Net Zero Energy Solar Buildings: An Overview and Analysis on Worldwide Building Projects

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Abstract

This paper summarises the state of two research phases within the scope of the IEA Task 40 / Annex 52 "Towards Net Zero Energy Solar Buildings" [1]. The first objective is a cross section analysis of a comprehensive collection of more than 280 international zero energy buildings. The aim is to show trends, motives of actors, as well as their method to reach the zero energy balance. Secondly, an in-depth study shows a rough analysis and characteristics of 50 exemplary Nets ZEBs from different countries and climate regions, as well as their combinations of measures concerning energy efficiency and renewable energy supply.

It is shown that diverse actors with miscellaneous motives have lead to a lot of different building variations. Typical strategies can be assigned to the typology groups "small residential building", "apartment building" and "non residential building". Net ZEBs are much more energy efficient than average buildings which were built according to national construction and energy regulations. None of the leading Net ZEB examples exist without generation of PV electricity. Trends give an outlook of current and possible future combinations of technologies and passive measures for the realization of (future) net zero energy buildings.

1. The Occasion

In 2010, the European Commission and Parliament adopted the recast of the Directive on Energy Performance of Building [2]. The directive requires that buildings should be "Nearly Zero Energy Buildings" after 2019. With this decision, the expectation is that by 2020 energy consumption, as well as CO_2-emissions are lowered up to six percent in the whole EU. By the 30th of June 2011, the EU member states are already required to develop national plans for conversion to this new directive [3].

The German Federal Government has defined in its fifth energy research program: "The long-term objective is zero emission buildings" [4], England expresses the intention: "all new homes to be zero carbon by 2016" [5] and even the USA formulate in their political programmes such buildings as well as suitable balance ideas [6]. During recent years the numbers of international realized projects with the claim of an equalized (Net) zero energy or zero emissions balance has raised strongly. For several typologies and climates, different concepts have been developed on how to calculate the annual energy balance for Net ZEBs [1, 7-8]. Net zero energy building, equilibrium building and carbon neutral building or in the German context:

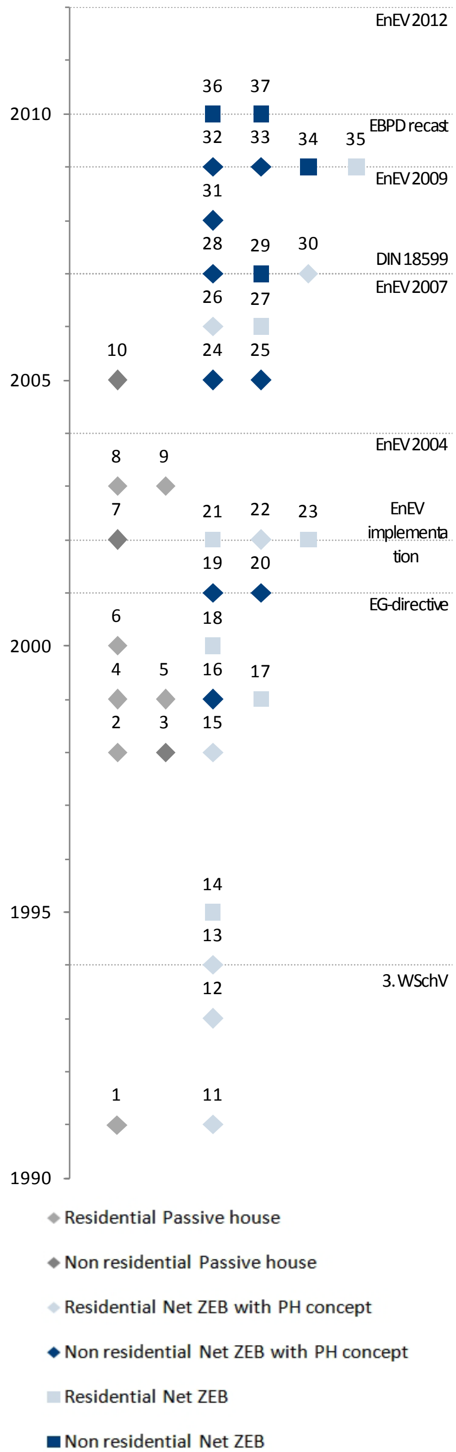

Fig. 1. Origin of the first Passive Houses and Zero Energy Buildings of different typologies related to energy standards in Germany

1 1. Passive house Darmstadt, DE
2 1. Detached Passive house
3 1. Passive house office building
4 1. Passive apartment building
5 1. Passive house settlement
6 1. Passive house social housing
7 Currently biggest Passive house office building
8 1. Passive house in USA
9 1. Renovation to Passive house
10 1. alpine Passive house
11 Self sufficient solar house, Freiburg, DE
12 Zero energy houses in Wädenswil, CH
13 Heliotrop, Freiburg, DE
14 1. Zero heating energy house, Berlin, DE
15 1. Net zero energy Settlement, Hannover Kronsberg, DE
16 1. Zero emission house Pola-Roid, Emmendingen, DE
17 1. Zero energy factory, Solarfabrik Freiburg, DE
18 1. Zero energy university building, Oberlin College, USA
19 1. Plus energy single family house, Thening, AT
20 1. Net zero energy apartment building, Sunny Woods, Zürich, CH
21 BedZED, Wellington, UK
22 1. Net zero energy office building, Office building AEE, Villach, AT
23 1. Zero energy hotel, Hotel Victoria, Freiburg, DE
24 1. House with ZeroHaus certificate, DE
25 Schiestl-Schutzhütte, Steiermark, AT
26 1. Renovation to zero energy apartment building, Blaue Heimat, Heidelberg, DE
27 1. Zero energy school, Solar active primary School, Lajen, IT
28 1. House with Code for sustainable homes, level 6, Lighthouse, Watford, UK
29 1. Renovation to zero energy office building, WWF-Headquarters, Zeist, NL
30 1. Plus energy sports hall, Herrieden, DE
31 1. Zero energy high rise building, Power tower, Linz, AT
32 Plus energy settlement Freiburg, DE
33 1. Net zero energy renovation of single residential house, Haus Moschik, Hohenthurn, AT
34 Princess Elisabeth research hub - polar science station, Antarctica
35 1. Zero emission super market, Cambridgeshire, UK
36 Zero energy Burger King restaurant, Waghäusel, DE
37 1. Zero energy stadium, Taiwan's Solar Stadium, Kaohsiung, TW

EnEV Energieeinsparverordnung - German Energy Saving Regulation
WSchV Wärmeschutzverordnung - German Heat Insulation Regulation
DIN 18599 - Calculation template for EnEV 2009

Nullenergiehaus, Nullemissionshaus, Plusenergiehaus® are the resultant building movement and energy balancing names. The variety of concepts indicates that today these aims are already realizable. However, it also shows that the there are many different bases on which these balance calculations can be built.

2. Worldwide Survey on Net Zero Energy Buildings

During the last 20 years more than 200 reputable projects with the claim of a net zero energy balance have been realized all over the world. The number of finished buildings per year has risen continuously. In the beginning, extreme pioneering examples were realized by researchers [9]. Within a short time, the first small net zero energy residential buildings were being built by ecologically enlightened developers and architects. They were often inspired by funded solar electricity generation and demonstrated a direct advancement beyond the then recently developed passive house concept (figure 1).

With the increase in availability of efficient technical solutions, bigger and more energy intensive building typologies have been built as Net ZEBs since 1998. Private building owner alliances and house building societies have implemented

Net ZEB apartment houses and small settlements. Their focus has been threatening resource shortage, climate protection as well as the avoidance of rising energy costs. In addition, architects used the concept of zero energy buildings to position themselves in the former niche and now current boom branch of ”high performance buildings”, “green buildings” and even “zero energy buildings”.

Medium-sized enterprises and real estate companies took up the increasing hype in the sector of "green" buildings. To improve the image of the company or to offer real estate’s more attractive than its opposition, they have built Net ZEB factories, office buildings and apartment houses. Often these buildings are certificated and equipped with sustainable technologies or materials. Nearly every tenth Net ZEB is also distinguished with a LEED-, DGNB-, Minergie-P, BREEAM- or a similar certificate. This shows the marketing strategies of these companies. The first large scale enterprises to become involved (Burger King, WalMart) are not known primarily for sustainable buildings but hope for competitive advantages from a "green" image improvement.

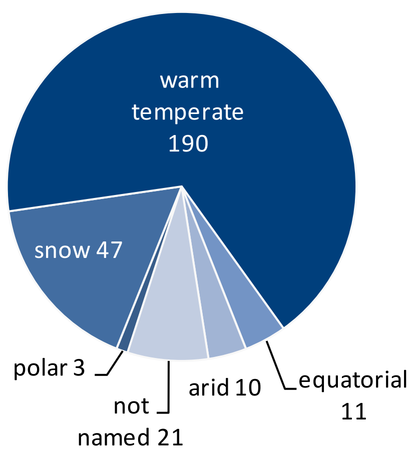

Fig. 2. Frequency of different climate types

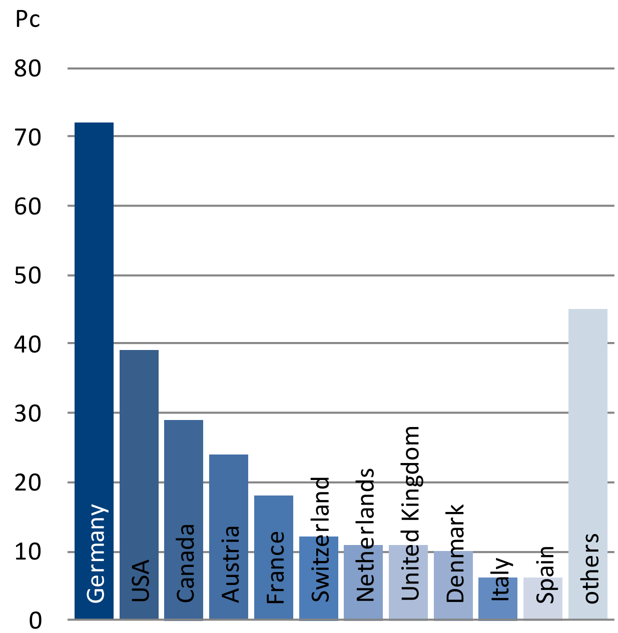

Fig. 3. Number of identified buildings in different countries

To date, most finished Net ZEB projects were realized and originate in northwesterly situated countries and climates (figure 2 and 3). Availability of economic resources, a head start in the field of technologies and knowledge of their energy and climate problem force these kinds of projects, even if the climatic conditions in central Europe and North America seem less suitable than in milder climates. The distribution of U-values of existing Net ZEBs in different climates (figure 4) shows that much more expenditure must be raised for the building cladding because of comfort and physical needs in these areas.

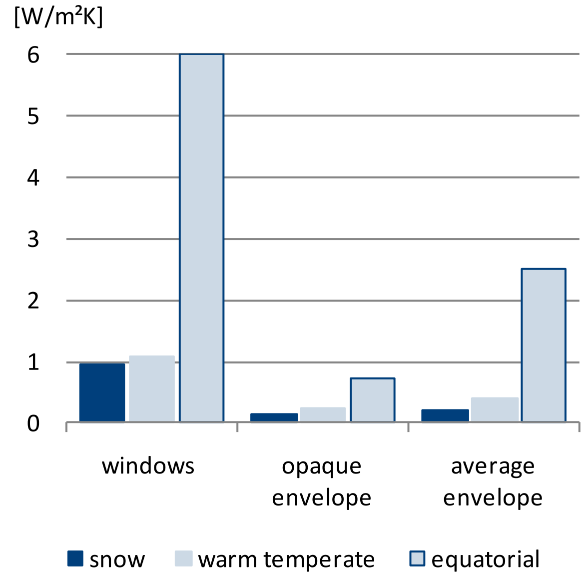

Fig. 4. U-values in different climates

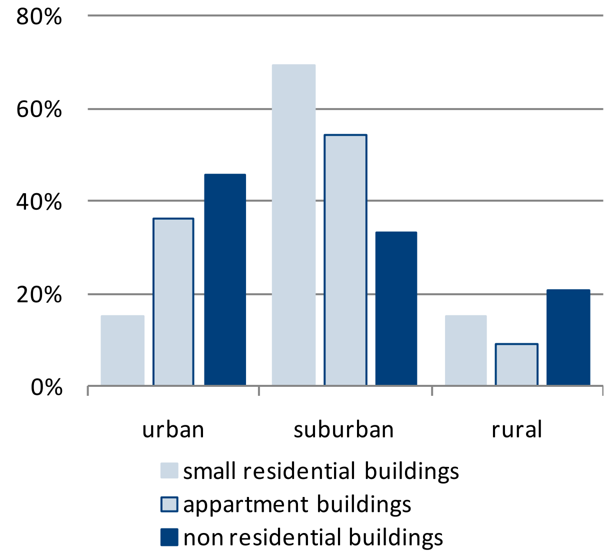

Fig. 5. Site context of 282 known Net ZEBs

3. Energy Efficiency as a Starting Base

Components of solar houses, passive houses or whole passive house concepts are a basis for the energy efficiency in many built examples. Approximately one third of the worldwide recognized Net ZEBs use this idea and lower the energy demand of the buildings in all typologies equally by nearly 60% in comparison to standard buildings which were build according to current building directives. This calls for very good insulation, use of passive solar heat gains and a high compactness. The average surface to volume ratio is around 0.6 in the residential sector and around 0.3 in the non residential sector. On the average, a maximum height of 3 stories is present in the residential sector and fewer stories in the office building sector. The latter is due to the strong cost pressure of this more energy intensive real estate sector.

Some measures promote in addition to a reduced energy demand also the user comfort. Mechanical ventilation systems, partially with heat recovery, advanced day lighting or solar shading devices are used nearly as often as solar-thermal domestic hot water processing or power saving HVAC technology. The latter reduces both the heat demand and electricity demand. In an international scope, this is only partially grasped by construction specifications or energy directives. Also, the load of e.g. household appliances or office equipment is not illustrated in these regulations, however, it is present in most of the Net ZEB balances. A restriction on partial sectors of the consumption prevents the continuous examination in practice and extracts essential parts of the consumption from its necessary optimisation. The consumption should be measured furthermore with renunciation of oversized meter equipment. The annual measurability of energy consumption is an excellent aspect of the net zero energy principle. By including the electricity consumption, the need to reduce the electrical demands is evident. Nevertheless, it is obvious that this is hard to achieve in practice. Sparing equipment in offices or flats, as well as LED lighting, have been realized only in cases in which users and owners are the same authority. In this consumption sector, further savings potential is present.

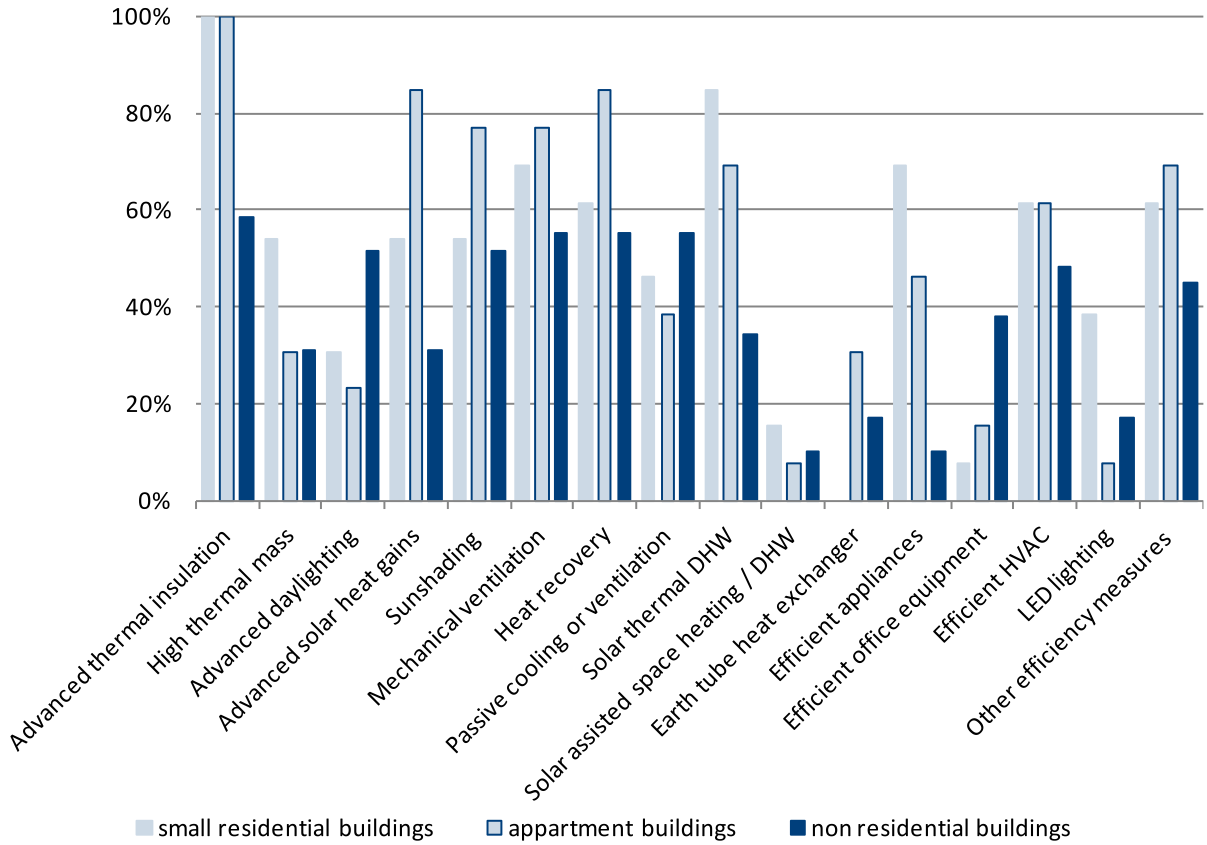

Fig. 6. Selected Energy saving measures applied in Net ZEBs

Beside the passive house concept, a big pool of single measures concerning energy conservation can be found (figure 6). Isolated measures are combined in integral draughts due to special exigencies. Besides, not all these measures have direct influence on the architecture of the buildings. The objection that efficient material and technologies are often not compatible to original design draughts is valid only partially. A great variety in possibilities can be found in the yet built projects.

4. On-Site Energy Generating Technologies

On the way to Net ZEBs efficiency measures are even as important as the cover of remaining energy demands with renewable energy sources and technologies. Figure 9 illustrates that a reduced consumption requires less on-site energy generation. Beside economic advantages, this offers bigger architectural options. An almost unavoidable tool on the way to equalized energy balanced buildings is the on-site generation of electricity with photovoltaics. Nevertheless, this has a great impact on the design and the appearance of the building because of the need for big coherent surfaces in non shaded southern orientations (northern orientations in the southern hemisphere). The more energy is needed to be generated, the greater the significance of the PV expanse and its aesthetical influence.

Not utilized potentials (see above), improved equipment in the view of the electrical needs, a rising amount of grid connected renewable energy sources and an improvement of PV technology available on the market as well as other systems (e.g. heat pumps, biomass CHP) will allow a reduction of necessary PV surfaces. The chronological analysis in figure 7 shows a decrease of the PV areas per m² net floor area in the still short history of zero energy buildings. This observation can be supported in spite of the increase of PV surfaces by office buildings. For some years they use less external credits and increasingly PV due to its risen efficiency. The increase in the sector of apartment buildings results from the plus energy aim and the very huge PV surface at the Plus-energy-Settlement in Freiburg.

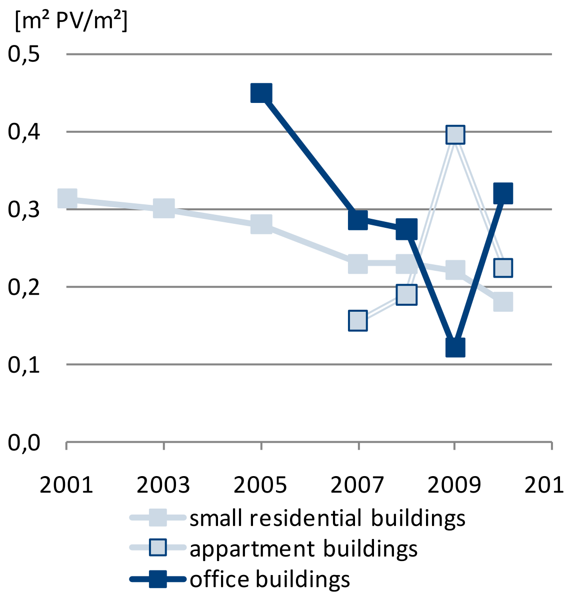

Fig. 7. Development of PV per building floor area

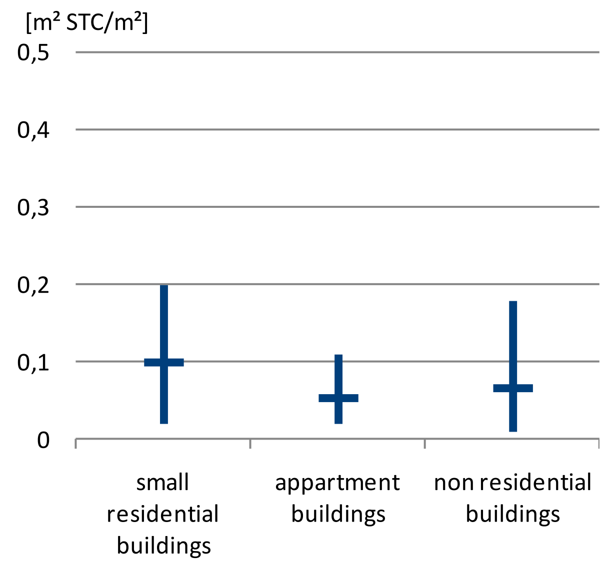

Fig. 8. Area of solar thermal collectors per building floor area

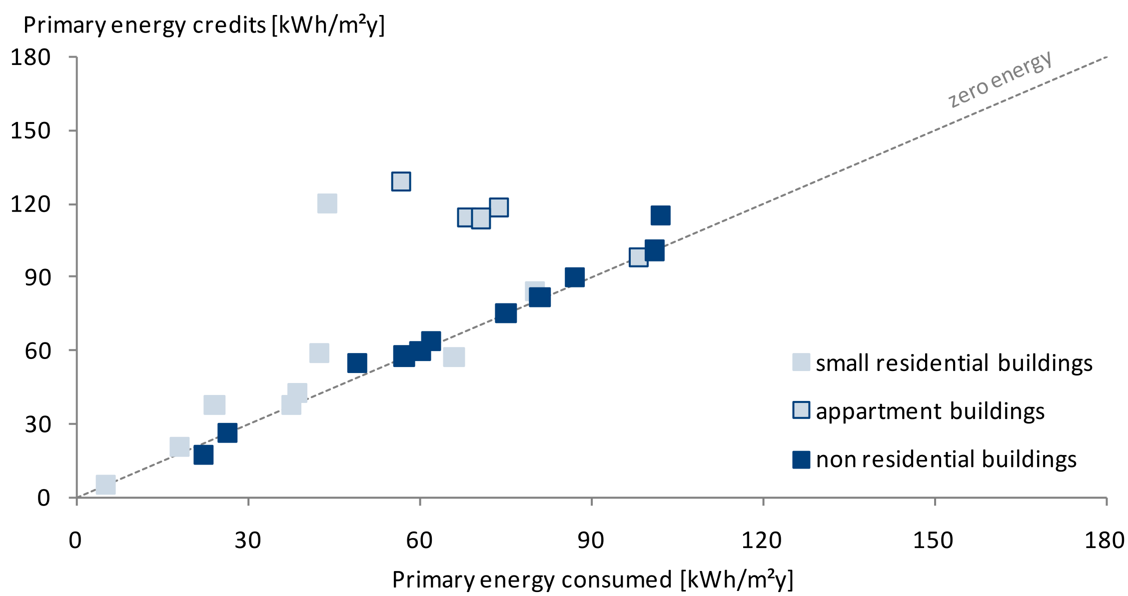

Fig. 9. Compendium of primary energy consumption and credit generation

Solar thermal systems are used as a demand reduction technology as long as heat is not fed into local grids. Due to the non grid connected operation of most solar thermal systems their smaller size offers more integration potential. In the sectors of bigger residential complexes and non residential buildings, solar collectors are substituted by combined heat and power (CHP) plants. The use of gas or even biomass with CHP opens an economically higher attraction and can supply bigger utilities with small district heating grids more steadily.

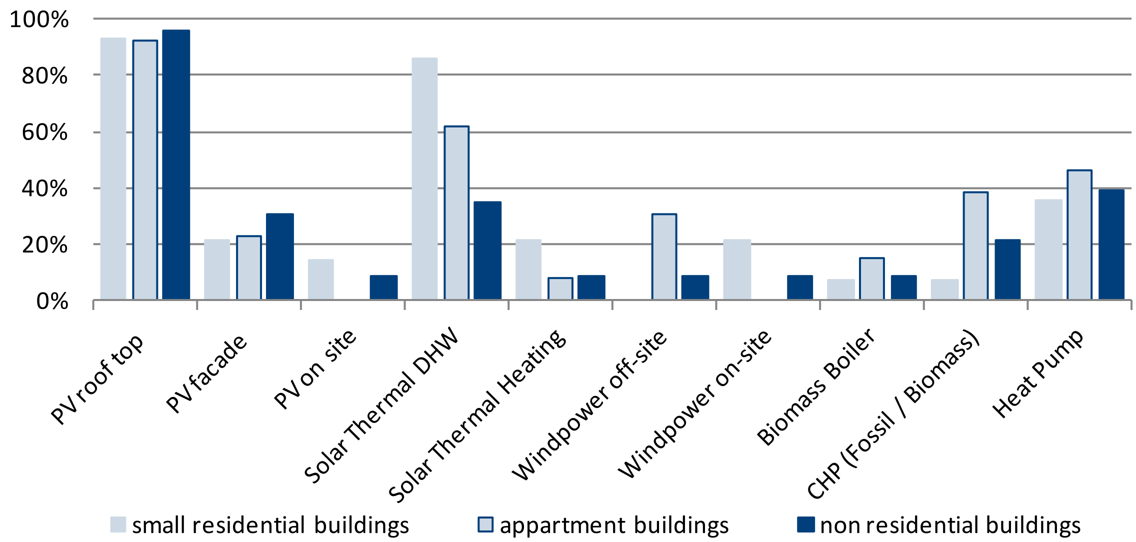

Fig. 10. Technologies applied in different building typologies

In the last couple of years, the number of zero energy buildings with heat pumps increase. The improved technology, decreasing investment cost [10], the surrender of a second base fee and no need to store fuels in the buildings or to build chimneys make this technology attractive. The use of electricity as the only energy source simplifies the measurement of necessary balance data.

For on-site Net ZEBs the use of solar energy is essential. While the availability of biomass from sustainable sources is limited, solar energy is an infinitely available energy source. The potential of this inexhaustible energy source is used building integrated as well as on-site and is the basis for the equalized energy balance. The lasting and day chronologically independent energy source wind can rarely be used in the building sector. Some projects used small wind turbines. But, these arrangements (still) do not have the potential to compensate the whole demands of the respective buildings. Low wind speeds in urban areas and the noise problems prohibit the use in larger scale. The investment or participation in big wind parks or off-site wind turbines, as well as the inclusion of the generated electricity in the energy balances, is often used at energy intensive buildings or renovation projects. Within their available or badly orientated roof surfaces, not enough energy can be generated with PV to compensate the consumed energy. In renovation projects more technical equipment is pursued in general which often encloses CHP plants. This also applies to factories. However, the potential of biomass can seldom be exhausted. Pellet or wood waste fired CHP plants are hardly used in the scope of buildings. Rape oil powered CHPP are a used alternative in spite of known discussions. Building related water power generation (e.g. micro-hydro) currently has no role in all known buildings.

5. Conclusion

The biggest challenge for all zero energy projects is the best fit of energy saving design and technology combined with renewable energy utilization, primarily on site. These challenges are especially huge if a renovation project has the aim of being a net zero energy building. Besides, factors like actor and stimulation play rather subordinated, climatic and typological peculiarities a bigger role.

Table 1. Typical solution sets used in indicated Net ZEBs

	Efficiency heat/cold	**Efficiency electricity**	**Heat/cold supply**	**Electricity generation**
Small residential buildings	Full Passive house concept with Solar thermal collectors	Efficient appliances	Heat pump	PV
Apartment buildings	Full Passive house concept with Solar thermal collectors	Efficient HVAC	CHP	PV / CHP
Non residential buildings	Mechanical ventilation with heat recovery, passive cooling	Low energy artificial lighting / day lighting, controls	Heat pump	PV / Wind off-site / CHP (in factories)

In the area of small residential buildings passive house and low energy house concepts are combined with solar thermal systems, heat pumps and photovoltaics. The use of energy efficient HVAC-technology and power saving household appliances can be identified here more often than in other typologies. However, big residential projects use at least energy efficient HVAC-technology and compensate reduced energy demands by passive house principles combined with CHP and PV systems. In the non residential sector the solutions are a little more extensive. The aimed efficiency in typologies except residential buildings is also achieved more and more by passive house ideas and the use of mechanical ventilation at least in heating dominated countries. The higher electricity loads and the mostly unfavourable relation of solar suitable surfaces on the roof or facade to the building floor area are compensated by on- and off-site CHP (only in some cases with biomass), as well as participation in external wind turbines or even "green" power supply.

Recently, detached buildings have originated increasingly in suburban and urban areas (figure 5). Narrow sites in dense city areas, as well as strict building regulations or development plans, often limit the active and passive use of solar energy. Within the EU goals, the nearly net zero energy building regulations may be frightening. Future electric mobility options may lead to concepts of running cars with on-site generated electricity [11]. Electric cars may be considered as part of the building energy load such as appliances and their batteries considered as part of the short term electric storage capacity for the building energy system. Also comprehensive life cycle assessments in addition to the comparison of operation energy and generation could acquire a greater significance [12].

6. Acknowledgements

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