

New Assessment Method for Buildings and Districts towards “Net Zero Energy Buildings” Compatible with the Energy Scenario 2050

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1 ABSTRACT

We present three extensions to current energy building and district assessment methods, which in contrast to previous evaluation methods, not only takes into account building specific energy parameters and balances, but also links them to the physical energy potential of the project site as well as the future national energy supply scenario. This facilitates the assessment of whether the building or the district is compatible with the energy scenario 2050 without later adaptations or refurbishments. This is necessary because according to current prognoses the current legal requirements in Austria are insufficient for meeting the Paris climate targets, even despite their slowly increasing thresholds.

Keywords: net zero energy buildings, district, building, assessment method, energy scenario 2050

2 INTRODUCTION

Which legal requirements would enable us to achieve a sustainable and carbon-free building stock by 2050? Since buildings and districts built today will be in existence at least until 2050, it must be possible to ensure that these buildings already reach the performance today, which is necessary for a sustainable future. Estimates for the aggregated performance of the building sector can be found in Austrian national studies on climate scenarios, the building sector and the overall energy supply (Krutzler, 2016; Streicher et al., 2010; Veigl, 2015).

"Plus-Energy Buildings", "Net Zero Energy Buildings" (NZEB, meaning energy autonomy) or "Zero Energy Buildings" (meaning energy autarky) represent the most ambitious energetic building standard that could be realized in practice ("Proof-of-concept"). They should be best suited to fulfil these average requirements, as they supply more energy than they need. But can all buildings of the future building stock be constructed or refurbished to a NZEB- or even plus-energy standard? And is that sensible or even necessary?

The potential for renewable on-site coverage of building energy demand depends on several factors (De Jaeger, Reynders, Ma, & Saelens, 2018), above all on the available plot size (limiting the solar and geothermal potential) and the relationship between plot size and gross floor area. Small buildings on large plots have a high energy potential in relation to demand. Very dense, compact buildings on small plots in turn have the smallest potential and thus the lowest chance or the highest expenditure to achieve a NZEB or even plus-energy standard.

In the presented approach, it is shown, that for a significant share of the building stock, especially in densely populated urban areas, plus-energy standard or NZEB standard is not practical for the near future with current technologies, system boundaries and economic incentives. Instead, we propose a new "climate compatibility" assessment, which not only takes into account the actual energy balance, but also the relative difficulty to achieve it within a given plot to building area ratio. As such, the approach is applicable for single buildings as well as for ensembles and districts (plus energy districts). In terms of "effort sharing", this approach suggests that low-density areas, which are characterized by a high degree of land use, have a greater obligation to reach the 2050 target than highly dense urban areas.

3 AIM

This paper aims to facilitate the debate on the effort sharing of the energy transformation and further research on this topic on a quantitative basis. Specifically, we set out to employ empirical methods to identify and define suitable normalization parameters for as-of-yet static energy target values of standards such as NZEB so that the specific energy potential and energy “effort” can be taken into account. This is important because we currently see a push both internationally and nationally for urban high-density “plus energy districts” (Koutra, Becue, Gallas, & Ioakimidis, 2018), which are not easy to achieve in terms of marginal costs (D’Agostino & Parker, 2018; Iturriaga, Aldasoro, Terés-Zubiaga, & Campos-Celador, 2018).

Furthermore, political leadership in this critical question is notoriously missing – a fact that might also be attributed to the absence of theoretical models that allow a quantitative analysis of the required effort sharing under different sustainable development scenarios.

4 STATUS QUO IN BUILDING ENERGY SYSTEM BOUNDARIES, PERFORMANCE INDICATORS AND ITS TARGET VALUES

4.1 Legal requirements: Operational energy

Historically, the first consideration of building performance was in its required operational energy and in moderate climate zones especially: heating demand. This is still the predominant perspective, and all regulatory guidelines include limits and thresholds to these performance indicators: In Austria, the legal requirements are defined by the Austrian Institute of Building Technology (OIB) and depend on usage type, year of construction (or renovation), as well as the method of proof of compliance (“OIB RL6 - Energieeinsparung und Wärmeschutz,” 2018). Similar system boundaries and (slightly increased) performance indicators, together with additions to ventilation and heat bridge requirements, are also used for Passivhaus certification. As pointed out by (Attia, 2016) these regulatory targets reflect a “efficiency paradigm”.

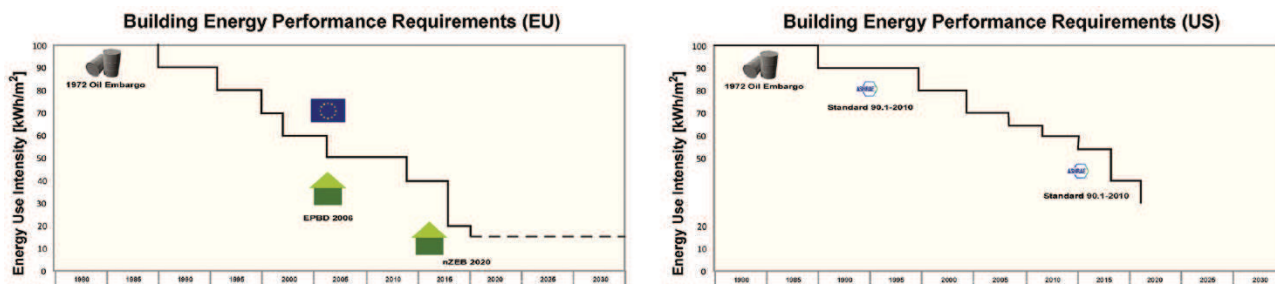


Fig. 0: Evolution of building energy performance requirements in the EU and the US (Attia, 2016)

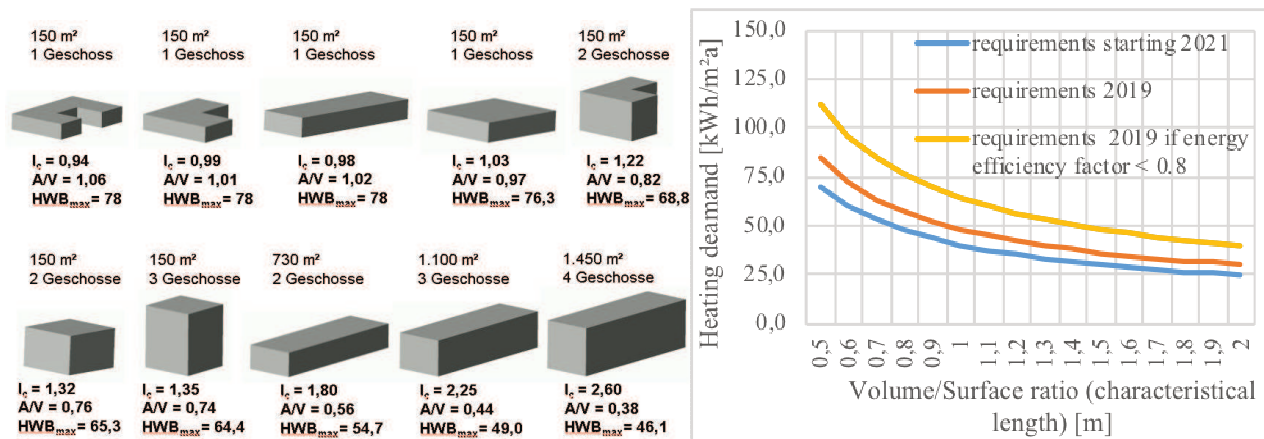


Fig. 1: Comparison (left, NOEN Bauordnung leaflet) between compactness as described by the characteristic length (l_c) and the surface to volume ratio and legally required heating demand (HWB_{ref}) and heating demand as function of l_c as defined in OIB-330.6-038/18

4.2 (Net) Zero Emission Buildings

Recently, Zero emission buildings (ZEB) and Net-Zero Emission Buildings (NZEB) further push the energy performance with the same system boundary of operational energy by achieving a neutral or positive primary energy balance at every moment of operation (ZEB, corresponding with energy autarky) or annually (NZEB, corresponding to energy autonomy). For a through definition of involved balances and terminology, see (Sartori, Napolitano, & Voss, 2012).

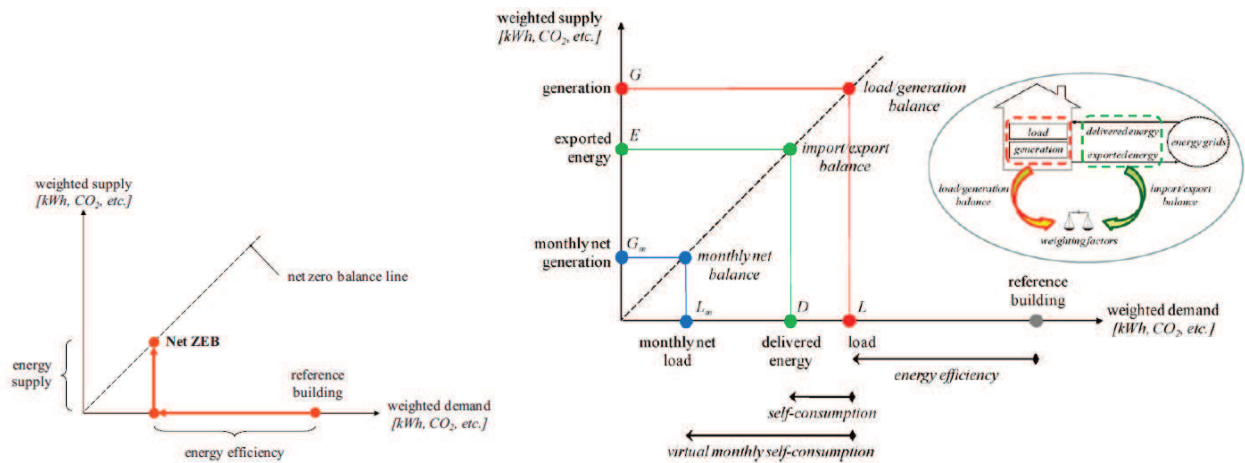


Fig. 2: Graph representing the net ZEB balance concept (left) and three balance concepts: import/export balance, load/generation balance and monthly net balance according to (Sartori et al., 2012)



Fig. 3: A regenerative sustainable building seeks the highest efficiency in the management of combined resources and a maximum generation of renewable resources. (Attia, 2016)

In his argument for a paradigm shift towards regenerative architecture, (Attia, 2016) describes regenerative sustainable buildings as being characterized by both maximum efficiency and maximum generation of renewables. Their ecological impact must be determined by thorough Life Cycle Assessment (LCA). This implies that increasing efficiency is lesser concern than minimizing negative ecological impacts altogether. With all else being equal, compactness positively affects the energy demand of a building. This is important because unlike other performance parameters such as building materials or technical systems, it is virtually impossible to alter the compactness of a building. In other words: In a comparison between new buildings with state-of-the-art technical equipment, compact and large buildings will always outperform extruding and small ones. On the other hand under the same premise, a building's own energy supply capabilities are limited by the available plot size (for solar and ambient energy), or more accurately by the ratio of the conditioned space to the available plot size (also known as "floor space index" or FSI). This is the predominant factor for the on-site renewable energy supply (RES) potential of any building.

Apart from the FSI as main predictor of NZEB-achievability, many possible technology choices inform the realization of NZEB standard (Deng, Wang, & Dai, 2014). These can vary highly in both cost and impact, and needs to be assessed for each project individually. Here, the most important factor is wheater and

climate: (Garde et al., 2014) show that the the design of a NZEB and the component technologies and measures can be attributed to and compared by climate. When comparing PV, PV/T and solar thermal generation systems and different combinations of those for reaching the NZEB standard in single family detached housing, (Good, Andresen, & Hestnes, 2015) found PV-only and PV with auxiliary solar thermal to outperform the other options. A fact that the authors attribute – in part – to the NZEB standard definiton, which tends to emphasise electricity generation due to its relatively high factor of primary energy substitution potential. An overview of system boundary definitions and calculation methods is given by (Marszal et al., 2011) as can be seen in Figure 4.

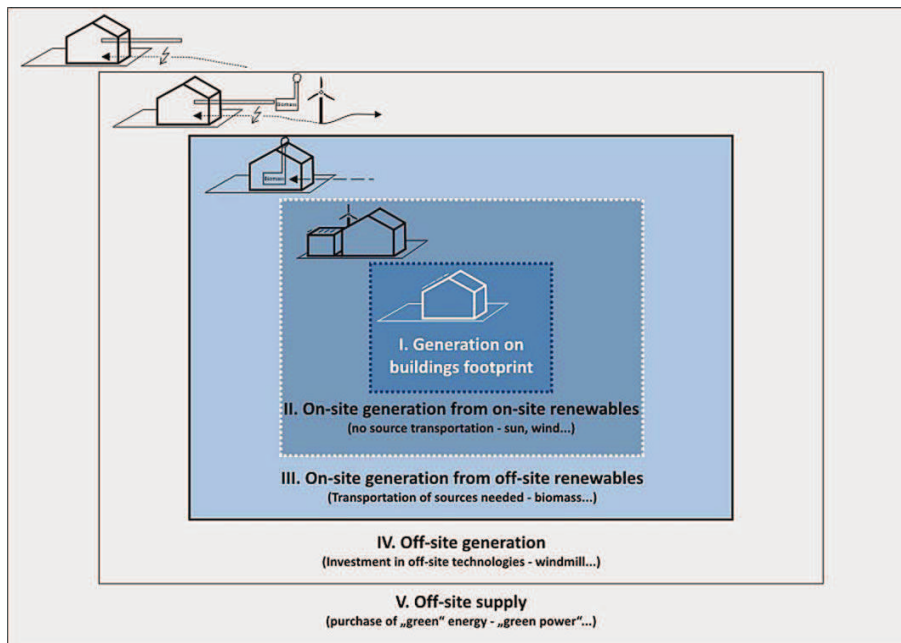


Fig. 4: Overview of system boundaries (Marszal et al., 2011)

Despite their validity as steering instruments to enforce building quality, energy efficiency and recently also the use of renewable energy sources, all classical building energy performance indicators lack one vital piece of information: Whether a certain standard for a certain building is sufficient to reach the national and international climate goals.

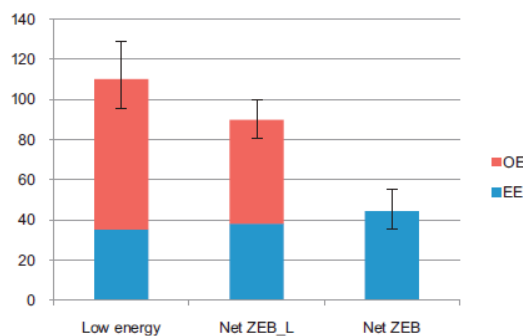


Fig. 5: Mean values of embodied energy (EE), operating energy (OE) and the variation of life cycle energy use (non-renewable primary energy), comparing three different building standards (Berggren et al., 2013), Net ZEBL Net zero energy building, limited balance; energy for lighting and other services are excluded.

4.3 Life Cycle Assessment (LCA)

Furthermore, the operational energy of a building constitutes only a fraction of the total energy and resource use in the life cycle of a building. Consequently, life cycle assessments incorporate all energy and material flows, including construction and assembly of the building and its parts, as well as refurbishment and maintenance and ultimately deconstruction, recycling and disposal. (Berggren, Hall, & Wall, 2013) showed that, as the operational energy of a NZEB is reduced, the share of embodied energy increases. In nearly NZEB, (Giordano, Serra, Tortalla, Valentini, & Aghemo, 2015) have found ratios of 25% to 30% of the total annual energy demand being embodied energy given a observation period of 50 years. First LCA results for

NZEB also show that their ecological footprints are not necessarily better than reference buildings when taken into account the additional resources and energy required for its construction (Yi, Srinivasan, Braham, & Tilley, 2017).

4.4 Energy flexibility

But operational energy and embodied energy do not paint the whole picture: It is expected that the energy system of tomorrow needs to incorporate 5 to 20 times more renewables (depending on technology) than there are in the current energy system (Fechner, Mayr, & Rennhofer, 2016). With addition of these large volatile sources, the energy system is expected to increase its flexibility in handling these loads (Berger et al., 2015). This is often referred to as “Smart grid” – a complex energy grid system that exchanges information about when and where to use, store and extract energy. Storage capabilities are hard to come by and utilizing demand side management potentials promise just the flexibility the future smart grid will need. A comprehensive overview of energy flexibility in buildings is given by the IEA EBC Annex 67 “Energy Flexible Buildings” (Jensen et al., 2017).

(Reynders et al., 2018) summarize the concept of energy flexibility in buildings as „the ability to adapt the energy profile without jeopardizing technical and comfort constraints“. They identify two main methods of quantifying this energy flexibility: Indirectly using past data assuming a specific energy system and/or energy market context, and directly predicting the energy flexibility potential of a building. Furthermore, energy flexibility can be described in three dimensions: (i) the temporal flexibility, (ii) the flexibility of power amplitude and (iii) the associated cost.

(Junker et al., 2018) define six “Flexibility Characteristics” of a System: (τ) Time of the signal, (Δ) the maximum change in demand following a signal, (α) the time it takes until Δ is reached, (β) the total time of the demand side measure (DSM), (A) the total amount of decreased energy demand and (B) the total amount of increased energy. These characteristics govern the energy consumption u_t^1 with DSM as opposed to the energy consumption u_t^0 without measures. Let λ_t be the cost (monetary or CO₂) of consumption at any time t and you can define a “Flexibility Index” (FI):

$$FI = 1 - \frac{C^1}{C^0}, \text{ with } C^0 = \sum_{t=0}^N \lambda_t u_t^0, \text{ and } C^1 = \sum_{t=0}^N \lambda_t u_t^1$$

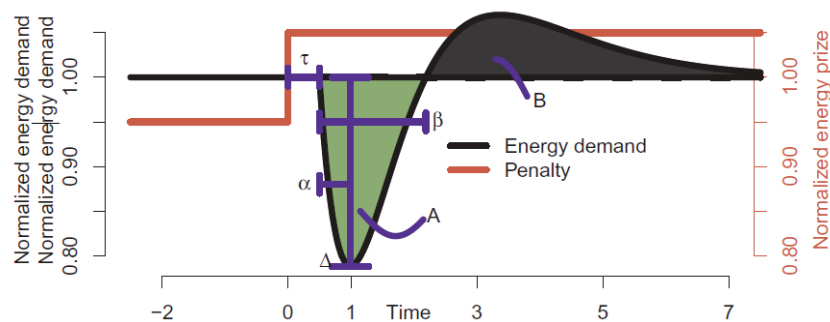


Fig. 6: Flexibility characterization according to (Junker et al., 2018)

This can be applied to quantify all building DSM such as building thermal mass activation such as in Fig. 7:

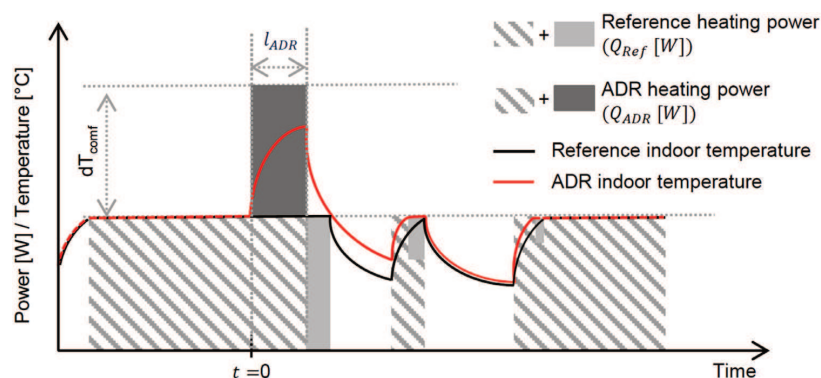


Fig. 7: Energy flexibility quantification method as defined by (Reynders, Diriken, & Saelens, 2017)

5 NEW SYSTEM BOUNDARIES FOR THE BUILDING STOCK!

As described in chapter 3, the current system boundaries serve many functions but they do not connect directly to local and national climate goals. To this end, we introduce three extensions to the common system boundary of primary energy balance for building operation:

5.1 System Boundary Extension 1: Primary Energy Balance Target including density factor

As shown below, the highest possible PEB for any given building standard and energy system still heavily depends on the floor space index. Contrarily to the energy demand, the local RES potential is approximately proportional to the plot size. Thus, the lower the floor space index of a building is, the easier it will achieve NZEB standard. Conversely, it is virtually impossible to achieve NZEB standard at a certain higher floor space index – there simply is not enough renewable energy potential onsite for the useable floor area. This leads to the effect that the more efficient a building is in terms of land use, the more difficult, if not impossible, to achieve NZEB standard.

Paradoxically, the classical NZEB standard, which aims to improve energy efficiency and use of renewables onsite, indirectly promotes less efficient use of the finite resource that is buildable land. Therefore, we propose to dissolve this discrepancy by placing the PEB threshold not at the symbolic yet arbitrary Zero but rather at a value depending on the floor space index.

5.1.1 Correlation of PEB and floor space index

The primary energy balance of a building can be given as follows:

$$PEB = RES - OE, \quad \text{with } RES \dots \text{Renewable energy supply within the System boundary,}$$

$$OE \dots \text{Operational energy of the building}$$

We can express both RES and OE as depending on its reference area. Physically, the RES of a plot is bounded by the available Plot area, as it determines the amount of available irradiation and environmental heat. Operational energy on the other hand is proportional to the conditioned gross floor area.

$$PEB = f_{RES}^* A_{plot} - f_{OE}^* A_{floor}$$

$$PEB \dots \text{Primary Energy balance } \left[\frac{kWh}{a} \right]$$

$$f_{RES}^* \dots \text{Primary Energy substitution potential of renewables onsite per plot area } \left[\frac{kWh}{m_{plot}^2 a} \right]$$

$$f_{OE}^* \dots \text{Primary energy demand for building operation per floor area } \left[\frac{kWh}{m_{floor}^2 a} \right]$$

$$A_{plot} \dots \text{Available plot area } [m_{plot}^2]$$

$$A_{floor} \dots \text{Gross floor area of the building } [m_{floor}^2]$$

$$FSI \dots \text{floor space index, } = \frac{A_{floor}}{A_{plot}}$$

Dividing the above formula by the gross floor area and using the above definition of the floor space index gives the specific primary energy balance on the left side as an inversely proportional function of the floor space index:

$$PEB(FSI) = f_{RES}^* \frac{1}{FSI} - f_{OE}^* \left[\frac{kWh}{m_{floor}^2 a} \right]$$

Analysis of the possible energy performance of 141 best-practice building and districts from (Fellner et al., 2018) reveals a correlation independent of project site, geometry or usage. As can be seen in Figure 8, the primary energy balance (PEB) of buildings mainly correlate with the predictors (i) building age, (ii) renewability of the energy system and the floor space index. The projects with the highest primary energy balance all have state-of-the-art thermal hulls and renewable energy systems.

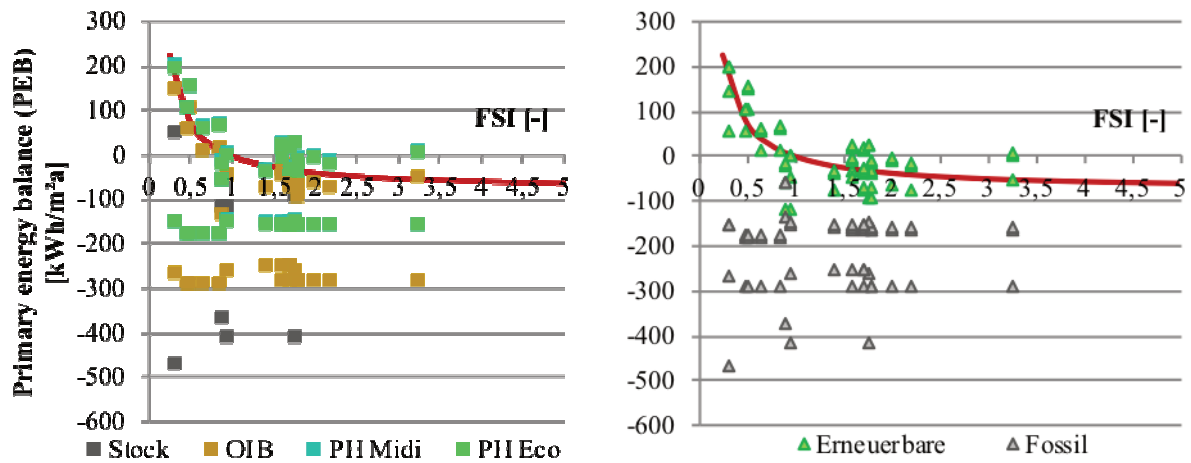


Fig. 8: Correlation between floor space index (FSI) and PEB for key parameters thermal hull (left) and renewable / non-renewable energy systems (right). The red line is a fit of the PEB(FSI) function with $f_{RES}^* = 75 \frac{kWh}{m_{floor}^2 a}$ and $f_{OE}^* = 75 \frac{kWh}{m_{floor}^2 a}$ respectively.

Naturally, assuming constant best-practice values for both the specific primary energy supply and demand is a simplification, which does not take into account site specifics, climate and the specific availability of certain technologies. However, the parameters communicate a general sense of achievability within a certain climatic and technological frame of reference. In this regard, they are no different from the legally required target values of heating demand as a function of compactness. This also represents a physical dependency being linked with technically feasible target values within a certain climatic and technological frame.

Nevertheless, the renewable energy supply and the energy demand include many unphysical variables as well such as the availability and choice of technology, the system environment as the primary energy supply to be substituted by renewable onsite generation to name a few. As these influences have not yet been thoroughly quantified, the PEB target function was scaled by a factor of 1/3 compared to the empirical fit to hedge against this uncertainty. The resulting PEB target value function of FSI is shown in Figure 9 and can be expressed like this:

$$PEB_{target}(FSI) = \frac{1}{3} \left(f_{RES}^* \frac{1}{FSI} - f_{OE}^* \right) \left[\frac{kWh}{m_{floor}^2 a} \right]$$

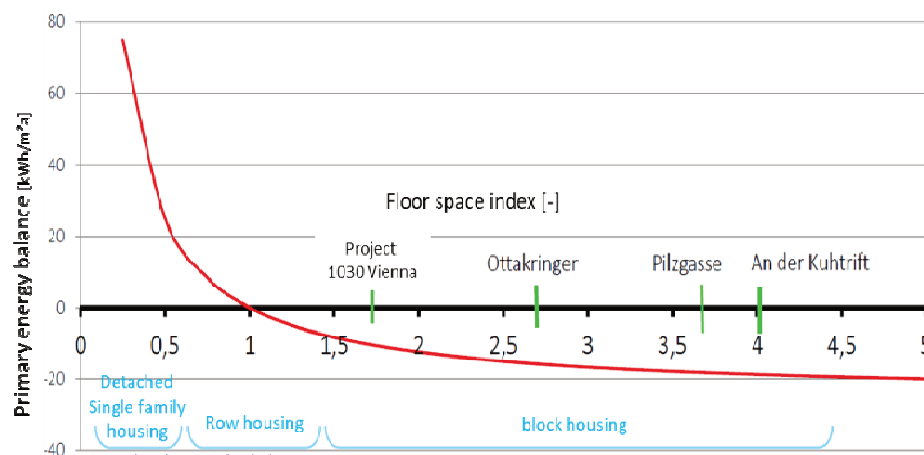


Fig. 9: Primary energy balance target as a function of the floor space index with a site scaling factor of $\frac{1}{3}$

5.2 National RES User Credit

On the basis of the “renewable Austria 2050” scenario, the renewable energy from large scale wind parks, water power stations and biomass will first be allocated to energy uses, which are difficult to supply locally: Industry, public transport and potential largescale power2hydrogen or power2gas. The remaining RES from large-scale power plants can be nationally allocated to all inhabitants as an “individual renewable credit”, which can then be taken into account for primary energy balancing of a building: The cumulative RES credit

of all building inhabitants counts towards its PEB. This also means, that it is easier for very dense accommodations to achieve a neutral PEB, despite the naturally higher total energy demand due to higher occupancy the land area.

5.3 Regional wind peak shaving

With the assumption of a fivefold capacity increase of windpower as required by the strategy for a renewable Austria 2050 (Österreich, 2015), how will this future volatile energy supply be utilized?

As discussed in chapter 3.1.4 energy flexibility in buildings and districts is the answer (Jensen et al., 2017).

(Alham, Elshahed, Ibrahim, & Abo El Zahab, 2016) and (Wu, Zhang, Jiang, Bie, & Li, 2019) show that it is both technically and economically feasible to dispatch wind power generation in accordance to building demand side response.

Therefore, we propose to extend the system boundary of plus-energy quarters to include possible peak shaving of regional wind power due to demand response potentials of the buildings. This means that buildings can absorb wind power that would otherwise be curtailed due to differences between forecast and actual generation and use it to “overheat” the building within thermal comfort boundaries. However, it requires large thermal masses and excellent insulation to achieve a sizeable effect.

5.4 Case study

The proposed system boundaries are applied to four NZEB quarters in Vienna (see Figure 10 for their project parameters). The results are shown in Figure 11. As can be seen, PV Installation size has by far the biggest impact on the achievable PE balance of the variants. Short of the extensive „optimized“ PV strategy, the more moderate variants all require adaptations to the classical primary energy balancing method to be plus-energy feasible, regardless of variation in energy supply system, fenestration percentage, climate scenario or even standard of the thermal hull. All four quarters achieve the classic NZEB standard of PEB > 0 only under the assumption of utilizing most of the building surfaces for PV power generation. Although technically possible, this is economically unfeasible.

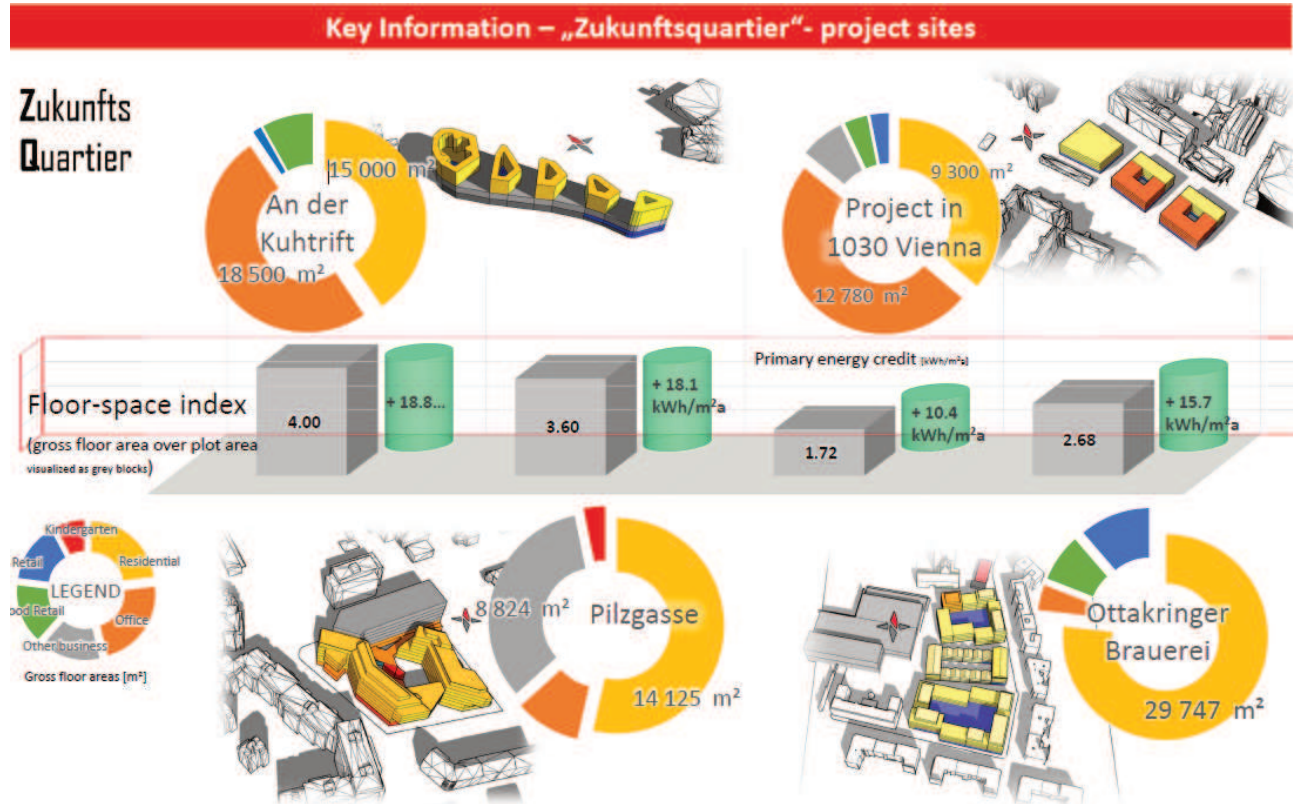


Fig. 10: Key information of the four case study plus-energy districts: gross floor areas (ring diagramms), FSI (grey blocks) and resulting PEB target value (green cylinders, called “Primary energy credit” in this depiction)

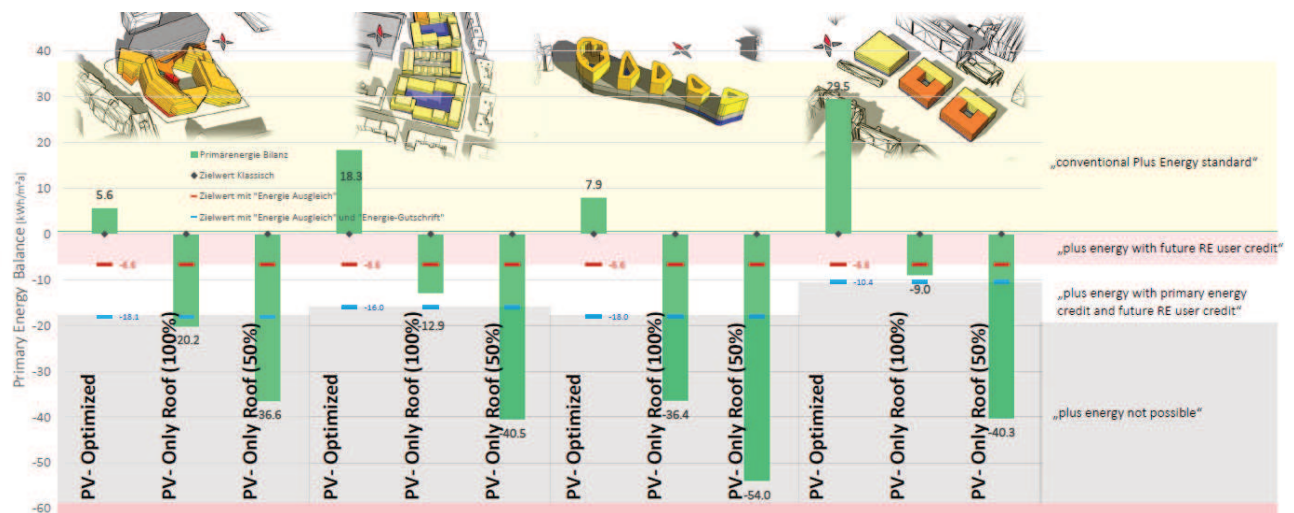


Fig. 11: Primary energy balance for four Plus-Energy Quarters. Each Quarter is visualized in three variants: (1) PV-Optimized: All building surfaces with an insolation >600 kWh/m²a are utilized for PV generation, (2) PV-Roof only (100%) PV utilization on the entire roof area and (3) PV-Roof only (50%): Only half of the roof.

6 CONCLUSION

We conclude from the presented study that the classic definition of NZEB by primary energy or emission balance of the plot system boundary is in need of refinement to be feasible in urban areas of high density.

Furthermore, crediting building projects a certain share of the available national pool of renewable energy from large power stations is methodically sensible, but needs further research of possible allocation rules.

Introducing a PEB target value based on the floor space index reflects physical reality (Chapter 4.1.1). It appears to be a practicable allocation method of the necessary on-site generation of renewable energy by the building sector as a whole. However, the achievable specific primary energy supply and demand need further research and should be further correlated with national and local energy transition scenarios.

The extension of the spatial system boundaries of a NZEB to include the PEB-neutral utilization of regional wind power peak shaving is reasonable only if the intake of this energy can be substantiated by dynamic simulation of at least hourly resolution. Furthermore, the physical localisation of the sources and a technical concept of operation should be given.

With these refinements it should also be possible to include embodied energy and – depending on the chosen national allocation of largescale RES – mobility into the system boundaries of the future building stock.

Finally, most of the building terminology reflects the predominant focus on operational energy whereas trying to fulfil the Paris agreement forces us to consider the full impact including embodied energy, user energy and mobility energy caused by a building. In this regard, the term “Net Zero Energy / Emission building” is not useful, as it is virtually impossible to achieve for all but the most space-inefficient buildings, when considering the full impact and not only operational energy. So you either use “NZEB” as a technically correct term with insufficient system boundaries or a vague term with uncertain, unintuitive system boundaries. Either way, this – together with the psychologically unattractive “zero”¹ – renders the term unsuitable for a paradigm to guide the energy transition of the building stock. Other alternatives might be “climate acceptable” buildings or simply “sustainable” buildings. However, the task remains to define what “sustainability” of an individual building for society really means.

7 ACKNOWLEDGMENTS

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¹ Here, the common German term „Plus-Energiegebäude“ has a psychological advantage.

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