "building-quarter solutions"—common generating systems shared by several buildings—can be taken into account.*   • *Electricity from photovoltaic systems presents the main practical application case for EnEV, § 5. This paragraph specifically takes account of the change to the funding pre-conditions according to § 33, Section 2 of the Law on Renewable Energy (EEG), which regulates its priority. As proof of the consumed amount of electricity must be obtained for application of EEG, § 33, Section 2, it can be assumed that not only the contractual framework but also the necessary conditions concerning the electric circuit and measurement technology will be fulfilled. Thus, for each individual photovoltaic system, it is possible to distinguish unambiguously between electricity "primarily consumed within the building" and that which is "fed into a public grid." The priority given to consumption within the building up to the amount of electricity needed is already documented by meeting the pre-conditions for applying the option of EEG, § 33, Section 2.*   • *The annual primary energy demand according to the energy-saving regulation (EnEV) is calculated . . . on the basis of monthly balances. According to a consistent extension of this approach, subtraction of electricity generated from renewable energy sources in the immediate vicinity of the building must also be calculated on a monthly basis. The greatest amount of electricity that can be taken into account thus results from monthly calculation of the "end energy demand for electricity."*   • *The electricity yield of the photovoltaic system is to be calculated monthly according to suitable technical regulations.*

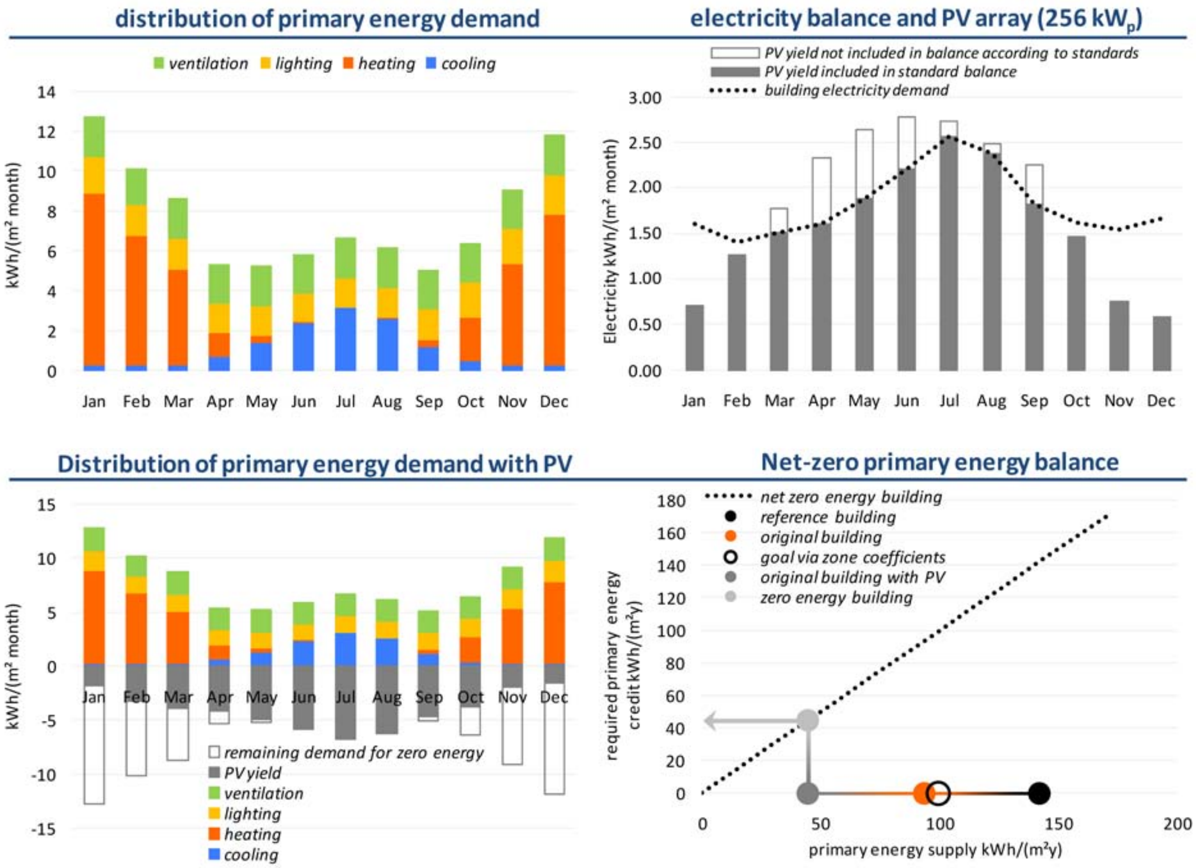


FIGURE 3. Graphical output of the energy demand calculation for an office building determined with EnerCalc [19]. The building uses natural gas for heating. The photovoltaic system is automatically dimensioned to meet the annual electricity demand of the building (30.9 kW_p). The excess power during some of the summer months is accounted as grid power und initially not considered for the building power balance or the seasonal balance. In a second step, an additional, virtual PV system is dimensioned to balance the total annual primary energy needs of the building, thereby taking into account seasonal compensation and fuel switching (86.3 kWh/m^2a primary energy credits due to a 40 kW_p PV power system). Monthly electricity surpluses from the first photovoltaic generator are also taken into account.

zero. As the balance is made on an annual basis, other forms of consumption in the building are included in the calculation. This aspect is another point in which this approach deviates from the described PV calculation approach.

Definitions or calculation procedures for net zero-energy buildings cannot (yet) be found in current laws or regulations. The commercially available calculation tools for energy passports are not designed for this case either. As seasonal compensation of photovoltaic electricity surpluses in summer by winter deficits is excluded, net zero-energy buildings cannot be achieved under German climatic conditions. The standards for calculating the primary energy balance also exclude cross-calculation of electricity export to the grid and acquisition of fossil fuels (fuel switching).

As part of a PhD thesis on simplified procedures for calculating energy balances in compliance with DIN V 18599 [17, 18], an EXCEL-based tool was developed that already transparently combines the calculation method for photovoltaic generation of electricity prescribed by the standards with energy balancing for a zero-energy building (see Fig. 3) [19]. It also already integrates the calculation of an energy goal for a building on the basis of the so-called energy-zone coefficient method. In this approach, the building energy goal is determined on the basis of goals for its usage zones and is presented in addition to the reference value according to the standards. A critical discussion of both methods is included in [20].

5 ROAD MAP FOR DEVELOPMENT

5.1. Methodology

5.1.1 Metric

As most buildings use other forms of energy in addition to electricity, it is not appropriate to calculate the balance at the end energy level. Most countries therefore apply procedures that use primary energy or the associated CO_2 emission as an indicator [7]. The subject of CO_2 emissions is not covered by standards in Germany, but is taken into account in the recently introduced sustainability certification [24]. In practice, the tabulated factors according to the GEMIS calculation models are generally used in the building sector to determine CO_2 emissions and credits, as tabulated, e.g., in [25]. A transition to building evaluation based on CO_2 values would make climate change rather than limited resources the central topic. It is noteworthy that both the energy research programme and the current energy concept of the German Federal Government focus on the zero-*emission* building or the *climate-neutral* building, respectively [2, 3].

Within the context of DIN V 18599, the primary energy evaluation concentrates on the non-renewable share. Among other effects, this results in the very low primary energy factors for biomass as a fuel (0.1 to 0.2). Whereas the approach for the use of solar energy in buildings appears to be appropriate (0.0), the limited availability of biomass from sustainable sources will already present a problem on the medium term.

The net zero-energy-cost building is addressed in only a few cases, as the balance result is strongly dependent on changes over time and political influence on the costs [26]. Using exergy as the basis for balancing fails due to the lack of comprehensibility for planners and communicability for the general public. Essential methodological aspects have not yet been clarified [28].

5.1.2 Accounting

Starting with primary energy as an indicator raises a question concerning the conversion factors that should be applied. In the European context, usually the averaged factors for the countries participating in the joint European grid are favoured. They deviate from those for the national grids to a greater or lesser extent, depending on the country, and thus lead to different balance results. In Switzerland, not only the calculated national primary energy factors are known but also politically determined weighting factors that are used as a strategic steering instrument [29]. Concepts with different factors for energy imported to and exported from the building are also possible. The development of *smart grids* with temporally variable tariffs could also result in temporally variable primary energy factors. Temporally variable primary energy and emission factors are already applied in some American grids.

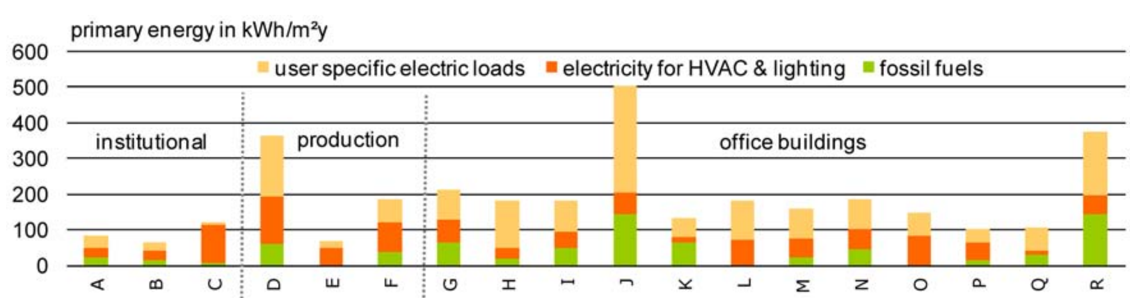
5.1.3 System boundaries for balancing

The balance as defined by German standards considers only the energy demand relating to technical building services, and does not do this completely. Two significant difficulties arise thereby:

- The calculated demand cannot simply be compared to the measured consumption of a building. Electricity meters do not differentiate between electricity consumed for different purposes, but between circuits or rental units. As a result, the balance cannot be verified by measurements without additional effort. The greater the success in reducing energy demand for HVAC, DHW and lighting (= the normative building energy demand in Germany), the greater is the influence of "miscellaneous consumption" (see Fig. 4). This effect applies not only to energy but also to power and peak power as important indicators for grid loads.
- As soon as the internal load match index becomes significant for the evaluation (see 5.1.5), the internal coverage rates determined within the system boundaries of the legal standard will be too high, as significant consumption categories are not included in the balance but are supplied with electricity from the building circuit. If the complete balance is calculated, the surpluses from the electricity generated on-site, which are not considered in the standard, would be smaller, as the included demand and consumption would be greater.

Both aspects lead to the necessity to extend the system boundaries, specifically for electricity consumers, to include all consumption sectors. Initial approaches to quantify other electricity consumers are provided by building-specific benchmarks for existing buildings [30]. The SIA standards

FIGURE 4. Measured primary energy coefficients for selected buildings in the EnOB research programme that is funded by the German Ministry of Economy and Technology. The data have not been corrected for meteorological effects, relate to the useful floor area, and are separated into the sectors covered by the German building energy code (fossil fuels, HVAC, DHW & lighting electricity) and "user specific electric loads." On average, the user specific loads make up about 60% of the total primary energy consumption in the investigated buildings. It varies significantly from one building to another.



in Switzerland [29] or the passive building projection packet PHPP [31] have taken this step and allow planning with standard values (SIA) or project-specific planning data (PHPP). Inclusion of electro mobility as part of the building balance is a topic that has already been addressed in some of the first projects [32]. Electric vehicles are included as electricity consumers in the same way as household appliances, as they draw electricity from the same grid.

By contrast, it does not seem to be sensible to extend the system to include systems that are not located in the vicinity of the actual building (purchase of green electricity, shares in wind parks, and others), as such systems are part of the public grid and do not primarily meet the building demand. Also, they are measures that can easily be replaced, particularly the purchase of green electricity. They use the transport and storage capacity of the public grid and reduce both the primary energy factor and the associated emissions. These effects are already taken into account on the expenditure side of the building energy balance. Similarly, including electricity from photovoltaic systems on buildings is also problematic if they are primarily intended to feed into the grid rather than meet demand on-site.

5.1.4 Balancing period

Net zero-energy buildings are defined in most cases by a balanced annual energy budget. The planning is based on meteorological data for a typical year at the location, often in the form of a Test Reference Year (TRY), not an extreme year. In practice, both types of year can occur, so that the energy budget may be balanced in one year but not in another.

To date, evaluation factors, which are constant over time, have been assumed, so that calculation for one year is sufficient to analyse the operating energy. If net zero-energy buildings are considered in the context of future scenarios, account must be taken of the primary energy factors for grids, which will change with time. The factor to be applied according to German standards for grid electricity has already fallen from 3 to currently 2.6 over somewhat more than a decade. Whereas this effect does not change the balance for all-electric buildings, the balance deteriorates in those cases where credits from electricity export to the grid have to compensate for import of a different form of energy, e.g., woodchips for a heating boiler or natural gas for a CHP system.

In general, the energy to construct or to demolish and dispose of the building is not taken into account. Its share in the energy balance over the entire life cycle of a building increases with decreasing operating energy demand, which is usually accompanied by an energy increase for production. "Embodied energy," which also includes energy for the replacement and renovation measures that are required during the service lifetime, typically accounts for 20 to 30% of the total primary energy expenditure for an energy-efficient building with a lifetime of 80 years; this represents about 30 kWh/(m^2 a) [33]. The values vary significantly depending on the type of building construction (wooden or masonry construction) and further features (with/without an underground garage). First calculations indicate that these differences are greater than those caused by constructing a net zero-energy building. Due to their relatively high energy demand for production, the dimensions of the photovoltaic systems on the building represent a critical factor. This is a further argument for ensuring that the energy demand is low, so that the energy budget can be balanced with the smallest possible photovoltaic system.

Building certificates such as the new German label issued by the DGNB (German Society for Sustainable Building) already include embodied energy in the evaluation. However, usually a general approach is applied due to the major effort (still) involved in acquiring relevant data. The large amount of energy embodied in an existing building acts as a credit that significantly improves the total energy balance for building renovation compared to new construction. It thus appears that a balance over the entire life cycle is the right approach on the medium term but that immediate adoption would be premature. This approach conforms to the growing trend toward cost analysis in the form of building usage costs, which is also oriented toward the building life cycle.

On the other hand, it should be noted that the public grid infrastructure is also underpinned by production energy. As the proportion of electricity generated from renewable energy sources increases, the production energy required for public grids also increases due to the lower energy density of renewable energy resources compared to fossil fuels. The values documented in [25] give an impression of the accumulated energy expenditure for generation of grid electricity.

5.1.5 Load match

If the local generator is grid-connected, decentrally generated electricity is used both a) to reduce the amount of external energy required, and b) to feed into the public grid.

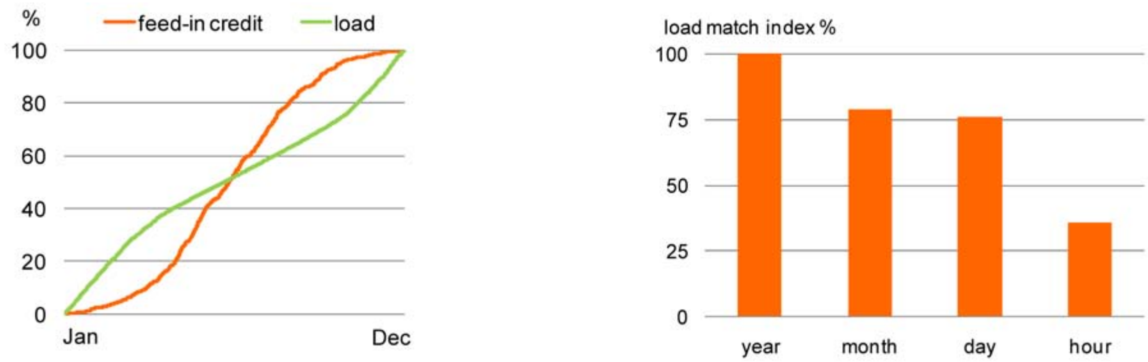
A load match index serves to describe the relative proportions and can be formulated as follows:

$$f_{load,i} = \min\left[1, \frac{\text{on-site electricity generation}}{\text{electricity consumption}}\right] \cdot 100\ [\%]$$

$$i = \text{time interval (hour, day, month)} \qquad \text{(eq. 1)}$$

The load match index calculated in this way is influenced by the consumption profile and thus by the building usage, the generation profile and the time interval for evaluation. A comprehensive treatment is offered by [34]. Starting with monthly balances, the annual average load match index for a photovoltaic system that meets the annual electricity demand of a building in total is on the order of 60 to 80%. Similar annual average values are obtained when the balance is based on weekly or daily values. If instantaneous values are considered ("net metering"), the load match indices fall to 30% and less if no measures are taken concerning load management or electricity storage within the building. This is essentially due to peak loads and to complete dependence on grid electricity during the night. Photovoltaic systems with larger dimensions hardly improve the load match index as long as the building lacks internal capacity for storing electricity.

FIGURE 5. Electricity credit and load profiles simulated by the Wuppertal Team for their entry to the Solar Decathlon 2010. The PV system is dimensioned to supply 100% of the annual demand for the all-electric house. The cumulative graph (left) describes the seasonal mismatch between demand and supply of electricity. The load match index (right) varies strongly, depending on the balancing period. Net metering typically leads to a load match index of 30 to 40% in a residential building in a Central European climate [35].



Introduction of a load match index leads to classification of the electricity generated on site. This approach allows distinction between those net zero-energy buildings that largely achieve the zero balance by internally consuming the electricity generated on-site and those that essentially use the seasonal storage function of the grids. The latter share is neither considered nor determined in German standards. The calculated load match index raises problems due to the user-specific electricity consumption that is not taken into account. It should also be noted that also monthly values are only virtual load match indices, as a balance based on instantaneous values results in significantly lower values. In this context, a further problem is caused by the differing treatment of photovoltaic and CHP systems. As there is no monthly cut-off limit for CHP systems, no distinction is made between on-site utilisation and export of surpluses to the grid. A load match index is not determined. Section 6 of this article explains how a consistent methodological treatment of electricity generated by photovoltaic and CHP systems can contribute to the definition of net zero-energy buildings.

5.2 Technology and Grid Integration

As already stated initially, it is the *optimisation* and not the maximisation of electricity exported to the grid that is an essential planning goal for net zero-energy buildings, in addition to the reduction of energy consumption. From the grid perspective, optimisation does not only affect the exported electricity but also the temporal profile of electricity export and import. An initial indicator for effects on the grid is the fluctuation range for the import and export values, expressed mathematically as the standard deviation [34]. However, definitive characterisation cannot be obtained in this way, as the quantitative effect of a building on a grid is also determined by the local grid infrastructure and the energy source mix of the grid in question.

However, the peak power demand is decisive in all cases, as it defines the grid capacity that must be provided. Whereas thermal storage units have already been introduced to buildings and can be further extended by application of new technology, the issue of distributed capacity to store electricity for short periods within the context of active load managements is still open. Batteries located either in buildings [35] or in vehicles [32] are being discussed and tested. Weather forecasts integrated into system controls, combined with active load and generator management, allow load and generation profiles to be predicted. Only once the public grids have been restructured to accommodate a higher quota of renewable energy will it be possible to determine how much effort in this direction is justified at the building level. Such solutions appear to be premature at present. On the long term, if buildings are to be interpreted as components of the grid, a total-energy evaluation at the building level no longer appears to make much sense.

6 CONCLUSIONS

The zero-energy building is often presented as a maximum goal in the political context. It was already argued at the beginning of this article that there are other equally useful approaches beyond that concentrating on a single building to define ways to reduce the energy consumption in new buildings and the existing building stock. The appropriate effort concerning a single building is determined economically and ecologically in the context of available alternatives to achieve the goal of a "climate-neutral building" [2]. The various approaches will complement each other. However, the subject of a building energy code such as the German EnEV normally is a *single* building that is placed in the context of a given energy infrastructure via the primary energy factors that are to be applied. In this framework, the net zero-energy building concept also describes the balance for a single building. There is no question that there can also be "net zero-energy building quarters" or "net zero-energy towns" [36]. They do not consist of a collection of net zero-energy buildings but profit from the compensation of supply and demand between individual buildings and from the economy of scale.

Based on the monthly energy balances and the regulation for photovoltaic electricity contained in the energy code, a definition for the net zero-energy building in the German context is proposed below. This definition is based on input/output balancing at the supply interface of a building according to Fig. 1 (= meter balancing). Here, it is not a matter of balancing renewable energy against non-renewable energy. The usage of solar energy and CHP systems is treated equally. A definition that focused on solar energy usage alone would not offer any potential for larger buildings or most of the existing building stock to reach the goal [37]. Electricity generated on-site is credited according to the code. Surpluses in the monthly balances are identified in the annual balance and are not used as a primary energy credit to reduce the effective consumption of other fuels on a monthly basis.

Following this approach, it is necessary that

a) the balance boundaries of the building code be extended to include the entire energy demand of a building, including the usage-specific electricity demand. A suitable method is the specification of demand coefficients for appliances, user-specific equipment, etc., in the usage profiles defined by standards [30].
b) the energy balancing of CHP systems be adapted to the existing procedure for photovoltaically generated electricity and that the balancing period be changed from a year to a month. This is the only way to distinguish between electricity consumed on-site and electricity exported to the grid.

In forming the abbreviation, the "net" modifier might be omitted in the German context to simplify communication. The specification of the primary energy credit indicates that it is the result of a balancing procedure. The concept of "plus-energy building" is not addressed, as the understanding of a "building as a power station" raises fundamental questions about the sense of balancing the primary energy demand of a single building in the context of the building energy code, and requires characterisation from the grid perspective. Furthermore, the term is a registered trademark.

Monthly balancing is a compromise with regard to the separation of internal consumption and electricity export (cf. Fig. 5). The focus of a label such as *ZEB 82* is the distinction between zero-energy buildings with the need for major seasonal compensation via the grid and those with low demands for seasonal transfer. The lower the number, the lower is the need for compensation. Furthermore, the numerical value is an indirect indicator for energy efficiency.

In the medium term, there is a need to clarify the standards with respect to the specified primary energy factors, so that they reflect the limited extent of biomass resources. Standardisation committees are already working on this point.

In the long term, life-cycle balancing of buildings, including their production, maintenance and demolition/disposal should be taken into account in the definition of zero-energy buildings.

DEFINITION

A zero-energy building is an energy-efficient building which in combination with the public electricity grid meets its *total* annual primary energy demand, as determined by monthly balancing, by the primary energy credit for electricity surpluses fed into the grid. The electricity generated on-site is used primarily to meet the building's own energy demand.

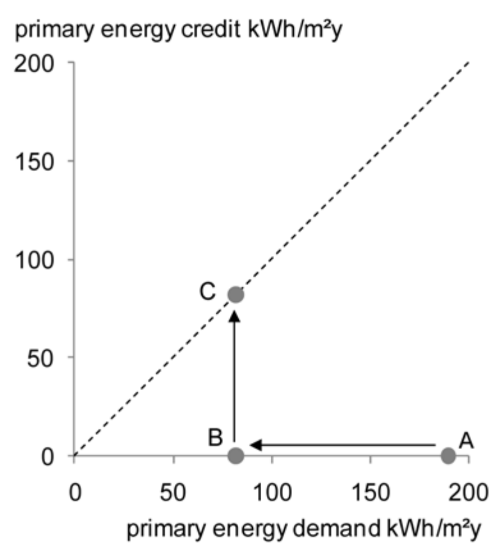
LABELLING

A zero-energy building is labelled by the abbreviation "ZEB" together with the specification of the primary energy credit, which is required and achieved to obtain a balanced annual energy budget. The primary energy credit is determined on the basis of the monthly balancing procedure, taking the priority of consumption on-site into account. Annual surpluses are not taken into account (as is usual for plus-energy buildings).

EXAMPLE

The entry by the University of Wuppertal to the Solar Decathlon 2010, an experimental zero-energy house with a floor area of 48 m^2 (Fig. 2), has a calculated total primary energy demand of 190 kWh/m^2 including household electricity (A). The monthly photovoltaic yields for building-internal consumption, which can be credited, reduce the demand by 108 kWh/m^2 (B). A further 82 kWh/m^2, representing generated surpluses, are exported from the photovoltaic system to the grid and serve as seasonal compensation for the balance (C). Accordingly, the correct label for this house is: ZEB 82. The relatively high value is explained by the inclusion of the household electricity demand in the balance.

GRAPHICAL PRESENTATION



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NOTES

1. The situation in Norway serves as an example. The energy supply for most buildings is based entirely on electricity. The electricity supply is based almost entirely on hydroelectricity.
2. Examples include district heating concepts for urban areas based on solar energy or the use of biomass with CHP. Temporal averaging of the energy demand between buildings (asynchronous profiles) and the greater economic viability of larger systems offer significant advantages.