Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 40

Heat Pump Concepts for Nearly Zero-Energy Buildings

Final Report

Operating Agent: Switzerland

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Preface

This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) which is an Implementing agreement within the International Energy Agency, IEA.

The IEA

The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of over 40 Implementing Agreements.

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the Heat Pumping Technologies Programme. Signatories of the TCP are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the TCP collaborative tasks or "Annexes" in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex. The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

The IEA Heat Pump Centre

A central role within the HPT TCP is played by the Heat Pump Centre (HPC). Consistent with the overall objective of the HPT TCP the HPC seeks to advance and disseminate knowledge about heat pumps, and promote their use wherever appropriate. Activities of the HPC include the production of a quarterly newsletter and the webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the IEA Heat Pumping Technologies Programme and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:

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IEA HPT Annex 40

Heat pump concepts for Nearly Zero Energy Buildings

Final Report IEA HPT Annex 40

Heat pump concepts for Nearly Zero Energy Buildings

Project outline and summary of main results

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Abstract

Since the mid of the 1990ties, low energy buildings with a significantly reduced energy consumption down to ultra-low energy standard (typical space heating energy need of 15 kWh/(m^2a)) have been realised.
These building concepts recently show strong market growth in different European countries. Based on this development, the objective of the political strategies in Europe, North America and Japan focus on so-called nearly or Net Zero Energy Buildings as next step of high performance buildings as part of the strategies to achieve climate protection targets in the frame of post Kyoto-process.
Due to the following features, heat pumps seem very suited for the application in nearly zero energy buildings:

- Heat pumps are highly energy-efficient with adequate system design, in particular in energy- efficient buildings with low loads and low supply temperatures, reducing thereby the need of on-site energy generation in order to meet the nearly zero energy balance
- Heat pumps can cover multiple building services of space heating, domestic hot water production, space cooling and dehumidification as needed even in simultaneous operation
- Heat pumps have good integration options with other building technologies like the ventilation system or solar components in the building envelope
- Heat pumps are often one of the main electricity consumers and thus offer potential of load shifting and demand response in order to optimise local use of on-site generated electricity or offer operation reserve to connected grids

In accordance with these features, heat pumps are already quite established in built pilot and demonstration nZEB.
The IEA HPT Annex 40 entitled "Heat pump concepts for Nearly Zero Energy Buildings" deals with the application of heat pumps as core component of the heating, ventilation and air-conditioning HVAC system in nearly or Net Zero Energy Buildings (nZEB or NZEB, respectively).

The main objectives of the IEA HPT Annex 40 are thus an evaluation and comparison of system solutions in order to characterise the role of heat pumps in nearly zero energy buildings and further develop heat pump systems for the application in these buildings, leading to the following objectives:

- Characterisation of the state-of-the-art of nZEB in the different participating countries
- Assessment and comparison of the energy performance of different system solutions for the application in nZEB in form of case studies
- Development and lab-testing of new system solutions of integrated heat pumps for the application in nZEB
- Accomplishment and evaluation of field tests of new developments and marketable systems in order to characterise the energy balance and the system performance

This report gives an introduction to the political background and the state of the definitions and labels of nearly Zero Energy Buildings and an outline of the Annex work and the national contributions. The main results of the IEA HPT Annex 40 are summarised.

Contents

1 Introduction to nearly Zero Energy Buildings

1.1 Political Background

Political strategies in different countries and continents strongly focus on nearly (nZEB) or Net Zero energy buildings (NZEB). However, neither in North America nor in Europe a uniform and consistent definition exists, yet, since e.g. the EU Energy Performance Building Directive (EPBD recast, 2010) only sets the boundary conditions and leaves the exact definitions to the member states. Moreover, the time horizon for a broad introduction of nZEB varies between 2020 and 2030. In the following the background in different countries is given.

1.1.1 North America

The US governmental Department of Energy (DOE) had the programme of a broad introduction of NZEB in the new building sector until the year 2020. Fig. 1 shows a possible transformation of the new building market until 2020. The market transformation reflect the working definition of a NZEB as "a home with greatly reduced needs for energy through efficiency gains (60 % to 70 % less than conventional practice), with the balance of energy needs supplied by renewable technologies". In Sept. 2015 the DOE Building technology office launched a definition of NZEB (see chap. 1.2.3), which is similar to the definition by CEN/ REHVA (see chap. 1.2.2).
Currently, the homes are also denoted as maximum efficiency homes, which also includes the retrofit sector. Thereby, the target of NZEB still remains, but the year 2020 is not so strict anymore.

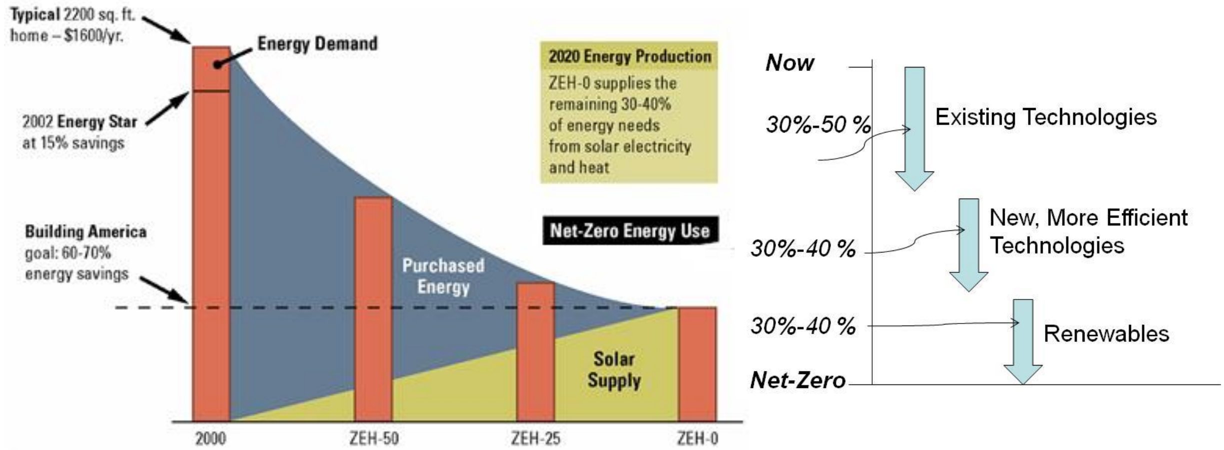


Fig. 1: Market development towards Zero energy homes (ZEH) in the USA (left) and strategies to reach Net Zero Energy consumption (right, source: Payne)

Also in Canada, the objective of the introduction of NZEB is intended within the period until 2030. In 2009 the Canadian Mortgage and Housing Corporation launched a field test project with a detailed monitoring of 13 NZEB concepts, which also had further requirements beside the zero energy balance, for instance a minimum impact on land and water use and multiplicability of the concept all over Canada.

1.1.2 Japan

Japan has also defined a target to reach the Net Zero Energy Buildings by the year 2030. The action plan for the introduction of NZEB, which is depicted in Fig. 2 comprises

- to make ZEH (Net Zero Energy House) the standard for new single houses by 2020
- to double the number of renovating energy-efficient houses by 2020
- to realize ZEH for all new houses on average by 2030

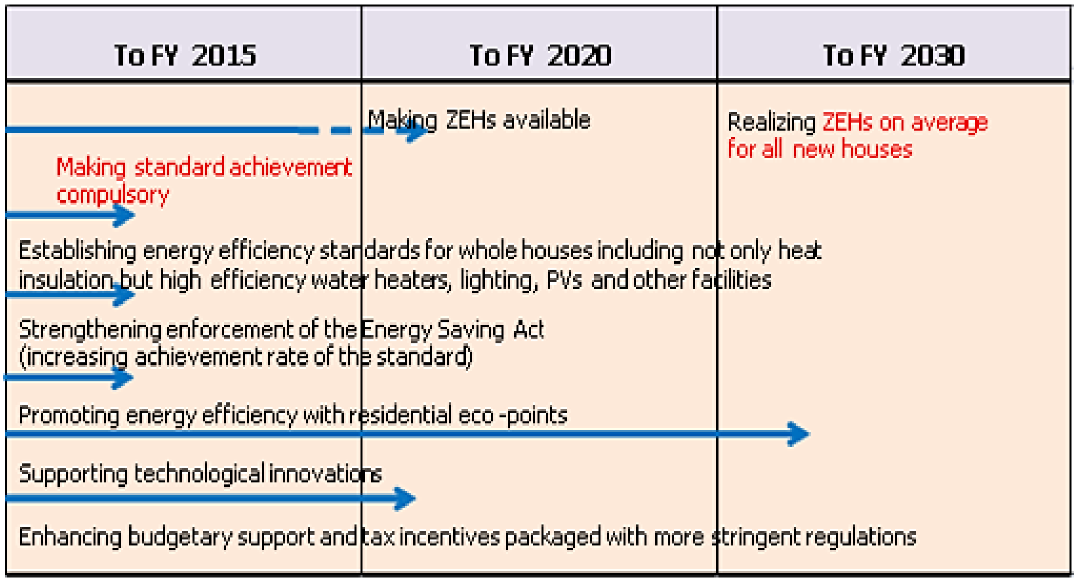


Fig. 2: Action plan for zero energy homes (ZEH) in Japan (Okumiya et al., 2013)

1.1.3 EU-energy strategy and related EU directives in Europe

In 2007 the EU published the so-called 20-20-20 by 2020 strategy shown in Fig. 3 left, referring to 20 % less CO_2-emissions, 20 % enhanced energy efficiency and 20 % renewable energy share to be reached by the year 2020.

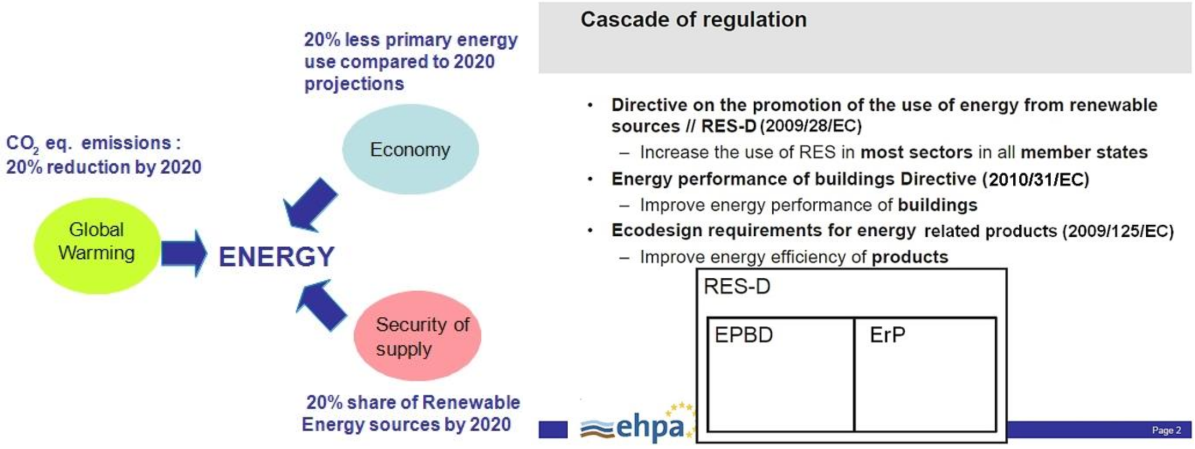


Fig. 3: Energy strategy 20-20-20 by 2020 of the EU (left, source: Dieryckx) and cascade of accompanying EU Directives (right, source: EHPA)

In order to implement the strategy three EU-Directives and a Guideline have been published, which are depicted in Fig. 3 right.

- **EU Directive on the Energy Performance of Buildings** (Directive 2010/31/EU of the European Parliament and Council of May 19, 2010 on the energy performance of buildings (recast), 18.6.2010)

  Besides an outline of energy efficiency measures and requirements for building energy labelling (building energy certificate) the recast of the directive sets the target that all new buildings in the EU shall reach near zero energy consumption by the year 2021.

- **EU Directive on Energy related Products** (European Parliament and the council of the European Union, 2009)
  The directive sets guidelines for product labelling, among others also heat generators and air-conditioners. The motivation is to make the EU products top runners in energy efficiency. If current drafts are realised, much higher minimum requirements for heat generators will be introduced between 2011-2015, setting the efficiency of an average condensing boiler as minimum requirement for heat generators by 2015. Products not fulfilling the requirement will be banned from the market. Heat pumps are ranked among most efficient generators.

- **EU Directive on the Promotion of Renewable Energy Use** (European Parliament and the Council of the European Union, 2009)

  The directive defines criteria and calculation methods and which energies are considered renewable. For heat pumps the directive defines the source energy to be considered renewable, if the Seasonal Performance Factor (SPF) reaches a value higher than 2.63 in 2010. This value depends on the average electricity generation efficiency, which was changed from 0.4 to 0.43 in 2010.

- **Guidelines on cost optimal levels for nZEB**

  The cost-optimal level is defined as *"the energy performance level which leads to the lowest cost during the estimated economic life-cycle"*. The EPBD requires the member states to report on the comparison between the minimum energy performance requirements and the calculated cost-optimal levels using the Comparative Methodology Framework provided by the Commission (EPBD Art 5.2, 5.3, 5.4 and Annex III). The report shall also provide all input data and assumptions made. (Aggerholm et al., 2011)

The recast of the EPBD (2010) defines the requirement that from the beginning of 2019 all new public buildings and from the beginning of 2021 all new buildings shall be nearly zero energy buildings (nZEB). More details on the time schedule for the introduction of nZEB in the member states of the EU is depicted in Fig. 4.

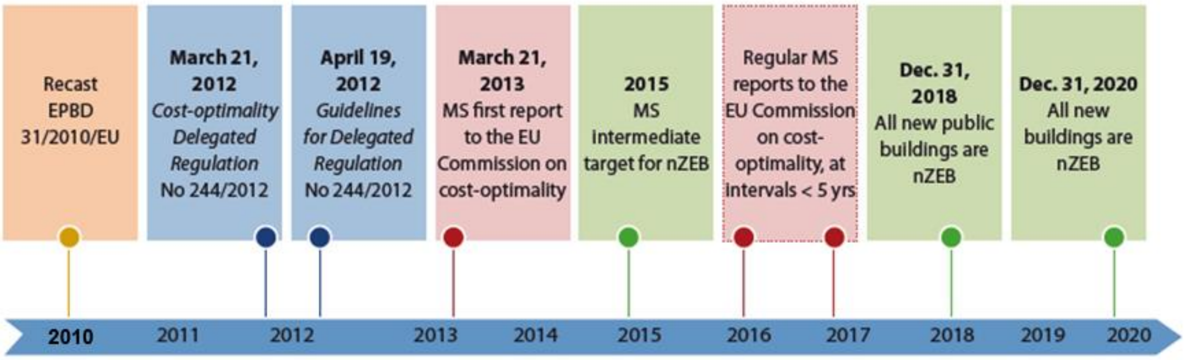


Fig. 4: Time schedule for the implementation of nZEB (source: Atanasiu and Kouloumpi, 2013) (Atanasiu, et al., 2013))

The contained definition of a nearly zero energy building, however, is quite vague, as it is only states:
A nearly Zero Energy Building

- means a building with "***a very high energy performance***"
- ***the nearly zero or very low energy amount*** should be covered ***to a very significant extent*** by energy from renewable sources, including renewable energy produced ***on-site or nearby***

The marked parts of the statement are not clear defined and can be interpreted differently, so that in fact, no common definition of an nZEB exists, yet. In the EU each of the member states has to declare, how an nZEB is defined on the national level.
Therefore, different approaches have been undertaken by different institutions to elaborate an unambiguous and harmonised definition of nZEB, which are described in the following chapters.

1.2 Definition of nZEB

Despite the strong focus of political strategies on nZEB there is no harmonised and consistent definition of an nZEB, yet. Based on the vague expressions in the EPBD European member states have the task of defining an nZEB. However, different initiative try to harmonise the definitions of nZEB in order to derive some comparability across the different definitions in the European member states. In the following different harmonisation initiatives are shortly described, starting with a definition framework which sets the criteria which should be contained in a complete and thorough definition of an nZEB.

In the common understanding, an Net Zero Energy Building is a grid-connected building, which produces (exports) as much energy on-site by renewable sources as it consumes (imports) on an annual basis.
In the term NET the balance is expressed, i.e. an NZEB is not a self-sufficient building, which can cover the demand at any time, but only for a certain balance period, currently mostly an annual balance period. Based on the REHVA Definition (see chap. 1.2.2) a Net Zero Energy Building (NZEB) and a nearly Zero energy building (nZEB) can be defined as follows:

net Zero Energy Building (NZEB)
According to the REHVA definition (Kurnitski, 2013) a Net Zero Energy Building is a building with a non-renewable primary energy of 0 kWh/(m^{2}a). The balance is normally achieved by import of delivered energy from connected electrical or thermal grids or fuels and export of on-site generated energy. For the balancing the energy is weighted, mostly with primary energy factors. The balances is thus achieved by energy generation under favourable boundary conditions, while energy is delivered from the connected sources otherwise.

nearly Zero Energy Building (nZEB)
nZEB hence is a “technically and reasonable achievable national energy use higher than zero kWh/(m^{2}a), but no more than a national limit values of non-renewable primary energy, achieved with a combination of best practice energy efficiency measures and renewable energy technologies which may or may not be cost optimal. Thus, "Reasonably achievable" is assumed by comparison with national energy use benchmarks appropriate to the activities served by the building” (Kurnitski, 2013)

However, these two definitions are not comprehensive, and for a thorough definition, further criteria regarding the nZEB balance have to be defined, which is currently the task of the EU Member states. Nevertheless, currently, definitions are quite different among the EU-member states (see chap. 1.2.4 and Appendix A.2). In the following approaches to harmonise the definition are presented.

1.2.1 Definition framework IEA ECBCS Annex 52/SHC Task 40

In the frame of the joint IEA ECBCS Annex 52/SHC Task 40 the subtask A was to elaborate a uniform definition of nZEB. On the background that the implementation of the EPBD recast (2010) is accomplished on the national level of the EU-member states, a consistent definition framework has been published in Sartori et al. (2012). Instead of the detailed definition, the criteria for the consistent definition are elaborated. The criteria are divided into 5 groups, which are given in Fig. 5, in conjunction with the basic concept of nZEB. For each item the options discussed for an implementation and the most common definition of the criteria is given, as well. The different criteria are shortly described in the following. More details can be found in Sartori et al. (2012).

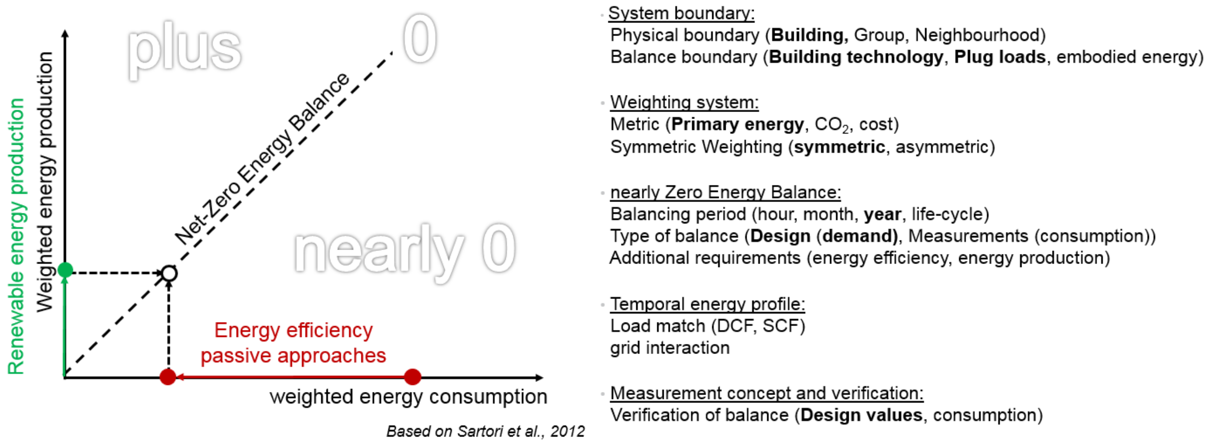


Fig. 5: Criteria for a consistent definition of NZEB (according to Sartori et. al, 2012)

As **first group of criteria** the basic boundaries have to be defined, consisting of the physical system boundary of what to consider as on-site energy production and the balance boundary, defining which energy is taken into account in the balance.
Moreover, the type of building and boundary conditions concerning the site of the building and weather data and comfort levels have to be given. In Fig. 6 different physical boundaries are depicted.

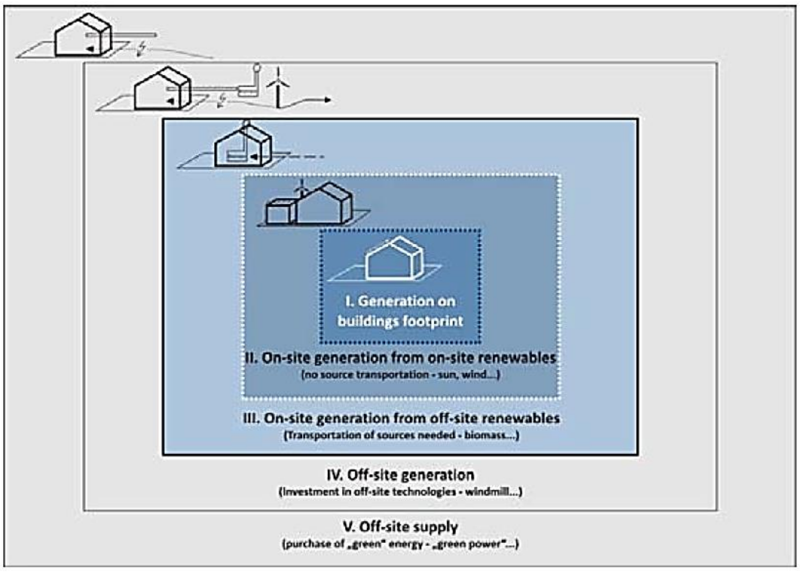


Fig. 6: Different physical balance boundaries (Marszal et al., 2010)

The closest physical boundary I. relates to the generation on the building footprint, i.e. all energies for the balance have to be produced on the building. In system boundary II. and III. the on-site generation is extended to the building estate and to transportation of source energy to the building, e.g. in form of biomass. For boundary IV. also investment in off-site renewable production plants is possible and for boundary V. off-site generation can be substituted by purchase of renewably produced off-site “green” energy, e.g. electricity from renewable sources.
The most common physical boundary is currently a boundary with on-site generation, i.e. the imported energy has to be compensated by on-site renewable energy production.
The second criterion concerning the balance is denoted as balance boundary and defines which energies are taken into account. Different balance boundaries are given in Fig. 7.

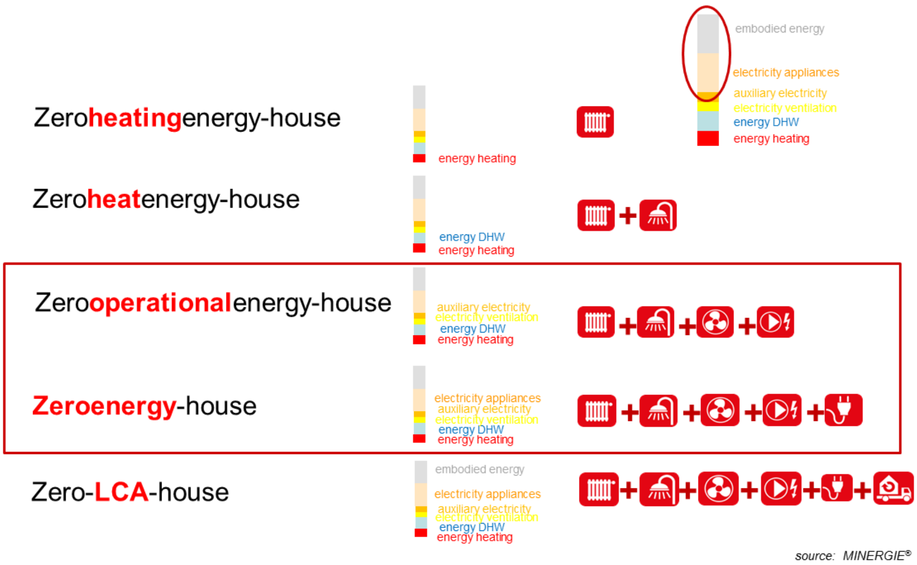


Fig. 7: Possible definitions of the balance boundary (source: MINERGIE®)

In Fig. 7 also the quantities of the energies for the different building services for a typical new residential building with efficient building envelope are illustrated. It becomes clear that about one third of the energy is used for the technical building system.

It is denoted as operational energy in Fig. 7. Another third is used for plug load of household appliance and one third is the fraction of embodied energy. If the embodied energy is not taken into account, the plug load typically makes-up half of the energy consumption.
Due to the different energies taken into account the balance boundary is also denoted as ambition level. Most definitions take into account either only the technical building system, which is called zero operational energy house in Fig. 7, or the consumption including household appliances, i.e. plug loads, which is denoted as zero energy building in Fig. 7.
In most definitions of plus energy buildings, i.e. buildings, which reach a surplus of exported energy in the annual balance, the balance boundary is normally set to a zero energy house, i.e. including the plug loads, since otherwise about half of the energy consumption would not appear in the balance, so the term “plus” energy building would be misleading.
The largest balance boundary is the ambition level of a zero life-cycle building, which is denoted zero-LCA-house in Fig. 7 and takes into account also the embodied energy in the building materials and sometimes also the mobility needs. The larger the balance boundary is chosen, the larger the energy generation system has to become in order to compensate for the weighted energy consumption, which has strong implications for the design of the systems.
As the energy consumption is also dependent on the boundary conditions, e.g. the climate data of the site and the comfort level to be reached, these boundary conditions also have to be defined.
The **second group of criteria** is the metric for the balance, where besides the common energy metrics delivered energy or primary energy, also CO_2-emissions, stressing climate change considerations, or monetary units, stressing the economics (zero energy cost building) can be thought of. In fact, e.g. the UK is heading for the introduction of zero carbon buildings, which sets the CO_2-emissions as weighting criterion.
Moreover, weighting of imported and exported energy could be symmetric to take into account the substitution effect in the grid, or asymmetric, e.g. to promote certain technologies or self-consumption. Volatile prices and grid interaction may also be reflected in time-dependent weighting in the future.
As **third group of criteria** the definition should contain details on the net zero energy balance. One criterion is the time period for the balance. Currently, mainly an annual balancing is applied, which, however, neglects the typical seasonal mismatch between on-site production surplus in summer and deficit in wintertime, which is typical for solar technologies like PV.
In order to better take into account this characteristic, also a monthly balance or some kind of limitation, e.g. a PV surplus in summer is not accounted in the balance, are in discussion.
Moreover, the type of balance, which, depending on the available data, could be the balance of the imported and exported energy (taking into account the self-consumption, which can only be evaluated when the building is in operation), or a load and generation balance (which is based on design data). Since the import-export balance requires information from the operation phase, mostly the load–generation balance based on design data is applied. Furthermore, additional criteria on minimum energy efficiency requirements and minimum required shares by certain technologies, e.g. minimum renewable generation, may be defined in order to secure energy-efficiency of the building envelope or the system, respectively.
The **fourth group of criteria** is related to the temporal relation between production and consumption and can be characterised by the terms “load match” and “grid interaction”. The load match describes the temporal match between the on-site consumption and production of the energy. The grid interaction is a characteristic for the stress that is put on the grid by import and export of on-site energy generation and consumption. With a broader introduction of nZEB, these criteria will gain importance and refer to the integration of nZEB into the connected energy grids in order to works in synergy with the requirements of the grids. This aspect is addressed by the flexibility which buildings can offer for the grid operation, e.g. as load shifting potential, and is denoted as demand response. Demand response capability may become a further requirement for the building technology in the future in order to achieve an optimal integration of nZEB into the connected energy grids. The objective is to design the building system in order to minimize the impact on the grid. nZEB which are able to work in line with grid requirements offer a better integration into a future smart grid which is an additional benefit. Up to now, criteria of the temporal match are hardly considered in the definition of nZEB.

Last but not least, the **fifth group of criteria** refers to the verification of the balance, which necessitates a certain monitoring of the consumption and generation. Thus, rules for the measurement and verification should be included for a complete definition.

1.2.2 CEN/REHVA Definition

The European federation of HVAC association REHVA has published a definition of nZEB in 2013 as update of the prior definition of 2011. The definition in 2013 has been elaborated in collaboration with the European standardisation organisation CEN, which has the mandate to develop accompanying standards for the implementation of the EPBD recast (2010).

Fig. 8 shows the definition of the building physical boundary distinguished to an on-site production and a nearby production. According to the REHVA definition, a nearby production can be accounted to the building, if a contractual long-term agreement exists, i.e. the nearby production has a long-term link to the building supply (Zirngibl, 2014). The target calculation value of the EPBD recast and the respective CEN standard prEN 15603 (2013) is the area specific non-renewable primary energy consumption E_p , which is calculated according to the following equations:

$$E_P = \frac{E_{P,nren}}{A_{net}} = \frac{\sum_i \left(E_{del,i} \cdot f_{del,nren,i}\right) - \sum_i \left(E_{\exp,i} \cdot f_{\exp,nren,i}\right)}{A_{net}} \qquad (1)$$

where

E_P - primary energy indicator [kWh/(m²a)]

$E_{P,nren}$ - non-renewable primary energy indicator [kWh/a]

$E_{del,i}$ - delivered energy on-site of nearby for the energy carrier i [kWh/a]

$E_{\exp,i}$ - exported energy on-site of nearby for the energy carrier i [kWh/a]

$f_{del,nren,i}$ - non-renewable primary factor of delivered energy carrier i [-]

$f_{\exp,i}$ - non-renewable primary factor of delivered energy compensated by the exported energy for energy carrier i [-] .

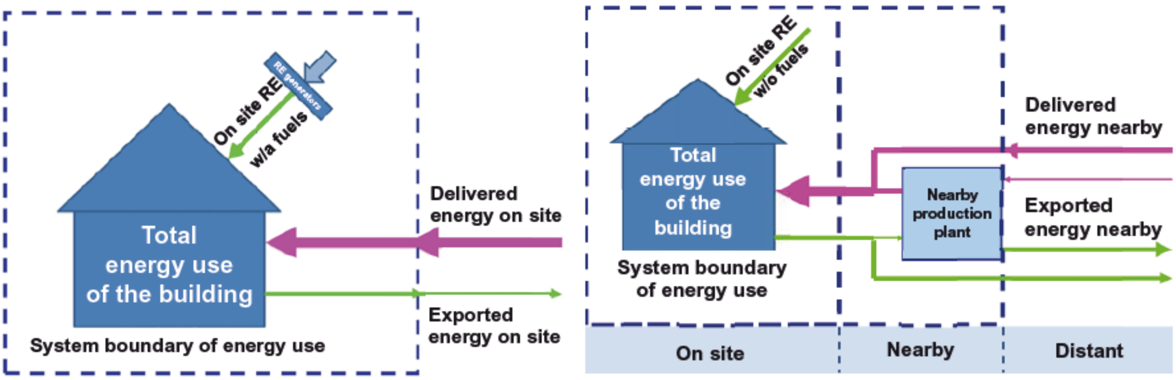


Fig. 8: Physical boundary of the REHVA definition regarding on-site and nearby production (according to Kurnitski, 2013)

The primary energy factor is by default the same value as the factor of the delivered energy, if not nationally defined differently. The following two definitions were developed for a uniform implementation of the EPBD (Kurnitski, 2013) corresponding to these calculated values.

"Net Zero Energy Building (NZEB)
Non-renewable primary energy of 0 kWh/(m² a)."

"nearly Zero Energy Building (nZEB)
Technically and reasonably achievable national energy use of > 0 kWh/(m² a), but no more than a national limit value of non-renewable primary energy, achieved with a combination of best practice energy-efficiency measures and renewable energy technologies which may or may not be cost optimal"

In this definition "'reasonably achievable' means by comparison with national energy use benchmarks appropriate for the activities served by the building, or any other metric that is deemed appropriate by each EU Member State."
Renewable energy technologies needed in nearly Zero Energy Buildings may or may not be cost-effective, depending on available national financial incentives.
The EU-commission has established a comparative methodology framework for calculation of cost-optimal levels (European Commission, 2012).

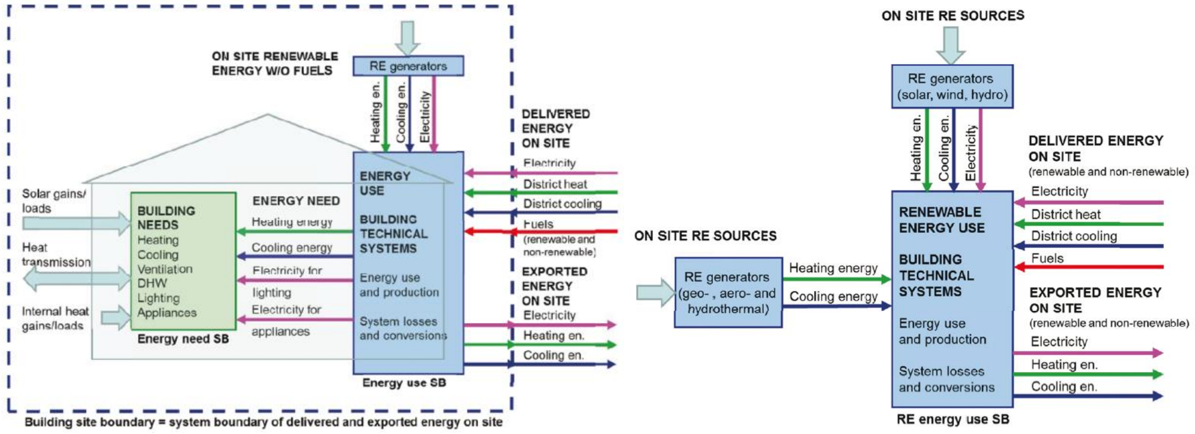


Fig. 9: Detailed physical boundary of the REHVA definition and boundary for the calculation of renewable energy use (Kurnitski, 2013)

Based on this definition, REHVA developed in co-operation with CEN a certification scheme with requirements for an nZEB rating procedure in the draft standard prEN 15603:2013. The requirements for the rating consists of four steps, which are depicted as hurdle race in Fig. 10. Each of the single requirements has to be fulfilled to receive the nZEB rating, i.e. each hurdle has to be passed.
The first requirement is related to the building energy needs, i.e. a certain efficiency of the building envelope is required.
The second requirement is set for the overall primary energy consumptions, which limits the total energy consumption. By this requirement the efficiency of the used building technology is set.
The third requirement is set on the non-renewable primary energy use, which defines in turn requirements for the minimum of renewable energy use.
Finally, the fourth requirement sets limits for the energy balance, i.e. how much primary energy consumptions is allowed to be rated as nearly zero energy building. Depending on the balance, the category A-G on the building energy certificate is determined. By this procedure, only the methodology is fixed, while the limit for the single "hurdles" can still be defined on the national level according to national requirements. However, despite different limits, the resulting nZEB rating is still comparable among the member states.

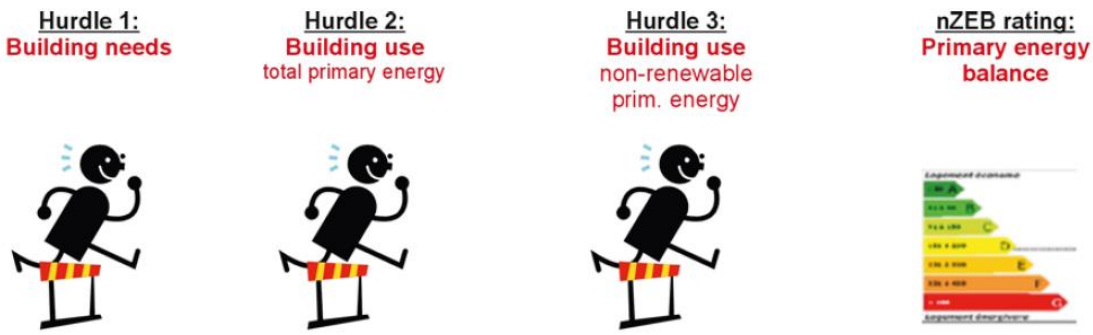


Fig. 10: "Hurdle race" of the single criteria for nZEB certification according to prEN 15603:2013 (Zirngibl, 2014)

1.2.3 Definition for Zero Energy Buildings by DOE of the USA

In 2014, the U.S. Department of Energy (DOE) Building Technologies Office (BTO) contracted the National Institute of Building Sciences to establish definitions, associated nomenclature and measurement guidelines for zero energy buildings, with the goal of achieving widespread adoption and use by the building industry. To present the results of that work, the institute prepared the report “A Common Definition for Zero Energy Buildings” (Peterson et al., 2015). Based on this work, the definition of a Zero Energy Building (ZEB) is stated as follows:
“An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.”(Peterson et al., 2015)
Therefore, the definition is based on annual balance of imported and exported primary energy. The definition is similar to the REHVA nearly Zero Energy Building (nZEB) definition. For a clear understanding about imported and exported energy, Fig. 11 shows the site boundary of the definition.

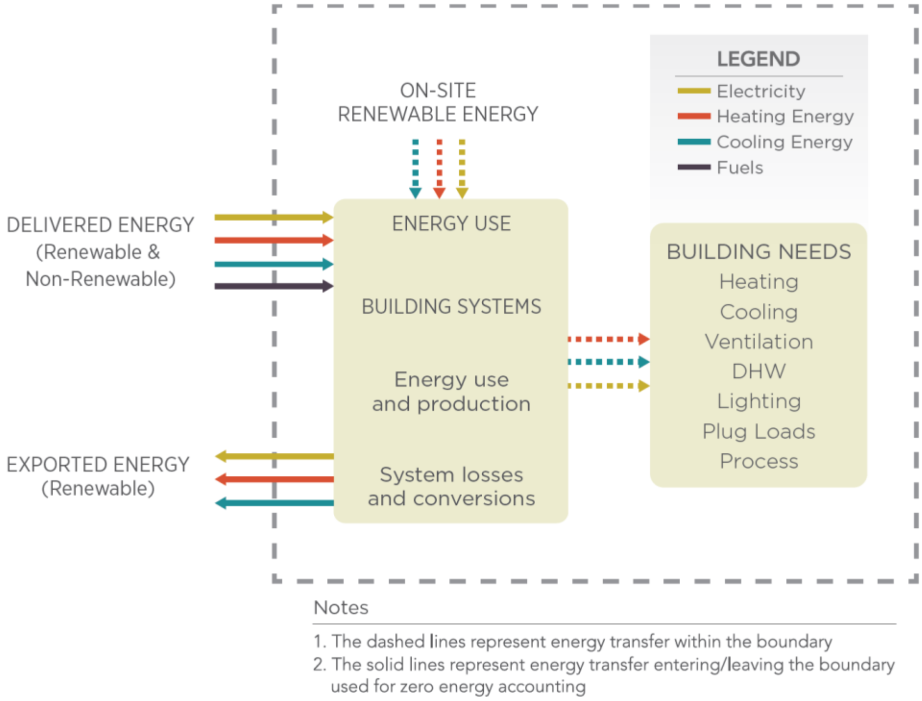


Fig. 11: Site boundary of energy transfer for zero energy accounting (source: Peterson et al., 2015)

As seen, the ZEB energy accounting include energy used for heating, cooling, ventilation and DHW, (indoor and outdoor) lighting, plug loads, and process energy. In addition, transportation within the building is included.
An important factor for the import and export of energy are the conversion factors, so if electricity is directly imported, a source energy conversion factor of 3.15 is given. For the calculation of the source energy, following equation is used:

$$E_{source} = \sum_i E_{del,i} \cdot r_{del,i} + \sum_i E_{\exp,i} \cdot r_{\exp,i} \quad (3)$$

where
$E_{del,i}$ - delivered energy for energy type i;
$E_{exp,i}$ - exported on-site renewable energy for energy type i;
$r_{del,i}$ - source energy conversion factor for the delivered energy type i;
$r_{exp,i}$ - source energy conversion factor for the exported energy type i;

Tab. 1 gives an overview of source energy conversion factors, corresponding to primary energy factors in Europe, for different energy carriers. Imported and exported electricity are weighted with the same factor, thus, for all electric buildings, no weighting is required.

Tab. 1: US national source (primary) energy conversion factors (source: Peterson et al., 2015))

Energy Form	Source Energy Conversion Factor ®
Imported Electricity	3.15
Exported Renewable Electricity	3.15
Natural Gas	1.09
Fuel Oil (1,2,4,5,6, Diesel, Kerosene)	1.19
Propane & Liquid Propane	1.15
Steam	1.45
Hot Water	1.35
Chilled Water	1.04
Coal or Other	1.05

Further information is available at http://www.energy.gov/eere/buildings/articles/doe-releases-common-definition-zero-energy-buildings-campuses-and

1.2.4 State of Definition in EU-member countries

In their national plans, most member states reported on intermediate targets to improve the energy performance of new buildings by 2015. Some countries went further and established measures to deliver a gradual transition towards nZEB levels:

- In some countries, a progressive tightening of the requirements has been put in place. For instance, in Denmark and the Slovak Republic, the requirement for the energy performance indicator became stricter after 2015.
- In some countries, a nZEB definition will be initially implemented for some types of buildings, such as in the Czech Republic and in the UK.
- Another example is the Brussels Capital Region, where nZEB requirements were officially defined in 2011 and enforced from 2015. In this case, the building sector has gradually adapted to them and today nZEB requirements are mandatory for all new buildings.

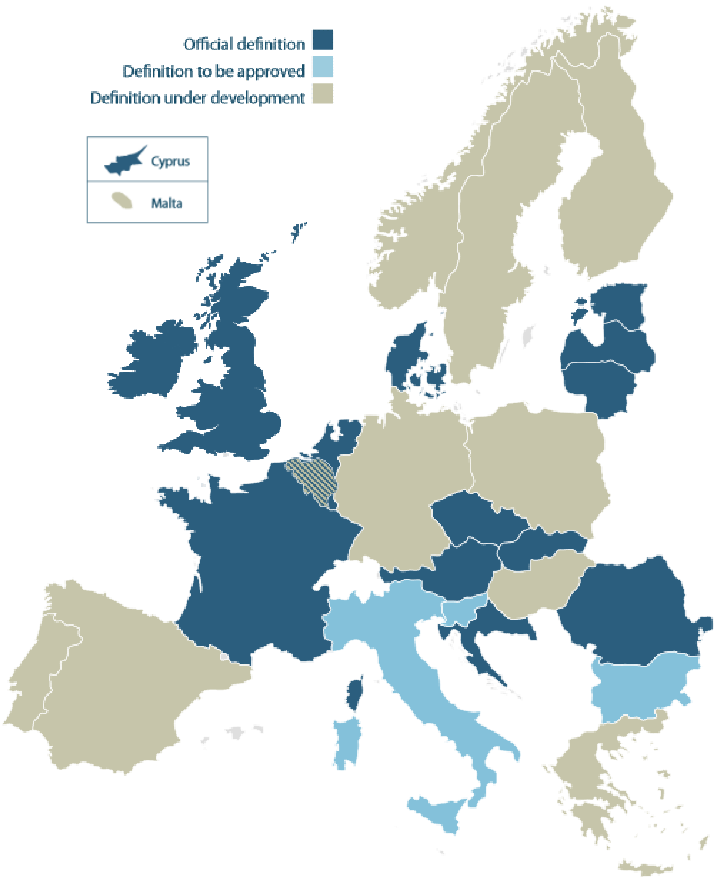


Fig. 12: State of the Definition in EU-member countries (BPIE, 2015)

By April 2015, a definition of nZEB has been available in 15 countries (and the Belgian regions Brussels and Flanders). In further 3 countries, the nZEB requirements have been defined and are expected to be implemented in the national legislation. In the remaining 9 member states (and Norway and the Belgian region Wallonia), the definition is still under discussion and has not been finalised, yet (as state of April 2015).
By the already existing definitions, though, it becomes clear, that the national definition differ both in criteria, which are to be kept to meet the requirements, as well as in the limits of the criteria. Therefore, in the first step no uniform or comparable definition of nZEB across the European member states can be expected. Further details on the single criteria and the current definition and limits are contained in Appendix A.2 (BPIE, 2015). In the following some examples of the definition in the participating countries are given.

1.2.5 Finland

Low Energy Building

National definitions for ultra low-energy buildings (passive houses) exist in Finland, Sweden, Norway and Denmark (Buvik, 2012).
In Finland, the definition of passive house is based on three characteristics: heating energy needs, total primary energy demand of the building, and measured air tightness (Nieminen et al., 2009). The Finnish passive house definitions for different parts of the country are shown in Tab. 2.

Tab. 2: The Finnish passive house definition (Nieminen et al., 2009)

	Coastal area including major cities (Helsinki, Espoo, Vantaa & Turku)	**Central Finland**	**North-East Finland + Lapland**
Heating energy demand of spaces (kWh/(m^{2}a))	≤20	≤25	≤30
Primary energy demand (kWh/(m^{2}a))	≤130	≤135	≤140
Measured air tightness (1/h)	0.6	0.6	0.6

nZEB – The FInZEB project

In order to define nZEB in Finland, the FInZEB project has been accomplished. According to the EPBD

- an nZEB has an extremely high energy efficiency
- the energy demand of a nZEB is covered at large extent by renewable energy sources
- an nZEB has a minimum energy use
- an nZEB includes on-site and nearby renewable energy

In order to fulfil the requirements, FInZEB made several proposals in dependency of different features of the building, as seen in Tab. 3.

The already existing targets for energy performance of buildings are defined by a so-called E-value. The requirements for buildings are defined by the Finnish Building Code D3/2012 and are calculated as follows:

$$E_{D3(2012)} = \frac{\sum_i E_{DE,i} \cdot f_{DE,i}}{A_{net}} \quad (4)$$

where

$E_{DE,i}$ – delivered energy i (DH, electricity, fuels used for energy production of the building and district cooling) [kWh/a]

$f_{DE,i}$ - weighing factors of delivered energy i (0.7 for DH, 1.7 for electricity, 1.0 for fossil fuels, 0.5 for renewable fuels, 0.4 for district cooling) [-]

A_{net} - heated net floor area of the building [m^2]

Tab. 3: FInZEB proposals in dependency of nZEB features (Rautiainen, 2015)

Features of nZEB	FInZEB proposal
Heat loss of the building	• Current heat loss balancing calculation with updated values for comparison • Requirements for the thermal transmittance of the structures remain mainly at the current level • Better windows regarding U-value • Tighter reference value for heat recovery efficiency: proposal 60% • Possibly an updated comparison value for air tightness as well
Electric power of the building	• Peak electric power of a building must be calculated • A certain percentage of peak power should be demand controlled • The rules for calculation require development • The goal is technology and market driven situation, such as demand side management • Objective is to reduce harmful impacts of the buildings' electric power peaks on electricity grid and to reduce emissions of the electricity production
Total energy performance, nZEB E-value	• The total energy performance of a building will be calculated with updated E-value calculation norms • Existing energy carrier factors • Renewable energy produced on-site or nearby is taken into account in reducing the annual use of delivered energy in the building • Renewable energy exported an partly be taken into account in reducing the E-value • The distribution of the energy • The distribution of the energy use and the use of delivered energy (E-value output) must be reported
Other requirements when applying for a building permit	• Indoor temperature analysis (indoor conditions during summer) • SFP value of the ventilation system • Renewable Energy Ratio (RER) value can be calculated (no requirement) • Energy certificate
Other requirements when commissioning	• Air tightness is measured • Energy consumption with actual estimated use is calculated • Energy certificate is updated • Instructions for operation and maintenance • The correspondence between the design and the real operation of the energy consuming systems must be checked

Tab. 4: Proposal for E-values for nZEB according to the FInZEB project used in the case study

Building Type	E-value acc. to D3/2012	Proposal for nZEB-E-value	Change
Small residential buildings (depending on the size)	160..204	120..204	
Apartment buildings	130	116	-11 %
Office buildings	170	90	-47 %
Schools	170	104	-39 %
Day care centres	170	107	-37 %
Retail/commercial buildings	240	143	-40 %
Sports hall	170	115	-32 %
Hotels	240	182	-24 %
Hospitals	450	418	-7 %

The current minimum requirement for apartment buildings E-value in Finland is 130 kWh/(m²a), with FInZEB, the proposal for nZEB E-value is 116 kWh/(m²a).

1.2.6 Norway

In Norway, different high performance building standards, among these a passive house standard, are defined. Tab. 5 provides an overview of the requirements for houses built according to the Norwegian building code of 2010, TEK10 ("Normal house", NH) as well as low-energy houses, passive houses built according to the Norwegian passive house standard NS3700 (2010) and Zero Emission Buildings (ZEB) (Justo Alonso et al., 2013).

Tab. 5: General requirements for the building envelope, the ventilation system as well as heating power and annual heating demands for "normal houses" (TEK10, 2007), low-energy houses and passive houses according to the Norwegian passive house standard NS3700 (2010) and ZEB center definition of nZEB

General requirements	**Normal house**	**Low-energy house**	**Passive house**	**ZEB center**
Bldg. envelope insulation	TEK10	Stricter than TEK10	NS3700	Better than NS 3700
Bldg. envelope – air tightness	TEK10	4 times better than TEK10	8 times better than NH	Better than NS 3700
Balanced vent. – heat recovery efficiency	70–80%	70–80%	80–90%	90%
Heating power demand	**Normal house**	**Low-energy house**	**Passive house**	**ZEB**
Space heating	55 W/m^2	38 W/m^2	22 W/m^2	Max. 18 W/m^2
Space heating – 150 m^2	8.3 kW	5.7 kW	3.3 kW	Max. 2.7 kW
DHW demand – average	500 W	500 W	500 W	500 W
Total heating dem. – 150 m^2	8.8 kW	6.2 kW	3.8 kW	Max. 3.2 kW
Annual heating demand	**Normal house**	**Low-energy house**	**Passive house**	**ZEB**
Space heating (SH)	80 kWh/m^2	58 kWh/m^2	22 kWh/m^2	18 kWh/m^2
DHW heating	25-35 kWh/m^2	25-35 kWh/m^2	25-35 kWh/m^2	25-35 kWh/m^2
Ratio DHW and SH	0.27	0.34	0.58	0.63
Total annual energy demand	110 kWh/m^2	88 kWh/m^2	52 kWh/m^2	48 kWh/m^2

A Low Energy Commission delivered a number of suggestions for increasing energy efficiency of all sectors in Norway in the summer of 2009. The report also included suggestions of future net energy frame values for new buildings as well as for major renovations. The Norwegian Building Code, TEK is proposed to be sharpened every fifth year with stricter constrains. TEK 07 was published in 1 February 2007; this was the first in Norway with an energy performance approach. Afterwards, the TEK 10 has been published in 2010, and the TEK 15 is to be published.The net energy use in the energy frame consists of heating, ventilation, cooling, domestic/ service hot water, as well as tenants' or users' electricity. The net energy includes cooling supplied to air-cooling coils or fan coils in the rooms. The energy requirements proposed for the different standards are summarized in Tab. 6.

Tab. 6: Proposed energy requirements for different TEK Standards (Dokka et al., 2012)

	Energy frame [kWh/(m² & a)]					
Building Code	**TEK07**	**TEK10**	**TEK15 - Passive house**	**TEK20**	**TEK25**	**TEK30**
Residential (detached house)	135	130	80 (Heating: 15)	nearly ZEB	Intermediate	ZEB
Residential (apartment block)	120	115	80 (Heating: 15)			
Non-residential (office)	165	150	75 (Heating: 20, Cooling: 10)			

The floor area used for these calculations is the heated floor area measured inside the external walls. Norway has four different climate zones. Among them, the values given in Tab. 6 are valid for the "standard" climate zone around the capital Oslo, which is in the Southeastern part of the country. The annual energy use of the proposed building is first calculated for the considered climate zone and then for the "standard" climate zone. The results for the standard climate zone must fulfil the required energy frame.

The current energy frames are specified for single-family houses, multi-family houses and eleven types of non-residential buildings.

Regarding the building restrictions in U-value, Tab. 7 shows the requirements for a possible NZEB, so that balance zero can be achieved. The last column shows examples of construction types enabling achieving the U-values described. These values are not standardized but only a proposal of maximum leakages.

Tab. 7: Proposed U-values required for ZEB (Dokka et al., 2012)

		Technical Solution
External walls	U = 0,12 W/m²K	Timber frame wall with 350 mm insulation.
External roof	U = 0,09 W/m²K	Compact roof with approximately 450 mm insulation.
Floor against cellar*	U = 0,11 W/m²K	Floor construction with 350 mm insulation, facing unheated basement.
Windows	U = 0,75 W/m²K	Three layer low energy windows, with insulated frame.
Doors	U = 0,75 W/m²K	Passive house door solutions.
Normalized thermal bridge value	ψ" = 0.03 W/m²K	Detailed thermal bridge design
Air tightness	N50 < 0,3 ach@50 Pa	Continuous vapour and wind barrier, good quality assurance in craft-manship and pressure testing of the building in two stages (when the wind barrier is mounted and when the building is finished).
Heat loss factor cellar	0,78	Taking into account the increased thermal resistance of the unheated basement

As for the HVAC system, requirements for the HVAC components in ZEB are shown in Tab. 8. Again, these values are not standardized but minimum requirements to make it possible to achieve the zero balance. The restrictions for example for heat recovery are enhanced but still no requirements regarding latent recovery are introduced (conversely to USA or Canada where one should always talk about total heat recovery).

Tab. 8: Specifications for HVAC installations in ZEB (Dokka et al., 2012)

	Values	**Technical solution**
Heat recovery	η = 90 %	Rotary wheel heat exchanger. No *moisture recovery is assumed* and the efficiency refers to heat recovery and not total recovery
Specific fan power	SFP = 1.0 kW/(m³/s)	Low pressure air handling unit (AHU) and low pres-sure ducting system.
Installed cooling capacity	Q"cool = 10 W/m²	Low installed capacity, so it can be run as free cooling (just circulation pumps) based on boreholes in bed-rock (vertical system).
Installed heating capacity, alternative 1	Q"heat = 30 W/m²	Installed capacity to preheat supply air, so no room heating is needed.
Installed heating capacity, alternative 2	Q"heat = 15 W/m²	Installed capacity for hydronic radiators.

1.2.7 The Netherlands

In the Netherlands, EPC (energy performance coefficient) is the characteristic number to measure energy efficiency in buildings. To determine the EPC, levels of insulation and installa-tions are taken into account.

The EPC gives an indication of the primary energy demand, but since the actual demand is partly dependent on the occupant behaviour, a difference between the EPC score and actually measured energy consumption should be made.

Over the years, the EPC demand for residential buildings has been tightened from 1.4 at the start in 1995, to 0.6 from January 2011 onwards.

Building companies have agreed with the Dutch government on a further tightening of the requirements in the near future, in order to move towards nZEB in the end of 2018 (governmental buildings) and the end of 2020 (all other buildings).

Tab. 9 shows an overview of EPC requirements for Dutch buildings for both the residential and non-residential sector (Gvozdenovic, 2014).

Tab. 9: Current and future EPC requirements for Dutch buildings (Gvozdenovic, 2014).

	EPC-demands			
	Current policy	**2015**	**2017[(1)(2)]**	**2020**
Residential buildings	0.6	0.4[(1)]		≈0[(1)] all buildings nZEB
Offices	1.1		0.8[(1)]	
Health, clinical	2.6		1.8[(1)]	
Health, non-clinical	1.0		0.9[(1)]	Governmental buildings have to be nZEB by the end of 2018
Educational	1.3		0.7[(1)]	
Retail	2.6		1.7[(1)]	
Sports	1.8		0.9[(1)]	

[(1)]According to the National Plan to promote nearly Zero Energy Buildings in the Netherlands
[(2)]50% decreased primary energy consumption compared to 2007 for governmental buildings

In addition to the EPC requirements, minimum requirements for building components are in place, for the R_c of all building envelope parts this means a value of 5.0 m²K/W after 2015 and the required U-value for windows (including frame) is 1.65 W/(m²K) at the present. These requirements apply to new buildings as well as major renovations of existing buildings.

Tab. 10: Energy labels and corresponding EPC for residential buildings

Label	EPC
A++++	EPC ≤ 0.20
A+++	0.20 < EPC ≤ 0.40
A++	0.40 < EPC ≤ 0.60
A+	0.60 < EPC ≤ 0.80
A	0.80 < EPC ≤ 1.05

Governmental buildings already have to show energy labels, which have to be clearly visible for the public. For residential buildings, the label will be adapted in the course of 2013 according to new legislation with additional labels A+++ and A++++. The dependence of the A-labels to the EPC are shown in Tab. 10.

1.2.8 Sweden

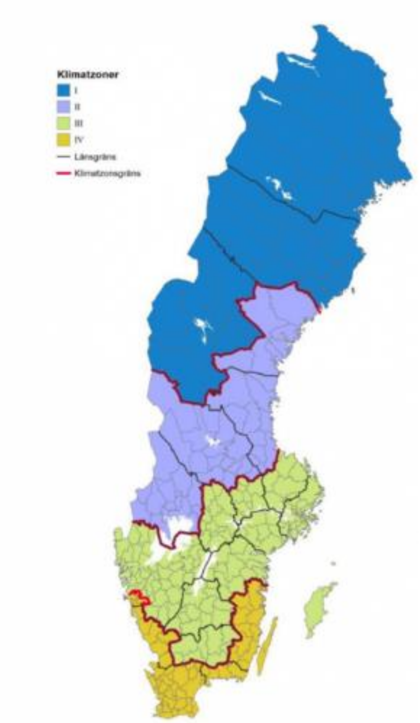


Fig. 13: Climate zones Sweden

In Sweden the discussion on the definition of a nearly Zero Energy Building is still on-going. Some stakeholders in the building sector are of the opinion that the current Swedish building regulation BBR22 is already fulfilling the EPBD recast, while others think that stricter requirements are necessary. Boverket, the National Board of Housing, Building and Planning, have proposed a definition that as in the existing building regulations is based on bought/ delivered energy (and where household and operational electricity is not included). The distinguishing between electrically and non-electrically buildings has, however, been removed by introducing a weighting factor for the electricity used to produce heat or cold. The proposed weighting factor is 2.5. The proposed requirements are also much stricter, especially when electricity is used for heating purposes. This proposal has been circulated for comments and a final proposal for the design of nZEB-requirements in the Swedish building regulations are expected in February 2016.

In 2010 the Swedish energy agency suggested a maximum specific energy consumption (ER 2010:39). The system boundary for nZEB balance in Sweden is decided to be delivered energy excluding household and operational electricity.

Proposed values of the Swedish energy agency are depicted in Tab. 11.

Tab. 11: Proposed maximum specific energy consumption (Swedish Energy Agency 2010)

	Non electrically heated [kWh/(m^2a)]			Electrically heated (including heat pumps) [kWh/(m^2a)]		
	Climatic zone*					
Type of building	I	II	III	I	II	III
Residential**	75	65	55	50	40	30

*) In 2010 there were only three climatic zones in the Swedish building regulations. Climatic zone III consisted then of the present climatic zones III and IV.

**) In 2010 the same requirements applied for single-family and multi-family residential building. In the present BBR 22 the requirements are slightly more stringent for multi-family buildings.

1.2.9 Switzerland

In Switzerland, a current implementation of an nZEB is mainly associated with the MINERGIE-A® label, which is described in more detail in chap. 1.3.3. Moreover, there is also an initiative to promote plus energy buildings in an innovation group, which is building up a data base of realised plus energy buildings (Energiecluster, 2013). Some cantons have introduced an approval method for plus energy buildings and with approved plus energy building, a dedicated subsidy can be granted for plus energy buildings.
In 2015, the MuKEn 2014 (2015) has been published, where it is stated, that from 2020 on, buildings shall supply themselves with heat and with a part of the electricity. The evaluation and the limits resemble the MINERGIE®-A characteristic. There are two requirements to be kept, one limit for the building envelope, and one limit for the overall weighted primary energy. Moreover, from 2020, an on-site electricity production of an installed power of 10 W/m^2_{ERA} shall be required, which will probably be met with a on-site solar PV system. The MuKEn 2014 is currently in the approval phase and shall be updated with the latest European standards, which are expected by 2017 before it will be enacted. Even though the EU-Directives are not binding for Switzerland, the EPBD will be implemented in the same way as in the EU-member countries. Moreover, the current requirements for nZEB are in line with the CEN methodology of the hurdle race described in chap. 1.2.2, since a criterion for the building envelope and on the primary energy exists, and there is also a requirement for renewable production on-site, so all hurdles are defined with national values.
A database of the Plus-energy buildings is available at the website:
https://www.energie-cluster.ch/de/registre/base-de-donnees-batiments-a-energie-positive-9.html

1.3 National and international labels for nearly Zero Energy Buildings

Besides the definition of nZEB different labels referring to the target of nearly zero energy buildings have been introduced.

1.3.1 AT – Klimaaktiv gebaut

klimaaktiv

Klimaaktiv (Climate active) is an initiative started in 2004 by the Austrian Department of the Environment. The initiative is part of the Austrian climate strategy. The goal is a quick and wide market introduction of climate friendly technologies and services.
The label Klimaaktiv can be attained for residential as well as for non-residential buildings. Besides the energy efficiency, high requirements for planning, workmanship, quality of building materials and construction as well as central aspects for comfort and air quality are assessed and rated with this label. Buildings with Klimaaktiv quality guarantees the compliance of high standards at those aspects.

Further information to the Klimaaktiv label can be found on the websites:
https://www.bmlfuw.gv.at/umwelt/klimaschutz/klimapolitik_national/klima-aktiv.html
http://www.klimaaktiv-gebaut.at/

1.3.2 CA – EQuilibrium houses

Equilibrium™ is a national sustainable housing initiative created and led by the Canada Mortgage and Housing Corporation (CMHC). The initiative tries to balance the demands of the housing needs with those of the natural environment.

The EQuilibrium™ initiative strives to bring all together: occupant's health and comfort, energy efficiency, renewable energy production, resource conservation, reduced environmental impact and affordability. Equilibrium™ houses shall significantly reduce a home's energy consumption and environmental impact due to the usage of commercially available and on-site renewable energy systems. To reach the label of an EQuilibrium™ house, there are different indicators given, among these are:

- Energy consumption in buildings
- Neighbourhood use of renewable and waste energy
- Housing Affordability
- Potable water use reduction
- Proximity of daily destinations (job, civic amenities, etc.)
- Pedestrian route connectivity and safety
- Open space proximity and quality
- Natural habitat protected, restored, enhanced or created
- Access to locally produced food
- Watershed protection

Further information can be found on the homepage of the CMHC at
https://www.cmhc-schl.gc.ca/en/inpr/su/eqho/

1.3.3 CH – MINERGIE-A®

MINERGIE-A® has been established in 2011 with the focus on a balance of energy consumption and on-site production on annually basis expressed as primary energy characteristic. In accordance with the other MINERGIE®-labels, the balance boundary has been set to the building technology, i.e. the electricity consumption for plug loads (appliances) is not included in the balance. Thereby, the MINERGIE-A®-label established as a common implementation of a nearly zero energy building in Switzerland. Until May 2014, only residential buildings could be certified, but since then, also non-residential buildings can be certified, which is, however, still in a pilot phase to further develop the label criteria for non-residential applications.

Regarding the labelling criteria mainly three requirements have to be fulfilled

- Requirement for space heating needs:
  90% of building code (like MINERGIE®).
- Characteristic for weighted delivered energy:
  0 kWh/(m^2a).
- Embodied energy:
  Over the whole life-cycle of 60 years, the embodied energy must not exceed a limit of 50 kWh/(m^2a).

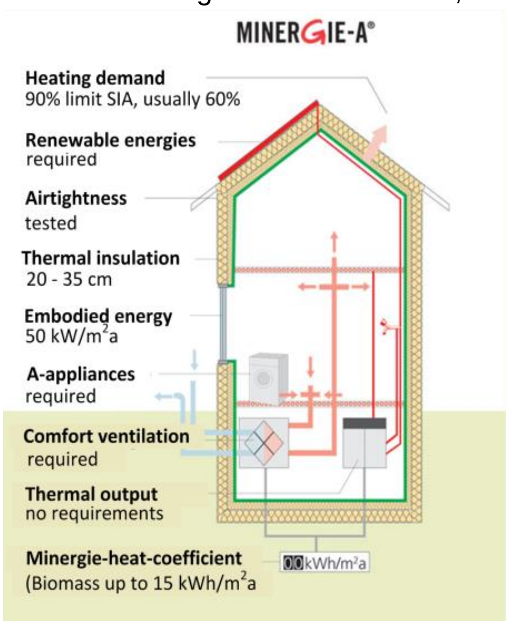


Fig. 14: Characteristics of MINERGIE®-A buildings

Fig. 14 gives an overview of the MINERGIE-A® features.

Fig. 15 gives an overview of the different requirements for the certification according to the different MINERGIE®-labels. The label MINERGIE® as basis defines a good low energy house.

The MINERGIE-P®-label is an implementation of the ulta-low energy house (passive house) approach in Switzerland, where a focus is set on the highly efficient building envelope.
The MINERGIE-A® label sets the focus on the weighted delivered energy and implements the nearly zero energy approach.
The label MINERGIE-Eco® has a focus in the direction of green buildings, i.e. there is a special focus on building materials, comfort and health. The Eco-label can be combined with the –P and –A label
Since the introduction, more than 600 certificates for MINERGIE-A® and MINERGIE-A-Eco® have been assigned (state March 2016). There is also a database, where basic information on the certified buildings are given and a search routine for different features of the buildings. An evaluation of the building technical systems installed in MINERGIE-A® buildings based on the MINERGIE®-Database in given in chap. 1.5. Further information can be found on the websites:

MINERGIE®-labels: https://www.minergie.ch/baustandards.html
Database: http://www.minergie.ch/gebaeudeliste.html

Comparison of MINERGIE labels: Concepts for new buildings

	MINERGIE® Low-energy-buildings	MINERGIE-P® Lowest-energy-buildings	MINERGIE-A® Plus-energy-buildings
MINERGIE-key-figure heat	38 kWh/m^2a (3.8 l of heating oil)	30 kWh/m^2a (3 l of heating oil)	0 kWh/m^2a
Primar requirements (Heating demand)	90% of the legal requirements	60% of the legal requirements	90% of the legal requirements
Tightness of the building envelope	no requirements	Air change below 0.6/h at a pressure difference of 50 Pa	
Outside air supply	Systematic air renewal increases living comfort and reduces energy demand		
Auxiliary energy heat	not considered	considered	
Domestic electricity	no requirements	Best appliances. For office buildings: Lighting according to SIA-standard	high efficiency appliances, high efficiency lighting
Embodied energy	no requirements	no requirements	< 50 kWh/m^2a
Combinations	combinable with ECO		
	–	combinable with MINERGIE-A	combinable with MINERGIE-P
Additional costs	< 10%	< 15%	no requirements
Explanatory notes	MINERGIE is the basic standard. The requirements for the building envelope correspond to those of the cantons with the most stringent specifications	MINERGIE-P is a zero- energy construction presupposes a very good building envelope	MINERGIE-A is very precisely defined form of the zero- or plus-energy-house. The label is only reachable with use of solar energy at the building site.

Fig. 15: Overview of requirements of the different MINERGIE® labels and MINERGIE-A® requirements (translated from www.minergie.ch, 2015)

1.3.4 CH/DE - Sonnenhaus

SONNENHAUS INSTITUT e.V.

The main criteria for a so-called Sonnenhaus (engl. solar house) is a solar thermal fraction of at least 50% for the coverage of the space heating and DHW needs. For this high fraction of solar thermal yield, extensive collector area and storage volume has to be installed. Meanwhile, more than 2000 of these solar houses have been built and the concept is a kind of archetype for the nearly zero energy building using solar thermal energy.
The concept can be extended to a solar self-sufficient house, where a thermal seasonal storage is integrated into the house. Several of these self-sufficient solar houses have been realised by the Swiss solar company Jenni Energietechnik in Oberburg.

The detailed criteria for a Solar house certificate are for

- New Buildings:
  - Solar coverage: The gross energy demand for space heating and DHW has to be covered by at least 50% solar radiation energy (thermal collectors or PV generators).
  - Primary energy demand: Specific primary energy demand of max. 15 kWh/(m^{2}a). With a fossil auxiliary heating, the demand can be max. 30 kWh/(m^{2}a), to get this value, usually a solar coverage of over 50% is necessary.
  - Insulation standard: The specific heat transmission losses have to be by 15% lower than the one of a reference building defined in the German building code EnEV.
- Refurbishment:
  - Solar coverage: Same as for new buildings.
  - Insulation standard: The specific heat transmission loss shall not be higher than 15% compared to the one of an EnEV reference building.
  - Primary energy: The specific primary energy demand has to be lower or equal than the one of an EnEV reference building.
- Solar house plus:
  - Solar coverage, primary energy demand according to EnEV and insulation standard are the same criteria as for normal solar houses.
  - The annual primary energy demand with calculation of household electricity has to be negative.
- Solar house self-sufficient
  - Solar house self-sufficient: Criteria of solar house plus and additionally a self-sufficiency degree of at least 50%.
  - Solar house plus autarkic: Additional to solar house autarkic, the annual primary energy demand criteria has to fulfil the requirement of the solar house plus.

Some field monitorings have been accomplished in built solar houses. Fig. 16 shows the measurements of a solar house built in Munich with a floor area of 549.1 m^2. The shown measurements are of the year of 2012 and a good self-consumption can be seen.

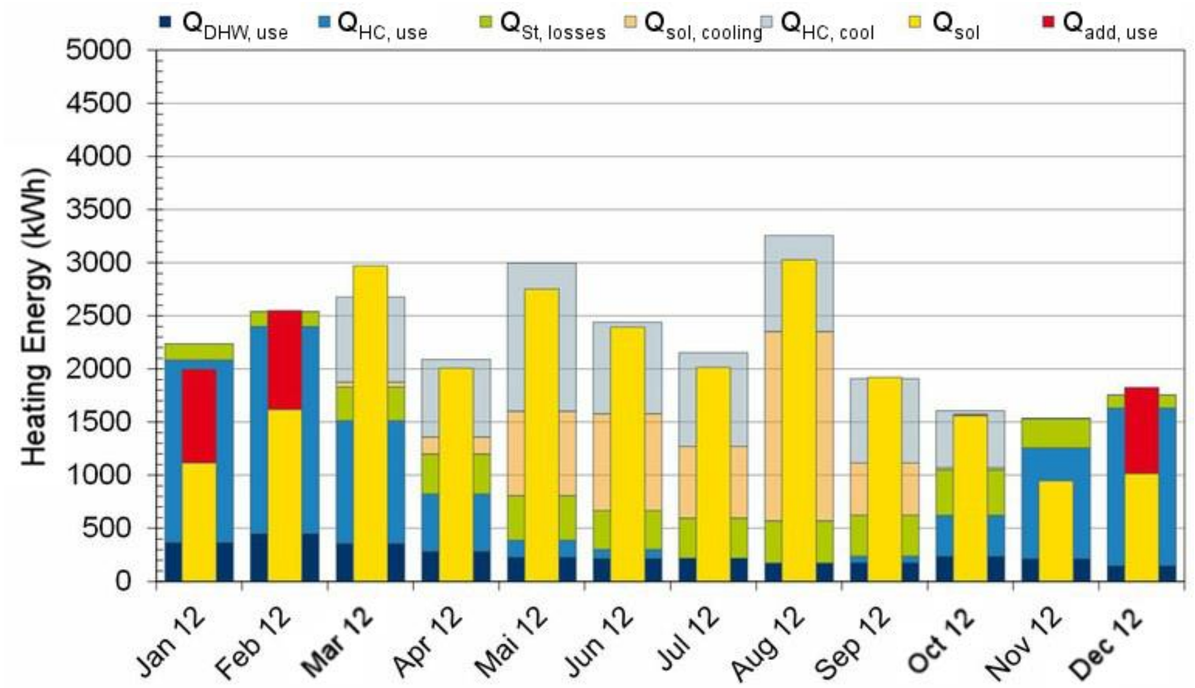


Fig. 16: Field test results of Solar House in Munich

Homepage: http://www.sonnenhaus-institut.de/
Criteria: http://www.sonnenhaus-institut.de/wp-content/uploads/1-Sonnenhauskriterien-2014.pdf (in German)
Database: http://www.sonnenhaus-institut.de/das-sonnenhaus/heizen-mit-sonne-suche.html

1.3.5 DE – Passive House

The passive house is the archetype of a building with a high performance building envelope. The main criteria to comply with the passive house standard is thus a very efficient building envelope, which is expressed in the characteristic space heating need lower the 15 kWh/(m²a). Moreover, an air-tightness of the building envelope $n_{50} = 0.6\ h^{-1}$ has to be approved by measurements (blower door testing), and the overall primary energy demand must not exceed 120 kWh/(m²a). These requirements refer to a so-called classic passive house standard without renewable electricity production on-site.

Recently, two further categories of passive house certification have been introduced, denoted as passive house plus and passive house premium, where also requirements to an on-site electricity production is set as depicted in Fig. 17.

Regarding the accounting of the on-site electricity production, there is the particularity, that the electricity, which is produced on-site, but not consumed instantaneously and exported to the grid, has a different weighting factor than instantaneously consumed on-site electricity. By this weighting factor it is taken into account that the grid is used a virtual storage, and thus, in the weighting factor, a storage efficiency is considered, which diminishes the value of the electricity compared to electricity used directly on-site.

Further information about the criteria can be found on the passive house homepage.

Homepage: http://www.passiv.de/

Passipedia: http://passipedia.org/basics

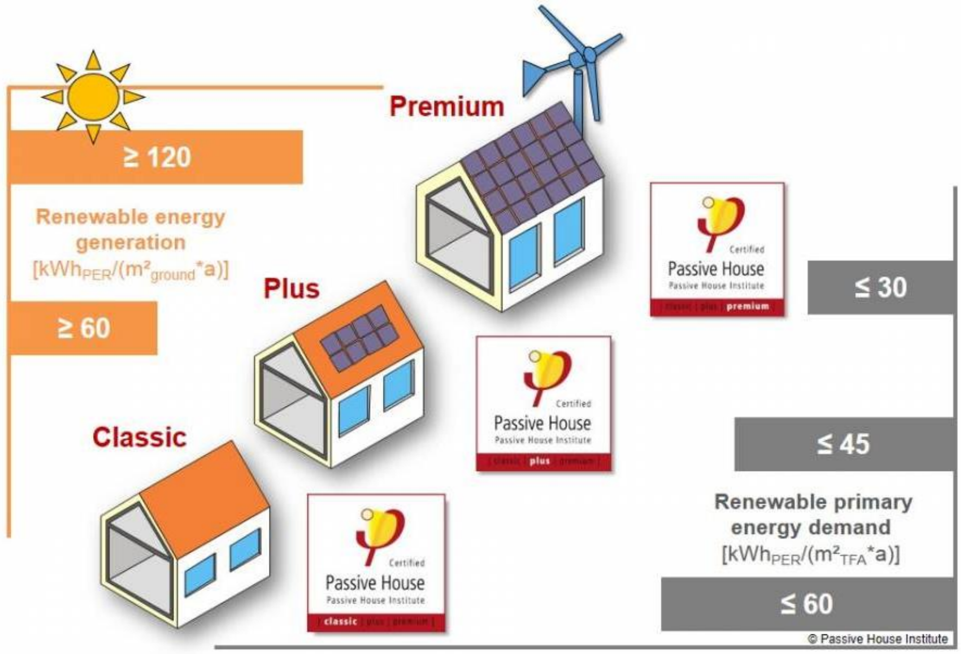


Fig. 17: Requirements for different types of passive houses (source: Passivhaus Institute)

1.3.6 DE – ActivPlus

ActivPlus e.V. is a non-profit initiative of planners and scientists with the goal to develop a future standard for buildings and districts and establish the standard in the building sector and real estate industry.

The ActivPlus building standard aims at a decentralized, consumer-oriented supply of buildings and districts with renewable energy.

Therefore, especially the networking and usage of synergies including E-mobility shall be promoted. In parallel, aspects of the living quality such as user comfort, optimised and flexible room usability, healthy living, well-being, indoor environment and daylight, transparent depiction of the consumption and autonomy of the use shall be considered and promoted. The ActivPlus initiative is linked the Danish Activehouse Alliance, which itself is also linked to initiatives in other European countries, e.g. the Activehouse NL initiative in the Netherlands.

Homepage: http://www.aktivplusev.de/wir-ueber-uns/arbeitsgruppen/

1.3.7 DE - Effizienzhaus plus

The Effizienzhaus plus project is an idea of a very energy efficient building, which also shall produce more energy than it consumes on an annual basis. By definition, the Effizienzhaus Plus level is reached, if the building has a negative annual primary energy demand as well as a negative annual delivered energy demand.

The other requirements are to be fulfilled according to the german building code EnEV. Note, that the Effizienzhaus plus is not an official certification, yet. This is just a program of the German government to test the performance of these buildings in different locations.

In order to evaluate the concept an accompanying field monitoring at sites all over Germany has been performed.

For the field monitoring the following boundary conditions have been set:

Physical Boundary: The building footprint is set as physical boundary. In case of more than one building on the estate, the renewable energy generated on-site is accounted to the energy reference area of the buildings.

Other requirements: Best labelled household appliances have to be used. Also, the ratio of self-consumed and self-generated renewable energy inside the physical boundary is to be evaluated.

Different results of the field monitoring are given in Fig. 18.

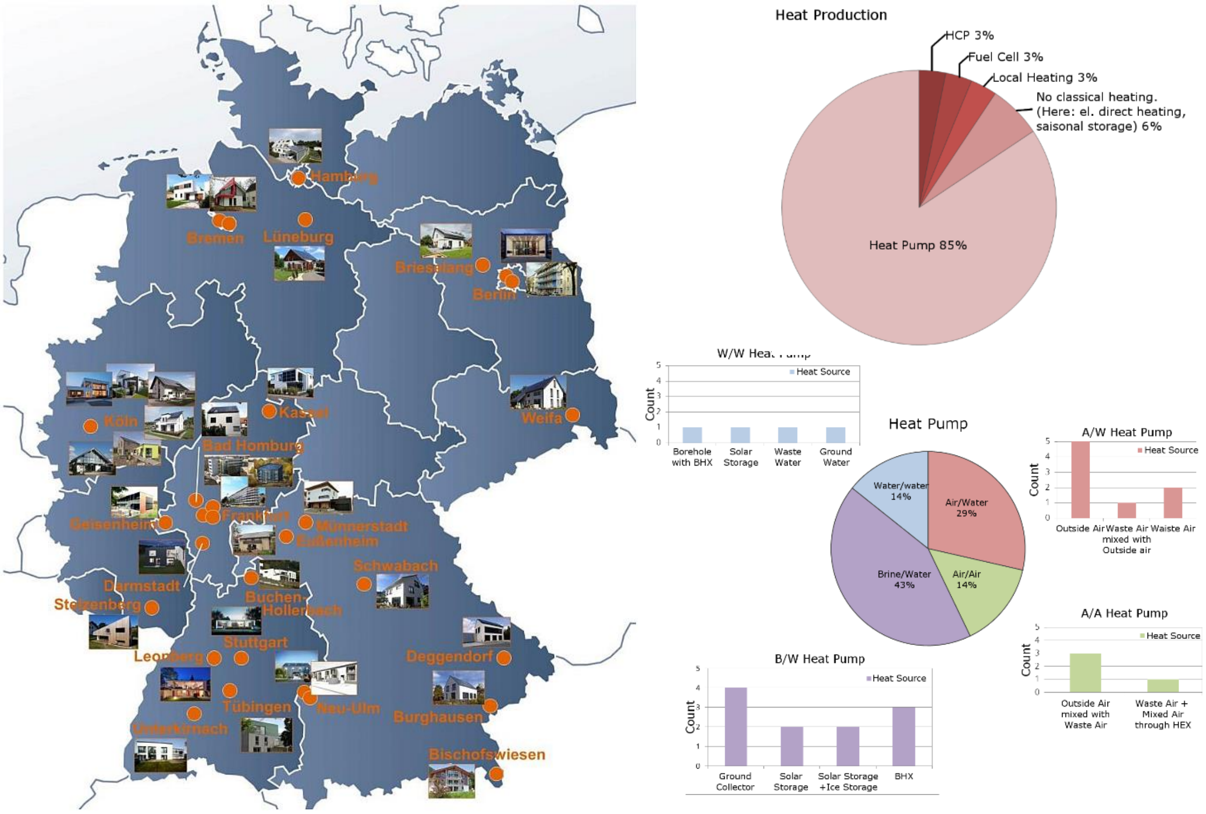


Fig. 18: Building sites (left) and applied system technologies (upper right) and heat pump concepts (lower right) in the Effizienzhaus Plus building accompanying research (source: Erhorn et al., 2015)

Further information on the field monitored buildings and field test results can be found on the website:
http://www.forschungsinitiative.de/effizienzhaus-plus/modellvorhaben/netzwerk/

1.3.8 DK - Active House Alliance

The Active House Alliance is an association of industrial companies, experts and institutions with a special interest in defining "an Active House: a building that combines energy efficiency with specific attention to user comfort, indoor climate and the environment".

The second version of the Active House specifications has a scope on residential buildings. Besides the key principles, the technical specification can also be used as a tool for designing nearly zero energy buildings (Eriksen et al., 2013). Fig. 19 left shows the three basic evaluation criteria comfort, energy and environment, which can be further divided as depicted in the "active house radar" in Fig. 19 left.

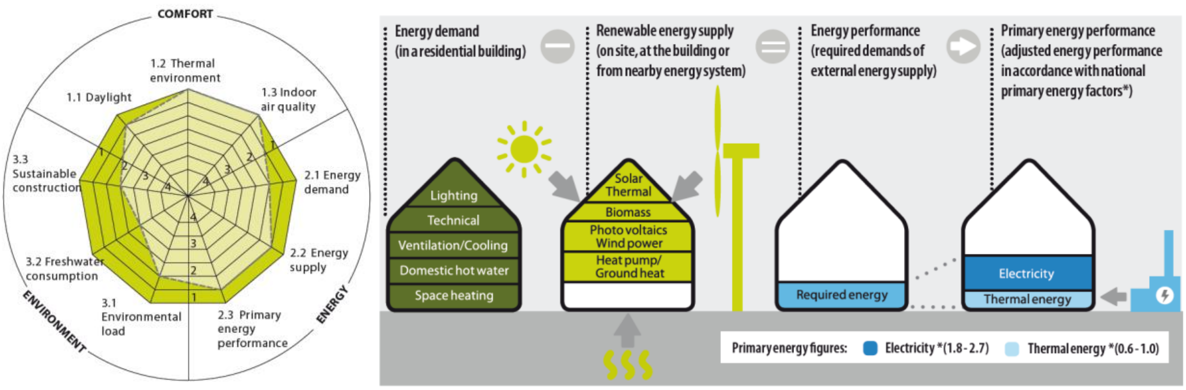


Fig. 19: Active house radar (left) and energy principles for active houses (source: Eriksen et al., 2013)

Comfort aspects to be evaluated are the daylight situation, the thermal environment and the indoor air quality. The energy criterion is further subdivided into energy demand, energy supply and primary energy performance. The environmental sub criteria refer to sustainability of the construction, the freshwater consumption and the environmental load.

Fig. 19 right summarises the design principles of an active house, which are the same as for a nearly zero energy building, combining a good building envelope quality with reduced loads of the building and a good comfort by use of renewable energy on-site.

The used primary energy factors depend on national definitions and are in the range of 1.8 - 2.7 for electricity and 0.6 - 1 for thermal energy. As shown in the figure, appliances are not included in the balance boundary.

More information can be found on the website:
http://www.activehouse.info

1.3.9 US – DOE Zero Energy Ready Home (Energy)

"A DOE Zero Energy Ready Home is a high performance home which is so energy-efficient, that a renewable energy system can offset all or most of its annual energy consumption."

The DOE Zero Energy Ready Home is a new and compelling way to recognize builders for their leadership in increasing energy efficiency, improving indoor air quality, and making homes zero energy ready.

The program is built upon the comprehensive building science requirements of ENERGY STAR® for Homes Version 3, along with proven Building America innovations and best practices.

DOE Zero Energy Ready Homes are verified by a qualified third-party and are at least 40%-50% more energy efficient than a typical new home. This generally corresponds to a Home Energy Rating System (HERS) Index Score in the low- to mid-50s, depending on the size of the home and region in which it is built. DOE Zero Energy Ready Homes must meet all DOE Zero Energy Ready Home National Program Requirements (Rev.05) for homes permitted on or after 8/11/2015. Homes permitted prior to this time have the option of using the Rev.04 specifications. They must:

- Comply with ENERGY STAR for Homes and the Inspection Checklists for
  - Thermal Enclosure
  - HVAC Quality Installation (Contractor and HERS Rater)
  - Water Management
  - The target home/size adjustment factor used by ENERGY STAR
- Feature energy-efficient appliances and fixtures that are ENERGY STAR qualified.
- Use high-performance windows that meet ENERGY STAR specifications. Note that the ENERGY STAR window criteria have been updated and that DOE Zero Energy Ready Home has established an extended phase-in period for the new window specs (see End Note #12 of the Rev.05 specs).

Further information can be found on the website:

http://energy.gov/eere/buildings/guidelines-participating-doe-zero-energy-ready-home

1.4 Evaluation of building technologies in international P&D projects

In the frame of the joint IEA ECBCS Annex 52/SHC Task 40 NZEB have been gathered in a data base and selected buildings have been documented in Voss et al. (2012). Fig. 20 gives a summary on installed building systems in these documented buildings. Unlike MINERGIE-A® these buildings also comprise non-residential buildings.

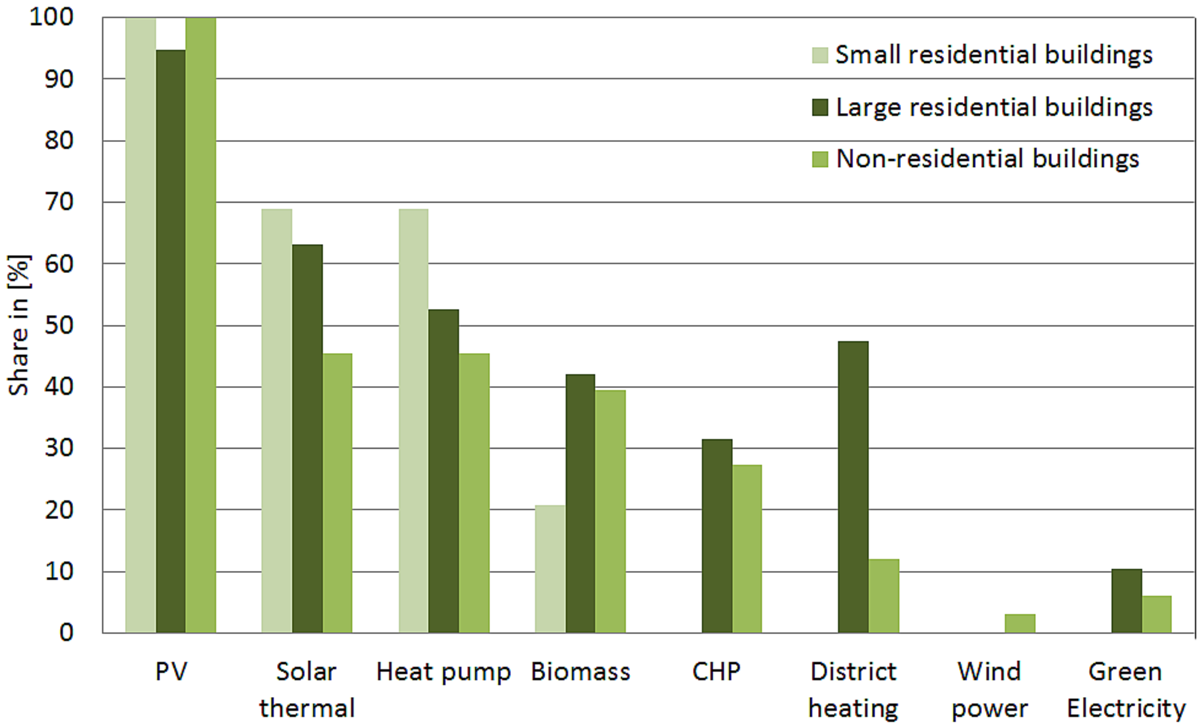


Fig. 20: System technology installed in different NZEBs documented in Voss (2012)

By this evaluation it is confirmed that solar PV is the dominating technology in NZEB. In smaller residential buildings, heat pumps and solar thermal systems with a share of 70% and some wood systems with about 20% represent the technology variants.

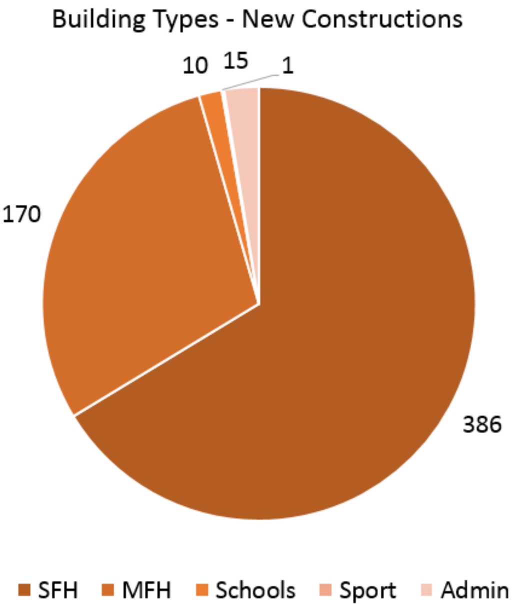
Solar thermal systems, though, are mostly applied to the DHW operation, either in combination with a heat pump or a wood system, while heat pumps can be the only heating system. In larger residential buildings, also CHP systems and connection to district heating grids become more important and biomass systems increase to 40%, while solar thermal systems and heat pump range between 50% and 60%. For non-residential use the solar thermal collectors and heat pump shares further decrease to about 40% to almost the same values as biomass. As in larger residential buildings, CHP and district heating are more important.

Wind and the purchase of green electricity produced offsite only reach shares below 10% in all building uses.

1.5 Evaluation of building technologies in MINERGIE-A®-Buildings

1.5.1 Certified MINERGIE-A®-Buildings

The available data of the certified buildings according to the MINERGIE-A® label allow an overview of the building technologies installed presently in Swiss nZEB. Details on the MINERGIE-A® label and the balancing are given in chap. 1.3.3. As depicted in Fig. 21 left most of the certified buildings are single-family houses. This may be due to the fact, that it is easier to reach the required balance with a single-family house, since the available building envelope surface for PV per m^2_{ERA} is generally larger than in multi-family buildings.
Also noteworthy is the ratio between new built and refurbished buildings with MINERGIE-A® label, as seen by the comparison of Fig. 21 left and right. The majority of certified buildings are new built, while retrofitted buildings only make-up a small share up to now.



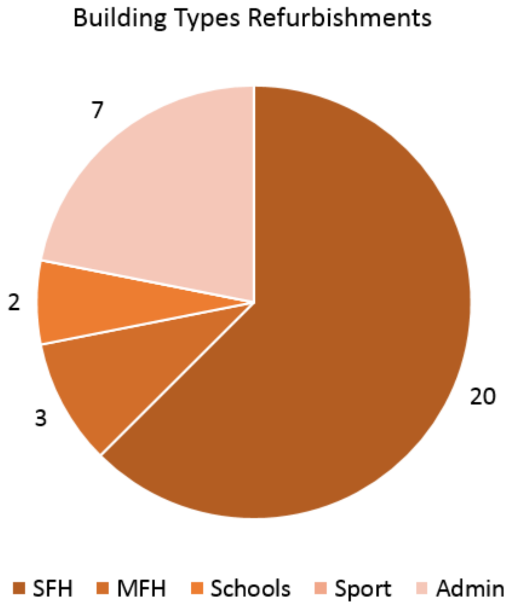


Fig. 21: Building use for MINERGIE-A® in new constructions (left) and retrofitting (right)

1.5.2 Energy demand

The analysis of 392 MINERGIE-A® buildings shows a mean energy value of 43.9 kWh/(m²·a) for heating, DHW, ventilation, air-conditioning and auxiliary electricity for the building technology.
In Fig. 22 the energy demand is plotted vs. the surplus of generated energy for a net zero energy balance. The average surplus is about 40% regarding the balance, i.e. the PV systems are often over-dimensioned to fulfil the MINERGIE-A® balance, in some case up to 300%.
In Tab. 12, mean values for the design of the installed PV-generators are depicted. The mean installed peak power varies for the buildings.
The largest specific solar PV installations related to the energy reference area ERA are found in single family houses, which is, however, also the largest sample of the certified houses. For the sport use, for instance, the sample is just one building, since the certification was not possible before May 2014. The installed solar PV area has been recalculated by the installed kWp with a size of 7 m².

Tab. 12: Analysed data for PV-generators

	SFH	MFH	Sport	Administration
Installed peak power [kW]	5.6 ± 3.8	28.8 ± 25.9	77.5	41.0 ± 19.6
Installed peak power/Energy reference area [kW/m^2_{ERA}]	25.9 ± 13.6	18.1 ± 8.4	44.0	18.8 ± 16.6
Installed PV area*/Energy reference area [m^2_{PV}/m^2_{ERA}]	0.2 ± 0.1	0.1 ± 0.05	0.3	0.1 ± 0.09

* Since no data for installed PV area was available, a mean value of 7 m² per kW_p has been assumed to calculate the installed PV areas.

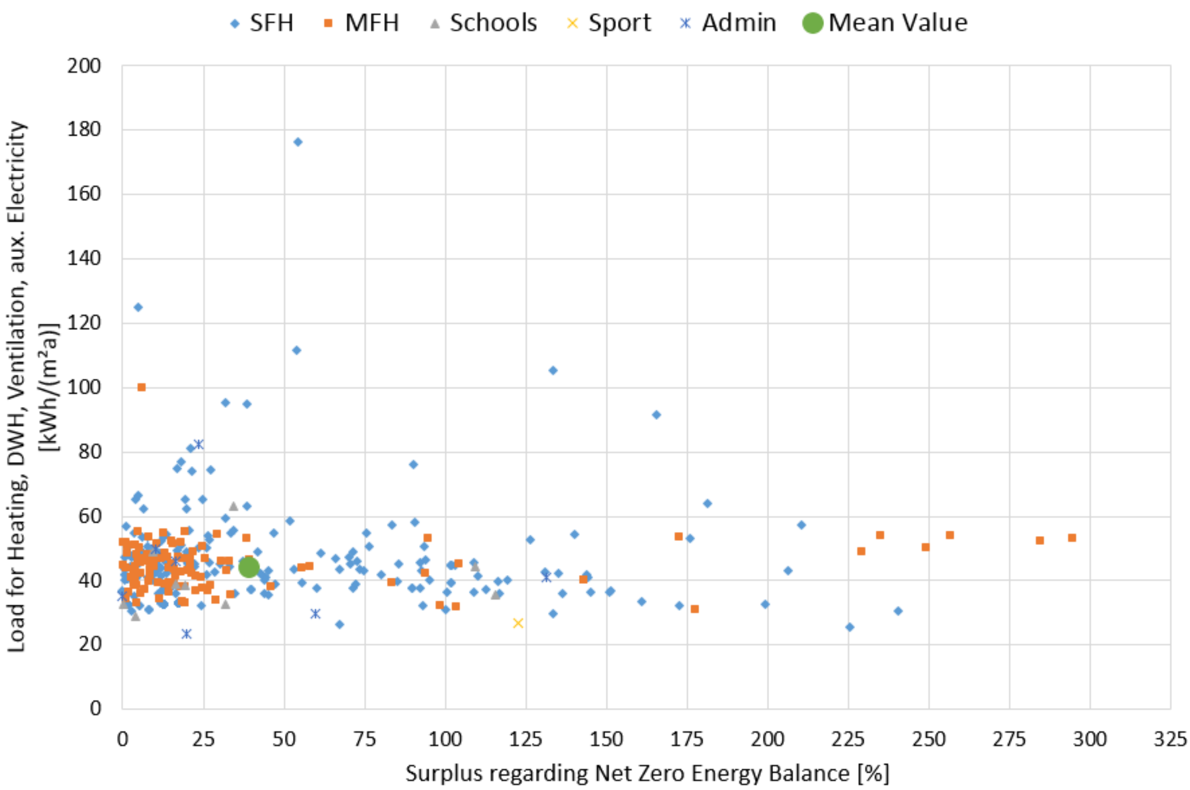


Fig. 22: Surplus regarding net zero energy balance according to the MINERGIE-A® boundaries

1.5.3 Heat generation for space heating and DHW

To reach the MINERGIE-A® standard, different systems configurations and generator types for space heating and DHW production are possible. The most common system applied in MINERGIE-A® is a heat pump with PV-generation on the roof to cover the electricity generation to reach the balance, also denoted as all electric building, since only electricity is used as delivered energy. In the investigated systems often multivalent systems with several generator are applied for space heating and DHW production, since for instance a solar thermal systems is often only applied for DHW production and normally not designed to cover the whole DHW demand.

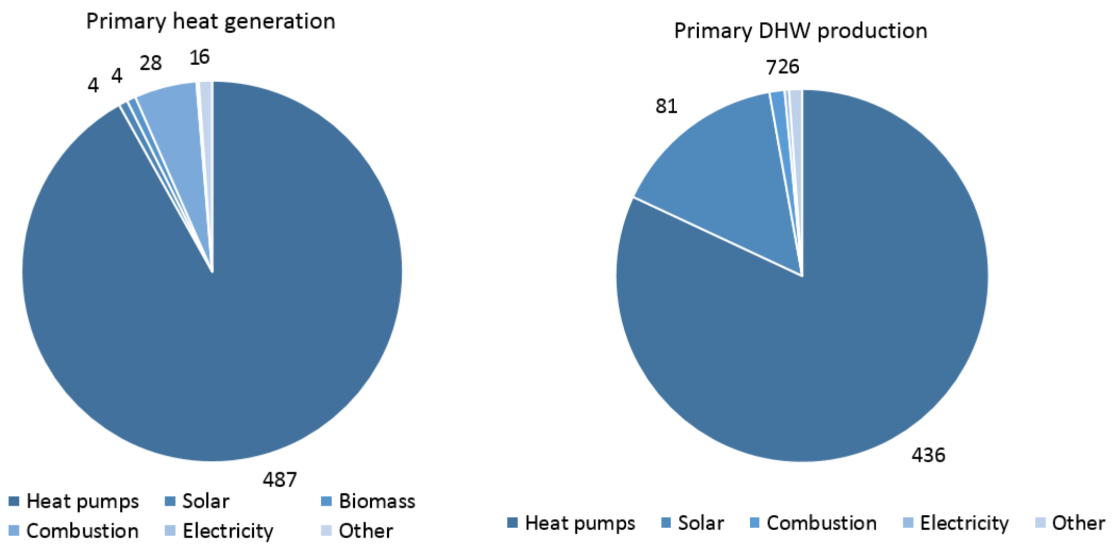


Fig. 23: Primary heat generator for space heating (left) and DHW production (right)

In Fig. 23, only the primary generator with the largest degree of coverage for the respective application is depicted.

As seen in the figure, heat pumps are the system most frequently used for space heating operation as well as in DHW production. More than 90% of the MINERGIE-A® certified buildings are equipped with heat pumps for the space heating operation, and in about 80% of the buildings a heat pump is also used for DHW production.
This means that heat pumps have already become a standard system for residential nZEB, since the MINERGIE-A® certification is dominated by residential application.
Regarding the heat pump type and heat sources the majority of the systems are ground-coupled heat pumps. Most of them use vertical borehole heat exchanger. This is different from the market in Switzerland, which is dominated by 64% air-source heat pumps. Also the fraction of water-source heat pumps is relatively large compared to the Swiss market, where only 3% of the installation use water as heat source. The heat sources do not change much for the DHW operation as seen in Fig. 24 right, since typically the same heat pump is used for space heating and DHW production.

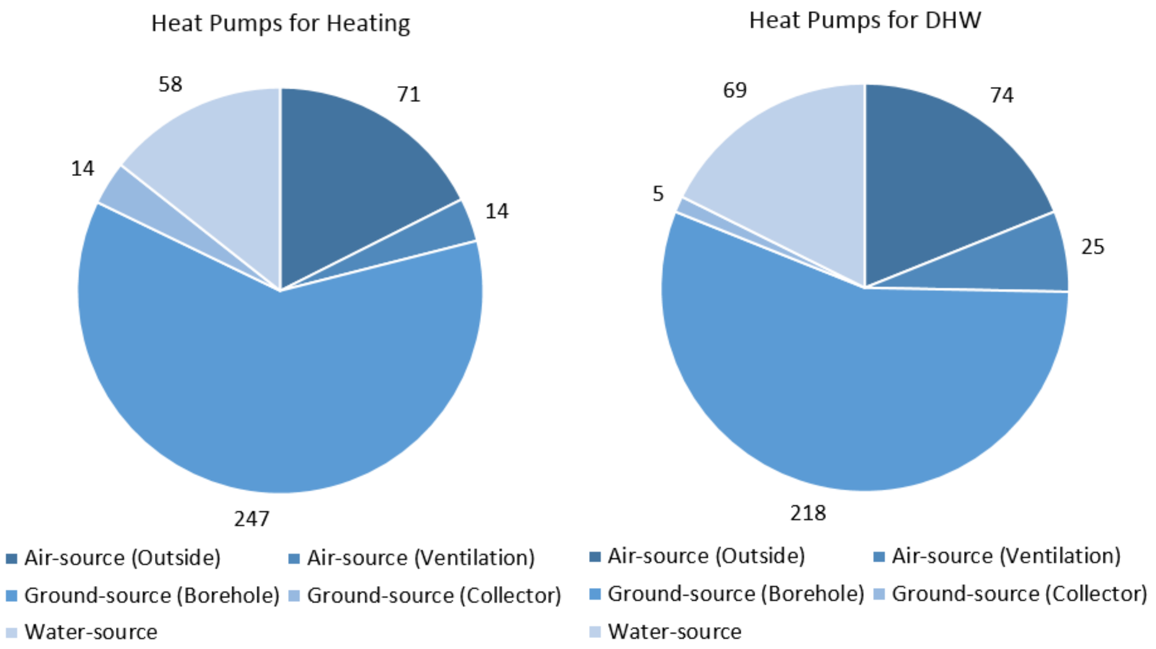


Fig. 24: Heat sources of the heat pump for space heating (left) and DHW production (right)

1.5.4 Seasonal Performance

Based on the design data for the MINERGIE-A® certification it was possible to evaluate the calculated seasonal performance factor of the different heat pump types. If no detailed values are available in the design process, default values can be set for the certification. Heat pumps with the default value have not been taken into account for the evaluation. For this evaluation, they have been gathered into five groups:

- Vertical borehole heat exchanger
- Ventilation air-source (exhaust air)
- Horizontal ground collector
- Water-source
- Outdoor air-source

As already stated above, the biggest group are the ground-source heat pumps with borehole heat exchanger. In total 313 heat pumps with borehole could be taken into account for the evaluation, as depicted in Fig. 25. Maximum SPF values are higher than 6. The borehole heat pumps have an average of 4.20, which is slightly below the average of the water heat pumps and the horizontal collectors. Lower values go down to an SPF slightly above 2, which is significantly below the default value of 3.1 for space heating and 2.7 for DHW, so it could not be clarified, why lower values have been stated for the certification.

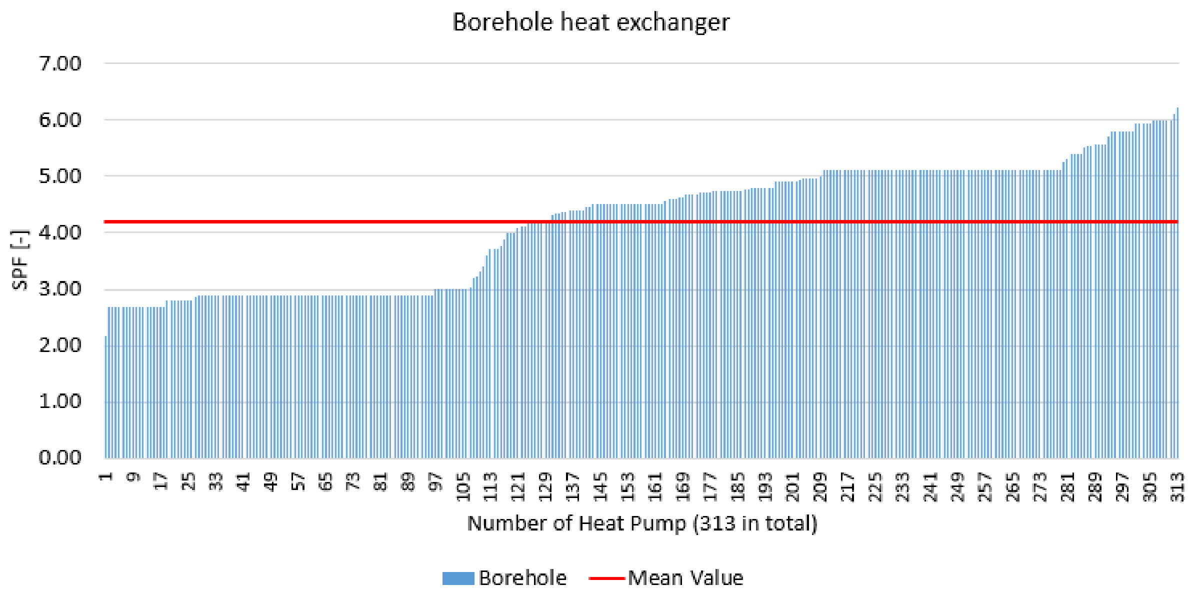


Fig. 25: SPF of the evaluated ground-source heat pumps with borehole heat exchanger

In Fig. 26 the ground source heat pumps with a horizontal ground collector are depicted. They reach the highest average SPF with 4.55, but only 14 heat pumps have horizontal collectors, so the sample is very low compared to the vertical borehole heat exchangers and the values as described above the average of the borehole heat pumps is distorted by the lower values, which could not been explained.

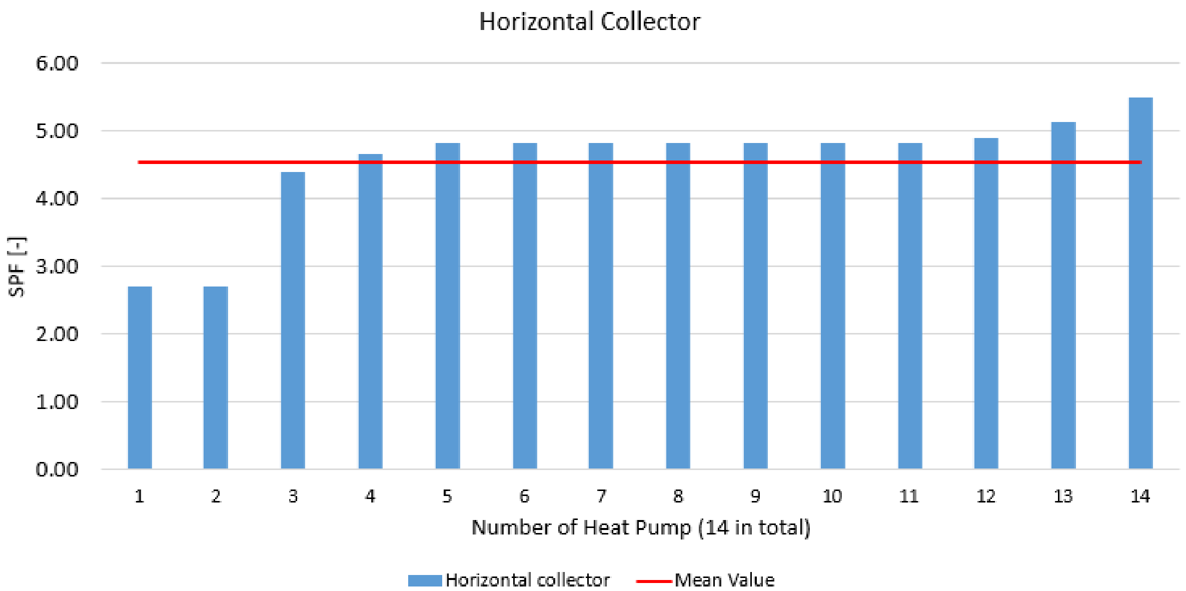


Fig. 26: SPF of the evaluated ground-source heat pumps with horizontal collector

Outdoor air-source heat pumps have an average SPF of 3.26 out of a total of 218 evaluated heat pumps illustrated in Fig. 27, which is a quite high average values for the heat source outdoor air.

However, the top values are unrealistic high up to 5, which could not be explained by the available data, so also the average values may be augmented by these values. Maybe in these cases some kind of preheating is applied. Lowest values are slightly higher than 2 which is below the default values of 2.3 each for the space heating and DHW operation.

The 38 evaluated exhaust air heat pumps are shown in Fig. 28. The SPF of the heat source exhaust air are in the range of 2.5 to 4, which is a realistic range. The average is with a values of 3 is also realistic and above the defaults values of 2.3 – 2.7 depending on the application.

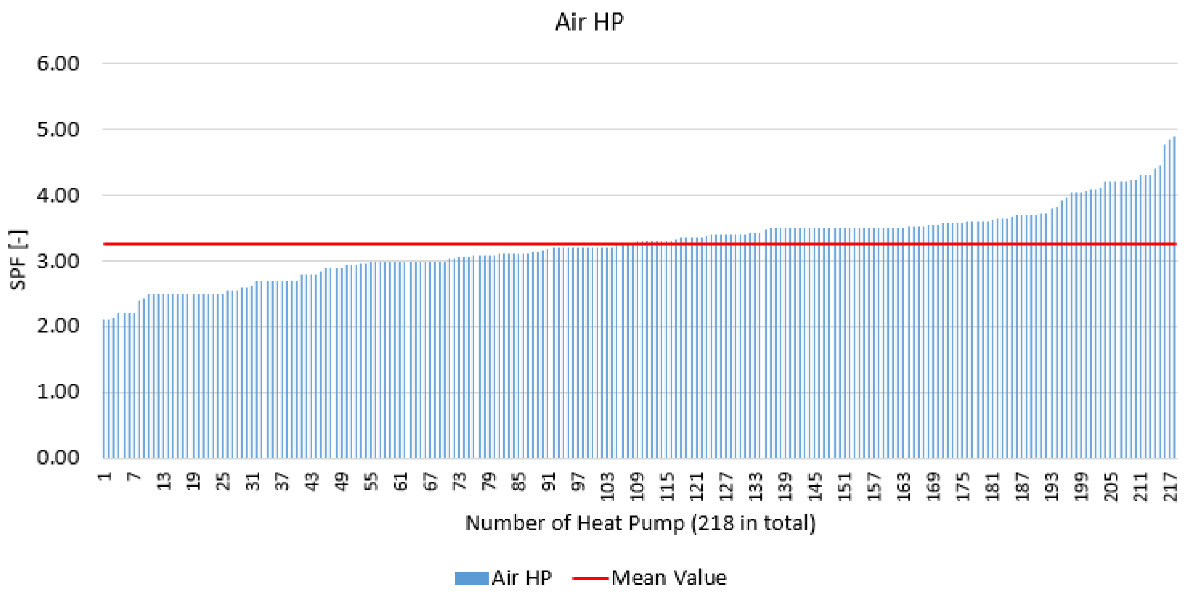


Fig. 27: Seasonal performance factor of the evaluated air-source heat pumps (outdoor air)

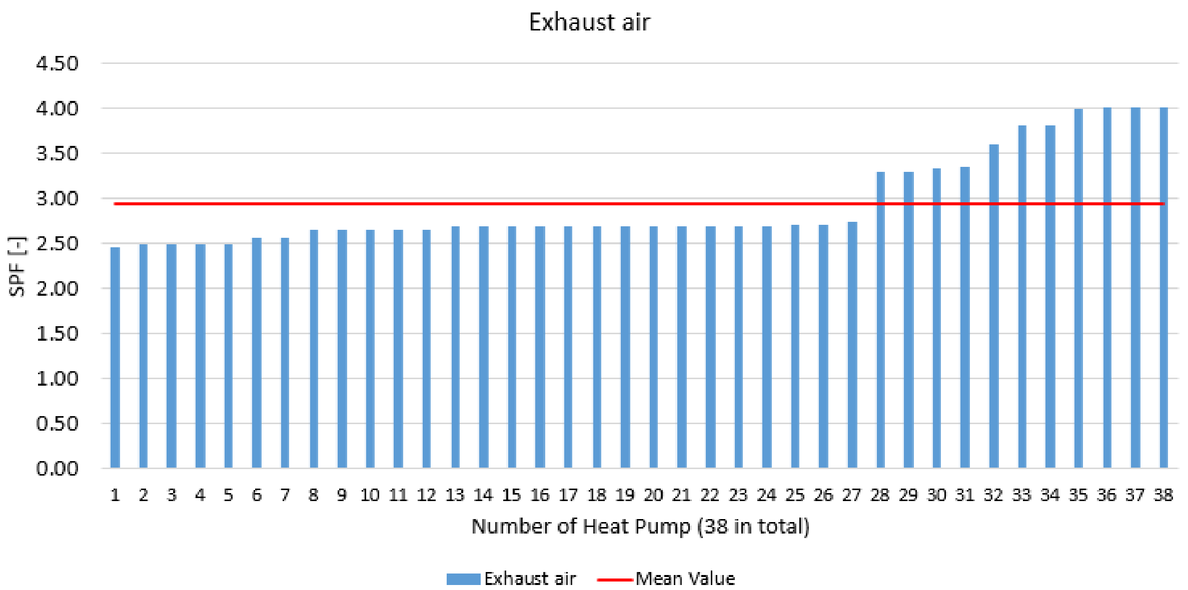


Fig. 28: SPF of the evaluated ventilation air-source heat pumps (exhaust air)

The water-source heat pumps have the second highest average SPF with 4.33 out of a total of 67 evaluated heat pumps which is shown in Fig. 29.
The highest value reaches and SPF of 7, but there are only few SPF above 5, so on average, the performance of the water-source heat pumps is rather low, since source temperature have normally the best conditions for ground water. On the other hand, it is not stated, if the water source is ground water or surface water, thus, source temperatures for the different systems may vary depending on the water source.

Concluding the heat pumps show quite of range of different SPF values used for the certification.
It has to emphasized again that the values are not measured values, but calculated values based on COP measurements taken from the data base of MINERGIE-A® certified buildings.

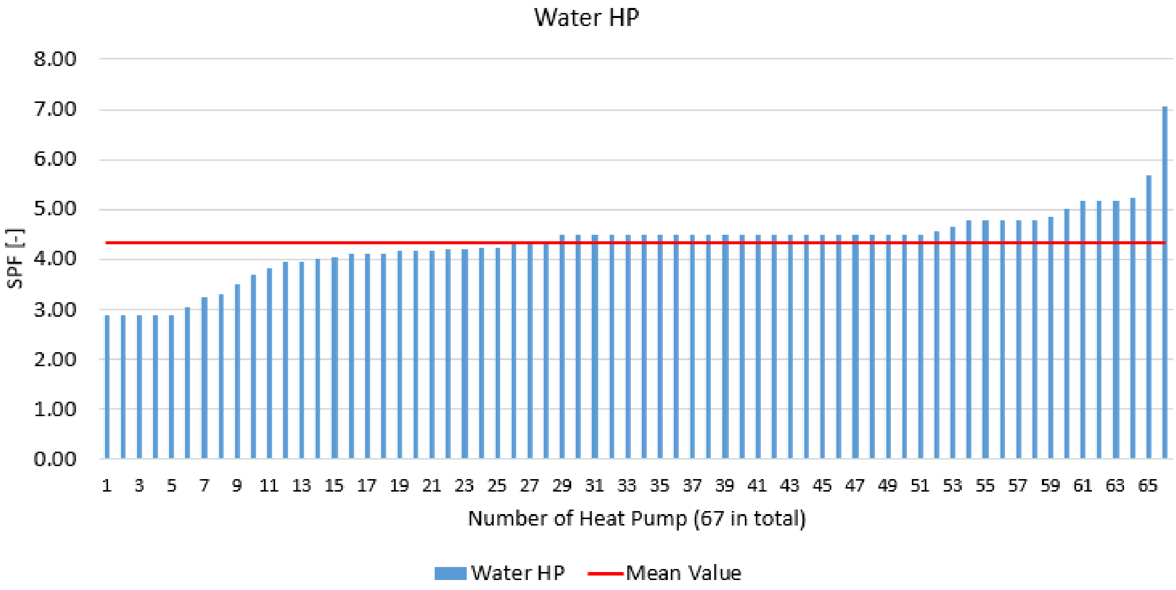


Fig. 29: Seasonal performance factor of the evaluated water-source heat pumps

2 IEA HPT Annex 40 project and national contributions

The IEA HPT Annex 40 entitled “Heat Pump concepts for nearly Zero Energy Buildings” in the Heat Pump Technologies (HPT) Implementing Agreement of the International Energy Agency (IEA) is carried out cost- and task-shared with the nine participating countries Canada (CA), Switzerland (CH), Germany (DE), Finland (FI), Japan (JP), the Netherlands (NL), Norway (NO), Sweden (SE) and the United States of America (US). The project management (Operation Agent) is accomplished by the Institute of Energy Technologies (IET) of the University of Applied Sciences Rapperswil (HSR) in charge of the Swiss Federal Office of Energy (SFOE).
The main objectives of IEA HPT Annex 40 are

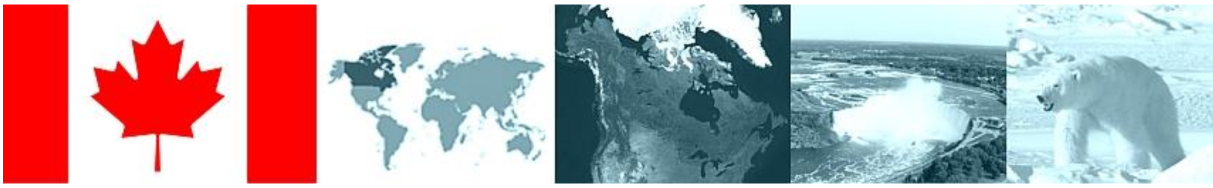
- System assessment and improvement
  - Assessment of applied concepts with heat pumps in nZEB
  - Case studies of heat pump application in nZEB
  - Development of tools for the design of well-performing heat pumps in nZEB
- Technology development
  - Development of heat pumps for the application in nZEB
  - Evaluation of integration options, e.g. with solar components
  - Testing of new technologies for nZEB application
- Field monitoring and integration of nZEB into the energy system
  - Evaluation of real heat pump performance in nZEB by field monitoring
  - Evaluation of nearly zero energy balance
  - Options for load shifting and demand response

Tab. 13 gives an overview on the focus of the national contributions of the participating countries in IEA HPT Annex 40.

Tab. 13 Overview of national contributions to IEA HPT Annex 40

Country	Contribution to IEA HPT Annex 40
CA	Combination of heat pumps with other heat generators (solar technologies, CHP), Case studies for different building types and –uses, technology development: solar assisted heat pump system with ice-slurry storage
CH	Integration of solar absorber and heat pump for multifunctional operation in offices, system comparison of heating systems for MINERGIE-A®, field monitoring MINERGIE-A® with electro-mobility, evaluation of load management options
DE	System integration and field monitoring of low energy office buildings, evaluation of load management options and grid-supportive operation
FI	Development of energy- and cost-efficient heat pump systems for nZEB in Finland by simulation of case studies for single- and multi-family houses
JP	Case studies for nZEB office buildings with heat pumps for Japanese and European load conditions, documentation of monitoring, technology developments for nZEB
NL	Field monitoring „Energy leap“ for market implementation of nZEB, evaluation of user comfort and cost-effectiveness as well as retrofit concepts to nZEB
NO	Design software for heat pumps with natural refrigerants in nZEB-office buildings, documentation of field monitoring results of nZEB buildings in Norway
SE	System comparison of nZEB for single- and multi-family houses with Swedish weather conditions, prototype developments of adapted heat pump solutions for nZEB
US	Field monitoring of integrated and multifunctional heat pumps (IHP), Commissioning of NZEB test facility (Net Zero Energy Residential Testing Facility – NZERTF) for testing of NZEB-technology under reproducible conditions, software development for comfort evaluation of low-ex heating and cooling systems

2.1 Canada



National Team leader	
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Involved national institutions	
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	Solar Building Research Network, http://www.solarbuildings.ca

Project overview

First, the Canadian project will provide an overview of heating and cooling concepts for new nearly Zero Energy Houses integrating heat pumps, already in-field implemented and tested, or currently in a development and/or design process (Task 1).
Second, the most promising concepts capable to be successfully implemented in the future in the Canadian nearly Zero Energy Houses, will be analysed, optimised and improved at the level of the global system integration with renewable energies (geothermal, ambient air, solar), house waste heat recovery, and overall control sequences (Task 2). A techno-economic analysis of the integration of HPs and renewable systems to houses of three construction vintages will be presented, including

- A typical existing home (1980s)
- A typical newly constructed home
- A highly efficient low energy home

Some analyses of heat pumps integrated with renewable systems will be presented as well.
Third, a laboratory- and in-field-scale heating and cooling system for nearly Zero Energy Houses will be presented. It consists of a solar assisted HP system equipped with a cold storage for space heating, space cooling and domestic hot water production. The main thermodynamic parameters will be determined and the simultaneous performance factors in both heating and cooling modes will be evaluated (Task 3).
Finally, a low-energy house built in eastern Canada (province of Québec) within the Equilibrium Housing Pilot Demonstration Project is described. This project is a national initiative led by Canada Mortgage and Housing Corporation (CMHC) that brought the private and public sectors together to develop homes producing as much energy as they consume on an annual basis. Monitoring results, including energy performances of the house and heat recovery devices, as well as a long-term (i.e. over four years) design validation of the two ground-source heat exchanger operating in the Canadian cold climate are also presented.

Results and contributions to Annex 40

- Intermediate and final reports including optimised design and system layouts
- Modelling and simulation results
- Laboratory and in-field experimental parameters and seasonal energy performances
- Best practice cases

2.2 Finland

National team leader	
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Involved manufacturers	
Ensto Oy, Suomen Lämpöpumpputekniikka Oy, Oilon Oy, Rettig Oy, Scanoffice Oy, Kaukomarkkinat Oy, Nibe Oy, Fidelix Oy, Gebwell Oy, Järvenpään Mestariasunnot Oy	
National contribution financially supported by	
	Dr. Arto Kotipelto, TEKES

Project overview

The main objective of the Finnish "HP4NZEB"-project is to outline energy-efficient and cost effective nearly zero energy building solutions utilising heat pumps in Finland. The project consists of energy and cost optimisation in three building types:

- Apartment building (new building in planning phase)
- Detached house (new building in planning phase)
- Apartment building (existing building that is being renovated)

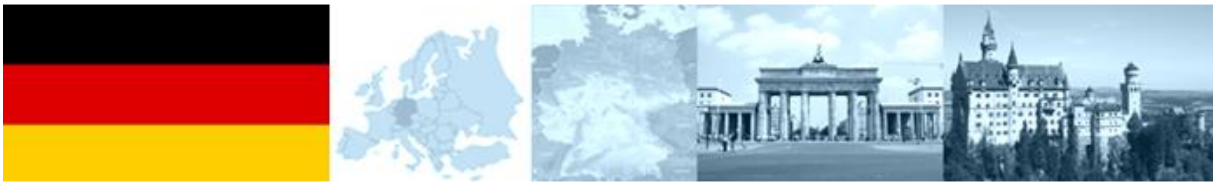
The project work includes defining and outlining the energy-efficient and cost-effective solutions for building services, structures and renewable energy production. The heat pump types investigated are ground-source heat pump, air-source heat pump and exhaust air heat pump and an evaluation of the life-cycle cost.

Results and contributions to Annex 40

Main result of the project is to know which nZEB-levels are achievable with heat pump concepts under Finnish boundary conditions.

- Definition of the state-of-the-art of nZEB in Finland
- Documentation of the listed building types and evaluation of the results
- Preparation of new concept for a field testing

2.3 Germany



National team leader	
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National contribution financially supported by	
	Bundesministerium für Wirtschaft und Technologie, http://www.bmwi.de

Project overview

The central goal of the project is the analysis of the quality of state-of-the-art heat pump systems in low energy office buildings. By this, this study shall present the status quo concerning energy performance, energy efficiency, operational performance as well as hydraulic integration of heat pumps in low energy buildings and nearly zero energy buildings. Furthermore, weak points and success factors for an energy-efficient implementation of heat pumps in nZEB will be identified.
The analysis is based on realized heat pump systems in non-residential buildings. The installed heat pump capacity is hereby typically higher than 25 kW_{th}. Measurement data of 20 demonstration buildings with a high temporal resolution is available. The measurement data include heat flows, flow temperatures and electricity consumption of compressors of heat pumps and chillers as well as circulation pumps.
The evaluation of the energy performance of the heating and cooling systems is conducted concerning different system boundaries from the environmental heat sources and sinks, over heat pumps and chillers, buffer storages and heat distribution system to the building's thermal zones.
In a cross-analysis the buildings and plants are compared to each other. The results of the analysis of German buildings will be discussed and compared to results in the frame of European and international buildings.

Results and contributions to Annex 40

- Results of field monitoring of 20 demonstration buildings with high temporal resolution
- Characteristic numbers and benchmarks for evaluation and optimisation of heat pump systems in net zero energy buildings
- Evaluation and optimisation of building operation with criteria of grid supportive features
- Best practice examples of facilities with good efficiency

2.4 Japan

National team leader	
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National contribution financially supported by	
	Nedo, http://www.nedo.go.jp

Project overview

In the project, several NZEB will be simulated under Japanese and European boundary conditions to derive recommendations for the design of the building envelope and to evaluate the system performance under NZEB conditions.
The main focus of the Japanese activities is on Task 2, in which an analysis and optimisation of an office building with regard to reach of NZEB standard were made. During the analysis, loads and system technologies of the building are rated by simulation, and system solutions are evaluated in several steps.
In Task 3, field measurements of several nZEB, studies of different HVAC systems with temperature and humidity individual control, heat recovery heat pumps and a testing method for evaluation of solar thermal system operation are documented.
For Task 4, a demonstration project called “Keihanna Eco City” about future energy systems in cities is documented. Moreover a study about building envelopes, technologies integrated with building equipment such as air-conditioners, lightings etc. regarding demand response is made.

Results and Contributions to Annex 40

- Case study with analysis of system solutions for nZEB under Japanese and European boundary conditions (Task 2)
- Documentation of field measurements of nZEB, evaluation of a study about HVAC systems with temperature and humidity individual control (THIC), heat recovery heat pumps and technology evaluation of solar thermal systems (Task 3)
- Documentation of the demonstration project “Keihanna Eco City” on future energy systems in cities (Task 4)

2.5 Netherlands

National team leader	
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Project overview

Platform31 is responsible for the Energiesprong ("Energy leap") program, financed by the Dutch government. The Energiesprong program aims to create market conditions for development towards energy neutral buildings, with the ultimate goal of a large increase in renewable energy and a large decrease in the use of fossil fuels. To reach this goal, several barriers are transformed into chances. The program aims to organize the demand side, facilitate supply chains, show real-life examples, disclose all relevant knowledge and promote innovative co-operations. Energiesprong is not a technology development program.
The total program funding is 60 Mio. €, which is partly spent on building projects with high ambition levels. Since 2010 several subsidy schemes have been made available, for residential buildings, districts, office buildings and retail buildings. The energy ambitions vary from 45%, 60% to 80% reduction in total (fossil) energy use, compared to the reference energy use for these buildings. Total energy use means that all energy consumed in the building is considered, so not only building-related but also user-related energy.
These high-ambition building projects will be monitored in detail. Not only energy use will be monitored, but also user satisfaction (by questionnaires) and the process of realization (co-operations, design process, operation and maintenance, etc.) will be evaluated. This monitoring aims to compare the initial projected performance of the building with the actual performance, related to the way the building was created and the way the building is being used.

Results and contributions to Annex 40

- Study about Net Zero Energy buildings "Roadmap to nearly Zero Energy Buildings"
- Documentation of the results of the field measurements of the refurbishments with particular technology evaluations
- Documentation of the results of the user satisfaction after the refurbishment

2.6 Norway

National team leader	
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National contribution supported by	
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National contribution financially supported by	
enova	Enova SF, http://www.enova.no

Project overview

The Norwegian project contribution is supported by Enova SF and is part of the research framework on zero emission buildings of the Norwegian Research Centre for Zero Emission Buildings (ZEB). The work package 3 of the project is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings with zero greenhouse gas emissions related to their production, operation, and demolition. The centre will encompass both residential, commercial, and public buildings. Norway will thus develop HVAC solutions for the application in NZEB with a focus on Nordic climate conditions and the use of natural refrigerants, in particular CO_2.
Moreover, also field evaluations are included in the project. 7 pilot buildings are under development. Several projects will be realized in 2014 and a monitoring of these projects, comprising new buildings as well as retroffiting will start in 2014. Results will be contributed to the IEA HPT Annex 40. In particular, monitoring data of a CO_2 heat pump water heater for DHW operation in 3 blocks of flats with ca. 800 flat, an air-source heat pump installed in an office building on passive house level with air heating systems and a retrofitted office building to plus energy standards equipped with two ground coupled heat pumps are monitored and investigated.
The definition of ZEB is a topic, too. Therefore, also ZEB concept studies will be performed. Decision and design tools are in focus of these project activities. The development of a tool for the design of heat pumps and back-up heaters for the application in nZEB has been started at SINTEF.

Results and contributions to Annex 40

- State-of-the-art of nZEB in Norway in Task 1
- Simulation of buildings and CO_2 heat pumps for passive- and Net Zero Energy buildings as well as a development of a design tool in Task 2
- Results from field monitoring of three different buildings in Task 3

2.7 Sweden

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National contribution financially supported by	
	Swedish Energy Agency, http://www.energimyndigheten.se

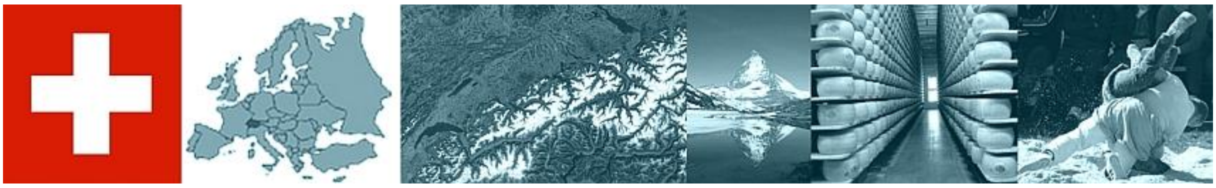
Project overview

The aim of the Swedish national project was to develop competitive heat pumps for the Swedish and export market for the application in nearly zero energy buildings. Moreover, it should be shown by field monitoring, how an nZEB in Sweden can be realised most energy-efficiently and cost-effectively using heat pumps in combination with other heat generators and energy efficient building envelope technologies. The system boundary for the nZEB evaluation comprises both energy for the HVAC technologies as well as plug loads for appliances.
As a part the Swedish project a single family ground source heat pump adapted for very low heat loads has been developed and put on the market. During the project time also two other small ground-source heat pumps has been put on the market by Swedish heat pump manufacturers. In collaboration with a Swedish heat pump manufacturer an improved system for the production of domestic hot water in multi-family buildings has been developed and tested in laboratory. The design targets for the heat pump development have been to pass the requirements for nZEB, Fgas, Eco Design and RES directives. Another goal has been to make ground-source heat pumps a cost-effective alternative for a low energy single family houses. The developed heat pump for the single-family house has been tested in real houses in 2014-2015. Furthermore, calculation models for nZEB has be developed linked to the assessment process of the heat pump prototypes.
In another nZEB-related project, initiated by the Swedish Energy Agency and the National Board of Housing, Building and Planning, monitoring in more than 20 Swedish low energy houses has started. Heat pumps are installed in several of these.

Results and contributions to Annex 40

- State-of-the-art of nZEB and technologies in Sweden
- System comparison of heat pumps in combination with other heat generators for Swedish boundary conditions
- Development of prototypes of heat pumps - which are prepared for Swedish climate conditions - for nZEB single-family and multi-family buildings

2.8 Switzerland



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	Bundesamt für Energie, Forschungsprogramm Wärmepumpentechnologien und Kälte, Programmleiter: Stephan Renz http://www.bfe.admin.ch, http://www.bfe.admin.ch/forschungwkk/

Project overview

The Swiss project deals with the integration of heat pumps into the energy system of nZEB. Since nZEB include renewable components in the building façade, one aspect is the building and system integration of the heat pump and solar components for the space heating, DHW production and space cooling in office buildings.
The project partner Energie solaire SA is a manufactures of uncovered solar absorbers with selective coating, which can be directly integrated in the building roof or façade. The project partner has already realised buildings with solar components and the heat pumps connected by an ice-storage in canton Valais in southern Switzerland.
The objective is to find an integration and product design, which can reach good operational performance for the different operation modes in multifunctional use. In the project system configurations shall be analysed by simulations and lab-tests. Evaluations of field measurements of a multi-family house and a MINERGIE-A® certified building with mixed office- and residential use are also documented regarding to energy balance as well as domestic electricity usage and options for load shifting.

Results and contributions to Annex 40

- Documentation of the state-of-the-art of nZEB and used technology for nZEB (Task 1)
- System comparison based on simulations (Task 2)
- Documentation of lab-measurements and simulation results (Task 3)
- Documentation of field measurements of two buildings (Task 4)

2.9 United States of America - USA

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National contribution financially supported by	
	Antonio Bouza, US Department of Energy, Building Technology Program, http://www.doe.gov

Project overview

In the US team three institutions are involved and will work on the following projects:

- Oak Ridge National Laboratory (ORNL) has several integrated heat pump (IHP) systems developments. An electric ground-source (GS-IHP) and air-source (AS-IHP) versions and an gas engine driven AS-IHP version will be further developed by a field testing. The first commercial GS-IHP product was introduced to the market in December 2012. This work is a contribution to Task 3 of the Annex.
- The University of Maryland will contribute a software development project to Task 2 of the Annex. The software ThermCOM is to evaluate thermal comfort accounting for all radiative and convective heat transfer effects as well as local air properties.
- The National Institute of Standards and Technology (NIST) is working on a field study in the NIST Net Zero Energy Residential Test Facility (NZERTF). During the first (baseline operation) year the house was equipped with an highly efficient air-to-air heat pump. Outdoor conditions, internal loads and modes of heat pump operation were monitored. Field study results with respect to heat pump operation were reported and recommendation on heat pump optimisation for a net-zero energy building were provided. This work is a contribution to Task 3 of the Annex.

US technical contributions related to Task 4 of Annex 40 will mostly be related to the parallel work under the Annex 42 entitled “heat pumps in smart grids” and reported in Annex 40.

Results and contributions to Annex 40

- State-of-the-art of heat pumps and NZEB in the USA (Task 1)
- Developed software to evaluate comfort of surface heating and cooling systems (Task 2)
- Developed prototypes and results from field testing on integrated heat pumps (Task 3)
- Documentation of results from field measurements of the test facility NZERTF and evaluation of heat pump technology of NZEB (Task 3)

3 Summary of main results

Based on the structure and national contributions of the IEA HPT Annex 40 presented in chapter 2, i.e. the case studies in Task 2 as well as the technology development and field monitoring in Task 3 and 4, the main results are summarised in this chapter.

3.1 Task 2: System comparisons and case studies for nZEB

Different system comparisons and case studies, respectively, for building technology in nZEB were accomplished in IEA HPT Annex 40. Thereby, country specific boundary conditions in respect to weather data, load profiles and economic boundary conditions were considered. Residential as well as office buildings were evaluated.

3.1.1 System comparison Switzerland

As single-family building for the Swiss energy and cost comparison of different building systems, the reference framework of IEA HPP Annex 38/SHC Task 44 (Dott et al., 2013) was adapted. As multi-family building a five-storey building was taken. As example for an office building the headquarter of the Marché restaurants in Kemptthal was chosen. The results confirm that for Swiss boundary conditions of the MINERGIE-A®-label, which is a current implementation of nZEB in Switzerland, heat pumps in combination with PV are the most cost-effective systems for single-family buildings regarding energy efficiency and 20-year life-cycle cost, as depicted in Fig. 30 left. For low heat load at MINERGIE-P® level, air-to-water (A/W)-heat pumps reach the lowest annual cost due to the lower investments. For higher loads and larger buildings, ground-source heat pumps are more favourable regarding life-cycle cost. Systems with biomass, especially biogas, have the highest life-cycle cost.
In multi-family- and office buildings combined heat and power (CHP) and district heating reach similar life-cycle cost as the heat pumps under the set boundary conditions of system and energy cost, which is depicted in Fig. 30 right. While smaller office buildings with three storeys can still reach a nearly zero energy balance according to MINERGIE-A® with PV installed on the roof, larger buildings also need PV installation in the facade or even CHP as further electricity producing technology. Biomass systems, in particular biogas, are the most expensive system solutions like in single-family houses.

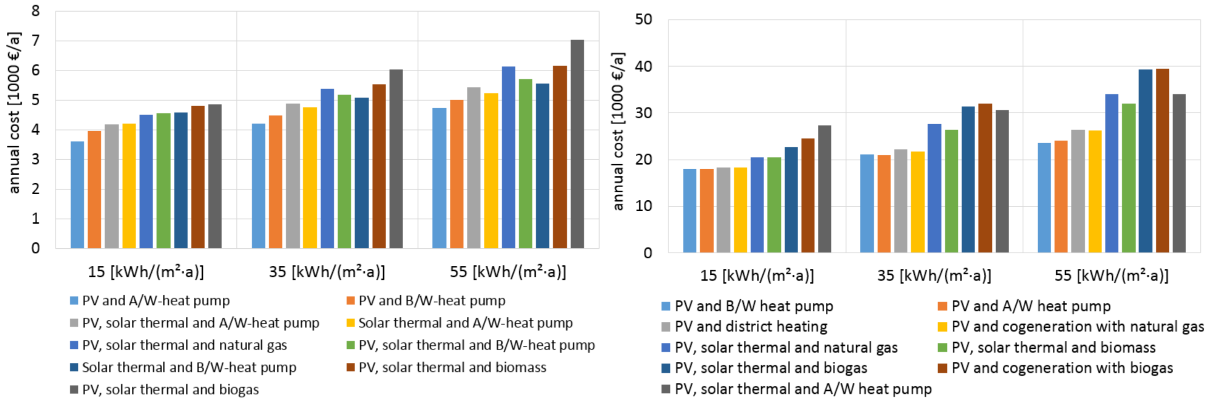

Fig. 30: System comparison for single-family (left) and multi-family houses (right) in Switzerland (Schwarz et al., 2015)

3.1.2 System comparison Sweden

In Sweden, the system comparison led to similar results as in Switzerland, as the cost comparison in Fig. 31 illustrates. It could be verified by the case study, that despite the higher investment cost, ground-coupled heat pumps can be an economic solution also for the lower space heating demand in nZEB. The system solution with ground-source heat pump combined with PV reached the lowest life-cycle cost, even lower than air-source heat pumps. District heating is more expensive in single-family buildings. Pellets combined with PV reach similar life-cycle cost and are an alternative for nearly zero energy balance at low life-cycle cost.

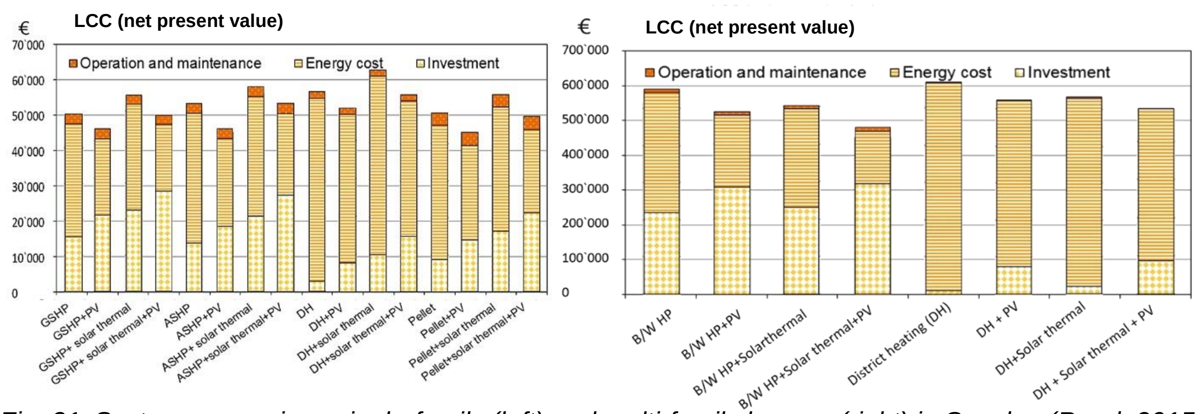

Fig. 31: System comparison single-family (left) and multi-family houses (right) in Sweden (Ruud, 2015)

Based on the results for single-family houses, ground-source heat pumps and district heating has been compared also for multi-family houses. In multi-family houses, ground-source heat pumps are preferable to district heating due to lower costs and higher independence from future developments in energy prices. District heating alone does not reach the proposed requirements for nZEB in Sweden, and an additional technology like PV or solar thermal collectors is necessary.

3.1.3 System comparison Finland

In bigger cities, Finland has a well-developed district heating supply, so the role of heat pumps in future nZEB in Finland should be evaluated by the Finnish case study. In particular, it was a question, whether heat pumps can be a competitive solution for nZEB under Finnish boundary conditions. A Finnish definition for nZEB has been developed in parallel in the FInZEB project (Rautiainen, 2015). Results of the Finnish case studies already use the FInZEB recommendations as boundary condition. Investigations were done by simulations, and results confirm that A/W-heat pumps as well as B/W-heat pumps fulfil the requirements of the FInZEB limits, so called E-values. Regarding system configurations heat pump solutions are more cost-effective than district heating which is an important result of the project, since district heating systems are very common in the bigger cities in Finland. As well as in the Swedish case study also in the Finnish case study it was confirmed that despite the higher investment cost, ground-source heat pumps reach the lowest 25-year life-cycle cost. Fig. 32 shows the system comparison for the life-cycle cost of different heat pump systems and different E-values (ground-source with maximum solar energy systems (GSHP/S), ground-source (GSHP), outdoor air source (ASHP), Exhaust air (EAHP) and Air-to-Air (AAHP)).

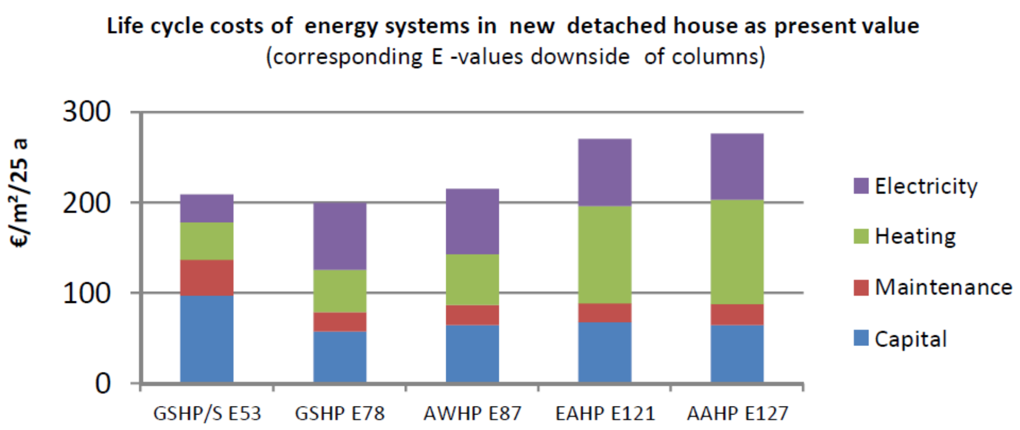

Fig. 32: System comparison in Finland for single family houses (Häkamies et al., 2015)

3.1.4 System comparison Canada

The system comparison in Canada does not show a uniform picture regarding preferable system solutions, but it reflects the influence of the market situation, i.e. the influence of the energy cost and prices, respectively, as shown in Fig. 33.

While in the Eastern provinces represented by the cities Halifax and Montréal, ground-source heat pumps (GSHP) and special air-source heat pumps for cold climate conditions (CC ASHP) are the cheapest systems based on 20-year life-cycle cost, these system solutions are more expensive in the Western provinces represented by the cities Toronto, Edmonton and Vancouver due to very low gas prices. This underlines the dependency of the most cost-effective technologies on present energy prices.

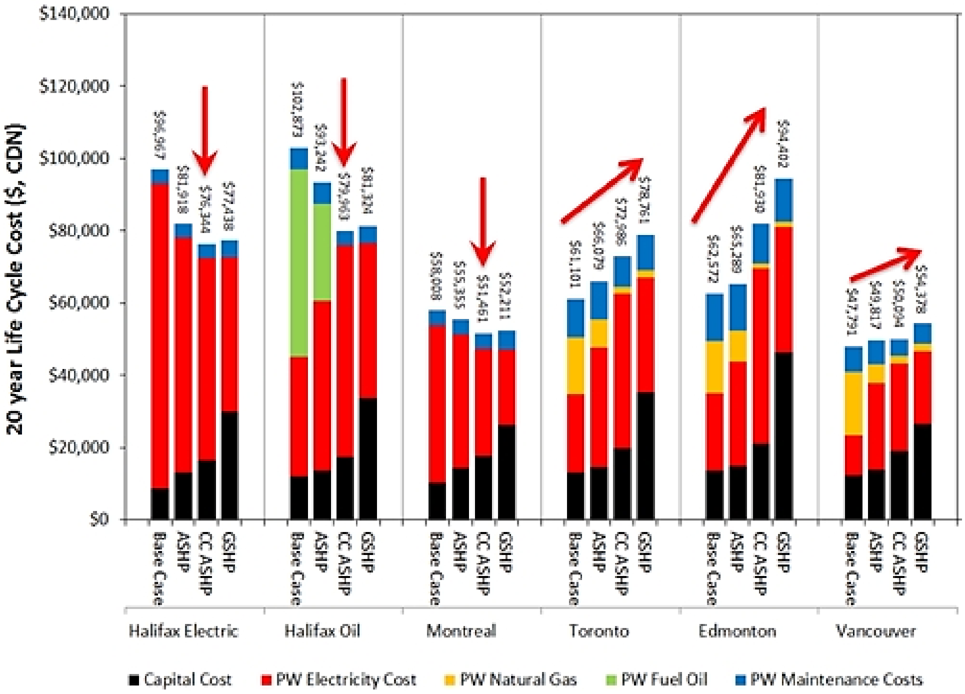

Fig. 33: System comparison by regions in Canada (Kegel et al., 2014)

3.1.5 Case study in Japan for nZEB office buildings

The balance boundaries for the case study in Japan includes the whole energy including the whole lighting and appliances. The different building types – standard, low energy and NZEB – as well as the results of the case study are shown in Fig. 34. The reference building is dominated by lighting and cooling demands. Compared to the reference building, the low energy building has a better insulation, energy-efficient windows and different efficiency technologies for lighting and appliances.

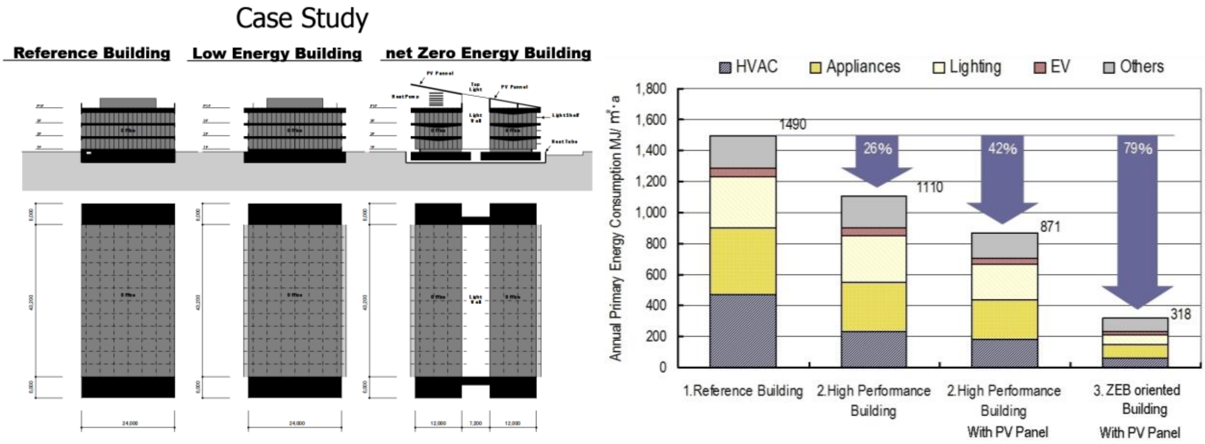

Fig. 34: Case study in Japan for nZEB office building (Okumiya et. al, 2015)

The energy consumption is 45% lower than in the reference building. Furthermore, the nZEB is optimised in respect to daylighting and energy generation on-site. The building is divided into two wings with an atrium inbetween. Due to the atrium, also in the former inner rooms daylight can be used. Furthermore, a highly efficient heat pump for heating and cooling as well as a PV-generator on the rooftop are installed.

The energy needs, especially for the lighting, could be reduced by 65% in comparison to the reference building. Due to the PV-generation almost the total energy needs can be balanced on an annual basis. For office buildings up to three storeys, a zero balance and therefore a Net Zero Energy Building can be reached, if all energy reduction potentials are effectively used. Case studies for larger office building and case studies for European boundary conditions have also been performed.

3.1.6 Summary of case studies performed in Task 2

In Task 2 of Annex 40, case studies to compare system solutions in nZEB have been performed for different boundary conditions both for central European and Nordic climate conditions as well as in Japan, where pronounced air-conditioning needs occur. As building types both residential and office buildings have been considered. Thereby, the boundary conditions regarding the nZEB definition and economic aspects have been based on the current national state of definition and the present market conditions. Despite the partly different boundary conditions the case studies yield the results, that both in central European as in Nordic countries heat pumps are a favourable building system technology for the application in nearly Zero Energy Buildings both in terms of energy-efficiency and life-cycle cost. With the heat pump solutions, requirements of nZEB can be reached. Even though heat pumps may have higher investment cost compared to other heating systems on the national markets of the individual countries, heat pumps are among the systems with the lowest life-cycle cost.

Despite the differences in the nZEB balance definition, climate, and the economic boundary conditions, the resulting ranking of the different system solutions is quite similar, where heat pumps are among the most appropriate system solutions. This shows a certain robustness of the results regarding both the energy performance evaluation and the economic boundary conditions. For the energy evaluation heat pump solutions benefit from the high energy performance in nearly Zero Energy Buildings with good building envelopes enabling low supply temperatures. Thereby, the nZEB balance can be reached more cost-effectively, since less on-site generation is required for the compensation of the energy demand of the building. On the other hand, heat pumps may have higher investment cost on the national markets, but regarding the life-cycle cost, this initial disadvantage is compensated by less investment in generation technologies, e.g. PV systems can be designed smaller. Moreover, the higher energy performance of heat pumps reduces the operational cost, which is seen in the life-cycle consideration, too. According to these results, heat pumps are very favourable system technology for the application in future nZEB also for Nordic climate conditions.

3.2 Task 2: Development of design tools

In two of the projects within Task 2 of Annex 40 design tools were developed.

3.2.1 Design-Tools for comfort evaluation of surface heating- and -cooling systems

In the USA, at the Center of Environmental Energy Engineering (CEEE) of the University of Maryland, a tool to evaluate the thermal comfort of surface heating and cooling systems for rooms has been developed. Motivation of the tool development is the objective to reach the lowest possible supply temperature for heating and the highest possible supply temperature for cooling, respectively, in the room to optimise the Coefficient of Performance (COP) of the heat pump/chiller. The tool can display different comfort criteria for rooms with different geometries. The basis for the evaluation of a given room geometry are detailed computational fluid dynamic (CFD) simulations. By the proper orthogonal decomposition *(*POD) approach reduced order models are derived, which can be used for the investigation of the different comfort criteria in the given room with less computational expense than the full CFD simulations. Using the reduced models the comfort criteria Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) according to the Fanger algorithm, which is standardised in ISO 7730, as well as the influencing factors like room air temperatures, air velocities and radiative temperature can be evaluated in high spatial resolution.

Fig. 35 left shows a basic room configuration for the evaluation of a radiative wall-mounted cooling system and solar radiation entering the room by a window on the opposite wall.

Due to the low temperature levels, surface heating and -cooling systems have been in the focus of the development, but also conventional convective cooling systems like inductive units or ducted air-handling systems as well as ductless room air-conditioners have been implemented in the design tool. Fig. 35 right shows an example of a case study regarding the temperature fields of a ducted air-handling unit and a ductless room air-conditioner with different supply temperatures.

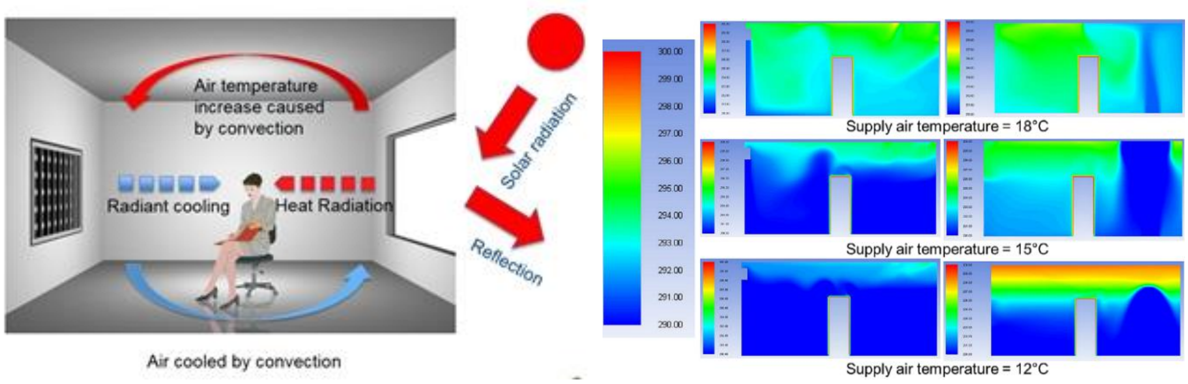

Fig. 35: Typical room of the design tool with surface heating and -cooling system for the evaluation of the indoor thermal environment (left) and evaluation of the temperature field of a ductless and ducted space cooling system for different supply air temperatures (Baxter et al., 2015)

3.2.2 Design-Tool for CO_2-emissions and cost in Norway

Simulations of CO_2-heat pumps for the application in nZEB as well as a development of a design tool for heat pumps and back-up heating regarding cost and CO_2-eq.-emissions have been accomplished at SINTEF Energy in Trondheim, Norway. Based on the load profile, which is generated in a pre-processing with standard building simulation software, the tool performs an iterative optimisation of the design of the system components to minimise CO_2-eq.-emissions and system life-cycle cost. Fig. 36 shows the current state of implemented system configurations. The system can be composed of the heat pump as main heat generator, a back-up heater, the storage and the emission system. As operation modes space heating and domestic hot water (DHW) operation as well as a free-cooling operation by a ground-source borehole heat exchanger and an active cooling operation by a heat pump in reverse operation mode shall be covered by the design tool. Based on the pre-processed load, the respective system configuration can be simulated and simulation results serve to iteratively optimise the design of the system components.

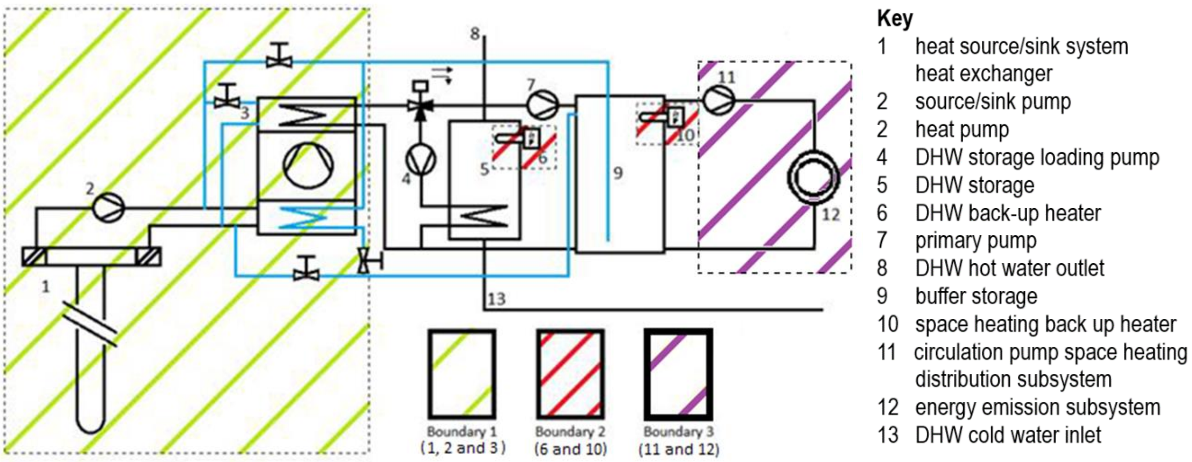

Fig. 36: Principle design of the modelled system: Boundary 1 – heat pump with heat source/sink, Boundary 2 – peak load system, Boundary 3 – DHW system and a heating/cooling system (Småland, 2013).

Fig. 37 shows the single calculation steps of the Net Zero Emission Programme (NZEP). After the pre-processing, the system configuration is chosen. The objective function for the optimisation is the design of the heat pump and a back-up system regarding minimal CO_2-eq.-emissions and life-cycle cost.

Presently, the objective function is a cost-optimal design of the heat pump and the back-up system regarding a nearly zero CO_2-eq.-balance, i.e. a Net Zero Emission building. However, it is possible to change the weighting factors to a primary energy weighting to create nearly Zero Energy buildings.
As shown in Fig. 37 left, after the building pre-processing and definition of the system configuration, the parameters are set. In the next step the system simulation is accomplished. Based on the simulation results, the optimisation variables system cost and CO_2-eq.-emissions are evaluated. Dependent on the results, the design of the system is adapted and another simulation is started. The current state of the tool, the optimisation is accomplished as a series of parameter variations of the system design in order to evaluate the minimum values of life-cycle cost and CO_2-eq.-emissions. However, since the entire calculation including the simulation has been transferred to a Matlab-Simulink® environment, also the optimisation algorithm available under Matlab® can be coupled to the simulation in order to perform automatic optimisation of the system design variables as shown in Fig. 37. The tool is still under development, and will be extended regarding the system configurations and the optimisation loop.

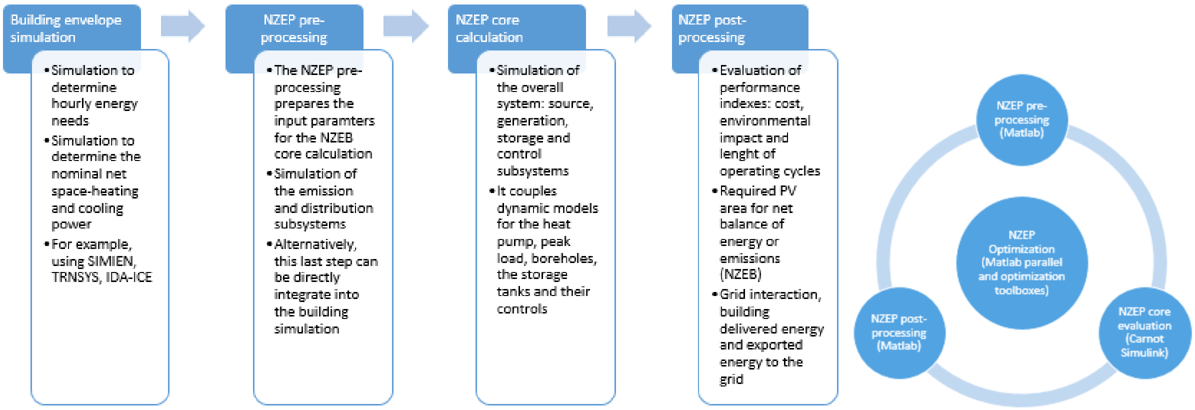

Fig. 37: The overall algorithm for the NZEP simulation tool and optimisation process by iterating on the three calculation phases: pre-processing, core calculation and post-processing, of which each step can be done in Matlab environment (Justo Alonso et al., 2015)

3.3 Task 3: Technology developments

In Task 3 prototypes of integrated heat pumps were developed and analysed in lab- and field tests. Field monitoring on built nZEB were carried out, in order to evaluate, whether the net zero energy balance was reached and to characterise and optimise the heat pump performance.

3.3.1 Integrated heat pump (IHP) development in the USA

The development of highly integrated heat pumps (IHP) at the Oak Ridge National Laboratory (ORNL) in the USA has already begun in 2005. The integration includes the functions space heating, space cooling, DHW production and dehumidification, a function, which is essential in the southern states of the USA. Within the framework of Annex 40 the earlier developed prototypes were analysed in field monitoring and new variants of the IHP concept were evaluated.
A ground-source version of the IHP is already on the market, while for the air-source IHP (AS-IHP) three different embodiments have been developed and investigated in lab- and field-testing in the frame of the Annex 40. Two of them are electrically-driven, and the third is a gas-engine driven system configuration.
Fig. 38 shows the conceptual design and the field object as well as the results of the field monitoring in summer operation. The different combined operation modes are distinguished. As overall seasonal performance, values above 5 for cooling operation and 4.4 for DHW operation are reached. As expected the simultaneous operation modes reach higher performance values than the single operation modes. As variant of the AS-IHP system design also a so-called two-box system and a gas-engine driven system are under development.

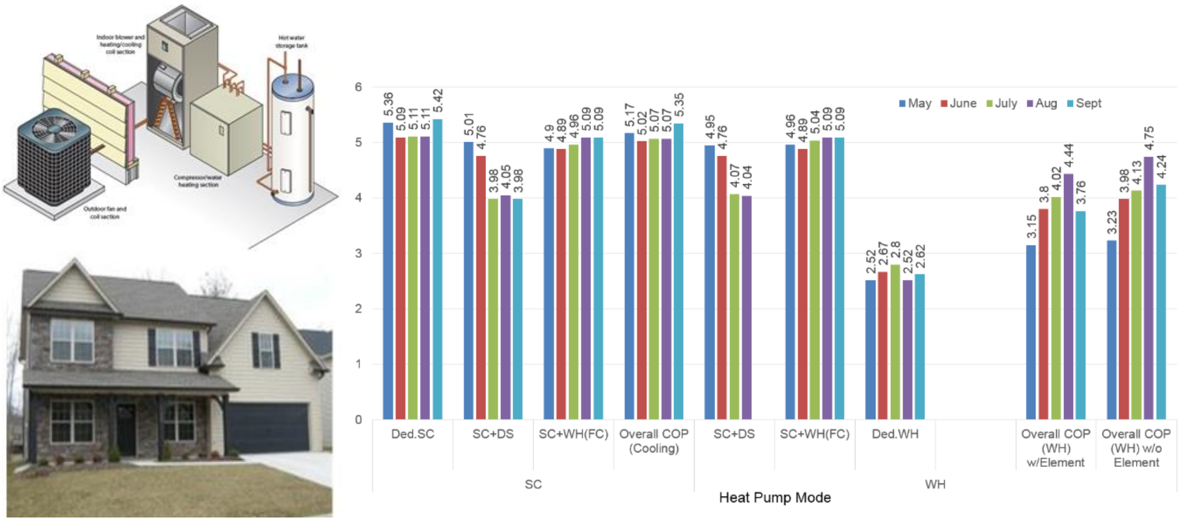

Fig. 38: Layout of the integrated heat pump (left, top) and field monitoring results (right) from Knoxville, TN (left, bottom)(Baxter et al., 2015)

Several field-tests have already been performed, leading to improved prototype designs for the systems. The motivation for the two-box systems is the separation of the space heating and sensible space cooling function from the dehumidification (DH) and domestic hot water (DHW) production, i.e. a central high-efficiency air-source heat pump is coupled with a prototype water heating/dehumidification (WH-DH) module.

The WH-DH module can be integrated with the air-source heat pump unit by a parallel secondary duct loop around the central air handler, receiving a portion of the central return air when the secondary (WH-DH) blower is operating and returning this air to the supply air stream. It also has an optional connection to an outdoor air intake to provide a means for conditioning and circulating ventilation air through the central duct system. A dedicated DH cycle addresses humidity control and integration of heat pump WH is expedient, since the small vapour compression components can perform double-duty. This integrated, yet independent operation of the WH-DH unit provides dehumidification of the central return and ventilation air as well as a central heat source for the WH mode.

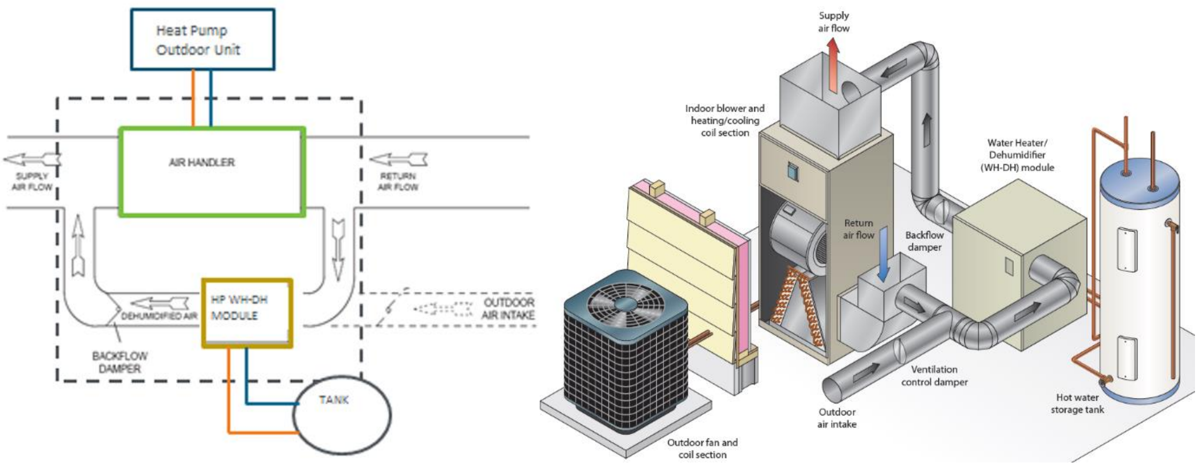

Fig. 39: Principle of the two-box design of the AS-IHP and layout for the field test of the unit (Rice et al., 2014)

The independent operation is especially useful in the shoulder months which often require dedicated DH, along with WH, but little or no SC or SH. The principle of the two-box system and a system layout for a field test are shown in Fig. 39 (Rice et al. 2014).

Another significant advantage is that this IHP approach can be relatively easily applied to retrofit/upgrade applications as well as new construction, utilising standard electric water heaters and a wide range of multi-capacity and variable speed air-source heat pumps.

In retrofit applications, even if the tank is remote from the heat pump indoor section, the WH-DH unit can be located at the WH tank and the system will still retain most or all of the IHP advantages.
As a further variant, a Gas Engine-Driven Heat Pump (GHP) is developed. It can be an attractive economic choice in parts of the USA where the typical engine fuels such as natural gas, propane or liquefied petroleum gas (LPG), can be less expensive than electricity (Mahderekal et al., 2012). Compared to conventional fuel-fired furnace heating systems they are projected to reduce fuel consumption for space heating by 35% and for water heating by 80 % (Vineyard, 2014). They also significantly reduce summer cooling electric peak demand compared to electric air-conditioning (AC) systems. A GHP can be a more attractive climate control system than conventional single-speed electric heat pumps for a number of reasons, e.g. variable speed operation can be realized at high efficiency, thus well adapting to the load conditions and heat recovery from the engine can increase the winter capacity for space heating and be used for DHW preparation throughout the year. Moreover, lower gas prices exist in several regions of the USA, and by integration of a small power generator, the unit can be operated independent of the electricity grid and can provide basic electricity supply for the units auxiliary components and the base load of the home.

3.3.2 Solar assisted heat pump development in Canada

CANMET Energy of Natural Resources Canada is working on a solar assisted heat pump. The integration of solar components and heat pump is done by an ice-slurry storage. Similar to concepts with ice storages in Europe, the ice-slurry storage is integrated as source storage. The principle system configuration is shown in Fig. 40 left. The configuration has several advantages, namely an enhanced storage density by the phase change of the ice-slurry, a stable source temperature for the heat pump and improved efficiency and longer running time for the solar component due to the low temperature levels. The ice-slurry storage is charged by a solar component, which can be a solar thermal collector, but due to the low temperature in the ice storage this may also be a photovoltaic-thermal (PV/T)-hybrid collector. The heat pump discharges the storage and forms the ice while transferring the heat to a warm water storage, which serves for the space heating and DHW preheating. In times of sufficient solar irradiation, a direct heating of the warm water storage is also possible by the solar component. In summer operation, the source storage can be used as cold storage for cooling applications, while the condenser waste heat in cooling operation may be recovered for the DHW operation or is rejected to the ambiance by a separate heat exchanger. The DHW can be produced directly by the collector in summer operation with sufficient solar irradiation to reach DHW operating temperatures.

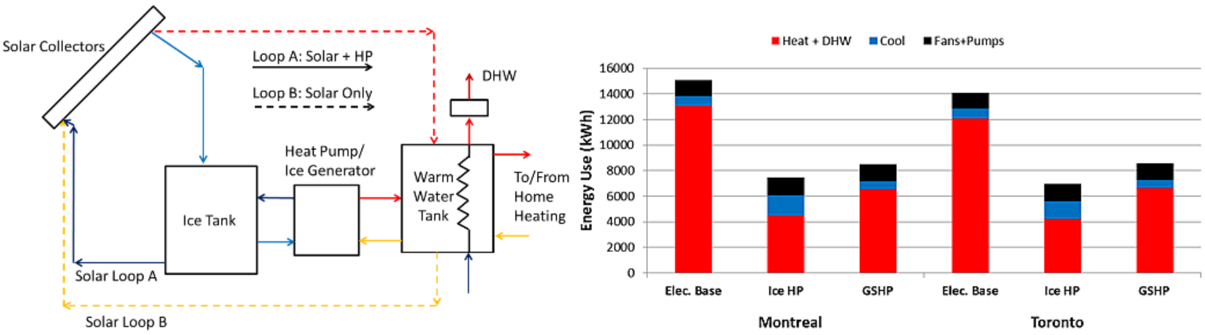

Fig. 40: Integration of solar collector with ice-slurry storage in Canada (Tamasauskas et al., 2015)

The system is intended to replace direct electric baseboard heating systems, which are still relatively common in Canada. For the investigation of the real behaviour of the single system components and the integration, a test bench has been built and commissioned. Besides characterisation of the component behaviour under different operating conditions, the test results have also been used to create and validate component models based on the test bench results. By integration of the component models in the system simulation software TRNSYS, whole year system simulations for a specified low energy building for different sites could be performed. Fig. 40 right shows the results of system simulations for the weather conditions of Montreal and Toronto.

The system simulations confirm that both in Montreal, which has a cold but clear winter climate with more solar irradiation in wintertime, and in Toronto significant energy reduction can be achieved compared to electric baseboard heating. The simulation results also demonstrate that the solar assisted heat pump system has even a slightly lower energy consumption than a ground-source heat pump.

3.3.3 Integration of heat pumps and solar technologies in Switzerland

The HSR University of Applied Sciences Rapperswil and the University of Applied Sciences Northwestern Switzerland FHNW have analysed the combination of an uncovered solar absorber and a heat pump for space heating and cooling operation. The principle of the system integration is shown in Fig. 41.

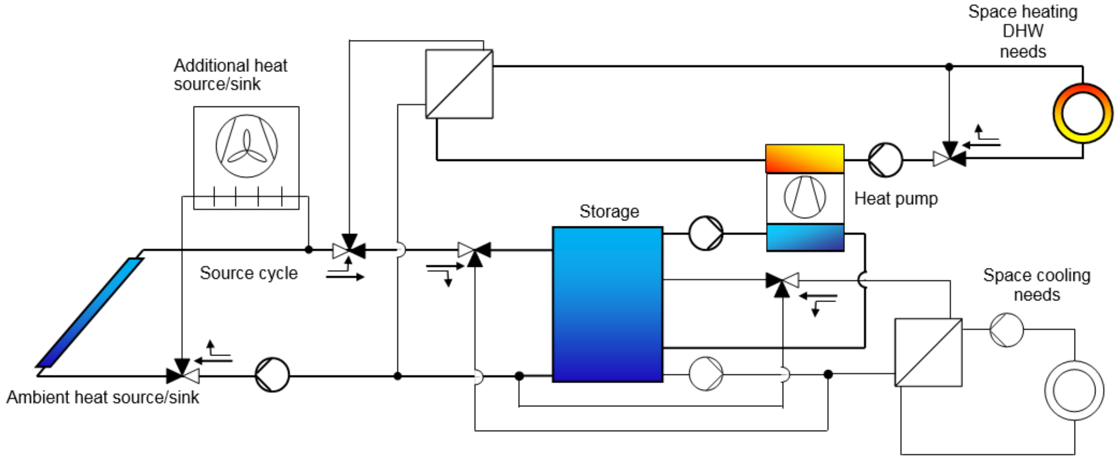

Fig. 41: System integration for space heating with absorber as heat source (Wemhoener et al., 2015)

In heating mode, the absorber works as heat source for a heat pump. The storage is operated as a source storage for the heat pump. With enough direct solar irradiation in the transitional period, also a direct solar heating can be performed.
In cooling mode, the absorber is used as an outside heat exchanger to reject heat to the colder ambient temperatures at night-time. In this mode, the cooling energy can be stored in the source storage, which acts as a cold storage in cooling mode, or directly coupled to thermally-activated building systems which are often installed in the room zones of an office building.

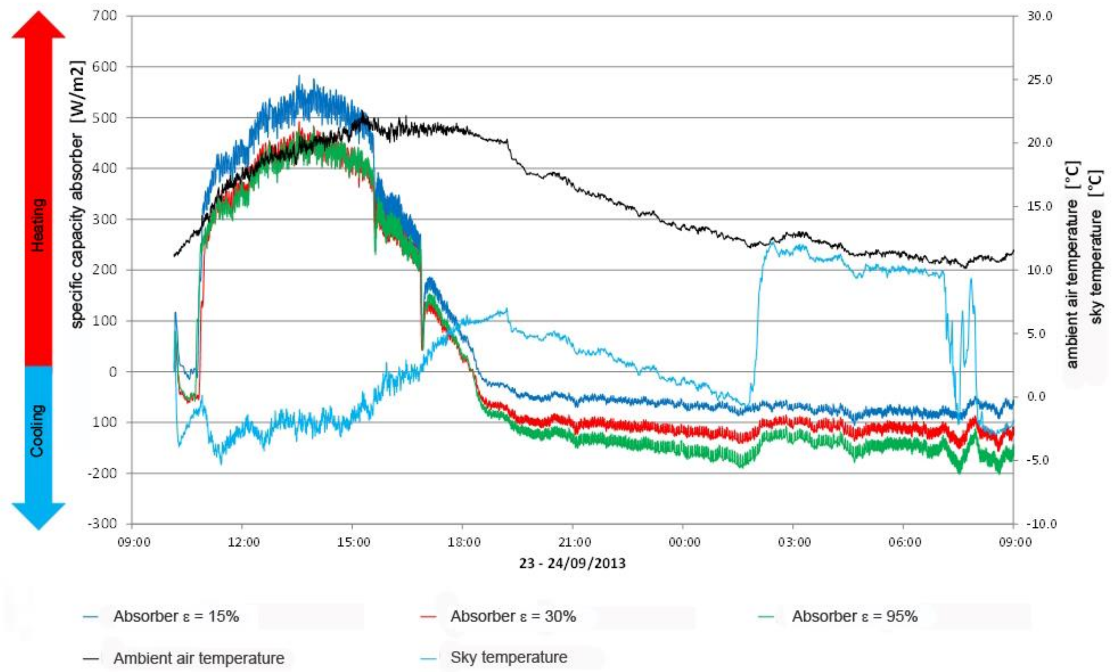

Fig. 42: Lab testing of uncovered absorbers with different selective coatings (Wemhoener et al., 2015)

Lab test measurements have been performed for three absorbers with different degree of selective coating of a long-wave emissivity of ε_{IR} = 0.15 (selective), ε_{IR} = 0.3 (faint selective) and ε_{IR} = 0.9 (non-selective).

Fig. 42 shows the lab measurement results for a sunny day followed by a clear night. The absorber inlet temperature is kept constant at 25 °C during the measurements. Heating capacities are in the range of 500-600 W/m^2_{abs} with direct solar irradiation during daytime, where the selective absorber reaches the highest values due to its reduced radiation losses. Cooling capacities during the clear night are in the range of 70-200 W/m^2_{abs}. In cooling operation, the non-selective absorber reaches the highest capacities due to the radiation losses, which are inhibited by the selective coating. The test results show that in the middle of the night, clouds appeared. This reduces the radiation losses to the sky, which caused the three absorbers capacities to approach each other. Thus, the absorber capacities depend on the selective coating of the absorber regarding the radiative fractions of the cooling capacity. Thereby, requirements for a high space heating and cooling capacity are contrary, since selective coating limits the radiation and environmental losses, which is good for the space heating operation, while it limits space cooling operation.

Based on lab-test measurements, a model of the absorber component was implemented in a simulation environment and validated with the test data. After validation annual system simulation of the space heating and cooling operation have been performed using weather data of Zurich Meteoschweiz for an average year for two office zones in north and south orientation and single office use. The office zones are equipped with thermally activated building systems (TABS) as concrete core activation, enabling a maximum supply temperatures of 29 °C in heating operation. The design of the collector is 33% of the energy reference area of the office space, which corresponds to the entire roof size of a three storey office building. The investigated absorber can be used directly as roof material.

Results show good seasonal performance factor (SPF) of an overall SPF in space heating mode between SPF_h = 4-5 for heating mode with heat pump and direct solar heating. The SPF differs depending on the absorber properties and inclination. While the selective coating is not as important in operation as heat source, it enables higher percentages of direct solar heating due to higher absorber temperatures. In summer operation 80-90% of the cooling load can be covered by free-cooling in moderate climate conditions of an average summer using Zurich weather data. This of course depends on the properties and inclination of the absorber. In free-cooling operation, the typical high performance factors of up to 30 are reached for an optimised hydronic integration. Non-selective coating is important in climates where the heat loss by convection is limited due to higher night-time temperatures, when radiative heat rejection is the main cooling mechanism.

3.3.4 Evaluation of HVAC system in Japan

In Japan a novel heating, ventilation and air conditioning (HVAC) system has been evaluated by testing in two office rooms. The HVAC system applies two innovative components, a heat pump (HP) Desiccant system and an enhanced temperature control of a variable refrigerant flow (VRF) heat pump.

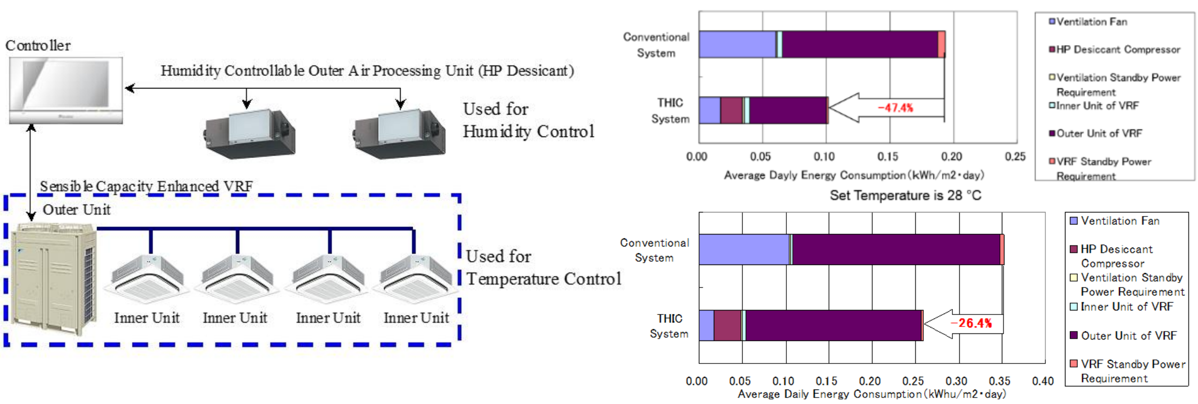

Fig. 43: Configuration of the HVAC system (left) and energy reduction in summer (right, top) and winter operation (right, bottom) (Okumiya et al., 2015)

The system denoted as Temperature and Humidity Individual Control (THIC) performs a separation of the sensible cooling load and the latent dehumidification load. The latent load is covered by a HP Desiccant system which has been further developed to decreased regeneration temperatures of the desiccant of 40-50 °C, so the regeneration can be accomplished efficiently with the heat pump. Adsorption and desorption are accomplished in parallel while the heat pump transfers the heat from the adsorption to the desorption process, which significantly increases the performance.
Due to separation of the latent load, pressure difference for the VRF heat pump can be decrease. The VRF heat pump has been optimised for low pressure differences. A new scroll compressor was developed which is far more tolerant for the operation with the small pressure difference operation, which makes it possible to notably reduce the pressure difference and increase the performance.
The test of the unit was accomplished in two office rooms in summer and in winter operation. Fig. 43 left shows the system configuration of the THIC and Fig. 43 right show the achieved energy savings during the summer and winter test. Despite the energy saving of about 50% the control of the indoor condition has been better by the THIC system than by the conventional system. In winter test, energy saving of about 25% have been achieved. Based on the measurements a model of the system was developed. The overall energy saving were determined by year-round simulations. Results of the overall energy saving are depicted in Fig. 44 yielding an energy saving potential of about 75%. Concluding, the impressive energy saving without any reduction of the indoor thermal environment conditions has been achieved by the reduction of air-conditioning loads by individual control of temperature and humidity, the development of the HP desiccant for efficient humidity control and the development of the sensible capacity enhanced VRF for efficient temperature control, especially in spring or autumn. By the energy reduction, it is much easier and more cost-effective to achieve an nZEB consumption due to reduced generation needs on-site to meet the balance. An nZEB can be reached by the application of the THIC relatively easy for 2-3 storey office buildings, but also in high-rise buildings, the technology offers a huge energy saving potential.

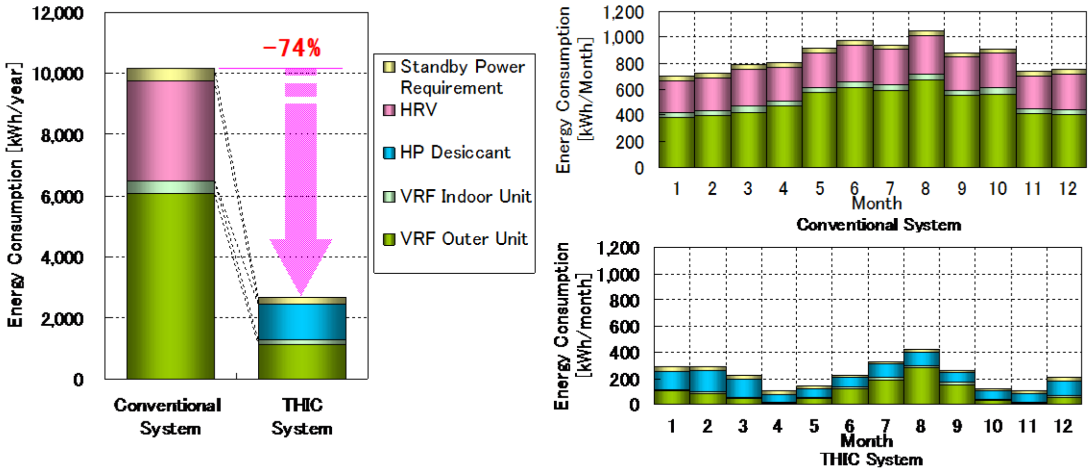

Fig. 44: Comparison of energy reduction by the THIC system with conventional air-conditioning systems without decoupling of sensible and latent loads (Okumiya et al., 2015)

3.3.5 Test platform for nZEB technologies on the NIST campus

The National Institute of Standards and Technologies (NIST) has built and commissioned a Net Zero Energy Residential Testing Facility (NZERTF). The test house is used for testing of NZEB technologies on the campus of the institute, which is shown in Fig. 45 left. The house is equipped with adjustable loads and extensive monitoring technologies in order to provide a reproducible test environment for real world testing of NZEB technologies. In the first year of operation the NZERTF was equipped with an air-to-air heat pump and a ventilation heat recovery. Fig. 45 right shows the energy balance of the first year of operation, which ended-up with a slight plus energy balance. Also the second year of operation achieved a plus energy balance. The test facility offer manifold opportunities for performance and comfort measurements and the testing and development of new technologies to be applied in NZEB.

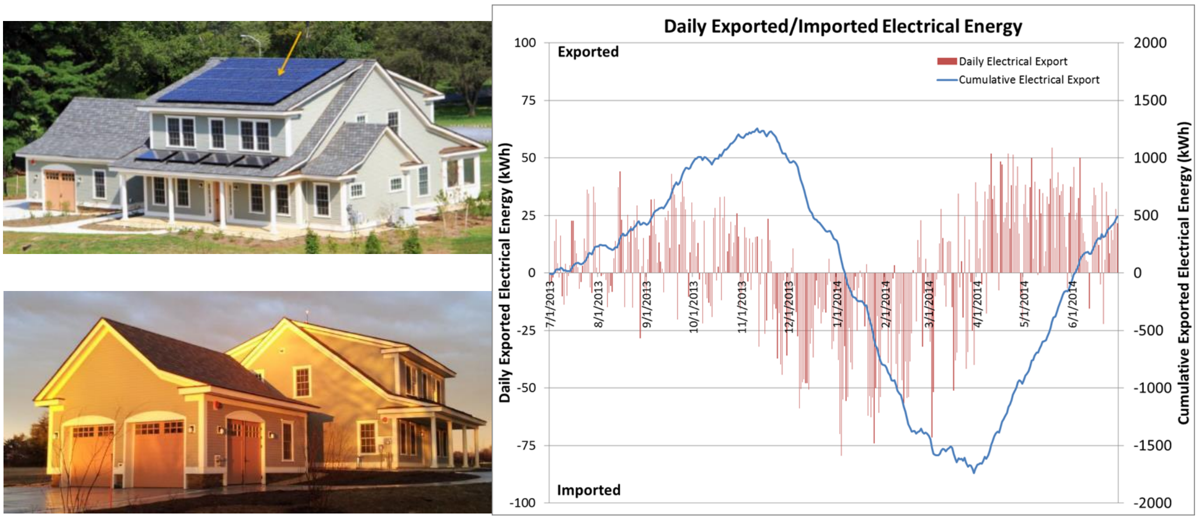

Fig. 45: Net Zero Energy Residential Testing Facility (NZERTF, left) on the NIST campus and annual balance in the first year of operation (right) (Baxter et. al., 2015)

3.4 Task 4: Field monitoring

3.4.1 Field monitoring of the first nZEB in Norway

Within the projects of the Research Centre on Zero Emission Buildings (ZEB) the first nZEB in Norway are being currently built and monitored as pilot projects for Norway. "Powerhouse Kjørbo" is one of the pilot and demonstration projects of the ZEB and has been monitored by the NTNU. The project refers to the retrofitting of an office building to a plus-energy building in Sandvika near Oslo. Fig. 46 shows the retrofitted building and a hydraulic scheme.

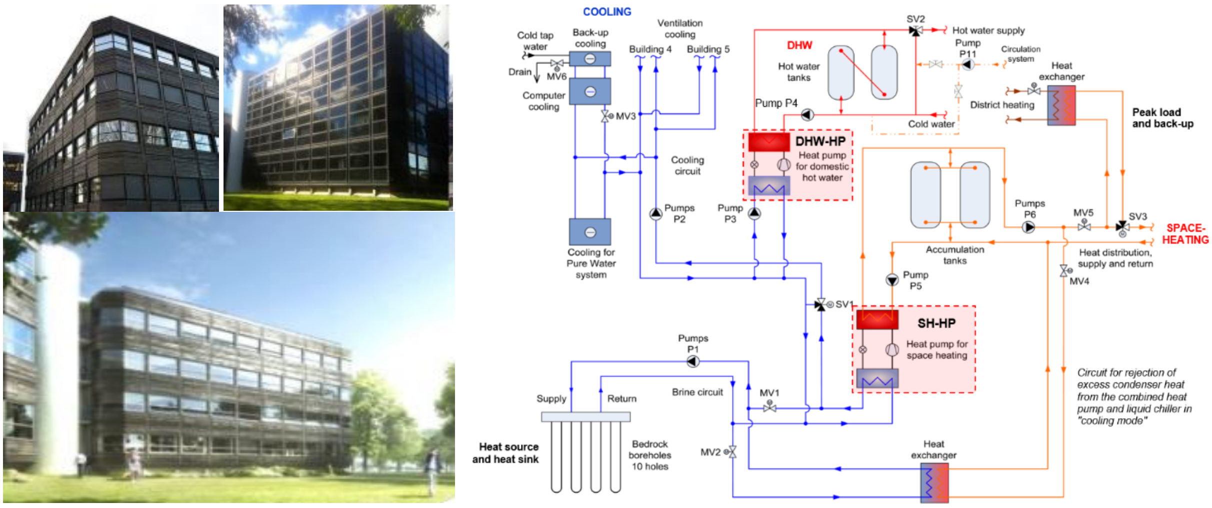

Fig. 46: View of Powerhouse Kjørbo (left, source ZEB) and hydraulic scheme of the building (right, Nordang, 2014)

The building with an energy reference area of 5200 m² has a calculated specific heating energy need of 19.1 kWh/(m²a), a design heat load of 52 kW and a DHW need of 4.8 kWh/(m²a) after the retrofitting. The cooling load is 65 kW and the specific cooling energy needs 1.8 kWh/(m²a). The heating and cooling needs are provided by a 64 kW brine-to-water (B/W) heat pump with 10 single U-tube borehole heat exchangers of 225 m depth each. The heat pump is also used as chiller for back-up cooling. For back-up heating the building has a connection to a district heating grid. Furthermore, an 8.5 kW B/W heat pump for DHW production is installed. For balancing the energy demand a solar PV-generator of 1,556 m² is installed, which yields a calculated electric energy of 225,000 kWh/a. The measured heating energy demand of 24.6 kWh/(m²a) is 29% higher than the calculated value, the measured DHW needs are with 1.9 kWh/(m²a) about 60% lower as planned. The cooling energy is 11% higher with the measured value of 2 kWh/(m²a).

The measured peak load for heating of 14.4 W/m^2 is about 37% and the peak cooling load of 13.5 W/m^2 around 29% higher than the design values. Despite the high design temperatures of 50 °C for space heating due to retrofitted building, the monitoring shows a good SPF_{SH} of 3.9 including the auxiliary energy for the source pumps of the boreholes. In DHW mode an SPF_{DHW} of 2.9 is reached.
Optimisation potentials are seen in the dimensioning of the borehole field (only 5 boreholes to cover 90 % of the heating energy needs), frequency control instead of intermittent control of the compressors as well as in the use of buffer storages, application of natural refrigerants, and a better use of the waste heat from the active computer cooling.
Besides the Powerhouse Kjørbo, also monitoring projects of a CO_2 heat pump water heater (HPWH) installed in 3 blocks of flats of totally about 800 flats and an air-source heat pump installed in a new nZE office building in passive house standard were accomplished. The results of the CO_2-HPWH for the blocks of flats reached a SPF_{DHW} of 4.4 with 70 °C DHW supply temperature and an exhaust air heat source around 20 °C. These results are very good despite some identified optimisation potentials.

3.4.2 Retrofit projects in the frame of the Dutch field monitoring "Energiesprong"

Platform31 is responsible for the "Energiesprong" ("Energy leap") program, which is funded by the Dutch government. The objective of the program is to build good market conditions and to stimulating energy technology markets to increase the share of renewable energy use.

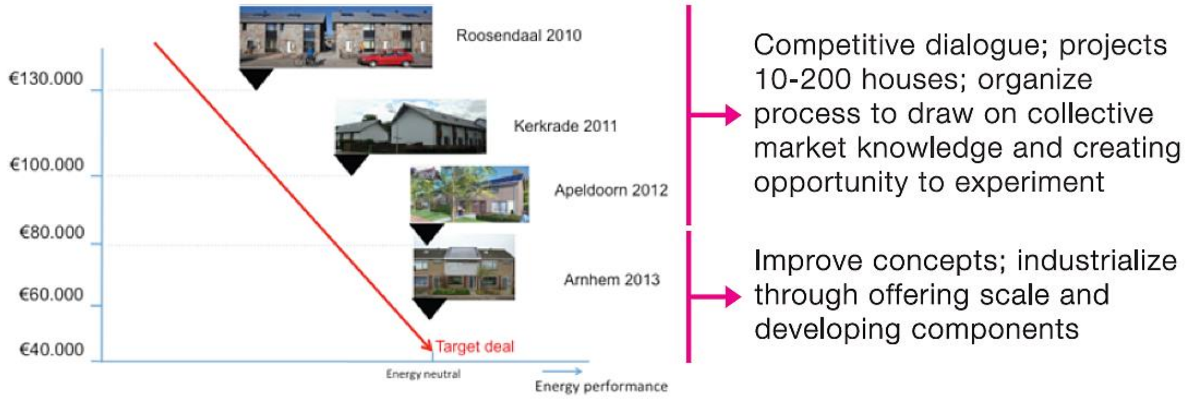

Fig. 47: Refurbishment projects in the framework of the "Energiesprong" monitoring in the Netherlands (Platform31, 2015)

Energiesprong initiated a deal between housing associations and builders to refurbish 111,000 houses to nearly zero energy level. The objective is to distribute technologies and make them competitive. The refurbishments are made within 10 days with pre-fabricated building components, which come with a 30-year guarantee. During the retrofitting, solar PV systems are also installed on the building roofs. Presently, a good feed-in tariff for PV electricity exists in the Netherlands, so parts of the refurbishment cost shall be covered by earnings from PV and decreased energy cost. Moreover, the cost for future refurbishments shall be further reduced. The cost of retrofitting have already decreased over the period from 2010 to 2013 as shown in Fig. 47.
The idea of the Energiesprong is to generate a massive demand for these net zero energy retrofitting projects and to make financers and governments tune their funding and subsidy schemes and regulations towards these type of refurbishments. This shall lead to an innovation process in the Dutch building industry and to a decrease of fossil fuel applications. Within the framework of the Energiesprong project, also technology evaluations and analysis of user satisfaction have been carried out. In some of the new and refurbished buildings there is often a dissatisfaction due to the summerly overheating. Therefore, different measures for energy-efficient cooling by night-time ventilation or by ground-coupling have been applied. Besides the Netherlands, the concept shall also be applied in France and the UK in order to spread the experience of the Netherlands to other European countries.

3.4.3 Long-term monitoring of nZEB office buildings in Germany

The Fraunhofer ISE in Freiburg performs a long-term monitoring in 16 nZEB office buildings and schools. The buildings have an energy reference area of 1,000 m²-17,400 m² and are equipped with heat pumps. The majority of room emission systems are TABS. The evaluation is made according to five different system boundaries from the source over the heat pump up to the overall system. Fig. 48 left shows the evaluation for the space heating mode containing the seasonal performance factors (SPF) in the boundary of the heat pump and boundary II, which comprises the heat pump including the source pump. The SPF (including the source pump) in heating mode are in the range of 2.9-6.1 kWh_{th}/kWh_{el}.

In case of higher sink temperatures than required, problems with hydraulic integration could be identified, e.g. the integration by a common storage for emission systems with different supply temperature requirement.

The difference between the green and blue diamonds in Fig. 48 left depicts the difference in SPF caused by the source pump. Thus, auxiliary energy can have a substantial impact on the SPF, and the hydraulic design should be undertaken carefully. The auxiliary energy fraction of the source system is in the range of 6-25% of the total energy use, which demonstrates the optimisation potential of the hydraulic system design.

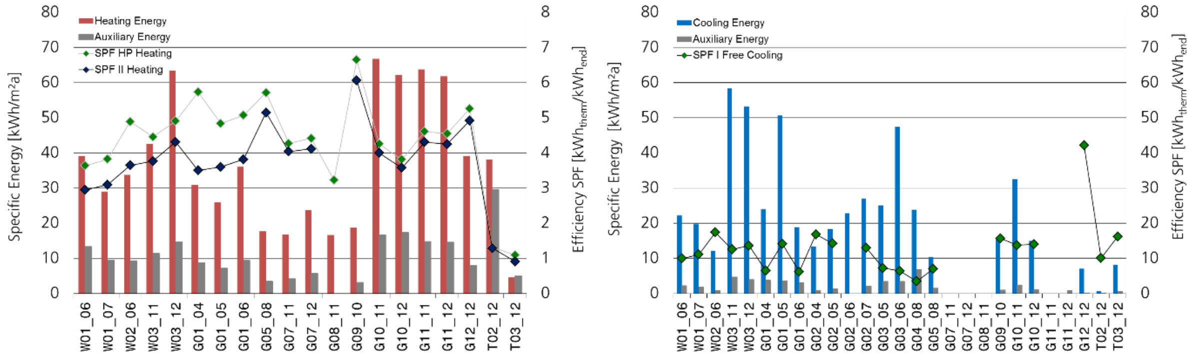

Fig. 48: Heating energy, auxiliary energy and SPF in space heating mode (left) and cooling energy, auxiliary energy and SPF in free-cooling mode (right) for monitored low energy office buildings in the German long term monitoring (Kalz et al., 2015)

Fig. 48 right shows the SPF I in the boundary of the source system in cooling mode, i.e. the performance of a free-cooling operation is depicted. The degree of coverage in free-cooling mode of 40-80% is reached. The seasonal performance factors are in the range between 3.5 and 42.1 kWh_{th}/kWh_{el} as depicted as green diamonds in Fig. 48 right.

On the other hand, also 16-56% of active cooling by reverse operation of the heat pumps were registered in systems with lower supply temperature requirements below 15 °C for the cooling operation. The respective seasonal performance factors of the heat pump in active cooling mode are in the range of 2.1 to 5.0 kWh_{th}/kWh_{el}.

3.5 Task 4: Integration of nZEB into the energy system

With the local energy production at the building site, the building gets a new role in the energy system. Besides the sole energy consumption, the building also acts as an energy producer what is often called a "prosumer". By the installed energy storages and the building structure, the building can furthermore also store energy. In the future nZEB will get more widespread and can provide operation reserve for the so-called intelligent (smart) electricity grid. Therefore, the integration of nZEB into the connected energy grids gets an increasingly important aspect.

Within the framework of Task 4, options of load management to optimise the self-consumption of the generated PV-electricity were analysed both in simulations and as evaluation of field monitoring projects.

3.5.1 Evaluation of self-consumption in Swiss field monitoring projects

In two Swiss monitoring projects evaluations of self-consumption were performed. The options to increase local energy by load shifting have been investigated. Fig. 49 left shows the evaluated load shifting options in a MINERGIE-P-Eco® certified small multi-family plus energy building in Rupperswil. The all-electric building includes three apartments with an energy reference area of 396 m². The building is equipped with a 20 kW_p solar PV system (projected annual yield of 18,000 kWh/(m²a)) and an 8.9 kW B/W heat pump which uses a 180 m deep borehole heat exchanger as source. The heat pump with an electricity amount of about 27%, the shared electric car, which can be rented by the inhabitants or via a car-sharing service, and the dish washer with around 5% were identified as shiftable loads. By these load shifting option, mainly from the heat pump, a rise in the self-consumption of 10-15% could be evaluated, reaching a self-consumption of more than 30%, which is a good value for residential use.

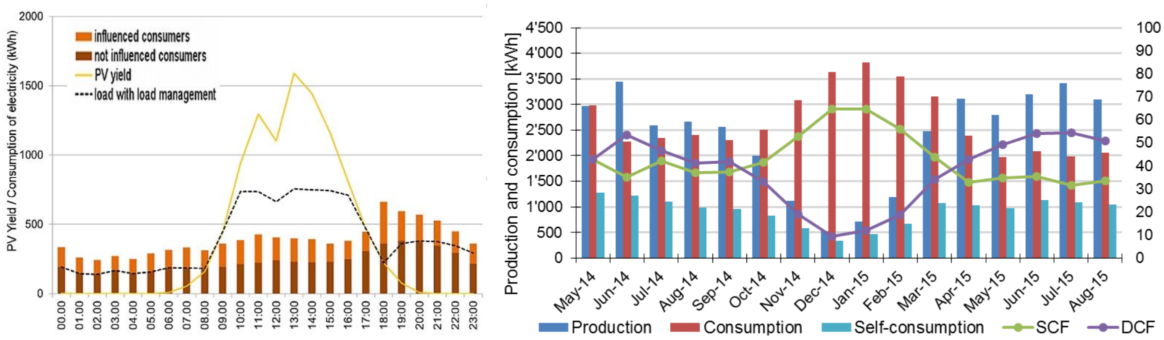

Fig. 49: Load shift in a multi-family building in Rupperswil (Dorusch et al, 2014) and demand and supply cover factor of the MINERGIE-A® building with office use in Uster (Hässig et. al, 2015)

Another evaluation of the self-consumption was accomplished at a MINERGIE-A® certified building in the centre of Uster. The building is one of the first MINERGIE-A® certified buildings with mixed residential and office use and is therefore used as a pilot project to further develop the MINERGIE-A® label for non-residential buildings. The energy reference area of the office part is around 30% of the whole energy reference area. The core component of the building technology is a 33.1 kW heat pump (at test point B0/W35) for space heating and DHW, which uses 11 boreholes of 79 m depth as source, and a 23.9 kW_p PV system. The evaluation of the first year of operation results in a MINERGIE-A® weighted delivered energy balance of -7.9 kWh/(m²a), which means the net zero energy balance regarding the building technology is surpassed. The SPF for the year 2015 has reached a value of about 4.3, the free-cooling operation in summer an SPF around 15. Potentials for optimisation have been identified by the field monitoring, so an increase of the seasonal performance factor in the second year of operation is expected. The office use is also interesting regarding the self-consumption due to a good load match of the PV production and office working hours during the day, which leads to self-consumption around 40% without particular load match measures. Fig. 49 right shows the monthly energy values of consumed and produced energy and the evaluation of the supply cover factor and demand cover factor on a monthly basis.

4 Conclusions

Nearly or Net Zero buildings, respectively, are the target in political strategies for the next generation of high performance buildings. Heat pumps are already integrated in building concepts of built nZEB. The energy balance for smaller residential buildings is mostly met by PV-systems, in larger residential buildings and office buildings, district heating and CHP are used, as well.

Although there are already several hundreds of nZEB built, most of them are built as prototypes and pilot and demonstration (P&D) projects with an extensive building technology and partly over-dimensioned building technology and PV-generators in order to meet a nearly zero energy balance and gain experience with the operation of the building or evaluate specific technologies.

Furthermore, there is no consistent definition of nZEB, yet, and therefore, a certain range of ambition levels concerning requirements for generated energy for the balance exists. Hence, these pilot buildings are not optimised regarding design of the components and cost, and tend to be still expensive buildings due to the use of PV.

As archetype of built nZEB, so called “All Electric Buildings”, that only use electricity as delivered energy, have established on the market. The heating systems in these buildings are heat pumps, i.e. heat pumps combined with PV systems are already a kind of standard combination.

In Annex 40, heat pump concepts for nearly zero energy applications were analysed in the framework of case studies and monitoring projects. Moreover, prototype technologies were tested in laboratory tesing and field monitoring. By these results the technologies have been further developed.

The results of simulations as well as field experience confirm that heat pumps reach a good performance for the application in nZEB and are favourable regarding to life-cycle cost compared to other heat generator technologies. Moreover, besides household electricity, heat pumps are the biggest electricity consumer in the building, which leads to the opportunity of a higher self-consumption of on-site PV-electricity by adapted operation times of the heat pump.

In Annex 40, also the development of design tools for heat pumps in nZEB have been started, although these developments have not been finished, yet. Furthermore, some development potentials regarding cost-optimised systems as well as improved self-consumptions have been identified. An improvement of on-site electricity use can be achieved by load shifting and storage integration, which was evaluated by simulations and field measurements.

An additional criterion for future building technology is the possible self-consumption and the thereby provided flexibility for the connected energy systems, respectively. Further research of the design regarding the impact on performance, costs and flexibility of the building system technology should assess these aspects to derive cost-optimised system solutions, which are also capable to perform system services in order to work in synergy with the connected energy grids. In this sense, the requirements to future system technology may get wider and more complex and heat pumps may enable grid-supportive operation due to link electric and thermal infrastructure for a flexible operation of the building technology. Under these boundary conditions, an integration of storage systems – with the prognosticated cost degression in the future eventually also electric storage systems – and solar technologies can yield further performance and cost advantages.

The results of the IEA HPT Annex 40 are summarised in four final reports. Reports and further information on the Annex 40 work are found on the project website at http://www.annex40.net.

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6 Abbreviations

A/W ... Air to Water
AAHP ... Air-to-Air Heat Pump
AC ... Air-Conditioning
ASHP ... Air-Source Heat Pump
B/W ... Brine to Water
CC XXHP ... Cold Climate XX Heat Pump
CEEE ... Center of Environmental Energy Engineering
CEN ... Comité Européen de Normalisation
CFD ... Computational Fluid Dynamics
CMHC ... Canda Mortgage and Housing Corporation
COP ... Coefficient of Performance
DH ... Dehumidification
DHW ... Domestic Hot Water, Domestic Hot Water
DOE ... Department of Energy
EAHP ... Exhaust Air Heat Pump
ECBCS ... Energy Conservation in Buildings and Community Systems
EHPA ... European Heat Pump Association
EnEV ... Energieeinsparverordnung
EPA ... Environmental Protection Agency
EPBD ... Energy Performance of Buildings Directive
EPC ... Energy Perfomance Coefficient
FhG-ISE ... Fraunhofer Insititute for Solar Energy Systems
GHP ... Gas Engine-Driven Heat Pump
GSHP ... Ground-Source Heat Pump
HERS ... Home Energy Rating System
HEX ... Heat Exchanger
HPT ... Heat Pumping Technologies
HVAC ... Heating Ventilation and Air Conditioning
IEA ... International Energy Agency
IHP ... Integrated Heat Pump
LPG ... Liquified Petroleum Gas
NIST ... National Institute of Standards and Technology
nZEB ... nearly Zero Energy Building
NZEB ... Net Zero Energy Building
NZEP ... Net Zero Emission Programme
ORNL ... Oak Ridge National Laboratory
PMV ... Predicted Mean Vote
POD ... Proper orthogonal decomposition
PPD ... Predicted Percentage of Dissatisfied
PV ... Photovoltaics
REHVA ... Federation of European Heating, Ventilating and Air-conditioning Associations
RER ... Renewable Energy Ratio
SC ... Space Cooling

SFOE .... Swiss Federal Office of Energy
SH .... Space Heating
SHC .... Solar Heating and Cooling
SPF .... Seasonal Performance Factor
TABS .... Thermally-Activated Building Systems
THIC .... Temperature and Humidity individual Control
WH .... Water Heating
ZEH .... Zero Energy House

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A. Appendix

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A.2 State of definition in EU-member states

					nZEB definition for new buildings						nZEB definition for existing buildings		
Country	Status of the definition	Main reference(s)	Year of enforcement		EPBD scope of nZEB definition [1]	Numerical indicator	Maximum primary energy [kWh/m²y]		Share of renewable energy	Other indicators	Status of the definition	Maximum primary energy [kWh/m²y]	
			Public	Non-public			Residential buildings	Non-residential buildings				Residential buildings	Non-residential buildings
Austria	✓	OIB Guidelines 6	1/01/2019	1/01/2021	✓ [7]	✓	160	170 (from 2021)	Minimum share proposed in the draft of OIB guidelines for all buildings	EP, CO_2	✓	200	250 (from 2021)
Belgium - Brussels	✓	Amended Decree of 21/12/2007	1/01/2015	1/01/2015	✓	✓	45	~90 [2]	✓ Qualitative	EP, OH	✓	54	~ 108 [2]
Belgium - Flanders	✓	Regulation of 29/11/2013	1/01/2019	1/01/2021	✓	✓	30% PE [5]	40% PE [5]	✓ Quantitative [4]	EP, OH	Under development		
Belgium - Wallonia	Under development	Consolidated report to EC	1/01/2019	1/01/2019	✓	Under develop-ment			Quantitative	EP	Under development		
Bulgaria	Still to be approved	National nZEB Plan, BPIE study	1/01/2019	1/01/2021	✓	Still to be approved	~30-50 Included in the calculation; building needs to comply with class A	~40-60	Quantitative	EP	As for new buildings	~30-50 Included in the calculation; building needs to comply with class A	~40-60
Croatia	✓	Regulation OG 97/14, National nZEB Plan	1/01/2019	1/01/2021	✓	✓	33-41[3]	Under de-velopment	Minimum share in current requirements for all buildings	EP	ND		
Cyprus	✓	Decree 366/2014, Law 210(I)/2012	1/01/2019	1/01/2021	✓	✓	100	125	✓ Quantitative	EP	✓ As for new buildings	100	125
Czech Republic	✓	Regulation 78/2013 Coll.	2016-2018 depending on size	2018-2020 depending on size	✓	✓	75-80% [2,5]	90% [5]	✓ Quantitative	EP, TS	✓ As for new buildings	75-80% [2,5]	90% [5]
Denmark	✓	Building Regulations 2010	1/01/2019	1/01/2021	✓	✓	20	25	✓ Qualitative	EP, OH, TS	✓ As for new buildings	20	25
Estonia	✓	Regulation 68:2012	1/01/2019	1/01/2021	✓ [7]	✓	50-100 [2]	90-270 [2]	✓ Qualitative		✗		
Finland	Under development	Consolidated report to EC	1/01/2018	1/01/2021	✓ [7]	ND			ND		ND		
France	Definition of Positive Energy Buildings under development [8]	Thermal Regulation 2012, National nZEB Plan	28/10/2011	1/01/2013	✓	✓	40-65 [2,3]	70-110 [2,3]	✓ Quantitative [4]	EP, OH, TS	✓	80 [3]	60% PE [2]
Germany	Under development	KfW Efficiency House, National nZEB plan	1/01/2019	1/01/2021	✓	Under develop-ment	40% PE [5]		Minimum share in current requirements for all buildings	EP	Under development	55% PE [5]	
Greece	Under development	Law 4122/2013	1/01/2019	1/01/2021	ND	ND			Minimum share in current requirements for all buildings		Under development		
Hungary	Under development	Amended decree 7/2006, study by University of Debrecen	1/01/2019	1/01/2021	✓	Under develop-ment	50-72 [2]	60-115 [2]	✓ Quantitative	EP	Under development		
Ireland	✓	Draft definition in National nZEB Plan	1/01/2019	1/01/2021	✓	✓	45	~60% PE [5]	✓ Quantitative [4]	CO_2	Under development	75-150	

					nZEB definition for new buildings						nZEB definition for existing buildings		
Country	Status of the definition	Main reference(s)	Year of enforcement		EPBD scope of nZEB definition [1]	Numerical indicator	Maximum primary energy [kWh/m²y]		Share of renewable energy	Other indicators	Status of the definition	Maximum primary energy [kWh/m²y]	
			Public	Non-public			Residential buildings	Non-residential buildings				Residential buildings	Non-residential buildings
Italy	Still to be approved (under publication)	Draft of the new EPBD decree	1/01/2019	1/01/2021	✓	Still to be approved	Included in the upcoming updated version of the National nZEB Plan [2,3]		Quantitative	EP, TS	✓ As for new buildings	Included in the upcoming updated version of the National nZEB Plan [2,3]	
Latvia	✓	Regulation 383/2013	1/01/2019	1/01/2021	✓	✓	95	95	✓ Quantitative	EP	✓ As for new buildings	95	95
Lithuania	✓	Regulation STR 2.01.09 :2012	1/01/2019	1/01/2021	✓	✓	Included in the calculation; building needs to comply with class A++		✓ Quantitative	EP	✓ As for new buildings	Included in the calculation; building needs to comply with class A++	
Luxembourg	✓ Details to be fixed	National nZEB Plan	1/01/2019	1/01/2021	✗ [6]	✓	Included in the calculation; building needs to comply with class A-A-A		✓ Qualitative	EP, CO_2	ND		
Malta	Under development	National nZEB Plan	1/01/2019	1/01/2021	✓	Current values to be revised	40	60	Qualitative	EP	ND		
Netherlands	✓	National nZEB Plan	1/01/2019	1/01/2021	✓	✓	Included in the calculation; building needs to comply with energy performance coefficient = 0		✗	EP	ND		
Norway	Under development	Presentation by Research Centre on Zero Emission Buildings	1/01/2021	1/01/2021	✓	Under development			Minimum share in current requirements for all buildings	CO_2 (main indicator), EP, TS	ND		
Poland	Under development	Consolidated report to EC	1/01/2019	1/01/2021	✓	Under development	60-75 [2]	45-70 [2]	✗		ND		
Portugal	Under development	Law 118/2013	1/01/2019	1/01/2021	✓	In current requirements for buildings			✗		ND		
Romania	✓	National nZEB Plan	1/01/2019	1/01/2021	✓	✓	93-217 [2,3]	50-192 [2,3]	✓ Quantitative	CO_2	ND		
Slovakia	✓	Decree 364/2012	1/01/2019	1/01/2021	✗ [6]	✓	32-54 [2]	34-96 [2]	✓ Quantitative	EP	ND		
Slovenia	Still to be approved	Official Journal 17/14, National nZEB Plan	1/01/2019	1/01/2021	✓	Still to be approved	45-50 [2]	70	Under development	EP	Still to be approved	70-90 [2]	100
Spain	Under development	Decree 235/2013	1/01/2019	1/01/2021	✓	Under development	Included in the calculation; it is foreseen that buildings will need to comply with class A		Minimum share in current requirements for all buildings	CO_2 (main indicator)	Under development		
Sweden	Under development	National nZEB Plan	1/01/2019	1/01/2021	✓	Under development	30-75 [2,3]	30-105 [2,3]	✗		ND		
UK (England)	✓ Details to be fixed	National nZEB Plan, presentation by Zero Carbon Hub	1/01/2018 (from 2016 for residential buildings) [9]	1/01/2019 (from 2016 for residential buildings) [9]	✓	✓	~ 44 (2) Included in the calculation; building will need to comply with carbon emissions ~ 0	ND	✓ Qualitative	CO_2 (main indicator), EP, TS	ND		

Fig. A 1: Definition criteria of nZEB in the EU member states ((BPIE, 2015)

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