Net Zero Energy and Net Energy Plus Buildings

Framework conditions, balancing and design approaches
Straight to the point

Buildings generally have the potential and infrastructure to generate the energy required by them on site. This provides the principle behind net zero-energy (Net ZEB) or net energy-plus (Net EPB) buildings, whose numbers are steadily increasing around the world and especially in Germany. They have names like “energy-plus house”, “zero emissions house”, “efficiency house plus”, “activated-plus house” or “solar active house“ and, internationally, “net zero-energy building”; “carbon neutral home”, “EQuilibrium™ House” and “Bâtiment à énergie positive”. Normatively introduced definitions are usually, however, not yet available. With the recasting of the EU’s “Energy Performance of Buildings Directive (EPBD)” in 2010, the European Union has already set out its aim of achieving “nearly zero energy buildings”, requiring that all new buildings in the Member States meet this building standard, which is not defined in any specific detail, from 2020 on.

Architects have long used zero energy concepts in order to position themselves in the growing market for “green buildings”. Private clients are thrilled about the sustainability and low operating costs of such buildings. With these concepts, housing associations and real estate companies want to increase the attractiveness of their properties and thus the tenancy rates. And it is not just companies from the eco-industry who are hoping for a marketing edge through Net ZEB. But how should these buildings be actually monitored and balanced in energy efficiency terms? Which period of time should be covered by the monitoring? What should be included in the balance? Are primary energy consumption, CO₂ equivalents or energy costs appropriate indicators and how are they converted? How will the buildings be implemented in technical terms and how will this impact on their architecture?

Scientists from 18 nations have addressed these questions under the auspices of the International Energy Agency (IEA). Within the “Towards Net Zero Energy Solar Buildings” Working Group they conducted an intensive dialogue on appropriate definitions and assessment methodologies, and discussed their experiences with internationally accepted balancing methods. The German participation was supported by the German Federal Ministry for Economic Affairs and Energy within the framework of its EnOB: Research for Energy-Optimised Building funding initiative. In this Themeninfo brochure, the German participants will be presenting some of their findings, illuminating the historical and energy policy background, and analysing examples from practice.

The BINE Editorial Team wishes you an enjoyable read

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Until now, buildings have been mostly pure energy consumers. They are supplied with electricity from power plants and produce their heat decentrally, mainly using fossil fuels. The general conversion to energy supplies largely from renewable energy sources raises the question as to what role the building sector can play in this regard in future.

Worldwide, buildings consume a considerable proportion of the energy. In 2010, the provision of space heating, domestic hot water heating, cooling and lighting comprised almost 38 % of the total final energy consumption in Germany (Fig. 1). Around two thirds of this energy flows into residential buildings. Here the heat supply outweighs the other consumption loads because many buildings were already built before the first German Thermal Insulation Ordinance came into effect in 1977 and have still not yet been fully refurbished to improve their energy efficiency.

Although the absolute energy consumption of German buildings has reduced in recent years as a result of the steady tightening of standards and laws, technological advancements and changes in consumer behaviour, the increasing demand for living space in Germany is having an opposing effect. Between 1960 and 2010, the per capita living space increased from 19 to 43 m².

Climate-neutral building stock – where will the energy be generated?

Until now, legal requirements have been primarily aimed at reducing the energy consumption in new buildings and refurbishments. The aim of a “climate-neutral building stock”, which is identified by the German federal government in its Energy Concept, also continues to allow for a purely external supply to buildings. Biomass, ground-mounted PV systems, wind and water power could theoretically meet the energy requirements of buildings climate neutrally. In practice, however, there is a lack of appropriate areas and locations, and there are conflicts regarding land use. Also problematic is that electricity from renewable energy sources is produced decentrally, often fluctuates across time and is difficult to store.

However, because buildings are fixed to their location (real estate), they can – unlike for example vehicles – tap the available renewable energy on site and utilise it directly. Solar radiation as well as environmental and geothermal energy provide possible sources of local, natural energy, as does wind in individual cases and – in exceptional cases – running water. Buildings can use this energy both passively and actively, and convert it into heating or cooling energy as well as electricity.

Original idea: Using the heat from the sun

Since the middle of the 20th century, researchers, architectural visionaries and ecological lateral thinkers have been working on buildings that do not draw on external energy for providing heat while still meeting modern comfort requirements. Most of these examples can be found in central Europe and North America as a result of the technological advances that have taken place there. Because local climatic conditions meant that the need to heat cannot be

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<th>Private households (PH)</th>
<th>Commerce, trade and services (CTS), industry (I)</th>
<th>Building-related energy</th>
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<tr>
<td>46 %</td>
<td>54 %</td>
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<td>PH: Hot water 4 %</td>
<td>PH: Space heating and cooling 21 %</td>
<td>PH: Hot water 4 %</td>
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<td>CTS: Space heating, cooling and hot water 8 %</td>
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<td>PH: Household, IT etc, 4 %</td>
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<td>CTS/I: Rail traffic and inland/coastal shipping 1 %</td>
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entirely avoided or offset by solar heat gain, the concepts initially focussed on meeting this heating requirement by means of large thermal solar collectors and storage systems.

Towards the end of the 1980s, construction research in Germany initiated technically-focussed demonstration projects. Ecologically minded developers and designers also constructed several experimental buildings. What these projects have in common are their energy saving strategies, such as the considerable use of insulation or the utilisation of solar thermal energy through windows that had very low $U$-values for that period. In order to save heating energy and reduce transmission and ventilation heat losses, many of these projects anticipated the aspects focussed on by the Passive House concept.

Neutral annual energy balance: net zero

Biomass boilers as heat generators have supplemented subsequent projects. They bridge low solar heat yields during periods of bad weather, can offset climatic variations between the years and enable small-scale solar thermal systems and storage components.

Although the biomass volumes used are very low, this has raised questions about the sustainability of supplying firewood or wooden pellets as well as the resulting local emissions. This has led to the idea of compensating for the remaining energy supplies or the associated greenhouse gas emissions through credits from solar power systems: an annual balance based on primary energy or CO$_2$ emissions. This concept makes it possible to dispense with the last percentage points when saving energy. This has resulted in projects described as “zero-energy house”, “energy-plus” or “zero emissions houses”. A common feature of all the approaches in heating-dominated climates is, in addition to a neutral energy and emissions balance, the principle of energy efficiency. This explains the large number of net zero-energy projects based on the Passive House concept, even if fixed energy characteristic values are usually dispensed with. The approach of balancing out all household energy loads in the annual energy balance – i.e. including domestic appliances, IT or lifts – eliminates the need for a comprehensive measurement technology to separately record the different consumption areas.

Grid-independent concepts too complex

In the 1990s, scientists also investigated concepts for buildings with no connection to the energy infrastructure. With such grid-independent buildings the energy supply is mostly secured at all times using solar energy systems and large energy storage systems. In the European climate, particularly the seasonal imbalance between the energy demand and the solar power availability requires a high level of technical and economic effort for storing the energy, especially with electricity. This approach has therefore not prevailed. Technologies are still not available that are both technically and economically convincing for storing electricity for extended periods in buildings. For this reason, only remote or temporarily occupied holiday homes, chalets or research stations have been built until now as off-grid structures.

Net Zero-energy and net energy-plus on a large scale

Efficiency improvements in solar power systems and the market introduction of decentralised CHP plants, which are sometimes powered by biomass, have helped transfer the zero energy concept to (non-residential) buildings that are also more energy-intensive. At the end of the 1990s, the first companies realised “zero-energy factories” in order to underline their sustainable credentials. Problematic is offsetting the high, production-related energy loads that are partially excluded from the energy balance. Nevertheless, other companies and industries are also gradually taking up the idea and are hoping for a marketing edge.

The Economic Recovery Plan launched in Germany in 2008, the expansion of day care places for infants and the good typological prerequisites provided by mostly single-storey buildings have encouraged the construction of net zero-energy kindergartens in Germany. Here the integration of solar power systems as defining architectural elements is based on the desire to correspondingly raise awareness about energy issues.
Solar Decathlon competition

Held for the first time in Washington in 2002, this international student competition presents experimental net zero-energy and net energy-plus buildings to a wide audience. In the competition, interdisciplinary university teams develop and build their own houses that produce more solar energy than they consume. Since 2009, the competition no longer stipulates off-grid prototypes but so-called “net zero energy buildings”. Constructed by their respective teams on the competition site, the prefabricated buildings compete against one another in ten categories (including architecture, sustainability, engineering and construction, comfort conditions and the electrical energy balance). Since 2010, the competition has taken place three times in Europe, most recently in 2014 in Versailles, France. Since Versailles, there have been ongoing efforts with German support to persuade the European Commission to take over the sponsorship of the competition. If these efforts prove successful, the next competition in Europe is scheduled to take place in 2017. The venue has still not been decided upon.

Combining refurbishment projects in settlement networks

The first renovation projects in both the residential and non-residential sectors aimed at achieving a neutral energy balance date back to 2007. These buildings generally do not provide the best prerequisites, as they tend to consume more energy than new-build schemes and the possibilities for utilising renewable energy on site are often insufficient and can hardly be influenced retrospectively. However, their integration into urban development concepts in which (local heating) networks connect different consumers and energy producers that are only first balanced on the settlement boundary enable the consumption to be offset in interconnected operation and beyond the scale of individual properties. Settlement buildings producing surplus energy can offset, for example, the energy consumption of refurbished existing buildings with a moderate energy efficiency or less potential to generate energy.

Lack of uniform definitions and standards

The majority of the realised net zero-energy and net energy-plus schemes are small residential buildings – promoted by motivated developers, grant-funded schemes and demonstration projects, as well as the mostly favourable ratio between the usable space and the roof area usable by solar power systems. Examples, however, can now be found for almost every type of building; in addition to housing, education and office buildings, there are also furniture stores, museum buildings, banks, factories and even sports stadia, whereby some projects are also used for marketing purposes or for communicating certain views.

In addition, new issues are being raised such as the amount of “embodied energy” in construction and how this can be incorporated into the energy balance. This can also be attributed to the fact that the specifications for net zero-energy buildings in Germany are still not standardised. In Switzerland, the “Minergie-A” label has brought together net zero-energy buildings under a single standard since 2011 (Infobox p. 13).

Embodied energy

Embodied energy refers to the primary energy required to obtain raw materials, produce and process components, transport them to the building site, install them and then dispose of them after renovating or demolishing the building. The use of natural and local resources and materials reduces the amount of embodied energy integrated into buildings.

The Passive House standard

In Passive Houses, efficiency measures reduce the required heating capacity to such an extent that the remaining heating requirement can be met solely through the ventilation system, making it possible to dispense with conventional heating systems. Especially good thermal insulation, including the windows, minimised thermal bridges, whereby the use of an airtight building envelope and energy-efficient ventilation systems with heat recovery reduces transmission and ventilation heat losses. Passive solar heat gain through the glazing and internal heat sources, such as appliances, lighting and users, largely compensate for any heat losses. In 2015, new Passive House classes are being introduced with a factor for determining the specific energy losses for an energy application, which also coincides with Version 9 of the PHPP design tool (Infobox, p. 12).
Based on the negotiations of the Kyoto Protocol and its successors, the European Union has formulated its own goals for climate protection: among other things, it is aiming to reduce greenhouse gas emissions by 20% by 2020 compared with 1990 levels. To achieve this, the share of renewable energy in the total consumption and the energy efficiency shall both be increased by 20%. In addition to a variety of other measures, the European Union adopted the “Energy Performance of Buildings Directive” (EPBD) in 2002. This initiated the introduction of uniform energy balancing methods for buildings throughout Europe. With the recast version of the EPBD adopted in 2010, the European Commission coined the term “nearly zero-energy building” and stipulated its implementation for new buildings from the end of 2020. According to Article 2 (2) of the Directive, a nearly zero-energy building “means a building that has a very high energy performance [...]. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.”

**German Energy Savings Ordinance and DIN V 18599**

In order to implement these objectives, the German Energy Savings Ordinance (EnEV) has been amended as the most important regulatory directive for the building sector. The revision came into force in 2014. In addition, the German Renewable Energies Heat Act (EEWärmeG) applies to new buildings and public buildings undergoing refurbishment. This is aimed at increasing the share of renewables in the final energy consumption for heating and cooling.

Apart from a limit value for transmission heat losses, the EnEV does not generally stipulate any concrete requirements for the energy efficiency of building components or the building systems equipment, since both are assessed jointly. It requires that the given maximum annual primary energy requirement is adhered to. This is calculated based on predefined heat transfer coefficients and a technical standard design for a reference building with identical geometry, floor space and orientation. The standard for the energy assessment of buildings (DIN V 18599) stipulates the computational basis for verifying this. In addition to the energy requirement for space and domestic hot water heating, the air conditioning and the electrical energy requirement for ventilation systems and artificial lighting (non-residential buildings only) are also taken into consideration. All other loads such as lifts, IT or domestic appliances are not depicted. It is intended that the next version of the EnEV shall include a definition for “nearly zero energy buildings”, whereby it is being discussed whether the EnEV and EEWärmeG should be combined together.

**The energy policy context**

*Since the fourth UN World Climate Report was published in 2007, the impact caused by human activity on climate change has been recognised internationally. According to this report, the CO₂ concentration in the earth’s atmosphere is constantly increasing, mainly as a result of burning fossil fuels. Policy and normative guidelines are aimed at reducing CO₂ emissions worldwide.*
Crediting energy yields from renewable sources

The existing standards and laws in Germany are primarily aimed at saving energy or operating buildings with very small amounts of (fossil) energy. Solar thermal yields from collector systems and the environmental energy (ambient air, geothermal energy) utilised via heat pumps are, in normative terms, classified as demand reduction (reduced final energy requirement for space and domestic hot water heating). Biomass utilisation is credited through favourable primary energy factors. Electricity yields from renewable energy sources (for example PV systems) or cogeneration plants (CHP) generated within the spatial context of the building are only credited in terms of the electricity requirements calculated for the building services equipment (pumps or fans) for the respective same month or via reduced primary energy factors for the heat generation (CHP). Electricity yields that exceed the building’s monthly electricity requirements are not credited, for example, in the annual balance and are therefore excluded in computational terms. This means that in the case of buildings that provide space and domestic hot water heating using natural gas, pellets or district heating it is therefore not computationally possible to offset the primary energy balance through own electricity yields. It is also almost computationally impossible to offset the annual balance using the solar electricity yields achieved in summer in the case of “all-electric building” that exclusively use electricity as the energy source via heat pumps, whereby the electricity consumed by the heat pump in winter usually exceeds the electricity yields from solar power systems (see Fig. 7 in comparison to Fig. 8).

Design tool for balancing net zero-energy buildings

Developed at the University of Wuppertal as part of a dissertation, the EnerCalC Excel tool makes it possible to balance the energy performance requirements for a building in accordance with DIN V 18599 with relatively little input expenditure. Here the level of detail and the result accuracy can be increased in parallel with the design process and allow an increasing differentiation of the building model. The software program also offers a number of special balancing algorithms for net zero-energy and net energy-plus buildings.

All the main calculation results are tabulated as effective, final and primary energy requirements as well as equivalent CO₂ emissions in the form of monthly figures. Primary energy and CO₂ balances incorporate the electricity self-generated from PV and CHP plants. The integration of the emissions calculation supports the assessment of buildings aimed at achieving climate neutrality. In addition, the seasonal balance or imbalance between the energy production and requirements as well as the proportion required to meet own requirements are depicted on the basis of monthly values.

The software can be obtained free of charge at: http://www.enob.info/?id=enercalc
When balancing the import and exports, the energy consumption of the building is offset in the annual balance using appropriate assessment procedure credits for feeding energy into the grid. The aim is a neutral balance (net zero-energy house) or a surplus of credits (net energy-plus house). The electricity grid mostly “stores” the energy produced by the building and then provides it to the building when required. Strictly speaking, the building described should therefore be called a “net zero energy building”. Its neutral annual energy balance is a computational result – it is not balanced at all times.

“All-electric building”

The balancing principle is easier to understand with buildings that only use electricity as the energy source. The building technology usually includes a heat pump and a solar power system. Here an explicit energy and electricity balance can be drawn up without requiring additional assessment using normatively specified conversion factors (primary energy factors). However, when determining the annual balance with only one electricity meter it should be ensured that the entire electricity consumption is recorded, i.e. the household electricity in addition to the consumption by the technical equipment.

The significantly greater amount of electricity used by heat pumps during the cold season means that during the wintertime a particularly high demand is placed on the generation capacity of electricity grids in the central European climate. This is because the self-generated solar power – counter to the consumption – is mainly produced in summer. The aspiration of having a climate-neutral building stock will therefore only first be met when there are appropriate grids with a high rate of renewable ener-

A normatively established method for balancing the energy of net zero-energy and net energy-plus buildings still does not exist in Germany. The basic principle behind many balancing approaches used in practice is that the amount of energy that a net zero-energy building draws from the grid corresponds to at least the amount of energy fed into the grid in the annual balance.
Balancing process

A neutral or positive energy balance can be achieved on an individual building level by deploying a multi-stage approach:

1. Reducing energy expenditure: Passive House or Minergie components, passive cooling, etc.
2. Using renewable energies on site: Solar power systems, combined heat and power generation with biomass, small wind turbines, etc.
3. Optimising the feeding in and drawing of energy from the infrastructure: control, storage, load shifting, etc.

Although this method appears simple at first glance, it is complex in detail, since the following aspects need to be determined for the balancing:

1. Suitable indicators (primary energy, CO2 equivalents, energy costs) with corresponding conversion factors,
2. The balance limit (What is included in the balance?),
3. The balance period (Which period is evaluated?)

The approaches previously applied in practice vary in this regard. They use the nationally usual calculation method for determining the energy consumption and usually supplement a separate evaluation of the local self-generated electricity and balancing.

Fig. 10 Method for balancing the energy drawn from and fed into the grid based on meter data and assessment factors. Source: Voss/Musall

Fig. 11 The balancing method applied to an “electricity-only building” with heat pump and solar power system. The optional solar thermal system reduces in mathematical terms the electricity consumption of the heat pump. Source: Voss/Musall

Living in the energy self-sufficient solar house

With its energy self-sufficient solar house, the Fraunhofer Institute for Solar Energy Systems already demonstrated how net zero-energy buildings might work back in 1991: without any connections to the electricity grid, the solar radiation on the building envelope is enough to meet the yearly energy needs of the residents. Windows, transparent insulated south facades, concentrating solar flat-plate collectors and solar modules utilise the solar radiation, whereby a solar hydrogen system balances out seasonal fluctuations in the radiation volume.

To develop an energy self-sufficient solar house and then live in it yourself was – and probably still is – a rare stroke of luck for a researcher. The bathroom, planned at the warmest place, was also the warmest place in the house. The displacement ventilation system was absolutely silent. Of course there were technical difficulties: the self-built electrolyser had problems coping with the fluctuating electricity supply. This meant that the hydrogen production did not accord with the forecasts. On the other hand the fuel cell, which had been tested in space, worked excellently. However, the direct reheating of the supply air with a 500 W hydrogen burner in the air supply duct, which the researchers had chosen as the sole active heating component, was only a perceptible success for sensitive people. More efficient was the hydrogen cooker, which enabled a perceptible warming of the kitchen. The fact that the actual living room also acted as a lecture room for a total of 3,500 visitors confirmed the considerable interest in the project and, of course, had an impact on the energy balance. This number of visitors was not planned. Today the number of net zero-energy buildings is steadily increasing. The energy self-sufficient solar house provided a starting point with considerable public appeal.

Fig. 12 One of the four catalytic hydrogen diffusion burners for the cooker. Source: Fraunhofer ISE

Fig. 13 As a Fraunhofer ISE employee, Professor Wilhelm Stahl lived with his family in the energy self-sufficient solar house for 18 months from 1993. Since 1990, he has headed with his partner Volker Weiß the Stahl + Weiß consultancy (energy efficient and building physics-related building optimisation). Source: Fraunhofer ISE (left) / Jonas Stahl (right)
gy, especially in winter, or there are suitable storage technologies.

Selecting indicators

In depicting the energy requirement of buildings, the majority of European countries use procedures that deploy primary energy as an indicator of the energy performance. This also applies to most net zero-energy and net plus-energy buildings previously realised in Germany. Here the consumption of the energy sources deployed in the building (final energy) is converted or evaluated using primary energy factors and then totalled together. The primary energy does not appear on the electricity meter or on the energy bill. This applies equally to the greenhouse gas emissions associated with the energy consumption, which provide a second possible indicator and are addressed in the German federal government’s Energy Concept by the requirement for a “climate-neutral building stock”.

A CO₂-based assessment of buildings that is aimed at achieving zero-emissions buildings makes climate change the dominant issue relative to resource scarcity. However, large differences between primary energy and emissions-based assessments only occur in countries that mainly produce their electricity with nuclear power, such as in France. The decoupling of greenhouse gases and the energy consumption is otherwise only possible when the energy supply is entirely based on renewable energy. Until now that has only been achieved in exceptional cases (Norway with approximately 98 % hydropower). The term “zero-emissions building” is also not directly plausible with buildings with biomass boilers. Although mathematically speaking the emissions do not have to be accounted for, since CO₂ from the atmosphere is bound in the biomass, given the visible emissions from the chimney the description “climate-neutral” would seem more accurate.

Conversion factors influence the balance

When net zero-energy buildings are discussed in the context of future scenarios, expected future changes to the primary energy and emission factors for grid-based energy provision also play a role. The growing proportion of electricity produced from renewable energy is reducing the grid conversion factors and thus the credits for the electricity fed into them. Whereas this effect does not change anything to the balance with “all-electric building”, the balance is worsened in cases where credits from feeding
electricity into the grid are used to offset energy drawn from other energy sources (for example, wood pellets). With such a building, in future more energy efficiency would be required to ensure that lower credits for the same input volumes would still be sufficient for neutralising the balance. An alternative would be to increase the energy harvested by the building. Concepts with different weighting factors for the energy drawn from and fed into the grid (asymmetric weighting) are also conceivable. The development of “smart grids” could also lead to time-variable electricity rates and, accordingly, time-variable primary energy and emission factors, and thus provide incentives for targeted operational management strategies. However, regardless which indicators and assessment systems are used, only in a few cases will a neutral balance also mean that no energy costs are incurred.

**Defining the balance limits**

Most normatively introduced energy balance methods in Europe only consider the energy requirements for the building’s technical services (space and domestic hot water heating, auxiliary energy for pumps and fans, ventilation, cooling and – with non-residential buildings – lighting). Not included are user-specific loads (e.g. domestic appliances, IT or central facilities such as escalators or cold rooms) and the structurally necessary technical equipment (e.g. fire and smoke protection systems and lifts). However, examples from practice show that the loads not normatively covered in many energy-efficient, non-residential buildings on average account for more than half of the entire primary energy consumption. In residential buildings this proportion is even higher. In this respect, the calculated energy requirement cannot simply be compared with the consumption measured for a building. A balance strictly according to normative limits for electricity is therefore often not verifiable without additional measurement technology. Especially in the residential building sector, a majority of the realised net zero-energy projects therefore take into account the entire building energy consumption, including user-specific loads (Fig. 27).

Extending the balancing scope to systems beyond the actual construction scheme (purchase of “green electricity”, shares in wind farms, etc.) makes little sense in terms of assessing the building’s energy efficiency. Such systems feed electricity into the grid outside the building network and these are not recorded on its meter, whereby they make use of the transport and storage capacity of the grid. These effects are already taken into account in the building’s energy balance by the respective weighting factors for primary energy and emissions on the expenditure side (info box, p. 10).

**Meeting own requirements or feeding electricity into the grid?**

Calculation and measurement results are published in different ways: some compare on-site generation and consumption, but some also compare the input and output of energy at the interface to the electricity grid. On closer inspection, the two balancing types differ in terms

**How do we achieve a climate-neutral building stock?**

“Climate neutrality is a goal that is probably impossible to achieve alone in the building stock. Cities and our buildings will also rely in future on the supply of energy from rural areas, although these will be exclusively renewable energy sources. This must be done without destroying the landscape. This requires that our existing building stocks are refurbished in a sensible fashion so that their energy consumption is reduced and their cultural identity is maintained. It makes little sense to have legally prescribed insulation standards that are even more stringent. Decisive is the balance of energy consumption and production in the building. This is where the building’s active contribution comes into play: its ability – alone or in combination with other buildings – to generate and store renewable energy. With active buildings we can create carbon neutrality that takes into account all the energy services provided by buildings, including power and mobility. That is quite possible in the housing sector, but less so in energy-intensive building types such as offices or commercial buildings. Each building should make its possible contribution to energy generation and storage. That will stabilise urban networks while reducing the requirement for long-distance transmission lines and the use of the countryside.”

“To achieve this goal, the Passive House construction method is of central importance, since it is sensible, widely available and economical. However, by this I don’t mean indiscriminately insulating all existing buildings. Architecturally significant facades should not be insulated or only from inside with considerable expertise in regard to the building physics. In addition to facade insulation there are fortunately a variety of ways to achieve our climate protection objectives: photovoltaics, solar thermal energy, heating with district heating, cogeneration or biomass, the refurbishment of basement ceilings, roofs and windows in combination with ventilation systems with heat recovery. With most existing buildings, proper refurbishment can achieve an almost zero energy demand. The energy-plus principle must be extended in climate-neutral cities: in an energy network the electricity and heat can be alternately generated, stored and consumed in all the buildings in a district. The realignment of the electricity supplies must therefore be followed with an Energy Transition 2.0 with gas and heat. When we understand that it is about efficiency and sufficiency, about quality rather than quantity – then we can achieve a lot, for all and for climate protection.”
of which proportion of the own consumption is met by on-site electricity generation. In the case of on-site solar power and CHP generation, this refers to the portion of the electricity generated that does not leave the building. With solar power systems in residential buildings, usually only a third or even less of the electricity produced is consumed on site. With small CHP plants integrated into the building power supply, the ratios are similar but in seasonal terms inverted. A much greater coverage of the self-consumption is only achievable when batteries are used.

Taking the lifecycle into account

Until now the focus of the energy balance has been on the operating energy. The energy for the building construction, maintenance and disposal is usually not included. However, the proportion of embodied energy over the entire lifecycle of a property increases with decreasing operating energy input. Along with the replacement and renewal measures necessary during the use of a building, the embodied energy during the lifecycle of an energy efficient building makes up about 20 to 40 % of the total primary energy input. Converted to one year, this ranges between 20 and 50 kWh/m², depending on the building construction method (wood or masonry) and the amenity features (for example, with or without an underground car park). Variant calculations indicate that the impact of such features is greater than that caused by constructing a building as a net zero-energy building, whose additional input of embodied energy in comparison with standard designs results, for example, from the increased insulation thicknesses or additional solar systems.

In order that the zero-energy standard in terms of a neutral balance is achieved across the entire lifecycle, the annual surpluses in the operating energy balance must also balance out the energy input required for production and maintenance (and demolition). The annual operating energy balance must therefore achieve a plus. In practice such dimensions are only ever found, if at all, with single-family homes, since the additionally required generation capacities cannot usually be accommodated on buildings. In the medium term, however, balancing based on the lifecycle of a building would appear to be a productive approach in order, for example, to enable the computational results to be also taken into account when deciding between new construction or renovation. When renovating existing building stock, the equivalent value of the shell construction as a credit improves the results of the overall energy balance. It accounts for about one quarter of the energy used to produce a building.

### Passive House Plus / Passive House Premium

In 2015, the Passive House Institute introduced a system that now also evaluates the total energy consumption of the building, including the energy required to provide the final energy delivered to the building. The basis is provided by a new evaluation scheme: the primary energy requirement is replaced by the total “renewable primary energy” requirement (PER / Primary Energy Renewable).

According to this scheme, renewable energy sources supply primary electricity. Part of this electricity can be used directly. In order to transfer surpluses in times of reduced energy provision, these surpluses have to be stored, which leads to losses. Secondary electricity is then drawn from these storage systems as required. Depending on the type of energy utilisation, the proportions of primary and secondary electricity vary, and with them the losses for providing the energy. These specific losses are described by the specific PER factor.

<table>
<thead>
<tr>
<th></th>
<th>Heating requirement</th>
<th>Total requirement for renewable Primary energy (PER)</th>
<th>Self-generated energy (relative to the built area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive House Classic</td>
<td>max. 15 kWh/m²p.a.</td>
<td>max. 60 kWh/m²p.a.</td>
<td>–</td>
</tr>
<tr>
<td>Passive House Plus</td>
<td>max. 15 kWh/m²p.a.</td>
<td>max. 45 kWh/m²p.a.</td>
<td>min. 60 kWh/m²p.a.</td>
</tr>
<tr>
<td>Passive House Premium</td>
<td>max. 15 kWh/m²p.a.</td>
<td>max. 30 kWh/m²p.a.</td>
<td>min. 120 kWh/m²p.a.</td>
</tr>
</tbody>
</table>

Fig. 16 First apartment building certified as a Passive House Plus. Source: Neue Heimat Tirol
MINERGIE-A, Switzerland

With its introduction of the “MINERGIE-A” label in 2011, Switzerland is regarded as a pioneer in the establishment of standards for net zero-energy buildings. In line with national legislation, the MINERGIE base standard limits the thermal heat and hot water requirement to 30 kWh/m²p.a., whereby the heating requirement may not exceed 90 % of the limit value for the current standard. With MINERGIE-A, the focus is also on the final energy requirement for heating, cooling, hot water and building services systems. Own energy yields must fully compensate for these in the annual balance. Only permitted are generators of renewable energy that are installed on the building itself. In terms of the practical implementation, this leads either to a combination of thermal solar collectors with wood heating (plus possibly PV to compensate for the electricity consumption) or heat pumps with PV. In each case, the size of the solar power system is directly dependent on the quality of the building envelope and the heating requirement. This especially applies to the combination of solar thermal energy and biomass boilers, since according to the provisions the collector system must generate at least 50 % of the heat.

The production energy across the lifecycle (embodied energy) is not included in the annual energy balance. However, an upper limit of 50 kWh/m²p.a. is formulated. It is calculated using standard values for the specific useful life and the energy content of individual components, which is then related to the energy reference area and annual values. If more embodied energy is required, the difference can be compensated for with self-generated energy. The household and lighting electricity requirement is also not balanced. However, domestic appliances, office equipment and lighting with the maximum efficiency classes must be deployed.

A special requirement of the Minergie-A provisions is that building owners may neither sell their generated solar power on a solar power exchange nor claim the feed-in tariff.

The Minergie© association, which is jointly supported by business, the cantons and the government, certifies buildings according to the Minergie energy standard.

Efficiency House Plus, Germany

In 2010, the “Efficiency House Plus” funding programme, which forms part of the Zukunft Bau (Future of Construction) research initiative conducted by the German Ministry of Transport, Building and Urban Affairs, formulated its own net energy-plus house assessment method for participating buildings (www.forschungsinitiative.de). The method further develops the existing method stipulated in the German Energy Savings Ordinance (EnEV), whereby an Efficiency House Plus (Effizienzhaus Plus) is defined as a building that produces more energy than it consumes in the annual balance. This requirement must be met both at the primary and final energy levels. Essentially, the balance limit of the current standard (heating, hot water, ventilation, cooling and lighting) is extended: added are the energy expenditure for user-specific loads (for example, domestic appliances or IT) and the ability to take into account renewable energy that is self-generated or generated on the building (the site boundary applies). The balancing based on the final energy and its compensation is intended to ensure that good thermal insulation is realised without increasing the Energy Savings Ordinance’s minimum requirements for thermal insulation.

A special feature of the Efficiency House Plus is the asymmetric weighting of the electricity fed into the grid (primary energy factor of 2.8 kWhₑ/kWhₚ) and the electricity drawn from the grid (factor of 2.4 kWhₑ/kWhₚ). The ratio of the self-used energy to the total energy generated is calculated and verified in a monthly process.

Some buildings in the funding programme with a positive energy balance for the loads described above also include electromobility to allow electricity storage or a desired increase in the self-consumption of the generated solar power.
Comparing the approximately 400 buildings realised internationally with the aim of a neutral energy or emissions balance (http://www.enob.info/en/net-zero-energy-buildings/nullenergie-projekte-weltweit) reveals particular features and implementation priorities: regardless of the type of building, it is endeavoured to reduce the energy consumption for operating the building as far as possible. Only in this way it is possible to compensate for the energy consumption by using credits from utilising renewable energy sources on site. With central European residential buildings, the average total primary energy consumption (including user-specific loads) is 75 kWh/m²p.a. with a credit of 100 kWh/m²p.a.

**Passive House as the basis**

The following sections take a closer look at the investigated central European net zero-energy buildings: in general the aim of achieving the greatest possible efficiency can be recognised by the total primary energy loads at or below the Passive House level of 120 kWh/m²p.a. (Fig. 28). In heating-dominated climates, about 80% of all types of net zero-energy buildings match the energy concept used by the Passive House or Minergie standards and utilise the components as a basis for reducing the heating requirement. Including the domestic hot water generation, this is less than 22 kWh/m²p.a. for an average net zero-energy residential building (including renovations). This means that it is around 60% lower than comparable buildings constructed according to the respectively applicable energy guidelines (Fig. 20).

**Minimising heat losses**

A low ratio of the heat-emitting envelope to the heated volume (A/V ratio) reduces transmission heat losses. The building envelope surfaces are highly thermally insulated and designed to minimise thermal bridges. With the housing projects, the average U-value of the entire building envelope, including the glass surfaces, is very low with an average of 0.21 W/m²K. Almost all the buildings rely on considerable air-tightness and use ventilation systems with efficient heat recovery (>80%). Centralised systems dominate in residential and office buildings. Earth-to-air heat exchangers are frequently used for preheating the supply air, protecting the exhaust air from freezing, or as a heat source for a heat pump.

**Utilising daylight**

In recent years, the designations net zero-energy or net energy-plus house have become the epitome of buildings that consistently combine effective energy savings and an optimised, decentralised use of renewable energies. Complete self-sufficiency is not sought and practical concepts are based on coupling with at least the electricity grid.
60 children in five groups are accommodated in Bayer AG’s children’s day care centre. All the areas used by the children are situated on the ground floor. The functional areas for the personnel are situated in an upper floor in the northern corner of the building.

In accordance with the Passive House concept, the building has optimised thermal insulation (average U-value 0.15 W/m²K). The prefabricated timber frame walls with intermediate, 24 cm-thick insulation are additionally covered with a 10 cm-thick thermal insulation composite system. The intermediate spaces in the 50 cm-thick timber beam roof structure are also insulated. A central ventilation system with heat recovery supplies all rooms with preheated fresh air. The special roof geometry with north-facing clerestory windows and large picture windows enable passive heat inputs and an optimum daylight yield in the central and inner areas. This reduces the need for artificial lighting in combination with presence- and daylight-dependent, high-efficiency lighting elements and a daylight deflecting control system. External solar shading screens and fixed, tilted louvres between the panes in the clerestory glazing prevent unwanted heat input.

The remaining heat requirement is met using underfloor heating fed by a brine-water heat pump with four 98 m-deep borehole heat exchangers. In summer the underfloor pipe system can be flushed via a heat exchanger with cold water from the borehole heat exchangers in order to cool the rooms. A 22 m² solar thermal system on the roof feeds a 1,000-litre buffer storage tank. The fresh water that is primarily heated here is distributed via decentralised stations in each sanitary area. This reduces storage and circulation losses and ensures the necessary protection against legionella bacteria. The building’s refined roof geometry enables a favourable orientation of the 344 m² solar power system with an installed capacity of 49 kWp.

**Energy balance**

After only 12 months of operation, it was found that the total energy consumption undercuts the planning forecasts by 10%. A comparison of the measured consumption and yield values shows, however, that renewable energies did not manage to cover 100% of the electricity consumption loads for the heat pump, lighting, auxiliary energy, office equipment and kitchen as planned because the yields were slightly lower than projected. In 2011, the balance minus was only 1.14 kWh/m²p.a. electricity (Fig. 25). The total primary energy consumption, less the creditable monthly yields from the building-connected PV, amounts to a residual consumption of almost 39 kWh/m²NFA p.a. (b). If the surplus electricity yields are also credited that are not included in the monthly balance, this leaves a primary energy consumption shortfall of almost 3 kWh/m²NFA p.a. (c).

**Fig. 23 Building characteristic values**

<table>
<thead>
<tr>
<th>Net floor area NFA</th>
<th>969 m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross volume V</td>
<td>5,105 m³</td>
</tr>
<tr>
<td>Envelope area A</td>
<td>2,877 m²</td>
</tr>
<tr>
<td>A/V ratio</td>
<td>0.56 m²/m³</td>
</tr>
<tr>
<td>Construction costs</td>
<td>2,200 €/m²NFA</td>
</tr>
</tbody>
</table>

**Fig. 24 Consumption characteristic values (2011)**

<table>
<thead>
<tr>
<th>Heating consumption</th>
<th>10 kWh/m²NFA p.a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water consumption</td>
<td>Not specified</td>
</tr>
<tr>
<td>Final energy for heating (incl. hot water)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Electricity consumption (incl. heat pump)</td>
<td>43 kWh/m²NFA p.a</td>
</tr>
<tr>
<td>Primary energy consumption</td>
<td>112 kWh/m²NFA p.a</td>
</tr>
<tr>
<td>Primary energy generation</td>
<td>109 kWh/m²NFA p.a</td>
</tr>
</tbody>
</table>

**Fig. 25 A neutral energy balance was just missed in 2011. Source: Musall**

![Graph](image.png)
Almost all larger-scale residential, office and educational buildings use both movable and fixed solar shading systems (horizontal slats, cantilevered balconies or other protrusions) to prevent the ingress of large thermal loads caused by solar radiation. With smaller (residential) buildings, exterior, movable blinds or shutters are the rule. If these are designed in two parts and with a light deflecting function, they create a synergy between solar shading and daylight utilisation.

Passive cooling

The principle of passive cooling is used for all types of buildings: the activation of solid and unclad components, thick layers of (loam) plaster or applied phase change materials (PCM) as thermal mass makes it possible to buffer thermal load peaks during the day. In residential buildings, ventilation chimneys or simultaneously opened windows in the lower facade and the upper roof areas can dissipate heat stored during the night. In non-residential buildings, this chimney effect is achieved via atria or double facades. Alternatively, mechanical ventilation systems in combination with air vent openings in the facade (hinged windows, controllable air inlets) withdraw heat from the building structure through the increased air flow rate.

Providing space and domestic hot water heating

The energy source chosen to generate heat plays a decisive role when balancing the primary energy or CO₂ emissions. Thanks to the lower conversion factors, the use of biomass (wood, rapeseed oil, biogas, etc.) when using combustion boilers considerably reduces the primary energy requirement in comparison with fossil fuels. If in addition to solar power systems, buildings only use a heat pump as part of a streamlined overall technical system, and thus only use electricity as the energy source, neither a gas connection nor biomass deliveries and storage areas are required. Around half of the current net zero-energy residential buildings are such “electricity-only houses”. In the case of the more consumption-intensive non-residential buildings, almost 40 % use heat pumps, whereby these are mostly smaller educational or office buildings. Irrespective of the typology, the average thermal capacity of the heat pumps is, at almost 30 W/m²NFA, significantly below the value of the other heat supply systems.

The lack of small devices means that combined heat and power (CHP) with biomass only really offers an alternative with more energy-intensive buildings (renovations or larger non-residential buildings). In contrast to PV systems, here the electricity is mainly generated during the heating season and is credited in the energy balance. CHP plants

![Figure 26](image)

Examples of net zero-energy and net energy-plus buildings can be found in a variety of typologies and forms of construction. Source: VELUX/Adam Mark (left); SMA/Constantin Meyer (middle); kämpfen für architektur ag, Zurich

![Figure 27](image)

Measured electricity consumption of net zero-energy buildings from central European climates, divided into user- and building services-specific (MEP- mechanical, electrical and plumbing) electricity consumption loads. The electricity consumption of the building services (MEP) equipment is significantly lower in practice than the comparison values found in literature (un-shaded bars). Source: Musall

* The MEP electricity consumption includes an electric car.
with biomass have very low primary energy consumption loads.

More than half of the net zero-energy projects use solar thermal systems (approximately 70 % of residential buildings and approximately 50 % of non-residential buildings). In residential buildings, around 0.06 m² of gross collector area relative to one square metre of living space is sufficient to heat 60 % of the domestic hot water using solar thermal energy. If it is also intended to provide auxiliary space heating, the required area can rise significantly. Among other things, solar collectors are also used as a heat source for heat pumps, for feeding large seasonal storage systems or for providing heat via smaller heating networks and thus offsetting energy inputs. Because of the low incident solar radiation in winter, these systems are often integrated into the facade.

The importance of the electricity consumption

Unlike most building codes, the user-specific electricity consumption loads for many net zero-energy projects are included in the balance. With very efficient buildings and reduced energy consumption for heating, ventilation and air conditioning, the proportion of the electricity consumption increases considerably relative to the total primary energy consumption (Fig. 27, 28). With net zero-energy residential buildings heated via heat pumps, the household power consumption (approx. 22 kWh/m²p.a. including lighting) makes up on average almost 70 % of the total consumption. If electricity is not used for heating, this is considerably more. The user-specific consumption also dominates with office buildings.

Generating electricity on site

Almost all net zero-energy projects use building-integrated solar power systems to offset primary energy inputs in the annual balance. Their size is directly dependent on the consumption caused by the building operation. With small residential buildings that aspire to balance out all consumption loads, photovoltaic systems with an average capacity of 51 Wp/m²NFA are installed. If the balance limit only covers the normatively considered consumption loads caused by the building services equipment, the values are about half the size. Office buildings that only use photovoltaics for balancing purposes have a power requirement of just under 44 Wp/m²NFA. However, it is usual to supplement the solar power yields with CHP plants, wind turbines or acquisitions from local heating networks and green electricity, and with larger buildings where the ratio of the actively usable (roof) surface to the usable area is more unfavourable, it is mostly also necessary.

Irrespective of the type of building, net zero-energy projects with more than three full floors are generally very rare. This is because high buildings with more usable floor area per “solar roof area” quickly reach the limits of their ability to meet their energy needs just through solar power, even when the heating requirement is close to the Passive House standard and there are reduced electricity consumption loads.

Source: Musall

Fig. 28 Comparison of area-based primary energy expenditure and credits for energy yields achieved on the building including user-specific consumption loads (above) and a comparison of the building- and user-specific primary energy expenditure (below). (Country-specific primary energy factors, no climate adjustment).

Source: Musall

Fig. 29 Standardised solar power output for residential buildings in accordance with the balance limit, typology and implementation (new-build/refurbishment). The horizontal lines indicate typology-specific mean values (calculation based solely on the same typology and balance limit).

Source: Musall
Net zero-energy and net energy-plus concepts do not have to end at the site boundary. The inclusion of several buildings in a balance limit can therefore offer advantages. Since negotiations at the district scale usually only succeed with homogeneous ownership structures that are not too small in scale, or an overarching player is required, expansions of the concepts are often limited in scope.

In view of this, it can be expected that net zero-energy and net energy-plus districts can be created with lower specific construction costs than individual buildings with a similar aspiration.
In 2006, a construction group consisting of 24 parties realized two apartment buildings in Freiburg’s Vauban district. The aim is to reduce the average primary energy-related power expended for the living spaces to less than 500 watts per person. In addition to the garden, work and group room, the 75 residents also share laundry and drying rooms including very efficient dryers, freezers and washing machines. This reduces the heated room volumes, (heating) energy and procurement costs.

The buildings have been built to the Passive House standard (average U-value = 0.21 W/m²K) using reinforced concrete crosswall construction with timber frame facades. The floor layout with ancillary areas to the north and living spaces to the south follows the principles of solar construction. The extensively deployed triple-glazed timber windows enable passive heat gains while protruding balconies protect the underlying rooms from excessive solar radiation in summer. The nearly 30 cm-thick mineral wool insulation for the facades is furnished with rainscreen cladding elements. The main access is via covered walkways outside the heated envelope on the north side. The flat roof is insulated with expanded polystyrene. A PV system with a capacity of 23 kWp, is ground-mounted on the roof. The manually controllable ventilation systems in each apartment enable 85 % heat recovery. In addition to general energy-saving domestic appliances, power-saving lifts, efficient building technology, LED lighting both indoors and outdoors, and natural gas cookers reduce the energy consumption. 56 m² of solar thermal collectors are used for supplying hot water. Energy credits from a central, gas-powered micro-CHP unit (30 kWth /14 kWel) that supplies both buildings and solar power systems are used to renewably balance the energy consumption. A net zero-energy balance is only achieved with the help of electricity credits from financial participation in external wind turbines.

**Energy balance**

Whereas the measures described managed to more than offset the building- and user-specific consumption loads in 2008 and 2009, that was not quite achieved in 2010 (Fig. 34). Relatively cold winter months at the beginning and end of the year increased the gas consumption of the CHP plant. A change in the primary energy factor for electricity also meant a reduction in electricity credits. In order to counter this, an additional 16 kWp of solar power capacity was installed on a previously unused part of the flat roof.

In 2010, a total primary energy consumption of 152 kWh/m² p.a. was determined (including for household electricity) (a). If the monthly creditable yields from the building-connected PV and CHP systems are subtracted, a consumption of 73 kWh/m² p.a. remains (b). Subtracting an additional monthly credit for wind power shares amounting to 56 kWh/m² p.a. leaves 17 kWh/m² p.a. (c). It is only through the surplus, not yet credited electricity generated from wind energy amounting to 13 kWh/m² p.a. that an almost neutral energy balance is achieved (d).
Optimising calculation methods

Until now, almost all European countries have excluded household- and user-related electricity consumption loads in their national procedures for calculating the energy requirement. This results in purely fictitious values for the proportion of renewable energy in the provision. In reality, the total energy consumption loads of buildings are greater and the coverage rates for the renewable energy are correspondingly lower. In practice, most buildings do not have measurement equipment for separating normatively credited and normatively excluded consumption loads.

However, a correct separation in design terms into self-used and grid-inputted electricity fails not only in terms of what should be the balance limit. This is because, for the purposes of manageability, normative energy requirement calculations in most European countries are monthly balances. This means that incorrect values that are significantly too high for covering personal use are automatically indicated. The reasons for this lie in the daily course of the solar generation relative to the daily electricity requirement profile of the buildings: electricity is also required at night when it is not generated, and the peak loads often exceed the solar generation. On the other hand, it is not entirely possible to dispense with a computational separation into self-used and grid-inputted electricity: primary energy or emissions credits, with the factors standard for the respective country, should only be given for electricity fed into the grid, whereby grid and storage losses should also be taken into account. With the electricity that is directly self-used, the self-consumption should be deducted without any conversion factors and losses. Approximation methods for realistically calculating the coverage for own requirements have already been developed that closely match measurements. A high coverage of the self-usage is, however, not necessarily a priority: under certain circumstances it may make more sense in energy efficiency terms to export electricity for consumption in the neighbouring house than to temporarily store it in your own home in a battery with losses. The example shows that there are criteria beyond the building energy balance for justifying technological concepts.

A certain amount of homework therefore still needs to be completed before the next EnEV amendment. Ongoing support projects are concerned with this work. However, even without normative definitions and rules, the trend towards implementing net zero-energy and net energy-plus buildings continues. In addition to the broad market for single-family homes, other types of buildings are also being increasingly developed. In addition, the number of examples in the energy efficient building refurbishment sector is also increasing.

Links and literature

- task40.iea-shc.org
- www.enob.info/en
- www.eenneff-stadt.info/en

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