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Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 49

State of the Art of heat pump application in nZEB

Final Report Part 1

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December 2020
Report no. HPT-AN49-2

Published by Heat Pump Centre
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Production Heat Pump Centre, Borås, Sweden

ISBN 978-91-89385-28-3
Report No. HPT-AN49-2

Preface

This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), which is a Technology Collaboration Programme 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 nearly 40 Technology Collaboration Programmes.

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The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the implementing agreement for a programme of research, development, demonstration and promotion of heat pumping technologies. 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.

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The HPT TCP is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programmes or TCPs. The TCPs are organised under the auspices of the International Energy Agency (IEA), but the TCPs are functionally and legally autonomous. Views, findings and publications of the HPT TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

The 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 accelerate the implementation of heat pump technologies and thereby optimise the use of energy resources for the benefit of the environment. This is achieved by offering a worldwide information service to support all those who can play a part in the implementation of heat pumping technology including researchers, engineers, manufacturers, installers, equipment users, and energy policy makers in utilities, government offices and other organisations. Activities of the HPC include the production of a Magazine with an additional newsletter 3 times per year, the HPT TCP 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 Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) 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 49

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Design and Integration of heat pumps for nearly Zero Energy Buildings

Report Annex 49 part 1 State of the Art

Final Report IEA HPT Annex 49 part 1

State of the Art of heat pump application in nZEB

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December 2020

International Energy Agency
Heat Pumping Technologies

Imprint

IEA HPT Annex 49 "Design and integration of Heat pump for nearly Zero Energy Buildings"

The work presented here is a contribution to the Annex 49 in the Heat Pumping Technologies (HPT) Technical Collaboration Programme (TCP) of the International Energy Agency (IEA)

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Abstract

The IEA HPT Annex 49 "Design and integration of heat pumps for nearly Zero Energy Buildings" deals with the heat pump application as core component of the HVAC system for nearly or Net Zero energy buildings (nZEB/NZEB) and is structured in the following Tasks:

- Task 1. State of the art in different countries
- Task 2: Integration options for multifunctional heat pumps in nZEB
- Task 3: Field monitoring of marketable and prototype heat pumps in nZEB
- Task 4: Design and control of integrated heat pumps for nZEB

This report summarises the results of the state of the art analysis in Task 1 and gives an overview on nZEB implementation on the national level of the participating countries.

As introduction the political framework with the respective EU Directives and different approaches to support a harmonised definition for the implementation of nZEB in the EU member countries states are given. Based on a 10-year transition period for nZEB implementation for all new buildings, the nZEB requirement will become the standard by Jan 1, 2021. Due to a rather vague definition of an nZEB in the EPBD, different harmonisation initiatives published a definition of nZEB with the intention to harmonise the implementation of nZEB in the EU member states. REHVA and CEN published a definition and system boundaries for an nZEB rating. A similar definition has been published in the USA by the DOE. CEN additionally supported the nZEB implementation with an nZEB rating procedure and a set of standard for the energy calculations, which are currently also transferred to ISO level. The EU has made amendments of guidelines regarding cost-optimality and published benchmarks as orientation of the expected ambition level.

However, the implementation of the participating countries Austria, Germany, Norway, Sweden and Switzerland, which is analysed and described in more detail, confirms, that the implementation in the single participating countries differs in terms of system boundaries, criteria and limits for the nZEB rating, which is also backed-up by other comparative studies. Thereby, the ambition level to achieve a high energy performance in the new built sector is hard to compare, which is additionally hindered due to different calculation methods and different boundary conditions used in the single countries. Therefore, a methodology to compare the ambition level across different countries has been developed using building and system simulation and tested for the countries Germany, Austria and Switzerland for a single family house. The method transforms a standard single family house to the national nZEB according to the national implementation and then back to common boundary conditions. Compared to a reference building, a methodology allows a relative comparison among nZEB implementations, which show significant difference among the countries. While some countries make a step forward to higher energy efficiency and are actually approaching a nearly zero energy consumption, other countries stay virtually on the same level as before. However, the methodology has only been tested for single family buildings and heat pump heating systems. Based on the strong differences in the results, the method should be further developed to cover other building use and shall be tested for different heating systems in order to enable a more general evaluation.

Furthermore archetype concepts for nZEB are described, and upcoming technologies used in nZEB are linked to the Annex 49 contributions. As outlook, an overview of high performance building labels is given. As general conclusion heat pumps are already well establish in nZEB building concepts and are seen as a key technologies for nZEB. On the other hand, the introduction of nZEB will promote heat pump markets also for the application in larger buildings in order to reach ambitious energy requirements. Moreover, integration of storage and adapted controls can notably improve self-consumption and grid-supportive operation. However, larger storage design for higher energy flexibility is mostly not economic for the owner at current market conditions. These results are confirmed by the investigation of Annex 49 contributions and described in detailed in the other parts of the Annex 49 reports on field monitoring, prototype developments and accompanying simulation studies.

Contents

1 Introduction to nZEB

1.1 Political background

1.1.1 EU-energy strategy and related EU directives in Europe

In 2007 the EU published the so-called 20-20-20 by 2020 strategy referring to 20 % less CO_2-emissions, 20 % enhanced energy efficiency and 20 % renewable energy share to be reached by the year 2020.
In order to implement the strategy three EU-Directives and a Guideline have been published

- **EU Directive on the Energy Performance of Buildings (EPBD recast, 2010, latest update 2018)**

  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 (ErP Directive), European Parliament (2009), also known as Ecodesign Directive)**

  The directive sets guidelines for product labelling, among others also heat generators and air-conditioner and thermal storages. The motivation is to make the EU products top runners in energy efficiency. Different product groups are organised in so-called lots and were successively labelled. Since Sept. 2015 EU member states are required to introduce an eco-design labelling also for heat generators up to 70 kW. Thereby, different efficiency limits for the different heat generators have been introduced in the first step, and also combination of heat generator can be labelled as package, e.g. a combination of a boiler with solar thermal collector. The efficiency requirement will be periodically revised and tightened, and products not fulfilling the requirements will be banned from the market. Heat pumps are ranked among most efficient heat generators.

- **EU Directive on the Promotion of Renewable Energy Use (RES-Directive, 2009, latest update 2018 denoted as RED II – Renewable Energy Directive)**

  The directive defines targets for renewable energy in the member countries. In the current RED II the overall EU target has been raised to 32% based on the 20% target in the previous RES directive. Moreover, in the RES-Directive of 2009, criteria and calculation methods which energies are considered renewable were defined. For heat pumps 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 in the EU.

- **Guidelines on cost optimal levels for nZEB (EC, 2012)**
  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.

The recast of the EPBD (2010) – current version EPBD (2018) - defines the requirement that from the beginning of 2021 all new buildings should be nearly Zero Energy Buildings (nZEB). More details of the time schedule for the introduction of nZEB in the member states of the EU is depicted in Figure 1. The contained definition of a nearly zero energy building, however, is quite vague, as it only states:

A nearly Zero Energy Building

- means a building with "***a very high energy performance***"
- ***Nearly 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***

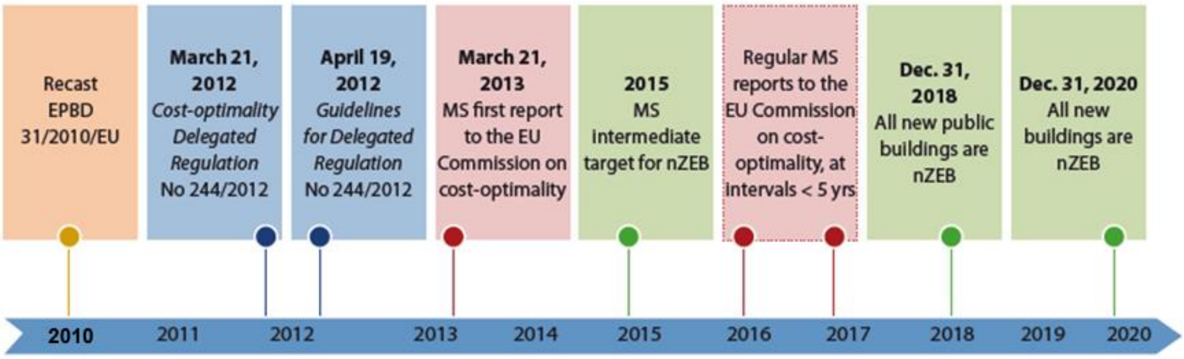


Figure 1: Time schedule for the implementation of nZEB (source: Atanasiu et al., 2013)

The marked parts of the statement are not clearly 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 have 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 initiatives 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 that should be contained in a complete and thorough definition of an nZEB.
In the common understanding, a 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 usually 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:

<u>Net Zero Energy Building (NZEB)</u>
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}yr). 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 balancing the energy is weighted, mostly with primary energy factors. The balance is thus achieved by energy generation under favourable boundary conditions, while energy is delivered from the connected sources otherwise.

<u>nearly Zero Energy Building (nZEB)</u>
nZEB hence is a "technically and reasonable achievable national energy use higher than zero kWh/(m^{2}yr), 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. 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 must be defined, which is currently the task of the EU Member states. Nevertheless, currently, definitions are quite different among the EU-member states. 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 in 5 groups, which are given in Figure 2, in conjunction with the basic concept of nZEB. To each item the options discussed for an implementation and the most common definition of the criteria is given, too.

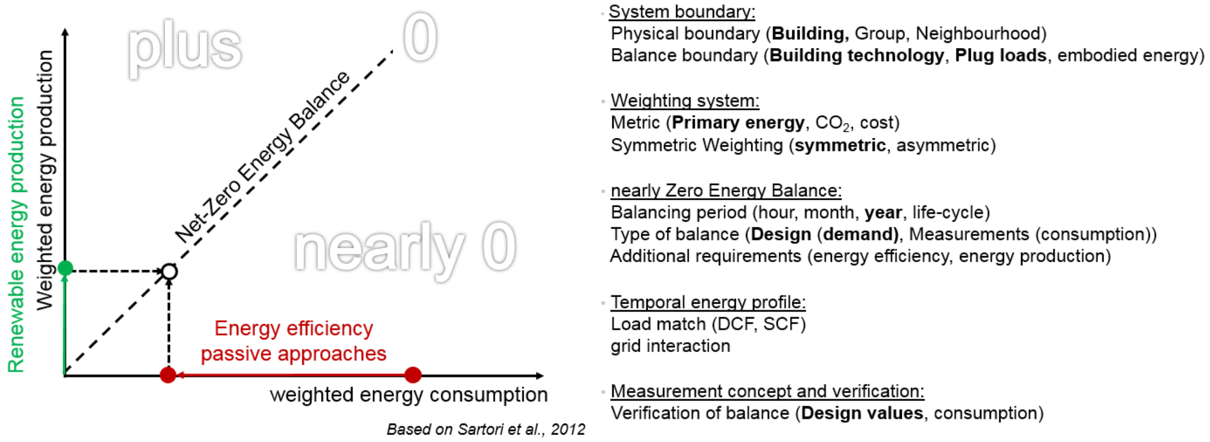


Figure 2: Criteria for a consistent definition of nZEB (according to Sartori et. al, 2012)

The different criteria are shortly described in the following. More details can be found in Sartori et al. (2012).

As a **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 the part of the energy taken into account in the balance.

Moreover, the type of building and boundary conditions concerning the site of the building in terms of weather data, and comfort levels have to be given. In Figure 3 different physical boundaries are depicted.

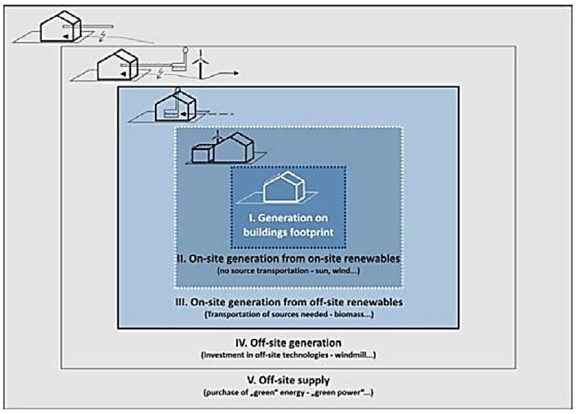


Figure 3: Different physical balance boundaries (Marszal et al., 2010)

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 the 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 the 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.
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 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 may also be reflected in time-dependent weighting in the future.
As a **third group of criteria** the definition should contains 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 solar 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 explicit 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 connect energy grids in order to work 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 heating, ventilation and air-conditioning engineering association REHVA has published a definition of nZEB in 2013 as an 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) – current version EPBD (2018).
Figure 4 shows the definition of the building physical boundary distinguished by 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 values of the EPBD recast and the respective CEN standard prEN 15603 (2013) is the area specific non-renewable primary energy consumption $E_{p,nren}$, which are calculated according to the following equations:

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

where

E_P - primary energy indicator [kWh/(m²yr)]

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

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

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

$f_{del,nren,i}$ - 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 [-]

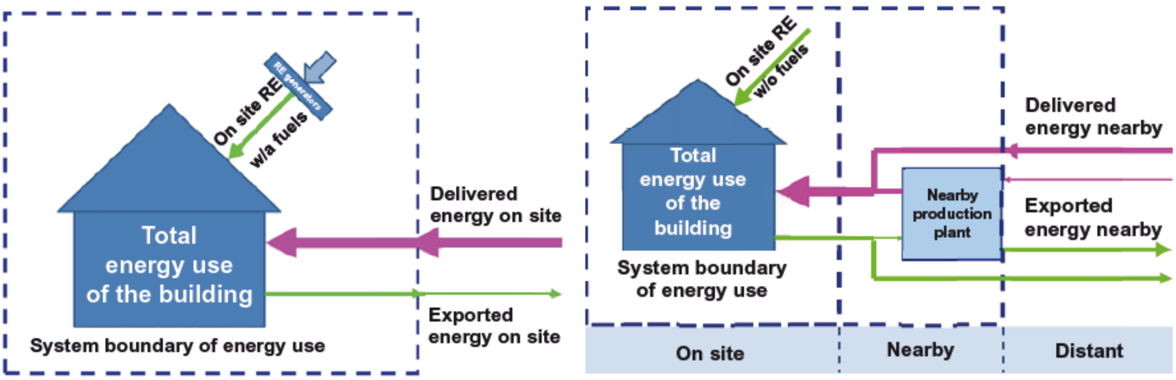


Figure 4: Physical boundary of the REHVA definition regarding on-site and nearby production (according to Kurnitski, 2013)

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.

"<u>Net Zero Energy Building (NZEB)</u>
Non-renewable primary energy of 0 kWh/(m² yr)."

"<u>nearly Zero Energy Building (nZEB)</u>
Technically and reasonably achievable national energy use of > 0 kWh/(m² yr), 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"

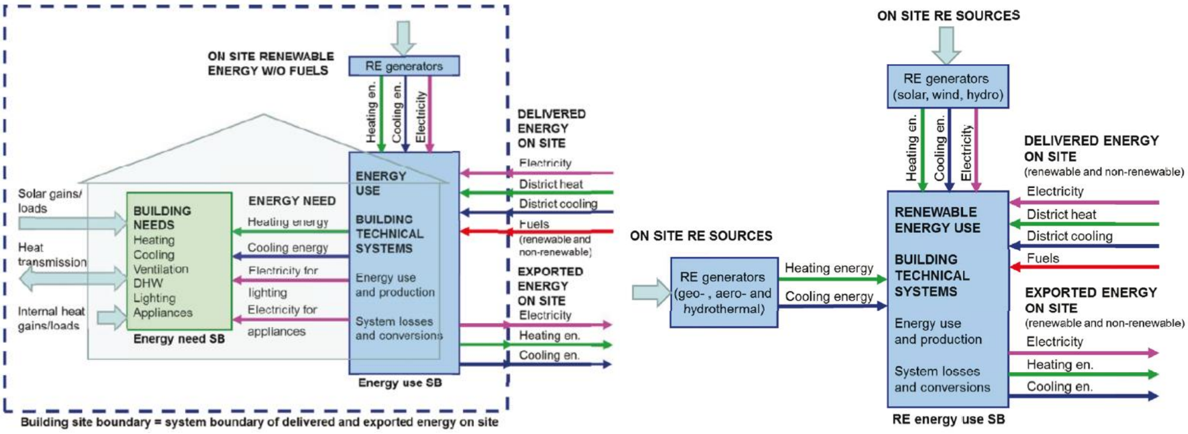


Figure 5: Detailed physical boundary of the REHVA definition and boundary for the calculation of renewable energy use (Kurnitski, 2013)

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).
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 current version of the overarching standard is EN ISO- 52000-1:2018, see chap. 1.2.4 The requirements for the rating consists of four steps, which are depicted as a hurdle race in Figure 6. Each of the single requirements has to be fulfilled to receive the nZEB rating, i.e. each hurdle has to be passed.
The first requirements is related to the building energy needs in terms of used energy, 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 system technology is set.

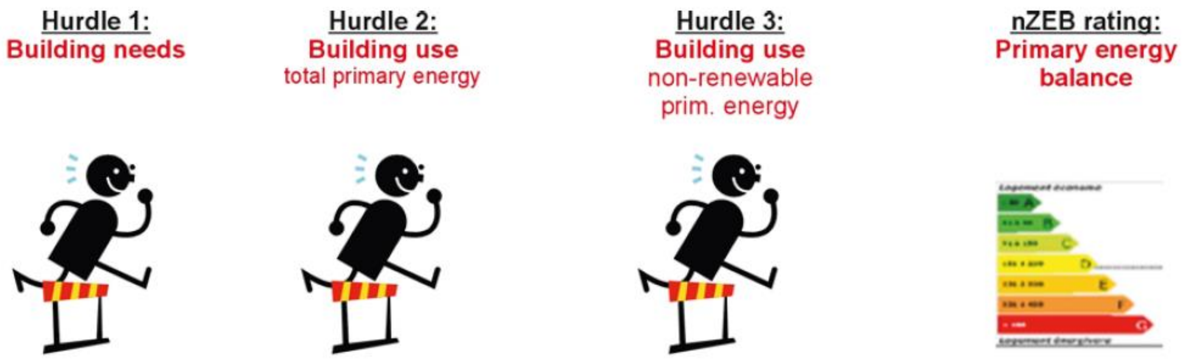


Figure 6: "Hurdle race" of the single criteria for nZEB rating and certification according to prEN 15603:2013 (Zirngibl, 2014)

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 consumption is allowed to be rated as a 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.

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" (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 an annual balance of imported and exported primary energy, denotes as source energy in the US. The definition is similar to the REHVA nearly Zero Energy Building (nZEB) definition. For a clear understanding about imported and exported energy, Figure 7 shows the site boundary of the definition.

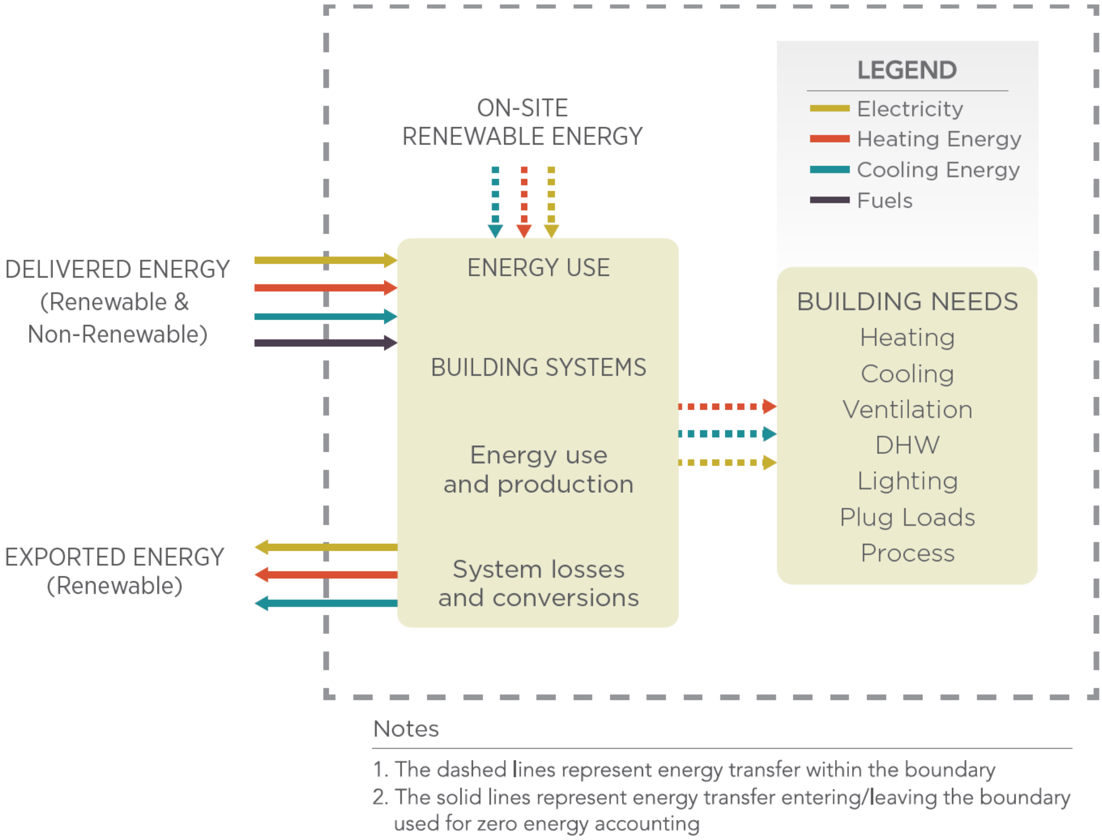


Figure 7: Site boundary of energy transfer for zero energy accounting (source: Peterson et al., 2015)

As seen, the ZEB energy accounting includes energy used for heating, cooling, ventilation and DHW (indoor and outdoor) lighting, plug loads, and process energy. Also 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, the following equation is used:

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

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

Table 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.

Table 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 Accompanying CEN Standards for nZEB implementation

In order to support a harmonised implementation of the EPBD with common calculation methods and energy balancing, CEN was mandated to develop an update of the first set of EPBD standards published in 2008. A preliminary version of the overarching standard containing the nZEB rating was the prEN 15603:2013 already referred to in previous chapters. These standards are currently also elaborated on an ISO level. The overarching standard EN ISO 52000-1 of 2017 replacing the prEN 15603 outlines the basic definitions and procedure for nZEB rating. Despite these harmonisation approaches for common calculation methods and despite the obligation to implement EN standards into the national standardisation in the EU member states, currently still national calculation methods persist in many EU member states for the nZEB rating.

1.2.5 EU guideline on nZEB implementation

In 2016, the Commission developed guidelines for the promotion of nearly zero-energy buildings in order to ensure that by 2020, all new buildings are nearly zero-energy buildings (EC, 2016). In this document also benchmark values for office and residential applications of single family houses for four different climate zones across Europe are provided:

Projecting the 2020 prices and technologies, benchmarks for the energy performance of NZEB are in the following ranges for the different EU climatic zones ([32]):

Mediterranean:

— Offices: 20-30 kWh/(m^2.y) of net primary energy with, typically, 80 — 90 kWh/(m^2.y) of primary energy use covered by 60 kWh/(m^2.y) of on-site renewable sources;

— New single family house: 0-15 kWh/m^2.y) of net primary energy with, typically, 50-65 kWh/(m^2.y) of primary energy use covered by 50 kWh/(m^2.y) of on-site renewable sources;

Oceanic:

— Offices: 40-55 kWh/(m^2.y) of net primary energy with, typically, 85-100 kWh/(m^2.y) of primary energy use covered by 45 kWh/(m^2.y) of on-site renewable sources;

— New single family house: 15-30 kWh/(m^2.y) of net primary energy with, typically, 50-65 kWh/(m^2.y) of primary energy use covered by 35 kWh/(m^2.y) of on-site renewable sources; and

Figure 8: Benchmarks for different climate zones (source: EC, 2016)

Continental:

— Offices: 40-55 kWh/(m^2.y) of net primary energy with, typically, 85-100 kWh/(m^2.y) of primary energy use covered by 45 kWh/(m^2.y) of on-site renewable sources;

— New single family house: 20-40 kWh/(m^2.y) of net primary energy with, typically, 50-70 kWh/(m^2.y) of primary energy use covered by 30 kWh/(m^2.y) of on-site renewable sources;

Nordic:

— Offices: 55-70 kWh/(m^2.y) of net primary energy with, typically, 85-100 kWh/(m^2.y) of primary energy use covered by 30 kWh/(m^2.y) of on-site renewable sources;

— New single family house: 40-65 kWh/(m^2.y) of net primary energy with, typically, 65-90 kWh/(m^2.y) of primary energy use covered by 25 kWh/(m^2.y) of on-site renewable sources.

Member States are advised to use renewable energy sources in an integrated design concept to cover the low energy requirements of buildings ([33]).

([30]) See footnote 24.
([31]) Commission's mandate M/480 to CEN on the elaboration of EPBD standards.
([32]) In the study 'Towards nearly zero-energy buildings- Definition on common principles under the EPBD' (http://ec.europa.eu/energy/sites/ener/files/documents/nzeb_full_report.pdf), carried out by Ecofys for the European Commission, DG ENERGY:
— Mediterranean is referred to as Zone 1: Catania (others: Athens, Larnaca, Luga, Seville, Palermo)
— Oceanic as Zone 4: Paris (others: Amsterdam, Berlin, Brussels, Copenhagen, Dublin, London, Macon, Nancy, Prague, Warszawa)
— Continental as Zone 3: Budapest (others: Bratislava, Ljubljana, Milan, Vienna)
— Nordic as Zone 5: Stockholm (Helsinki, Riga, Stockholm, Gdansk, Tovarene).

Figure 9: Benchmarks for different climate zones (continued, source: EC, 2016)

2 Definition of nZEB in participating countries

In the following the nZEB implementation in the participating countries are given.

2.1 Austrian Implementation of EPBD (guideline OIB-6)

2.1.1 Introduction

The Austrian nZEB is defined in the Austrian Institute of Construction Engineering (OIB) Guideline 6 (Österreichische Institut für Bautechnik, 2019). The history of the nZEB implementation in Austria is summarized in the following:

2008-2013 Member in IEA-Joint Project
2014 Publication of the National Plan, Definition of nZEBs, Report on cost-optimality study
2015: Publication of OIB-Guideline 6:2015
2017: Ökostromnovelle
2018: Publication of the Revision of the National Plan, Update of the report on cost-optimality
2019 Revision OIB-6, H5050, H5056, B8110-5, etc.

The previous versions of OIB-6 were published in 2015, 2011 and 2007. Detailed methods and boundary conditions used in OIB-6 are defined in related standards and documents, which were also updated in 2018 and 2019. Here, the most relevant official documents with the year of their publication (current and previous version) are listed:

- OIB-6: 2019, 2015, 2011, 2007
- National Plan: 2018, 2014
- H5056: 2019, 2014
- H5050: 2019, 2014
- B8110-5: 2019, 2011
- B8110-6: 2019, 2014

The work within the framework of IEA HPT Annex 49 started in 2017. The OIB-6:2019 guideline was published in the second half of 2019 and the implementation in the national calculation tools (i.e. GEQ) was available only in spring 2020. Therefore, in this report for the calculations of the case studies (Appendix A) the OIB-6:2015 applies, and changes that came with the version 2019 are reported in the general part. The overall conclusions should remain valid. However, some specific results might be subject to change.
During the planning of a new building, it has to be checked whether the application of an alternative energy system (i.e. heat pumps, district heating and biomass) is feasible from a technical, ecological and economic point of view.
The present national report focuses on new residential and non-residential buildings with electric heating and heat pumps. Therefore, only the requirements and results regarding these cases are presented.

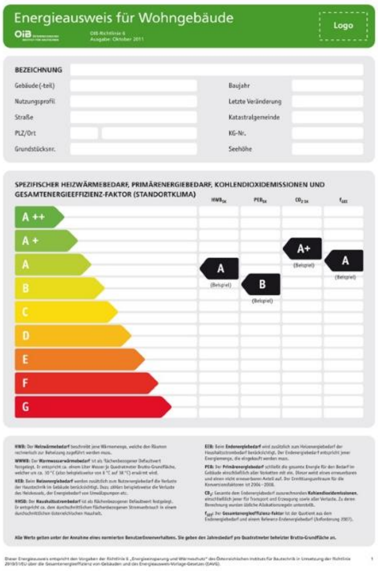
2.1.2 Austrian Energy Certificate

The Austrian Energy Certificate distinguishes residential and non-residential buildings. An example of a certificate for residential buildings is shown in Figure 10 left. The following informative performance indicators are shown for the site climate

- Heating demand (HWB)
- Primary energy demand (PEB)
- CO_2
- Total energy efficiency factor f_{GEE}

The site climate (SK) is specified in B8110-5 (2019), which distinguishes 7 climatic zones and a temperature correction with respect to the height above sea level is considered. The indicators are described in detail in the sections below. The classes for the performance indicators are given in Figure 10 right top. All specific indicators are related to the gross floor area (GFA). Each indicator is classified separately.

The heating demand $HWB_{Ref,SK}$ is the heating demand for the building calculated with the site climate (SK) and Ref indicates the heating demand assuming ventilation according to a residential building and without possible mechanical ventilation with heat recovery (MVHR). Thus, the class A++ cannot be achieved in reality. A class A++ building with MVHR would be a zero space heating building.



Class	$HWB_{Ref,SK}$	PEB_{SK}	$CO_{2eq,SK}$	$f_{GEE,SK}$
	[kWh/m²a]	[kWh/m²a]	[kg/m²a]	[-]
A++	10	60	8	0,55
A+	15	70	10	0,70
A	25	80	15	0,85
B	50	160	30	1,00
C	100	220	40	1,75
D	150	280	50	2,50
E	200	340	60	3,25
F	250	400	70	4,00
G	> 250	> 400	> 70	> 4,00

Classes	HD	DHW	H+ DHW	WHP+ AUX	APP	$W_{el,tot}$	PE_{tot}	CO_2
	[kWh/(m²$_{GFA}$ a)]							[kg/(m²$_{GFA}$ a)]
A+	15	7.7	22.7	9.1	13.9	23.0	30.3	5.2
A	25	7.7	32.7	13.1	13.9	27.0	35.6	6.1
B	50	7.7	57.7	23.1	13.9	37.0	48.8	8.4

Figure 10: Example of Austrian Energy Certificate for Residential buildings (left) and classes for the performance indicators for the energy certificate (top, OIB-6:2019) as well as simplified comparison of the classes for PE and CO_2 or a heating demand (HD) A+, A and B single family house with A/W-heat pump with a system performance of SPF_{sys} = 2.5, electricity conversion factors for PE and CO_2 according to OIB-6:2019 (bottom)

The primary energy demand as well as the CO_2-emissions include appliances/operational energy.

A simple example of a residential building (SFH) reveals that the classes are – at least for the application of heat pumps – not consistent. From 2021 on SFH must meet at least the requirement of heating demand lower than 50 kWh/(m² yr) for the reference climate, so new buildings must be at least class B.

Hence, assuming a building with a heating demand of 15 kWh/(m² yr) (A+), 25 kWh/(m² yr) (A) or 50 kWh/(m² yr) (B), with an air-to-water heat pump with system seasonal performance factor (including auxiliaries) of 2.5 (e.g. a moderately performing A/W heat pump) and the standard assumptions for domestic hot water and appliances as applying in OIB-6:2019 the following performance indicators are obtained: All buildings would be A++ buildings in terms of PE, the HD class A+ and A building would be a class A+ building concerning CO_2 and the B building would be a class A building concerning CO_2. From 2021 on, all buildings would need to be class A+ buildings with respect to f_{GEE}, while they can still be class B buildings with respect to the heating demand. The comparison in given in Figure 10 right bottom.

2.1.3 Austrian definition of nZEB

The Austrian nZEB definition, given in OIB-6 and in the so-called National Plan, takes into account the Austrian reference conditions (RK: reference climate) and is based on numerical indicators for heating demand, final energy demand and renewable energy sources.

2.1.4 Boundary conditions

2.1.4.1 Climate

The building in the energy certificate is evaluated always with two climates, the reference climate (RK) and the site climate (SK). ÖNORM B 8110-5 specifies the monthly temperature and solar radiation of the reference climate and distinguishes between 7 site climates. The site climate temperature is corrected by the height above sea level. The reference climate

represents an average of the Austrian climate, while the site climate is characteristic for each site.
As an example, Figure 11 shows the comparison between the external temperature according to the reference climate (Referenzklima) and according to the site climate (Standortklima) for Innsbruck (570 m above sea level) for B8110-5:2015 and B8110-5:2019.

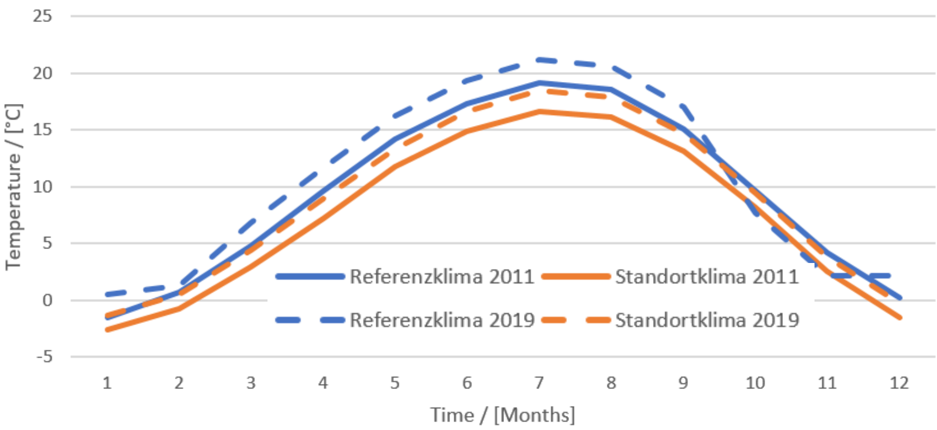


Figure 11: Monthly average values of the external temperature: comparison between the reference climate (Referenzklima) and the site climate (Standortklima) for Innsbruck (height above sea level of 574 m). Values according to standards B8110-5:2011 and B8110-5:2019

The external temperature according to the reference climate is on average around 2 K higher than the site climate for Innsbruck. Temperatures of the reference climate according to B8110-5:2019 are 2 K higher than in the previous versions of the norm.
This was changed to account for the increased temperatures during the last decade. Site climate temperatures according to B8110-5:2019 are on average 1.5 K higher than the values in 2011. Solar radiation was not changed. The annual solar radiation on the horizontal is 1102.2 kWh/m^2 for the reference climate and 1095.4 kWh/m^2 for the site climate.

2.1.4.2 Indoor temperature and internal gains

The indoor temperature and internal gains are also defined in the ÖNORM B8110-5:2019. The indoor temperature is now 22 °C for all the building typologies. In the previous versions (B 8110-5:2011), a temperature of 20 °C was considered for the residential sector. Internal gains depend on the type of building and are specified in Table 4 to Table 8 of B8110-5:2019.

2.1.5 nZEB requirements

To reach the Austrian nZEB requirements the following limits have to be fulfilled:

- U-values (building physics constraint)
- space heating demand depending on the characteristic length and on
- either total energy efficiency factor or final energy demand (so-called “dual path”, see below)
- renewable sources of energy (on-site or nearby)

In the following sections, the requirements are described in detail.

2.1.5.1 Overall heat transfer coefficients (U-values)

For building physics constraints, maximum U-values of walls, doors and windows are limited. The value depends on the typology of the construction. Detailed values according to OIB-6:2019 are shown in Table A 17 in the Appendix.

2.1.5.2 „Dual path“

The Austrian nZEB definition allows the so-called dual path, i.e. it is possible to choose between two different paths:

- “f_{GEE} path”: requirements on the space heating demand (HWB [kWh/(m^{2}yr)]) and on the total energy efficiency factor (f_{GEE} [-]).
- “EEB path”: stricter requirements on the space heating demand (HWB [kWh/(m^{2}yr)]) and on the final energy demand (EEB [kWh/(m^{2}yr)]).

The basic idea of the dual path is that a nearly zero energy building can be realized by either improving the thermal building envelope by stricter requirements on the heating demand ($HWB_{Ref,RK}$) or by improving the energetic quality of the HVAC system with increased on-site or nearby generated renewable energy by reducing the overall energy factor (f_{GEE}).
The limits depend on the end-use of the building. The requirements for new residential and non-residential buildings are shown in chapter 2.1.7 and 2.1.8, respectively.

2.1.5.3 Heating Demand

The space heating demand (HWB) is the amount of energy that must be provided by the heating system in order to heat the building to a certain temperature, i.e. 20 °C or 22 °C (from 2019 on). The HWB is evaluated as the difference between heat losses (i.e. transmission and ventilation) and heat gains (i.e. solar and internal). The share of actually useful gain is determined by using the utilization factor (η):

$$HWB = Q_T + Q_V - \eta \cdot (Q_S + Q_I)$$

where:

Q_T - transmission losses, Q_V - ventilation losses, η - utilization factor, Q_S - solar gains, Q_I - internal gains

The space heating demand is calculated for both the reference climate (HWB_{RK}) and the site climate (HWB_{SK}), in each case if applicable with and without mechanical ventilation heat recovery (HWB and HWB_{Ref}, respectively). In the energy performance certificate, the $HWB_{Ref,SK}$ indicates the heating requirement related to the site climate excl. a possible heat recovery.

2.1.5.4 HWB-Lines

The so-called HWB-lines limit the spae heating demand (HWB) depending on the characterristic length of a building.

$$HWB = \text{HWB-Line} \cdot (1 + \frac{\text{HWB-slope}}{l_c})$$

The HWB-Lines are summarized in the following table.

Table 2: So-called HWB-Lines

HWB	(HWB-Line/HWB-slope)
HWB 26;19;16;14;12;10;8	(26/2);(19/2.5);(16/3)(§4/3);(12/3);(107*);(8/3)

The 26-Line represents the reference building from 2007. The 16-Line represents the maximum allowed HWB since 2014 and the 10-Line was found to be the cost-optimal line, see chapter cost-optimality (below). In particular, for compact buildings, the U-values of the 10-Line are at least close to Passive House quality.

2.1.5.5 National Plan

The national plan indicates a stepwise tightening of the requirements towards 2020. In particular, compliance with minimum requirements can be achieved by two methods:

- Through tightened requirements on space heating demand (HBW_{Ref}), which means better building envelope in order to reduce the heating/cooling energy needed. This is reflected in the formula for nZEB 2020 buildings 10 × (1 + 3,0 / ℓc) where ℓc is the characteristic length (usually known as the building's 'shape factor'). The maximum allowed final energy demand is calculated with the reference HVAC system (HTEB) of 2007. This possibility is denoted by “EEB path” later on.

The total energy efficiency factor (f_{GEE}) reflects the building performance in comparison to a reference building from 2007. This possibility is denoted by “f_{GEE} path” later on. The maximum limit of the HWB to reach the nZEB level refers to the reference climate without heat recovery ($HWB_{Ref,RK}$) and it depends on the characteristic length. The characteristic length is the measure of the compactness of a building and is expressed as the quotient of the conditioned gross volume and the surface area of the conditioned gross volume

$$\ell_c = \frac{V}{A}$$

The maximum allowed heating demand depending on the characteristic length is shown in Figure 12.

The typical range of l_c for typical single family houses and multi-family houses is indicated for the so-called 16-Line and 10-Line. The compacter the building, the more restrictive is the maximum allowed heating demand.

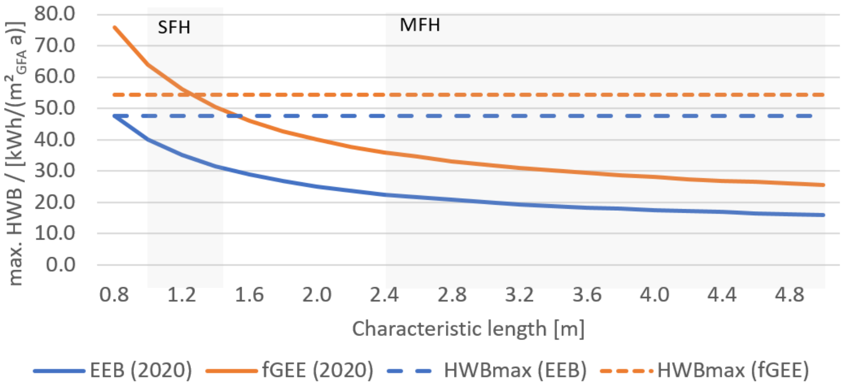


Figure 12: Maximum allowed heating demand according to the so-called 16-Line (f_{GEE}-path) and 10-Line (EEB-path) depending on the characteristic length (l_c), range of typical SFH and MFH/office

2.1.5.6 Final Energy Demand

The final energy demand (EEB) corresponds to the energy quantity that has to be purchased. In the case of residential buildings it is calculated as follow:

$$EEB = HWB + WWWB + HTEB + HHSB = HEB + HHSB$$

The domestic hot water heat demand (WWWB) and the household electricity demand (HHSB) are default values related to the treated area of the building. Values in force and values according to OIB-6:2015 are given for residential sectors in Table 6.
The heating technology energy demand (HTEB) is the amount of energy that must be used to operate the heating system. The detailed calculation schemes for different Heating, Ventilation and Air-Conditioning (HVAC) systems and configurations can be found in ÖNORM H 5056.
The EEB requirements for achieving nZEB refer to the reference climate. In the ÖNORM H5050-1:2019 the following definitions for the residential sector are given:

- The limit EEB (in order to reach the nZEB level according to the “EEB path”) is evaluated as:
  $$EEB_{RK} = HEB_{RK} + HHSB$$
- The maximum possible EEB value is defined as:
  $$EEB_{zul,RK} = HEB_{zul,RK} + HHSB$$
- And the EEB value for the reference building according to the 2007 standard is:
  $$EEB_{26,RK} = HEB_{26,RK} + HHSB$$

The EEB includes auxiliary energies for circulation pumps and mechanical ventilation, if applicable.
In the non-residential sector, EEB is evaluated as follows:

$$EEB = HWB + WWWB + HTEB + BSB + BelEB + KEB = HEB + BSB + BelEB + KEB$$

The domestic hot water heat demand (WWWB), the electric energy demand (BSB) and the lighting energy demand (BelEB) are default values related to the treated area of the building. Values in force and values according to OIB-6:2015 are given for residential sectors in Table 6. The cooling energy demand (KEB) is defined in the ÖNORM H 5050-1:2019.
Also for the non-residential sector, EEB requirements for achieving nZEB refer to the reference climate and the following definitions are provided in ÖNORM H5050-1:2019:

- The limit EEB (in order to reach the nZEB level according to the “EEB path”) is evaluated as:
  $$EEB_{RK} = HEB_{RK} + KEB_{RK} + BelEB + BSB$$
- The maximum possible EEB value is defined as:
  $$EEB_{zul,RK} = HEB_{zul,RK} + KEB_{zul,RK} + BelEB + BSB$$

- And the EEB value for the reference building according to the 2007 standard is:
  $EEB_{26,RK} = HEB_{26,RK} + KEB_{26,RK} + BelEB + BSB$

2.1.5.7 Total energy efficiency

The total energy efficiency factor (f_{GEE}) is a relative value and compares the actual building's performance to a reference building (defined according to the building standard of 2007). The higher the value, the worse the building is. It is calculated as follows:

$$f_{GEE} = \frac{EEB_{RK}}{EEB_{26,RK}} = \frac{\text{EEB of the building}}{\text{EEB of the reference building according to the standard of 2007}}$$

The final energy demand EEB used in the calculation of f_{GEE} refers to the reference climate.
If a heat pump (HP) is applied, the energy from the environment must be added to the final energy demand. In this case, according to ÖNORM H 5056-2019, the f_{GEE} is evaluated with the following equation:

$$f_{GEE,RK} = \frac{EEB_{RK} + Q_{Umw,WP,Bew}}{EEB_{26,RK} + Q_{Umw,WP,26}} \qquad (2019)$$

$Q_{Umw,WP,Bew}$ is the environmental energy required for the planned building construction (structural and technical) when using a reference COP. According to H5056-2019, the COP is calculated with a Thermodynamic/Carnot performance factor of 0.30 ($f_{0,Bew}$), independently of the HP technology, see Table 3. In the case of the previous version of the H5056 (2014), instead of the reference environmental energy $Q_{Umw,WP,Bew}$ the actual environmental energy $Q_{Umw,WP}$ was evaluated with the Thermodynamic/Carnot performance factor f_0 depending on the type of heat pump.

$$f_{GEE,RK} = \frac{EEB_{RK} + Q_{Umw,WP}}{EEB_{26,RK} + Q_{Umw,WP,26}} \qquad (2015)$$

$Q_{Umw,WP,26}$ is the environmental energy of the heat pump determined with Thermodynamic/ Carnot performance factor f_0, according to H5056-2014, see Table 3, which compares the Thermodynamic/Carnot performance factors f_0 according to H5056:2019 and H5056-2014.

Table 3: Thermodynamic performance factor f0 depending on the type of heat pump according to H5056-2014 and H5056-2019

			Carnot Performance Factor		
			H5056-2019		H5056-2014
Energy source	Medium	Energy medium	f_0 (from 2017)	f_0 (from 2005)	f_0 (from 2005)
Air, extracted air	Air	Water	0.36	0.30*	0.34
Ground water	Water	Water	0.43	0.40	0.45
Ground	Brine	Water	0.50	0.44	0.45
Ground	Refrigerant	Water	0.46	0.44	0.45
Air, Extracted air	Air	Hot water	0.37	0.26	0.30
Air, Extracted air	Air	Hot water (compact HP)	0.37	0.26	0.26
Extracted air	Air	Additional air (HR with integrated HP)	0.26	0.24	0.24
			*thermodynamic evaluation grade $f_{0,Bew}$ for evaluation of $Q_{Umw,WP,Bew}$ in the determination of total energy efficiency factor within standard H5050-1		

2.1.5.8 Renewable sources of energy

According to the OIB-6:2019 Section 5.2.3, the requirement about energy from renewable sources is fulfilled, if at least one of the following points from (a), (b) or (c) is applied:

a) The non-renewable primary energy demand ($PEB_{n.ern.}$ [kWh/(m^{2}yr)]) excluding household electricity demand or operational electricity demand fulfils the requirements depicted in the National Plan 2018 from 1.1.2021. Table 4 shows the maximum allowed values of PEB, comparing the current values (National Plan 2018) to the previous ones (National Plan 2014).

The PEB represents the energy demand for heating, domestic hot water and electricity including the process chains for generation, conversion and transport of the energy sources. PEB is indicated on the energy certificate only for the site climate and it is the result of the multiplication of the final energy demand by the respective primary energy factor (described in Table A 17 in the Appendix: f_{PE} = total primary energy factor; $f_{PE,n.ern.}$ = non-renewable primary energy factor; and $f_{PE,ern.}$ = renewable primary energy factor).
There were two major changes between the two versions of the National Plan with respect to the maximum primary energy limit. It was related to the total primary energy in 2014 and to the non-renewable in 2019. The final energy demand (EEB) included appliances (in residential) and operational electric energy in non-residential buildings in 2014 and excludes appliances or operational energies in 2019. It includes lighting energy in non-residential buildings.

Table 4: Maximum values of primary energy demand for new constructions: comparison between National Plan 2018 and 2014

	National Plan 2018	**National Plan 2014**
Residential building	$PEB_{HEB,zul,n.ern.}$ = 41 [kWh/(m²yr)]	PEB = 160 [kWh/(m²yr)]
Non-residential building	$PEB_{HEB+BelEB,zul,n.ern.}$ =84[kWh/(m²yr)]	PEB = 170 [kWh/(m²yr)]
In the non-residential sector, the limit for the non-renewable primary energy demand can be increased by 16 kWh/(m²yr) (related to a floor height of 3 m), if cooling technology is required in the building.		

b) Use of renewable sources outside the system boundaries "building":
It is required that at least 80 % of the heating demand for space heating and hot water is covered by renewable sources. The mentioned renewable sources can be:
- decentralised energy supply systems based on energy from renewable sources (biomass, renewable gas)
- combined heat and power generation
- district heating or cooling, in particular, if they are based entirely or partly on energy from renewable sources, district heating from high-efficiency cogeneration and/or waste heat
- heat pumps

c) Use of renewable sources on-site or nearby such that:
- Through active measures such as solar thermal energy, net final energy yields on location or in the vicinity of at least 20% of the final energy demand for hot water without these active measures have to be achieved;
- Through active measures, such as photovoltaics, net final energy yields at or near the location of at least 20% of the final energy demand for household electricity or operating current without these active measures have to be achieved;
- Net final energy yields at or near the site of at least 20% of the final energy demand for space heating without these active measures have to be achieved through active measures such as heat recovery;
- A combination of the three previous possibilities to reduce the EEB or the f_{GEE} by at least 5% through a combination of measures of solar thermal energy, photovoltaics, heat recovery, or efficiency gains.

2.1.5.9 Photovoltaic
Both in the residential and non-residential sectors, only part of the electricity demand can be covered by photovoltaic energy. The maximum shares depend on the application and are summarized in Table A 12 and Table A 13 in the Appendix.

2.1.5.10 Primary Energy and CO_2-Emissions
Despite the fact that Annex I of the EPBD requires to specify the total energy efficiency by the indicator (non-renewable) primary energy as a minimum requirement, in OIB-6: 2019 only the reference to the National Plan (2018) is provided. Hence, the primary energy indicator does not seem to be the minimum requirement, but only appears to be an informative indicator.
Reaching nZEB proving the fulfilment of $PEB_{n.ern.}$ (as described in chap. 2.1.5.8; i.e. without appliances or operational energy) is one of 3 options and the PEB_{RK} is not mentioned on the energy certificate. Further informative indicators are PEB_{SK}, $PEB_{n.ern.,SK}$ and $PEB_{ern.,SK}$, all evaluated with the site climate with total, non-renewable and renewable primary energy

factors, respectively. Primary energy conversion factors are summarized in Table A 16 in the Appendix. For electricity, the factors were reduced within the last years, which accounts for the fact that the share of renewables in the electricity mix increased (see also below for a discussion).
Also, the CO_2 emissions, which represents the total carbon dioxide emissions (including transport and generation of energy sources) is only an informative indicator. This indicator is calculated only for the site climate and depends on the final energy demand and the conversion factor, according to the following equation:

$$CO_2 = EEB \cdot f_{CO2eq}$$

2.1.5.11 Primary Energy and CO_2 conversion factors
It has to be noted that the conversion factors given in OIB-6:2019 changed significantly compared to the previous versions. Figure 13 shows the trend of the primary energy factors from 2011 to 2019 according to OIB-6 for electricity (left y-axis) and the renewable energy (RE) share in the Austrian electricity mix (right y-axis) according to own simplified calculations based on data published by the Bundesministerium für Nachhaltigkeit und Tourismus (2019). The dashed line assumes that the imported electricity is based on renewables and the solid line assumes fossil fuels.

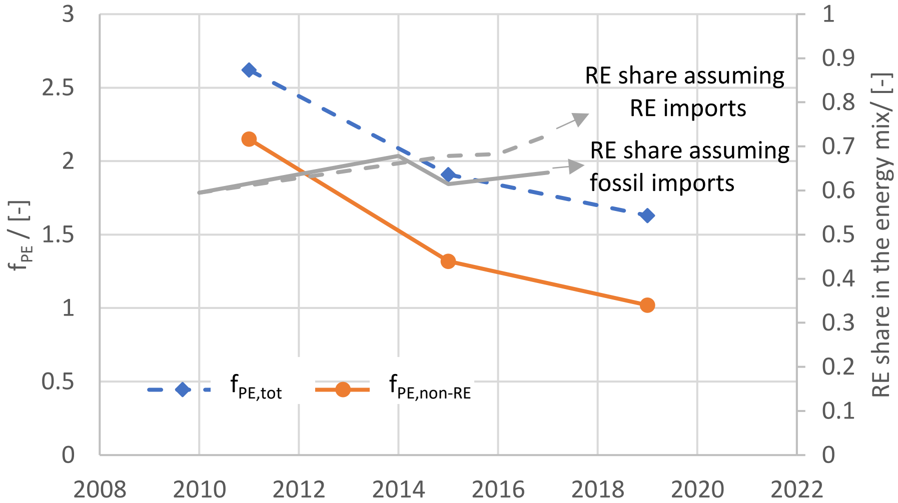


Figure 13: Trend of the primary energy factor f_{PE} for electricity acc. to OIB-6 and renewable energy share in the Austrian electricity mix over the years, acc. to own calculations based on Bundesministerium für Nachhaltigkeit und Tourismus (2019)

The decreasing trend of the primary energy conversion factors (both total and non-renewable) reflects the trend of the increasing share of renewable energy in the Austrian electricity mix. However, it is remarkable that the imported electricity has a significant influence and a more detailed investigation of the PE conversion factors including the influence of seasonal effects is recommended.
It is furthermore noteworthy that the Austrian non-RE PE conversion factor for electricity of 1.02 is very low compared to the European electricity mix with a non-renewable conversion factor of 2.3 according to EN ISO 52000-1:2018.

2.1.6 Cost-optimal methodology

The calculation of cost-optimality as required by the EU 2010/31/EU (EC, 2012) in order to define nZEBs 2020 was carried out by OIB in March 2013 (OIB 2014) and updated in 2018 (OIB, 2018). OIB concludes that the results from 2013 were confirmed by the update from 2018. To calculate cost-optimality, virtual buildings were chosen, which represented four different building categories. The cost-optimality methodology included the calculation of 4 parameters:

- space heating demand [kWh/(m^{2}yr)]
- primary energy demand [kWh/(m^{2}yr)]

- CO_2 emissions [kg/(m²yr)] (according to the conversion factors in the OIB Guidelines)
- total energy efficiency factor (f_{GEE}) [-]

The calculation of the cost-optimality consisted of a comparison between the value of the energy savings achieved using the different improvement packages and the costs that are directly and indirectly related to those energy efficiency measures alone. Based on the outcomes of the cost-optimality methodology, the requirements for achieving nZEB levels – both for residential and non-residential buildings – were defined (based on life cycle cost analysis). The detailed description of the parameters and boundary conditions can be found in OIB (2014) and OIB (2018). As can be seen from Figure 14 for the example of residential buildings, the cost-optimal solution depends on the type of building and technology (here, only so-called "alternative" technologies are presented).

One curve always represents different envelope qualities (expressed in the so-called HWB-Lines from 8-Line to 26-Line). Depending on the type of building and HVAC technology, different envelope qualities are cost-optimal. Cost-optimal is e.g. the combination of a moderate envelope with highly efficient systems or a better envelope with a moderately efficient system. (Remark: The variants with very low primary energy demand are these with biomass with a conversion factor of $f_{PE,non\text{-}RE} = 0.1$ and are not considered further here, as the application of biomass for heating of buildings is very limited).

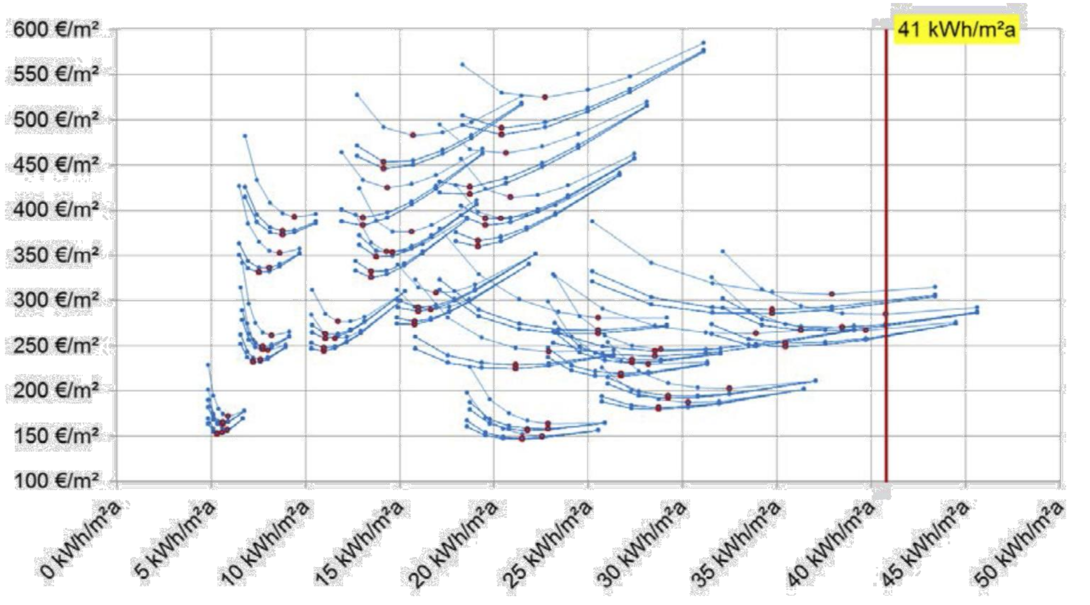


Figure 14: Result of the cost-optimality study from 2018 (source OIB) – non-renewable primary energy without appliances for new residential buildings (conversion factor for electricity was $f_{PE,non\text{-}RE}$ = 1.32 for the time the report was published); an example of a residential building with "alternative" technologies

The OIB concluded that the 10-Line is cost-optimal. It is remarkable that in combination with heat pumps, the 16-Line is not cost-optimal. It can be seen, too, that the limit of 41 kWh/(m²yr) was chosen such that with very few exceptions none of the so-called alternative technologies are excluded. In other words, the limit of 41 kWh/(m² yr) is not a limit.

2.1.7 Residential buildings

The nZEB requirements that have to be fulfilled for residential buildings are shown in Table 5 for the "EEB path" and the "f_{GEE} path" according to OIB-6:2019, National Plan (2018).

Table 5: nZEB requirements for residential building according to the "EEB path" (OIB-6:2019) and to the "f_{GEE} path" (OIB-6:2019)

	New building EEB path	New building f_{GEE} path
$HWB_{Ref,RK,zul}$ in [kWh/m²a]	10 × (1 + 3.0 / ℓ_c)	16 × (1 + 3.0 / ℓ_c)
$EEB_{RK,zul}$ in [kWh/m²a]	$EEB_{WG,RK,zul}$	
$f_{GEE,RK,zul}$ [-]		0.75

For a single family house with a characteristic length of 1.4 m, the maximum allowed heating demand is ca. 50 kWh/(m²yr) for the "f_{GEE} path" and around 30 kWh/(m²yr) for the "EEB path".

Table 6: Default values for DHW demand: comparison between OIB-6:2019 and OIB-6:2015

	OIB-6:2019		**OIB-6:2015**
	1-2 units	≥ 3 units	Single and multi family house
WWWB [kWh/(m^2_{TA} yr)]	7.665	10.220	12.775
HHSB [kWh/(m^2_{TA} yr)]	13.890	22.776	16.425

To show the impact of the variation of the default values for DHW demand, appliances and the primary energy conversion factor f_{PE} between OIB (OIB-6:2015 and OIB-6:2019) on the primary energy demand, the results of a simplified calculation for a single-family house (SFH) are reported in Table 7. An SFH with 140 m² of treated area and air-source heat pump (with seasonal performance factor SPF=2.5 (including auxiliary energies) is considered for this calculation. The heating demand (HD) is set to the maximum allowed value according to the "f_{GEE} path". The total primary energy (PE) as for the National Plan 2014 and the non-renewable primary energy ($PE_{non-ren.}$) as for the National Plan 2018 are compared. The final energy demand according to OIB-6:2019 is 11% lower than the value according to OIB-6:2015 due to the decrease of the default values (DHW and appliances). The non-renewable primary energy for electricity is further reduced because of the lower primary energy conversion factor (1.02 instead of 1.32).

Table 7: Simplified evaluation of primary energy of an SFH. (MFH in blue) Comparison between values according to OIB-6:2015 and OIB-6:2019 (default values are underlined). Maximum values of PEB according to National Plan 2014 and National Plan 2018

		OIB-6:2015		**OIB-6:2019**
ℓc	[m]	1.4 (2.4)		1.4 (2.4)
HD	[kWh/(m² a)]	50.3 (36.0)		50.3 (36.0)
DHW	[kWh/(m² a)]	12.8 (12.8)		7.7 (10.2)
HD + DHW	[kWh/(m² a)]	63.1 (48.8)		58.0 (46.2)
SPF (including auxiliaries)	[-]	2.5 (2.0)		2.5 (2.0)
Electricity (HD + DHW)	[kWh/(m² a)]	25.2 (24.4)		23.2 (23.1)
Appliances	[kWh/(m² a)]	16.4 (16.4)		13.9 (22.8)
Final energy demand	[kWh/(m² a)]	41.6 (35.9)		37.1 (45.9)
f_{PE}		tot	non-ren.	non-ren.
	[-]	1.91 (1.91)	1.32 (1.32)	1.02 (1.02)
PEtot	[kWh/(m² a)]	79.6 (78.0)		
$PE_{non-ren.}$ including appliances	[kWh/(m² a)]		55.0 (53.9)	37.8 (46.8)
$PE_{non-ren.}$ excluding appliances	[kWh/(m² a)]		33.3 (32.2)	23.6 (23.6)
PE incl. appliances (National Plan 2014)	[kWh/(m² a)]	160 (160)		-
$PE_{non-ren,max}$ excl. appliances (National Plan 2018)	[kWh/(m² a)]		(41)* ((41)*)	41 (41)
* interim state for 2018: OIB-6:2015 and National Plan 2018				

As a consequence, the PEB requirement in 2019 is fulfilled easier compared to the limit that applied in 2018 (when OIB-6:2015 and National Plan 2018 were into force). A similar analysis is conducted for a multi-family house with a characteristic length of 2.4 m. The heating system consists of an air-source heat pump (with SPF = 2.0 with higher distribution losses and again including auxiliary energies). The results are shown in the following Table 7.

A multi-family house with an envelope fulfilling the f_{GEE} requirement equipped with a moderately efficient air-to-water heat pump fulfils the PE requirement without the necessity of applying further efficiency measures such as MVHR or renewables such as ST or PV.

A case study for both residential single and multi-family buildings and for office buildings is given in the Appendix A.1 and A.2.

2.1.8 Office building

The nZEB requirements for the non-residential sector are shown in Table 8.

Table 8: nZEB requirements for office buildings according to "EEB path" and f_{GEE} path (OIB-6:2019)

	New building EEB path	New building f_{GEE} path
$HWB_{Ref,RK,zul}$ in [kWh/(m² yr)]	10 × (1 + 3.0 / ℓ_c)	16 × (1 + 3.0 / ℓ_c)
$EEB_{RK,zul}$ in [kWh/(m² yr)]	$EEB_{NWG,RK,zul}$	
$f_{GEE,RK,zul}$ [-]		0.75
$KB^*_{RK,zul}$ in [kWh/(m^2 yr)]	1.0	1.0

In general, the requirements are the same as those for the residential buildings (compare Table 5). However, for office buildings $HWB_{Ref,RK,zul}$ is related to a room height of 3 m. For buildings with different room heights, the limit can be adjusted accordingly, i.e. the allowed limit is higher for buildings with higher rooms.

Table 9: Default values of domestic hot water demand, operational power and lighting in the non-residential sector: comparison between OIB-6:2019 and OIB-6:2015

	OIB-6:2019	OIB-6:2015
WWWB / BelEB / BSB [kWh/(m^2_{TA} yr)]	2.42 / 25.76 / 16.96	4.71 / 32.2 / 24.64

Also, if a cooling system is present, the KB* (externally induced cooling load) requirement has to be met. The default values of WWWB, BelEB and BSB for the non-residential sector are shown in Table 9. As example, an office building with air-to-water heat pump (SPF=2.0, taking into account electric DHW and auxiliary energy) is considered to investigate the influence of the boundary conditions and parameters on the PEB. Table 10 compares the results of a simplified evaluation. Similar conclusions to the residential sector can be drawn. The final energy demand according to OIB-6:2019 is 21% lower than the value according to OIB-6:2015 due to the decrease of the default values (DHW, operational power and lighting). The non-renewable primary energy for electricity is further reduced because of the lower primary energy conversion factor. As a consequence, again the PEB requirements can be achieved with less effort in 2019 compared to the limit valid in 2018 (when OIB-6:2015 and National Plan 2018 were into force)

Table 10: Simplified evaluation of PEB of an office building. Comparison between values according to OIB-6:2015 and OIB-6:2019 (default values are underlined). Maximum values of PEB according to National Plan 2014 and National Plan 2018

		OIB-6:2015		OIB-6:2019
ℓ_c	[m]	2.27		2.27
HD	[kWh/(m² yr)]	37.1		37.1
DHW	[kWh/(m² yr)]	4.7		2.4
HD + DHW	[kWh/(m² yr)]	41.9		39.6
SPF (including auxiliaries)	[-]	2.0		2.0
Electricity (HD + DHW)	[kWh/(m² yr)]	20.9		19.8
Operational power	[kWh/(m² yr)]	24.6		17.0
Lighting	[kWh/(m² yr)]	32.2		25.8
Final energy demand	[kWh/(m² yr)]	77.9		62.5
f_{PE}		tot	non-ren.	non-ren.
	[-]	1.91	1.32	1.02
PE_{tot}	[kWh/(m² yr)]	148.7		
$PE_{non\text{-}ren.}$ including operating electricity demand	[kWh/(m² yr)]		102.8	63.8
$PE_{non\text{-}ren.}$ excluding operating electricity demand	[kWh/(m² yr)]		70.3	46.5
PE incl. operating el demand (National Plan 2014)	[kWh/(m² yr)]	170		-
$PE_{non\text{-}ren,max}$ excl. operating el. demand (National Plan 2018)	[kWh/(m² yr)]		(84)*	84
* interim state for 2018: OIB-6:2015 and National Plan 2018				

2.2 German nZEB definition - Energy Saving Regulation EnEV 2014/2016

The Energy Saving Regulation (EnEV) presents one of the most fundamental tools of the federal government's energy and climate policy. It defines requirements and implementation tools for residential, non-residential buildings and refurbishments.

The EnEV uses a reference-building-system, which is based on the calculation model defined in DIN V 18599. It adduces a fictitious reference construction which corresponds to the planned building. It differentiates between residential and non-residential buildings and includes the energy demand in both for heating, hot water, ventilation and auxiliary energy. In non-residential buildings lighting and cooling is additionally examined.

The illustration in Figure 15 describes the holistic calculation method to define the energy balance as well as the CO_2-emissions and environmental impact of buildings by the primary energy demand (EnEV, 2007). The calculation method is in line with other CEN standards from the Mandate M/343 (Schettler-Köhler, 2015).

Since 2009, the EnEV takes the generation of electrical power, produced by renewable energies, into consideration and grants credits on the presumption that surpluses are fed into the public grid. (EEWärmeG, 2009)

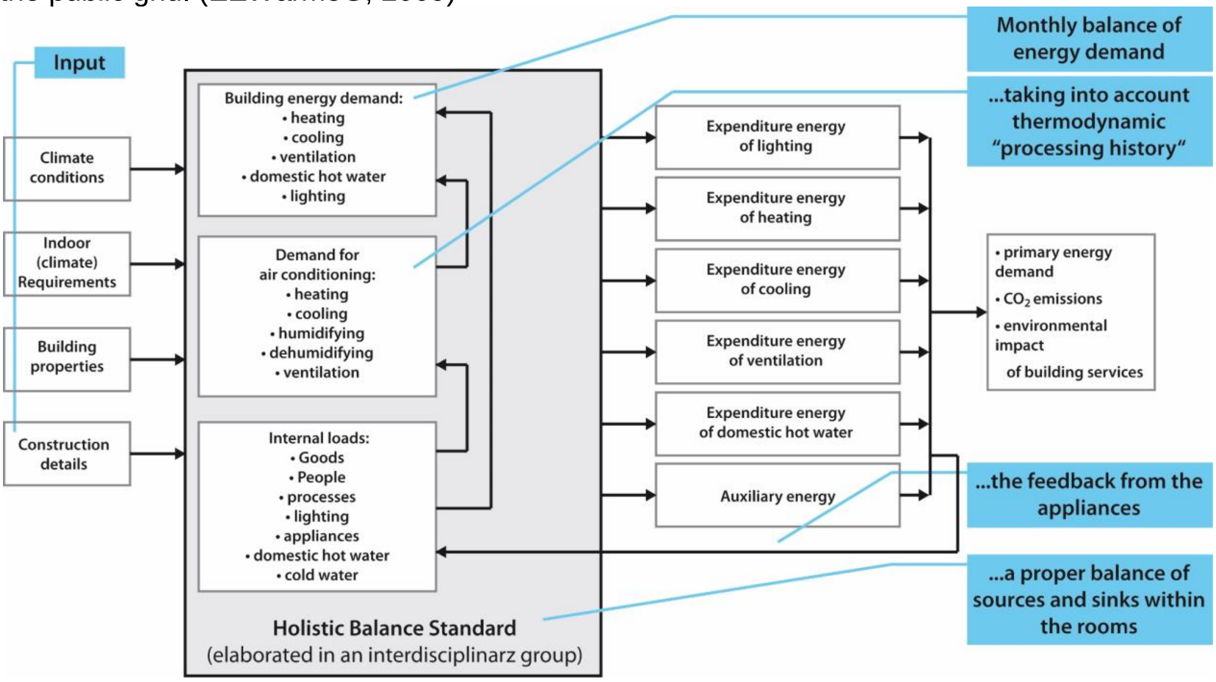


Figure 15: Outline and calculation scheme of DIN V 18599 (based on Schettler, 2008)

Requirements for residential and non-residential buildings are not defined by specific values, but as mentioned earlier by comparing the building with its corresponding reference building. The reference building is comparable to the individual building in terms of geometry, size, orientation and use, but defined with standardized components and technical systems as well as a specified building envelope. Therefore, the energy performance has to be calculated twice: once for the specifications of the reference building and once taking the real construction features and system performance into account. When compared the maximum primary energy demand of the building must not exceed the primary energy demand of the reference building.

2.2.1 Residential buildings

For residential buildings a choice between two different methods are given by the EnEV to calculate the two buildings (DIN V 4108-6 combined with DIN V 4701-10 or the DIN V 18599). Both calculation methods are steady-state calculation models and in principle in accordance with European and ISO standards.

The regulation reflects thermal bridges by providing two different default levels or by including a detailed calculation into the performance.

Permeability of the building envelope is also examined, through two different standardized procedures. One is the on-site air tightness inspection by means of a Blower-Door-Test and the other is simply an off-site simulation.
Furthermore, new residential buildings must meet several additional specifications: (Schettler-Köhler, 2015)

- Requirements which set up a threshold for the specific heat transfer coefficient U-Value (Figure 16 left) (EN ISO 13789 and EN ISO 13370) and the specific heat transfer loss H'_T (Table 11) to define a suitable thermal quality, even in the case of very low primary energy factors
- Additional requirements for technical buildings systems (heating, domestic hot water (DHW), ventilation, air-conditioning)
- Requirements for summer comfort regulations to avoid any energy consumption for cooling purposes.

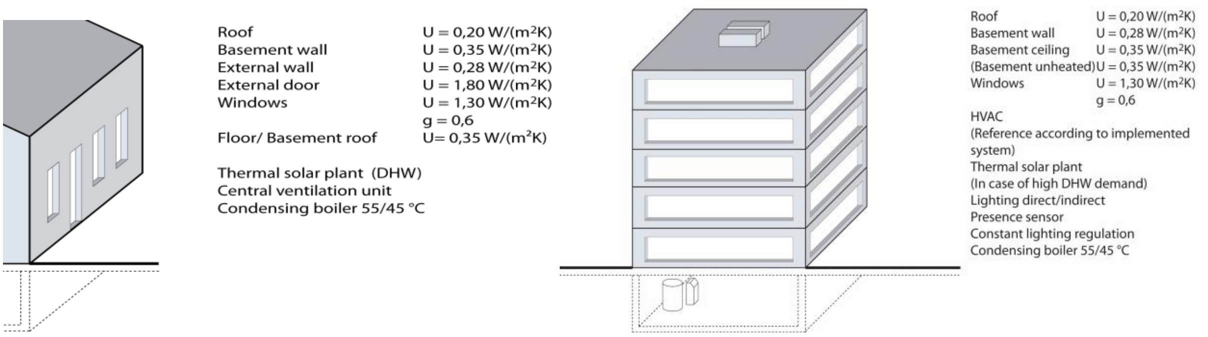


Figure 16: Residential Reference building of the EnEV 2014 / 2016 (left) and non-residential reference building (T_{room} ≥ 19°C) EnEV 2014 / 2016 (right)

Table 11: Maximum heat transfer losses according to residential building type, EnEV 2014/2016 (Appendix 1, Table 2)

Part	Building type		Maximum value of specific heat transfer loss
1	Detached building	with A_N ≤ 350 m²	H'_T= 0.40 W/(m²·K)
		with A_N > 350 m²	H'_T= 0.50 W/(m²·K)
2	Semi-detached building		H'_T= 0.45 W/(m²·K)
3	All other buildings		H'_T= 0.65 W/(m²·K)
4	Extensions and upgrades according to § 9 Absatz 5		H'_T= 0.65 W/(m²·K)

2.2.2 Non-residential building

Non-residential buildings comply with most of the same regulations defined for residential buildings. The EnEV implies that these buildings are kept at an average temperature of more than 19 °C, but also differentiates between those that kept at a temperature higher than 12 °C and those below 12 °C (EnEV 2014/16, 2013).
The minimum requirements of the building envelope differ from those of residential buildings and are described in two models. These are also defined by a reference building, illustrated in Figure 16 right and additionally by a maximum average heat transfer coefficient (U-value) of categorized building parts listed in Table 12.
Furthermore, it takes into account specifications for artificial lighting, cooling and ventilation, which a significant number of such buildings are equipped with. The mandatory calculation method, using the non-residential reference building is detailed by DIN V 18599. The method foresees zoning of the building, according to different use patterns. This means the zoning of the reference building has to correlate with the zoning of the real building matching the conditions of use. The most typical user behaviours are considered in this model and reflect accepted comfort needs. Therefore, the description of the non-residential reference building is more detailed.

Table 12: Maximum average heat transfer coefficient of the reference building according to building parts for non-residential buildings, EnEV 2014/2016

Part	Building Part	Maximum value of the average heat
1	Opaque exterior components	$\bar{U}$ = 0.28 W/(m^{2}K)
2	Transparent exterior components	$\bar{U}$ = 1.50 W/(m^{2}K)
3	Curtain walls	$\bar{U}$ = 1.50W/(m^{2}K)
4	Glass roofs, light tapes, light couplings	$\bar{U}$ = 2.50 W/(m^{2}K)

For individual user patterns, definitions for creating a customized set of conditions are also included in the standard. In order to simplify the effort of repeated calculations, the EnEV allows a relaxed approach for a number of frequently constructed building types, e.g., office buildings, standard retail buildings and schools (Schettler-Köhler, 2015, EnEV 2014/16, 2013).

2.2.3 Retrofitting of existing buildings

There are two different types of regulations regarding existing buildings. Some are conditional requirements and only apply to major renovations, while others are mandatory and may also apply to buildings undergoing minor changes.
Conditional requirements must be met in defined cases. Either for first-time installations of systems or for certain retrofitting measures applied to more than 10% of a building component (Figure 17). It therefore has to meet EnEV standards, but is allowed to exceed them by 40%. Common measures according to conditional requirements are e.g. the replacement of roof tiles, new layers of plaster or sheathings on outer walls as well as the replacement of windows or glazing.
Component requirements can also be achieved by fulfilling a certain whole building requirement, which optimizes the overall energy performance. Certain exceptions are made for owners and occupants of small residential buildings (Schettler-Köhler, 2015, EnEV 2014/16, 2013).

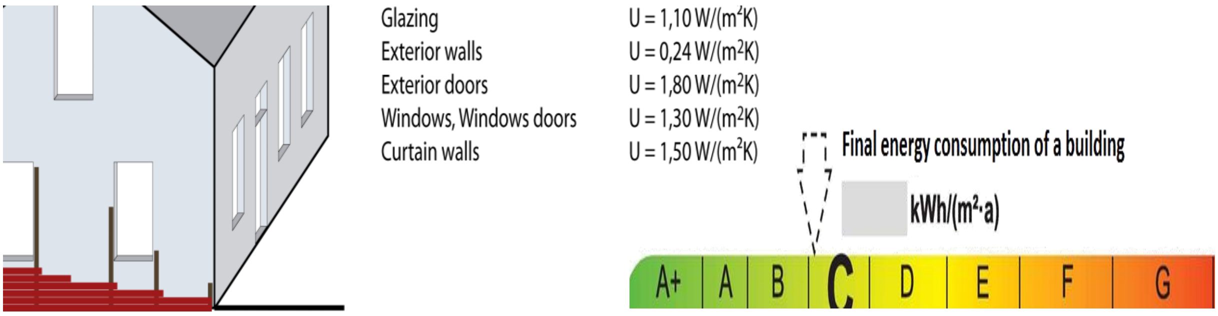


Figure 17: Maximum heat transfer coefficient values for single parts in existing buildings, EnEV 2014/16 (left) and final energy and specific primary energy classes for buildings acc. to energy performance certificate (EPC) (right)

2.2.4 Primary energy demand and CO_2-Emission

The EnEV's leading goal is to reduce energy consumption and consequently carbon emissions. To create a comparable measure the primary energy demand based on the reference buildings is calculated. It takes into account the different energy sources and their properties, such as losses during their extraction, their processing, their transport and storage. Depending on the type of building, heating, domestic hot water, ventilation and auxiliary energy as well as cooling and lighting have to be included in the final energy demand calculation measured per square meter. This can then be graded in different categories ranging from A+ to H and is presented in an energy performance certificate (EPC) (Figure 17 right). The structure of an EPC has been simplified and self-explanatory icons are used to meet the interests of the general public. Technical language is almost entirely avoided and only placed at the end of an EPC. Furthermore, terms like the European nZEB have been replaced by more recognizable terms to the German public like "Effizienzhaus Plus".

Opposite the final energy consumption on the EPC the primary energy demand is given and is calculated by multiplying the final energy consumption with factors according to their source (Figure 18), which are provided by the EnEV or by the standards DIN V 18599-1 and DIN 4701-10/A1. They are defined by the government to evaluate and compare efficiency and CO_2-Emissions of buildings, although these do not directly correspond to the actual emissions and may present buildings with a lesser environmental impact than in reality.

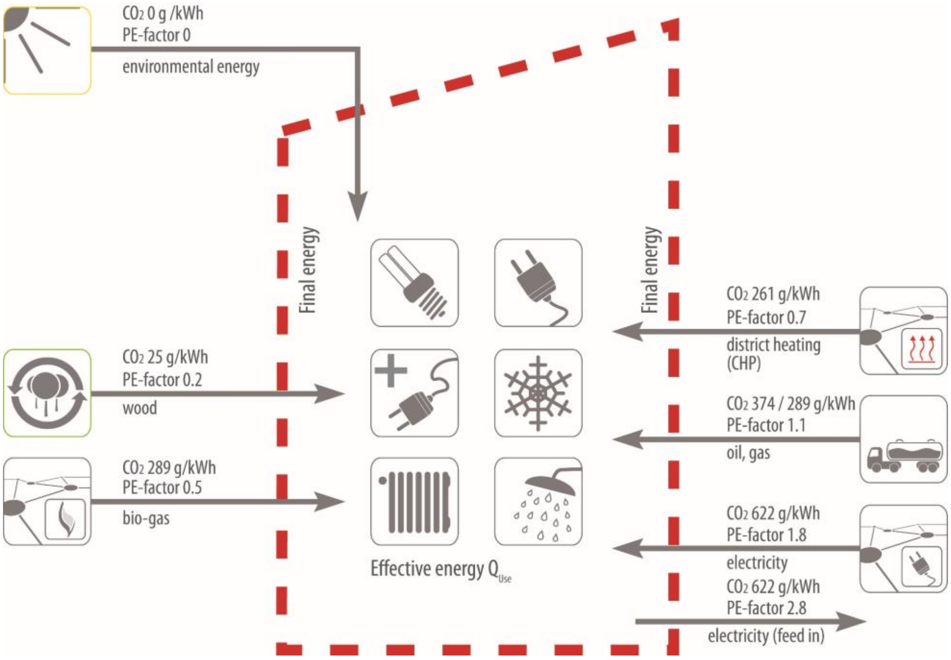


Figure 18: Primary energy factors (non-renewable) and CO_2-emissions (EnEV 2016 and Gemis 4.95)

2.3 Implementation ZEB in Norway

A definition of Zero Emission Buildings (ZEB) has been developed at the Norwegian Research Centre for ZEB (Fufa, Schlanbusch et al. 2016). Instead of primary energy, the balance is measured in terms of greenhouse gas emissions (CO_2-eq.), still compensated by on-site renewable energy generation.

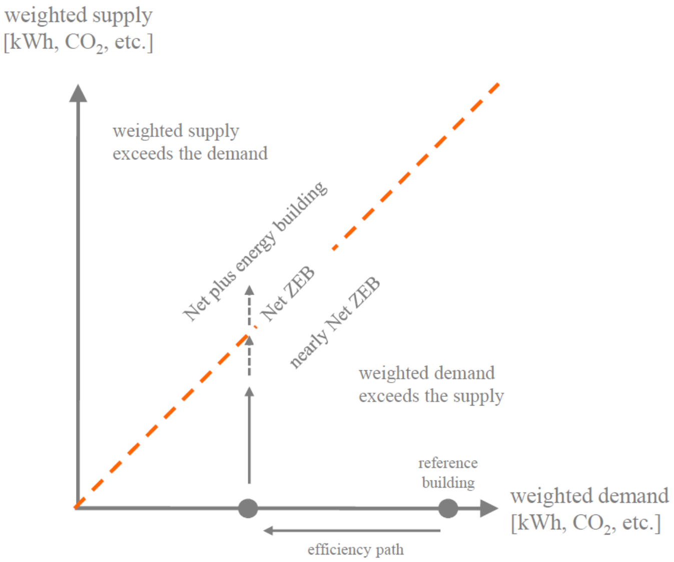


Figure 19: Graph representing the path towards a Net Zero Energy Building (Net ZEB), with the nearly and plus variants. (Sartori, Napolitano et al. 2012)

The balance of emissions is characterised based on the ambition levels (Dokka 2013) and (Kristjansdottir 2014) from ZEB O÷EQ to ZEB COMPLETE, where the latter is the most ambitious level.

Figure 20 illustrates how the different levels consider different emission items based on these criteria. Emissions related to Operational energy use is referred to with the letter "**O**". The term **"÷EQ**" suggests that emissions from technical EQuipment are not included. Embodied emissions associated with building Materials are denoted "**M**". Further, emissions associated with Construction and installation are referred to as "**C**", while embodied emissions at the End of life phase for the building are denoted "**E**". According to Fufa, Schlanbusch et al. (2016), the six ZEB levels are defined based on different boundaries for balance as:

1. **ZEB-O÷EQ** – Net emissions related to all energy use except the energy use for equipment (appliances) shall be zero. Energy use for equipment is often regarded as the most user dependent, and difficult to design for low-energy use.
2. **ZEB-O** – Net emissions related to all Operational energy use shall be zero, also including energy use for equipment.
3. **ZEB-OM** – Net emissions related to all Operational energy use plus all embodied emission from Materials and installations shall be zero.
4. **ZEB-COM** – Same as ZEB-OM, but also including emissions related to the Construction process of the building.
5. **ZEB-COME** – Same definition as ZEB-COM but also including the emissions related to the end of life phase "E". The end of life phase includes deconstruction/demolition, transport, waste processing and disposal. The end of life of processes of replaced materials are to be considered.
6. **ZEB-COMPLETE** – Emissions related to a complete lifecycle emission analysis must be compensated for. The reuse, recovery and recycling can also be included.

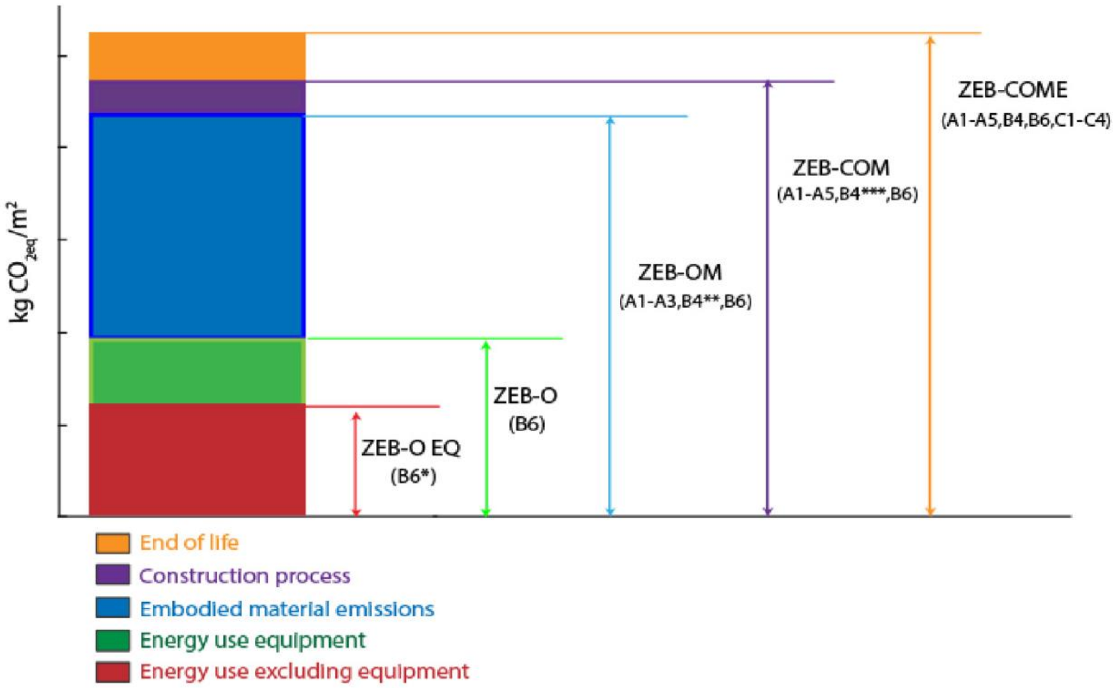


Figure 20: Illustration of five of the six ambition levels for Zero Emission Buildings (ZEB). (Fufa, Schlanbusch et al. 2016)

All the energy calculations to evaluate energy balances are to be done based using the Norwegian standard NS 3031. The net-ZEB energy balance is calculated over a year, using "normalized" climate data (Oslo climate). Assessment of environmental performance for all ZEB levels are calculated according to NS-EN 15978:2011.

2.3.1 Operational Energy and Emission Calculation Procedure

The operational energy use must be calculated according to the Norwegian standard NS 3031:2014 using dynamic simulations validated according to NS-EN 15265:2007.

The calculation of usable area is done according to NS 3940:2012. The standards NS 3031:2014, NS 3700:2013 and NS 3701:2012 give the requirements regarding set point temperatures, hours of use, levels of thermal losses, ventilation, etc.
If one building is so innovative that the solution is not covered by these three standards, the operational energy use must be calculated based on scientifically accepted methods and references should be given. For instance, SN-NSPEK 3031:2020 (previously SN/TS 3031:2016) is a supplement to NS 3031:2014 with a more detailed modelling of the technical installations and can therefore be used for documentation regarding nZEB and plus-houses. The greenhouse gas emissions from operational energy has to be calculated according to delivered and exported energy using symmetric CO_2-eq. conversions factors for each energy carrier. The ZEB centre has developed CO_2-eq factor for most energy carriers.

Table 13: Typical performance required for the building envelope of a 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

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 thermal performance of the building envelope, Table 13 shows the typical requirements for a possible NZEB so that a zero-emission balance can be achieved. The last column shows examples of construction type enabling achieving the U-values described. These values are not standardized, but only a proposal of maximum value to make it possible to reach a ZEB balance.

Table 14: Typical performance 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 pressure 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.

As for the HVAC system, requirements for the HVAC components in ZEB are shown in Table 14. Again, these values are not standardized, but minimum requirements to make it possible to achieve a zero balance.

The restrictions, for example for the 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).

2.4 Swedish definition of nZEB

- On the 1[th] of September 2020, the Swedish Planning and Building Ordinance has been amended in the part concerning the calculation of a building's energy performance. At the same time, new building regulations from the National Board of Housing, Building and Planning (Boverket) that are adapted to the change enter into force. The change will create a better balance between the different types of energy supply to buildings and is the final step in the introduction of nearly zero energy buildings in Sweden according to the EPBD recast of 2010 (current version EPBD, 2018).
- The amended regulation (BBR 29) means that weighting factors replace primary energy factors when a building's energy performance is calculated. A primary energy number will continue to be an expression of a building's energy performance, but the transition to weighting factors highlights that the way of determining the conversion factors is new.
- In the following the final Swedish definition of a nearly Zero Energy Building (nZEB) is presented. It is taken directly from the EU notification of the new building regulations made in January 2020 and shall, subject to shortcomings in the translation, be identical to the Swedish version published by Boverket on the 1[st] of July 2020. Changes regarding the previous regulation is marked with a vertical line on the left.

2.4.1 Definitions

A_f	Total surface area of windows, doors, front doors and the like (m^2), calculated using external frame measurements.
A_{temp}	The area of all storeys, including attic and basement levels, for temperature-controlled spaces intended to be heated to more than 10 ºC, which is enclosed by the inside of the building envelope. The area occupied by interior walls, openings for stairs, shafts and the like is included. The area of garages, within residential buildings or in building premises other than garages is not included.
Building's energy use, E_{bea}	The energy that, in normal use during a normal year, needs to be supplied to a building (this is generally called purchased energy) for heating (E_{uppv}), comfort cooling (E_{kyl}), hot tap water (E_{tvv}) and the building's property energy (E_f). If underfloor heating, towel dryers or other devices for heating are installed, their energy use is also included. Energy from the sun, wind, ground, air or water that is produced in the building or on its site and is used for the building's heating, comfort cooling, hot water and property energy is not included in the building's energy use. $E_{bea} = E_{uppv} + E_{kyl} + E_{tvv} + E_f$
E_{uppv}	Energy for heating [kWh/yr]
E_{kyl}	Energy for comfort cooling [kWh/yr]
E_{tvv}	Energy for hot tap water [kWh/yr]
E_f	Property energy [kWh/yr]
F_{geo}	Geographical adjustment factor [-]
Property energy of building E_f	That part of the building's energy use that is related to the building's needs where the energy-consuming device is within, below or affixed onto the exterior of the building. Property energy includes fixed lighting in public spaces or operating spaces. Energy used in heating cables, pumps, fans, engines, control and monitoring equipment and the like is also included. External locally placed devices that supply the building, such as pumps and fans for free cooling, are also included. Devices intended for other use than by the building, such as engine and cab heaters for vehicles, battery chargers for external users, and lighting in gardens and walkways, are not included. Property electricity refers to that part of the property energy that is electricity-based.
Primary energy	The value that describes the building's energy performance expressed as a primary energy number. The primary energy number is comprised of the building's energy

number of building (EP_{pet})	use, where energy for heating has been corrected by a geographical adjustment factor (F_{geo}), multiplied by a weighting factor for energy carrier and distributed at A_{temp} (kWh/m²/yr). The primary energy factor (EP_{pet}) is calculated by the formula below

$$EP_{pet} = \frac{\sum_{i=1}^{6}\left(\frac{E_{uppv,i}}{F_{geo}} + E_{kyl,i} + E_{tvv,i} + E_{f,i}\right) \times VF_i}{A_{temp}}$$

where

VF_i	Weighting factor per energy carrier
Water external design temperature, DVUT	The temperature, for a representative geographical location, that results from the 1-day value in ‘n-day mean air temperature’ according to SS-EN ISO 15927-5. The temperature may be increased, if the building’s time constant exceeds 24 hours. The increase is shown by the standard’s reported temperatures for 2, 3 or 4 days. The building’s time constant, measured in days, is used for the selection of the corresponding table value (n-day). Temperature increase depending on a time constant higher than 96 hours can be determined through special investigation.
Energy for comfort cooling	The amount of cooling or energy supplied to the building that is used to reduce the building’s indoor temperature for human comfort. Cooling energy that is taken directly from the surroundings without a cooling appliance, e.g. from sea or lake water, outdoor air or the like (so-called free cooling) is not included.
Average heat transfer coefficient, U_m	Average heat transfer coefficient for building components and thermal bridges [W/(m²K)] determined in accordance with SS-EN ISO 13789 (2017) and SS 24230 (2) and calculated in accordance with the formula below,

$$U_m = \frac{\sum_{i=1}^{n} U_i A_i + \sum_{k=1}^{m} l_k \Psi_k + \sum_{j=1}^{p} X_j}{A_{om}}$$

where

U_i	Heat transfer coefficient for building component i [W/(m²K)].
A_i	The area of the building component i’s surface against heated parts of dwellings or premises. For windows, doors, front doors and the like, Ai is calculated with the outer frame dimension. The building’s entire indoor height is used in the calculations, i.e. from the upper edge of the floor over crawl space to the lower edge of the attic joist floor.
ψ_k	The heat transfer coefficient for the linear thermal bridge k [W/(mK)].
l_k	The length of the linear thermal bridge k [m].
χ_j	The heat transfer coefficient for the point thermal bridge j [W/K].
A_{om}	Total area of the enclosing building components’ surfaces against heated parts of dwellings or premises. Enclosing building components means building components that border on heated parts of dwellings or premises towards the outside, towards the ground or towards partially heated spaces.
Building’s installation system	Technical equipment for heating, comfort cooling, ventilation, hot tap water, fitted lighting, property automation and the regulation of this, electricity generation within the building or on its site and the regulation of this, or a combination thereof, including systems that use energy from renewable sources.
Household energy	The electricity or other energy used for household purposes. Examples are the electricity used for dishwashers, washing machines, dryers (including those in a shared laundry room), stoves, refrigerators, freezers and other household appliances as well as lighting, computers, TVs and other home electronics and the like.
Indoor temperature	The temperature that is intended to be maintained indoors when the building is in use.
Installed electrical input for heating	The total electric input power that, as a maximum, can be used by the electrical appliances for heating needed to maintain intended indoor climate, hot tap water production and ventilation when the building’s maximum heat demand is present. The maximum power need can be calculated at DVUT and hot tap water use corresponding to at least 0.5 kW per dwelling, unless higher load cases are known at the project planning stage.

Normal year	The average outdoor climate (e.g. temperature) over a longer time period (e.g. 30 years).
Normal year correction	Correction of the building's measured climate-dependent energy use, based on the difference between the climate at a location during a normal year and the actual climate during the period for which the building's energy use is verified.
Weighting factor, VF_i	Factor for each energy carrier that is multiplied by the energy that is supplied to a building when calculating the building's primary energy number.
Specific fan power (SFP)	The total electric input for all fans in the ventilation system divided by the greater of the supply air flow rate or the extract air flow rate, [kW/(m^3/s)].
Activity energy	The electricity or other energy used for activities in the premises. Examples of this are process energy, lighting, computers, copying machines, TV, refrigerated/frozen food displays/counters, appliances and other devices for the activities, as well as ovens, refrigerators, freezers, washing machines, dryers, other household appliances and the like.

2.4.2 Dwellings and premises[1]

Residences and premises should be designed so that

- the primary energy number (EP_{pet}),
- the installed electrical input for heating,
- the average air leakage of the building envelope, and
- the average thermal transmittance coefficient (U_m) for those building components that enclose the building (A_{om}),

do not exceed the values indicated in Table 15. When determining the building's primary energy number, account shall be taken of the weighting factors according to Table 16 and the geographical location according to the Table A 18 in Appendix A.3.

A higher primary energy number and higher electric input than those stated in Table 15 can be accepted

- for premises intended for activity of a temporary nature, or
- in other cases where special circumstances are in place

General recommendations

As a general rule, activity of a temporary nature means activity that is under way for 2 years or less. Special circumstances means, for example, when alternatives to electricity for heating and hot tap water are not available and a heat pump cannot be used. How much the highest permitted primary energy number and electric input need to be exceeded as a result of the special circumstances should be shown in a special investigation.

If a building is supplied with heat or cooling energy from another nearby building or device, the type of energy or cooling method for the recipient building is considered to be the same as that of the supplier building, provided that the buildings are on the same property or have the same owner. The same applies to properties within the same building in the case of a three-dimensional cadastral survey.

For buildings that contain both dwellings and premises, the requirements regarding average heat transfer coefficient (U_m), primary energy number (EP_{pet}) and installed electric input for heating are weighted in proportion to the floor area (A_{temp}).

General recommendations

Handling of energy from the sun, wind, ground, air or water is regulated in the Swedish National Board of Housing, Planning and Building's mandatory provisions and general recommendations (2016:12) regarding determination of the building's energy use in the case of normal use and in a normal year, BEN.

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[1] Latest wording BFS 2018:4. This amendment means that the fourth paragraph is repealed.

Table 15:Maximum permitted energy number, installed electric input for heating, average heat transfer coefficient and average air leakage rate, for single-family houses, multi-dwelling blocks and premises.

	Energy performance expressed as primary energy number (EP_{pet}) [kWh/m$^2_{Atemp}$/yr]	**Installed electric input for heating [kW]**	**Average heat transfer coefficient (U_m) [W/(m^2 K)]**	**Building envelope's average air leakage rate at 50 Pa pressure difference [l/(s m^2)]**
Dwellings				
Single-family houses > 130 m^2 A_{temp}	90	4.5 + 1.7 × (F_{geo} – 1)[1)]	0.30	As per Section 9:26
Single-family houses > 90-130 m^2 A_{temp}	95			
Single-family houses > 50-90 m^2 A_{temp}	100			
Single-family houses ≤ 50 m^2 A_{temp}	No requirement	No requirement	0.33	0.6
Multi-dwelling blocks	75[4)]	4.5 + 1.7 × (F_{geo} – 1)[1) 5)]	0.40	As per Section 9:26
Premises				
Premises	70[2)]	4.5 + 1.7 × (F_{geo} – 1)[1), 3)]	0.50	As per Section 9:26
Premises ≤ 50 m^2 A_{temp}	No requirement	No requirement	0.33	0.6

1) Addition may be made by (0.025 + 0.02 × (F_{geo} -1)) × (A_{temp} – 130) where A_{temp} is greater than 130 m^2. If the geographical adjustment factor F_{geo} is less than 1.0, it is set at 1.0 when calculating the installed electrical power.

2) Addition may be made by 40 × (q_{medel} – 0.35) where the outdoor air flow in temperature-regulated spaces, for reasons of increased hygiene, is greater than 0.35 l/s per m^2, where q_{medel} is the average specific outdoor air flow during the heating season and may as a maximum be included up to 1.00 l/s per m^2.

3) Addition may be made by (0.022 + 0.02 × (F_{geo} -1)) × (q – 0.35)A_{temp} where the outdoor air flow, for reasons of continuous hygiene, is greater than 0.35 l/s per m^2 in temperature-regulated spaces, where q is the maximum specific outdoor air flow at DVUT.

If the geographical adjustment factor F_{geo} is less than 1.0, it is set at 1.0 when calculating the installed electrical power.

4) Addition may be made by 40 × (q_{medel} – 0.35) in multi-dwelling blocks where A_{temp} is 50 m^2 or greater and that predominantly (> 50% A_{temp}) contain apartments with a living area of no more than 35 m^2 each and q_{medel} the outdoor air flow in temperature-regulated spaces exceeds 0.35 l/s per m^2. The addition can only be used due to requirements for ventilation in special spaces, such as bathrooms, toilets and kitchens and may at maximum be included up to 0.6 l/s per m^2.

5) Addition may be made by (0.022 + 0.02 × (F_{geo} -1)) × (q – 0.35)A_{temp} in multi-dwelling blocks A_{temp} is 50 m^2 or greater and that predominantly (> 50 % A_{temp}) contain apartments with a living area of no more than 35 m^2 each. The addition can only be used when the maximum outdoor air flow at DVUT in temperature-regulated spaces q exceeds 0.35 l/s per m^2 due to requirements for ventilation in special spaces, such as bathrooms, toilets and kitchens. If the geographical adjustment factor F_{geo} is less than 1.0, it is set at 1.0 when calculating the installed electrical input.

Table 16: Weighting factors

Energy carrier	**Weighting factor (VF_i)**
Electricity (VF_{el})	1.8
District heating (VF_{fjv})	0.7
District cooling (VF_{fjk})	0.6
Solid, liquid and gaseous biofuel (VF_{bio})	0.6
Fossil oil (VF_{olja})	1.8
Fossil gas (VF_{gas})	1.8

2.4.3 Heating and cooling installations[2]

Heating and cooling installations in buildings shall be designed so as to provide good thermal efficiency during normal operation.

2 Latest wording BFS 2017:5. The amendment means that the second paragraph in the general recommendations is repealed.

General recommendations

The installations should be designed so that their adjustment, testing, controls, supervision, servicing and replacement are facilitated and a good thermal efficiency can be maintained.

Heating and cooling installations, as well as hot tap water heating systems, should be designed and insulated so that energy loss is limited.

Air conditioning installations should be designed, insulated and have sufficient air tightness so that energy loss is limited.

The need for cooling should be minimised by appropriate construction and installation technology measures.

General recommendations

In order to decrease the demand for cooling in the building, measures such as the selection of window size, window placement, solar screens, solar protective glass, electrically efficient lighting and equipment to reduce internal heat loads, night cooling and accumulation of cold in the building structure should be considered.

2.4.4 Efficient use of electricity

Technical building systems that require electrical energy, such as ventilation, permanently installed lighting, electrical heaters, circulation pumps and motors, shall be designed so that the power requirement is limited and energy is used efficiently.

General recommendations

Table 17: The efficiency of the ventilation system should, given designed air flow, not exceed the following values for specific fan effect (SFP)

	SFP, kW/(m^3/s)
Extract and supply air with heat recovery:	1.5
Extract and supply air without heat recovery:	1.1
Extract and supply air with heat recovery and cooling:	1.6
Extract air with heat recovery:	0.75
Extract air:	0.5

For ventilation systems with variable air flows, an air flow rate of less than 0.2 m^3/s or a running time of less than 800 hours per year, higher SFP-values may be acceptable.

Fixed installed fittings in kitchens and bathrooms should be equipped with efficient lighting sources. Fittings for outdoor lighting should be equipped with efficient lighting sources, reflectors and optics, as well as being controlled by twilight switches, movement detectors or the like. Fixed installed fittings for the lighting of premises should be equipped with proximity or daylight detectors when appropriate.

Electric towel dryers and comfort floor heaters should be equipped with timers or other control systems.

Circulation pumps, except for hot tap water systems, should be designed so that they are normally turned off when there is no need for flow.

2.4.4.1 The changes compared to the previous building regulation are the following:

Primary energy factors are changed to weighting factors for the energy carrier’s electricity, district heating, district cooling, biofuel, oil and gas. At the same time, it is clarified that the weighting factor for biofuel includes solid as well as liquid and gaseous ones. Consequently, the weighting factors for gas and oil include only fossil fuels. The weighting factors are developed according to a cost-optimal approach and provide the opportunity to consider technology neutrality and share of renewable energy in the energy carrier. The primary energy number is retained as a measure of the building’s energy performance, but the requirement levels for maximum permitted primary energy numbers are changed and the requirement for single-family houses is divided into three different levels depending on the size of the single-family house. The maximum permitted average heat transfer coefficient has also been lowered for single-family houses and other premises. And finally, the ventilation addition in Table 2a is adjusted and the specific fan power (SFP) values recommended not to be exceeded are lowered because of improved technical performance of these systems.

2.4.4.2 Further clarifications regarding the Swedish definition of an nZEB:

- The weighting factors are time independent and the same in all municipalities, e.g. regardless of the energy mix of the local district heating plant
- Plug loads (household and activity energy) are not included in the calculated energy performance (EPpet), but are of course included in the energy balance calculations
- The balancing period is a “normal year”
- No requirement on embodied energy or CO_2-emissions
- No requirement on renewable energy production on-site - but it´s easier to get below the maximum EPpet-value if it is used - for PV, especially when having heat pumps and other HVAC systems that use much electricity (and it´s even easier with a battery storage, but not cost effective) - and solar thermal is very favourable in combination with biomass boilers, i.e. renewable energy production on-site has a positive, but limited influence on the calculated energy performance (EPpet).

2.4.4.3 Measurement and verification

Requirements on verification is given in part 9:25 in the Swedish building regulations (not included in the EU notification above). It states that building’s energy use shall be determined either by measurements or by calculations and in accordance with a separate regulation; Boverket’s mandatory provisions and general recommendations regarding determination of the building’s energy use at normal use and in a standard year, BEN (BFS 2016:12 - 2017:5) that gives values for standardised use of buildings and instructions on how to

1. calculate the energy use for a building during normal use during a normal year
2. normalize measured energy use to a normal use during a normal year

2.4.5 Loads and boundary conditions for buildings

2.4.5.1 External loads

The external loads are mainly due to the external climatic conditions that vary quite considerably from the very north part to the very south part of Sweden. This is reflected by the geographical correction factors, going from 0.8 in the south to 1.9 in the north, used to even out these variations when calculating the energy performance (EP_{pet}) according to the building regulations (see Figure 21). Sweden has a set of climatic conditions for a normal year, on set per municipality except for very large once that have two. The climatic conditions compiled by the Swedish Meteorological and Hydrological Institute (SMHI), give the average outdoor climate (e.g. temperature) over the period 1981-2010 and are at http://www.sveby.org/ freely available. SMHI has also calculated the dimensioning winter outdoor temperatures for the same locations, freely available at www.boverket.se.

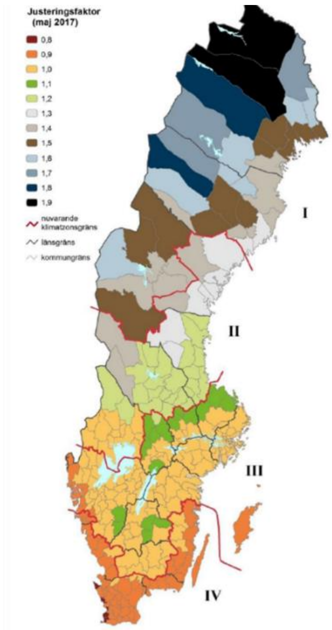


Figure 21: Geographic correction factors

2.4.5.2 Internal loads

Standardised internal loads for different buildings are given in BEN in the form of standardised indoor temperatures, standardised use of household and activity energy and standardised use of hot tap water. Examples of annual values are given below

- For dwellings the standardised use of household electricity is 30 kWh/m^2 A_{temp}
- For dwellings the standardised indoor temperature is 21 °C
- For single-family houses the standardised use of hot tap water is 20 kWh/m^2 A_{temp}
- For multi-family houses the standardised use of hot tap water is 25 kWh/m^2 A_{temp}
- For premises the standardised use of hot tap water is 2 kWh/m^2 A_{temp} (use exceeding 2 kWh/m^2 A_{temp} is activity energy)

In practice the internal loads vary quite considerably between buildings of the same type. When using measured energy to evaluate the performance of a building one therefore normally must do several corrections to compensate for deviations from the standardised values. BEN gives guidance on how to do this, but lack of necessary information and the formulas used sometimes leads to high uncertainty in the estimated energy performance.

2.4.6 System boundary

The system boundary in the Swedish building regulation is since the 1st of July 2017 (BBR25) primary energy according to C in Figure 22. However, it should be noted that as described in 1.2 above the weighting factors for different energy carriers used to calculate the energy performance (EP_{pet}) are not strictly physically based primary energy (neither were the primary energy factors previously used in BBR25-28). Another thing that makes the calculated energy performance deviate from a real primary energy calculation is the use of a geographical adjustment factors, meaning that a building in the very north part of Sweden can use twice as much energy for heating as the same building in the very south part, but still have the same calculated energy performance of a primary energy number.

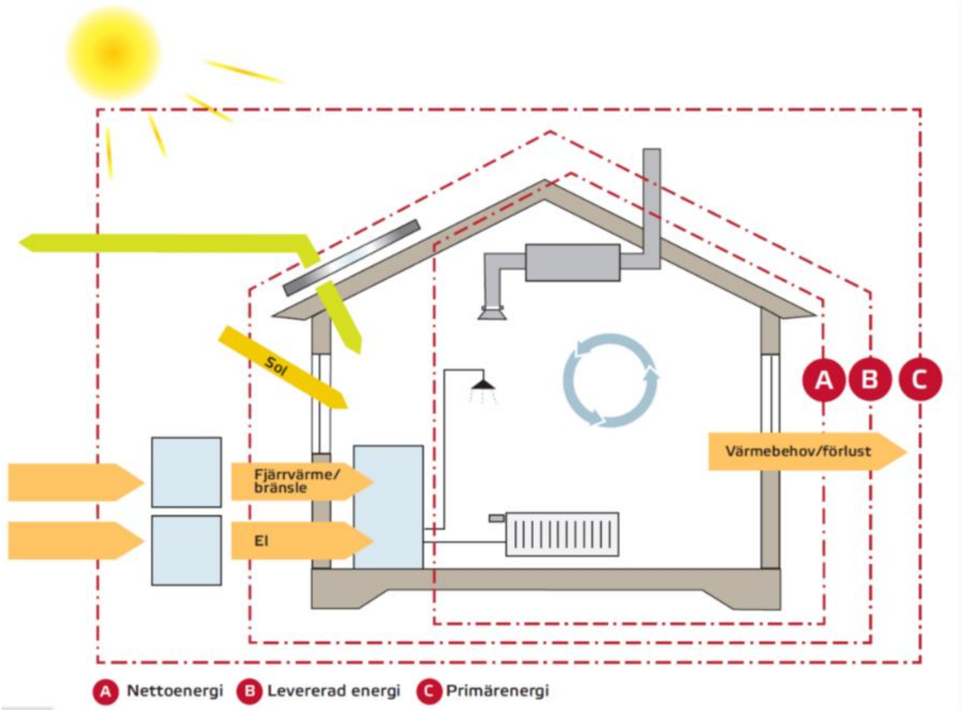


Figure 22: Different system boundaries for a building (text in Swedish).

In BBR12-24 the system boundary B was used in the Swedish Building regulations, i.e. the unweighted bought energy delivered into the building (excluding household and activity energy). Many actors have over the years advocated changing to system boundary A, i.e. net energy need excluding the type of heating system

2.4.7 Utilisation of on-site produced renewable energy

According to the regulation BEN the building's energy use shall be reduced by energy from solar, wind, ground, air or water generated in the building or on its site and used for the building's heating, comfort cooling, domestic hot water and the building's property energy. However, on-site produced energy that is used for other purposes (for example household electricity), is delivered to other buildings or to the electricity grid must not be credited, i.e. surplus production during the day / summer time must not be set off against deficit nights / winter time / cloudy days.

2.5 Swiss definition of nZEB

2.5.1 Building regulation

The building regulation in Switzerland is a cantonal legislation on the basis of the Swiss federal states, i.e. the federal states, called cantons in Switzerland, define the requirements for the new and retrofitted buildings. In order to harmonise the regulations among the cantons, the conference of cantonal energy directors ("Kantonale Energiedirektoren Konferenz (EnDK)") is publishing the Model rules for energy of the cantons ("Mustervorschriften der Kantone im Energiebereich – MuKEn"). This harmonisation is supported on the federal level by the building and HVAC standards, which are elaborated by the SIA – Swiss Society of Engineers and Architects ("Schweizerischer Ingenieur- und Architektenverein). For instance, the SIA 380/1 of 2016 is the current Swiss standard for the calculation of the space heating energy demand of buildings. The SIA 380/1 defines both limits for the building envelope in terms of individual components like prescribed U-values, defining insulation levels, and limits for the space heating energy demand for different building categories, i.e. as result of an annual energy balance calculated on monthly basis. This standard is thereby also the technical background for the further building regulations, directives and labels in the building sector on a national or on the cantonal level. The new requirements of the SIA 380/1 are also in correspondence to the requirement of the MuKEn 2014 (EnDK, 2018), are as strict, that the basic low energy house label MINERGIE® will become the standard building in the new built sector.

2.5.2 Model rules for energy of the cantons – MuKEn 2014

The implementation of legal requirements for nZEB is defined in the last revision of the MuKEn which was finished in 2014 and published as in January 2015. Due to updates in the underlying SIA standard 380/1 in 2016 the latest version with harmonized requirement to the present standardization has been published in April 2018. Despite the quite early publication of the MuKEn 2014 in January 2015, the implementation in the single cantons is still ongoing and was targeted to be finished 2020. However, this may be ambitious, since some cantons are still in an early phase of implementation, see chap. 2.5.3.

Based on the cantonal guidelines for the energy policy (EnDK, 2012), the goal of the EnDK is to implement nZEB in the new built sector by 2020 in line with EU requirements of the EPBD and in the long-term, all buildings shall fulfill nZEB requirements. Therefore, according to the guideline 10 of the cantonal energy policy "until 2020 all new buildings shall cover their energy demands for space heating and DHW with locally self-produced renewable energies on an annual basis and partly cover the electricity demand by on-site production".

To achieve this goal, basically four requirements are set to be fulfilled by new buildings to achieve an nZEB rating

1. The U-values of all building envelope components shall be below the limits in Table 18 and all linear thermal bridges ψ_{li} and spot thermal bridges χ_{li} below the limits given in Table 19

   or alternately

   the space heating demand $Q_{H,li}$ according to SIA 380/1 (2016) shall be below the limit according to Table 20, which is calculated by the two components

   $Q_{H,li} = [Q_{H,li,0} + \Delta Q_{H,li} \cdot A_{th}/A_E)] \cdot f_{cor}$

   where

   Q_{Hli} = limit of space heating demand, $Q_{Hli,0}$ - constant space heating limit, $\Delta Q_{H,li}$ - variable space heating limit, A_{th} – thermal surface of the building, A_E – energy reference area, fcor – correction factor for outdoor temperature of the building site

2. Heat load $P_{H,li}$ shall be below the limit according to Table 20
   (for building categories residential, administration/office, school)

3. Weighted delivered energy below the limit according to Table 21 or use of a standard system solution according to Table 22. The weighted delivered energy is calculated by

$$\frac{Q_{h,eff}[MJ/m^2]}{3.6} \bullet g/\eta + \frac{Q_{WW}[MJ/m^2]}{3.6} \bullet g/\eta + \frac{E_{LK}[MJ/m^2]}{3.6} \bullet g \leq \text{lMuKEn-limit } [kWh/m^2]$$

where

$Q_{h,eff}$ – space heating demand, Q_{ww} – DHW demand, E_{LK} – electricity ventilation/space cooling, g- weighting factor according to Table 23, η - efficiency, performance

4. Installed capacity for on-site electricity production 10 W/m^2_{ERA}

If the criteria are compared with the EU hurdle race in Figure 6 published in 2013 it can be seen that the Swiss criteria are mostly in line with the EU proposal. The space heating demand or the U-value requirement is a limit on the energy needs (first hurdle), the weighted delivered energy is a requirement on total energy demand (second hurdle) and the requirement for on-site electricity generation is a requirement for renewable energy share (third hurdle). However, in Switzerland, no balancing is made, so the two requirement on energy efficiency and the requirement on on-site renewable production are not balanced.
In Table 18 the limits for the U-values and in Table 20 the typical building loads $P_{H,li}$ according to MuKEn are shown. According to the Swiss calculation standard SIA 380/1 (2016), there are twelve building uses defined. For each building use the space heating demand limits are defined as energy use per Energy Reference Area (ERA) and added by a constant term and a variable term, which is the basis for the correction of the building site and the ratio of the thermal surface to energy reference area, which is a similar characteristic as the A:V ratio.
The prescribed maximum design temperature (limit/target values) for new built floor heating systems is 35 °C/30 °C and for new built radiator systems 50 °C/40 °C. For residential buildings, administrative buildings and schools, an additional requirement of a maximum heat load exist, which is also listed as $P_{H,li}$ in Table 20.

Table 18: Limits for the U-values according to SIA 380/1 (2016) and adaptations in MuKEn 2014 (EnDK, 2018)

	Limit U-value U_{li} [W/(m²K)]		**Limit U-value U_{li} Retrofitting [W/(m²K)]**	
Building component connected to	Outdoor air or less than 2 m in the ground	Unheated rooms or more than 2 m in the ground	Outdoor air or less than 2 m in the ground	Unheated rooms or more than 2 m in the ground
Opaque Component - Roof, Ceiling, Wall, Floor	0.17	0.25	0.25	0.28
Window	1.0	1.3	1.0	1.3
Doors	1.2	1.5	1.2	1.5
Gates (doors larger than 6 m)	1.7	2.0	1.7	2.0
Shutter box	0.50	0.50	0.50	0.50

For space heating, no direct electric heating is allowed anymore, a rule, which has already been introduced with the MuKEn 2008. Centralised direct electric heating is to be retrofitted within 10 years from 2015 on. For DHW small decentralized direct electrical heating systems are still allowed, if at least 50% of the DHW demand is generated with renewable sources or during the heating period the water is preheated with the space heating generator.

Furthermore, the MuKEn 2014 defines a criteria for the delivered energy of the building technology (space heating, DHW, air-conditioning and ventilation for the twelve building uses, as depicted in Table 21).
The standard DHW demand for residential buildings is set to 13.5 (19.8) kWh/(m²yr) for single-(multi-) family dwellings, respectively. The energy is weighted with the factors defined in Table 23, e.g. electricity is weighted with the factor 2.

Table 19: Limit for thermal bridges by linear and spot thermal transmittance

Linear thermal transmittance	**limit ψ_l [W/mK]**
Type 1 Cantilever, overhang	0.3
Type 2 interruption thermal insulation by walls, floors and ceilings	0.2
Type 3 interruption thermal insulation by horizontal/vertical building edge	0.2
Type 5 Window stop	0.15
Spot thermal transmittance	**limit χ_{li} [W/K]**
Type 6 point penetration thermal insulation	0.3

The self-produced electricity must not be subtracted for the E_{hwlk} value, except for the produced electricity of cogeneration systems.

Table 20: Building use categories and their limit value for heat demand per square meter with a mean annual ambient temperature of 9.4 °C and specific heat load of MuKEn 2014

Building use		**$Q_{H,li0}$ [kWh/(m²yr)]**	**$\Delta Q_{H,li}$ [kWh/(m² yr)]**	**$P_{H,li}$ [W/m²]**	**$Q_{H,li,retrofitting}$ [kWh/(m²yr)]**
I	Residential (MFH)	13	15	20	1.5*$Q_{H,li}$
II	Residential (SFH)	16	15	25	
III	Administration	13	15	25	
IV	Schools	14	15	20	
V	Store	7	14	-	
VI	Restaurant	16	15	-	
VII	Assembly rooms	18	15	-	
VIII	Hospitals	18	17	-	
IX	Industry	10	14	-	
X	Storage	14	14	-	
XI	Sport facilities	16	14	-	
XII	Indoor swimming pools	15	18	-	

Thereby, the focus is on efficiency, while renewable generation on-site is only taken into account in the balance of weighted delivered energy for thermal energy production, e.g. by solar thermal collectors, which are weighted with 0, i.e. can be subtracted from the space heating and/or DHW demand.

Table 21: Weighted energy use for heating, DHW, cooling/air conditioning and ventilation

Building type		**Limit value E_{hwlk} [kWh/(m²·yr)]**
I	Residential (Multi-family)	35
II	Residential (Single-family)	35
III	Administration	40
IV	Schools	35
V	Store	40
VI	Restaurant	45
VII	Assembly rooms	40
VIII	Hospitals	70
IX	Industry	20
X	Storage	20
XI	Sport facilities	25
XII	Indoor swimming pools	No requirement

For the building category SFH and MFH six standard solutions which fulfil the MuKEn 2014 requirements are given in Table 22.

Additional boundary conditions

- The seasonal performance factor of the gas heat pump has to be at least 1.4.
- 80% is the minimum heat recovery of the controlled ventilation.
- The fossil fraction of district heating is limited to 30%.

Table 22: Standard solutions according to MuKEn 2014

Building envelope	Electric HP borehole or water	Automatic wood firing	District heating of waste or renewable energy	Electric HP outdoor air	Wood firing	Gas HP	Fossil heat generator
Opaque components to outside 0.17 W/(m²K) Windows 1.00 W/(m²K) Controlled ventilation	X	X	X	X	-	-	-
Opaque components to outside 0.17 W/(m²K) Windows 1.00 W/(m²K) Thermal solar for DHW minimal 2 % of ERA	X	X	X	X	X	-	-
Opaque components to outside 0.15 W/(m²K) Windows 1.00 W/(m²K)	X	X	X	-	-	-	-
Opaque components to outside 0.15 W/(m²K) Windows 0.80 W/(m²K)	X	X	X	X	-	-	-
Opaque components to outside 0.15 W/(m²K) Windows 1.00 W/(m²K) Controlled ventilation Thermal solar for DHW minimal 2 % of ERA	X	X	X	X	X	X	-
Opaque components to outside 0.15 W/(m²K) Windows 0.80 W/(m²K) Controlled ventilation Thermal solar for H+DHW minimal 7 % of ERA	X	X	X	X	X	X	X

These standard solutions lead to very good insulation of every part of the building. Also, the minimal required area of the solar collector is quite big. Because of these two reasons, the system can be optimized, if it is proven by a system calculation. Therefore, the standard solutions are not used in any case of new buildings.

Table 23: National weighting factor for the calculation of weighted delivered energy

Energy carrier	National weighting factor
electricity	2.0
Fuel oil, natural gas, charcoal	1.0
Biomass (wood, biogas, sewage gas)	0.5
District heating (incl. waste heat of waste incineration, waste water treatment plants, industry) Fossil fraction ≤ 25% ≤ 50% ≤ 75% > 75%	 0.4 0.6 0.8 1.0
Solar energy, ambient heat, geothermal heat	0

2.5.3 Time schedule of the MuKEn 2014 and implementation state

Figure 23 illustrates the time schedule for the introduction of the MuKEn 2014 correlated to the time schedule for the introduction of nZEB in the EU. The time schedule for the introduction of MuKEn 2014 is coordinated with the EPBD time schedule.

In the single cantons is not finished and not all cantons will accept all criteria, as shown in Figure 24. Thus, the harmonisation of the building energy requirement may not be as uniform as with the last version of MuKEn 2008.

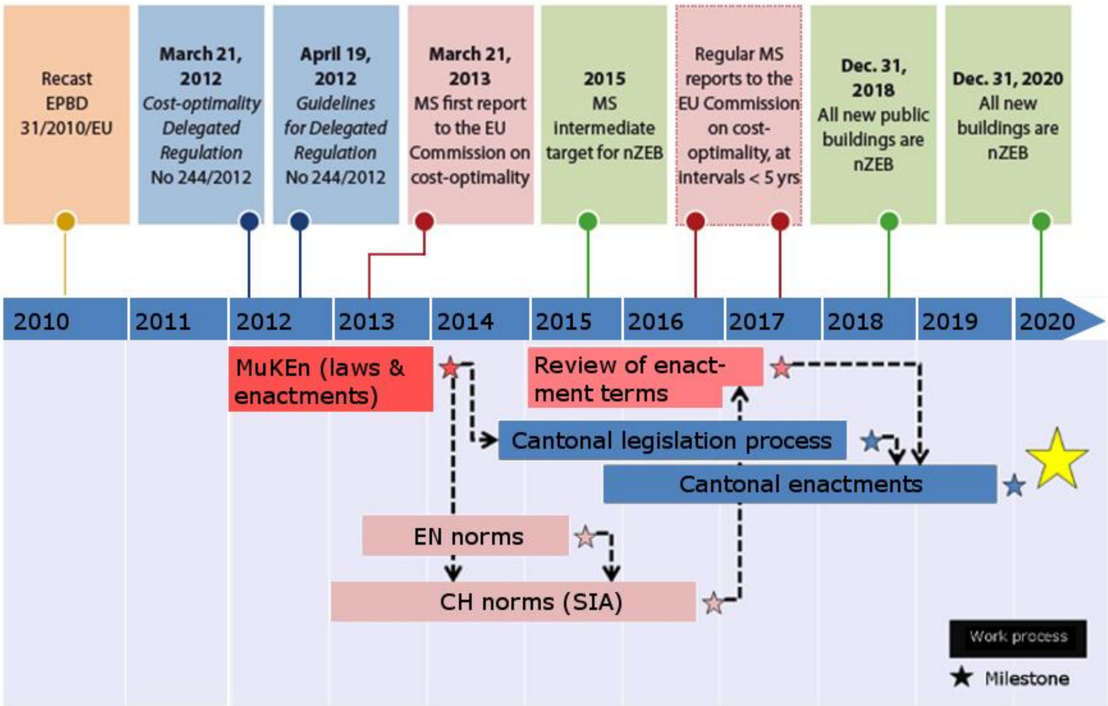


Figure 23: Time schedule for introduction of MuKEn 2014 in line with EPBD time schedule in the EU

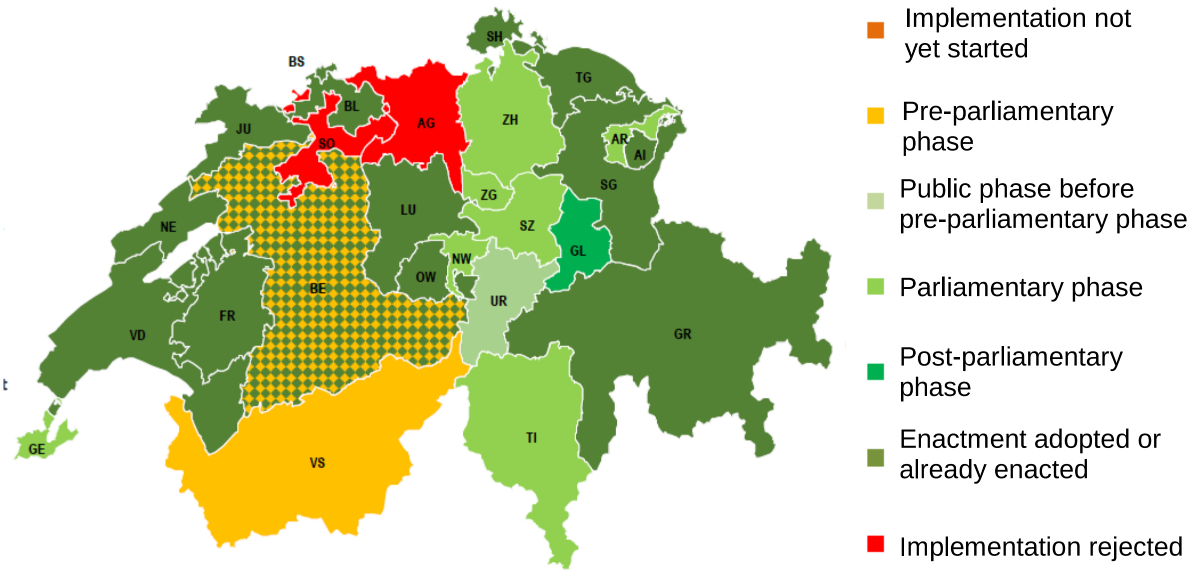


Figure 24: State of introduction of MuKEn 2014 in the Swiss cantons (state December 2020)

Figure 25 shows the state of implementation of single new criteria in MuKEn 2014. While for the implementation of the requirement of MuKEn 2014 for the building envelope (left) and the weighted delivered energy (middle) is quite well accepted by the cantons, the on-site electricity generation is not so well accepted and may need further discussion. In general it seems the implementation will not be as harmonised as the MukEn 2008 version, where the so-called base module with the main requirements was implemented by all cantons.

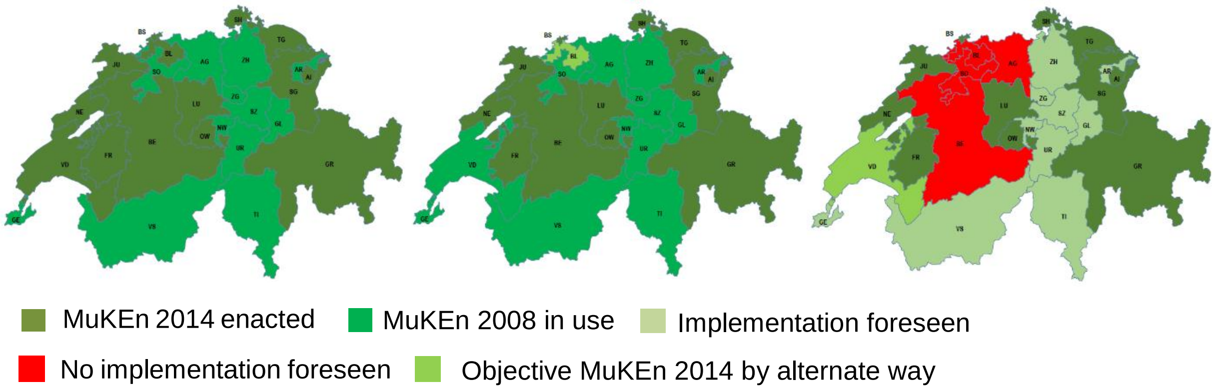


Figure 25: Implementation state of requirement on building envelope of MuKEn 2014 (left), of requirement on the weighted delivered energy (middle) and of requirement on the on-site electricity generation (right) in the Swiss cantons (state December 2020).

3 Methodology to compare nZEB rating

3.1 Simulation-based method for comparison of nZEB ambition level

The objective of the EPBD recast (2010), current version EPBD (2018) is to set higher targets for building energy efficiency to decrease energy use in buildings and promote renewable production on the building site and nearby.

Due to different metrics, system boundaries and limits, it is hard to compare ambition levels of the new requirements of an nZEB in the different EU Member States (MS). The assessment is even more complicated due to different national calculation methods and boundary conditions. For political legislation, a methodology to assess and compare the ambition level across EU-MS would be a means to promote better energy efficiency and higher shares of renewable energies in the EU building sector and can also serve to develop favourable system technology solution sets to comply with higher performance requirements. This would also facilitate the planning process and building technology manufacturers could develop adequate system packages.

Based on the state-of-the-art analysis a methodology was developed to assess and compare the ambition level of the EU-MS nZEB definition in both warm and cold climates. This approach is described in detail in Wemhoener et al. (2019).

The methodology is based on building and system simulations. The methodology has been tested with different simulation programs in Matlab/Simulink and TRNSYS 17 (University of Wisconsin-Madison, 2017). For Matlab-Simulink, two different model implementation according to the Carnot Toolbox 6.1 (Solar Institute Juelich, 2017) and the CarnotUIBK library (Siegele; Leonardi & Ochs, 2019) have been used. The used models have been calibrated by cross-comparison of the results in order to start the process with acceptable deviations.

As reference building, the so-called reference framework, which was introduced in IEA SHC Task 32 in the Solar Heating and Cooling (SHC) program of the International Energy Agency and further elaborated in the joint IEA SHC Task 44/HPP Annex 38 is used, since building parameters are well described in Dott et al. (2013) and thereby offer a good basis for the modelling in the different simulation programs. The building itself is a single-family building depicted in Figure 26. For the application as nZEB reference building, the smaller, south-oriented roof area is additionally equipped with solar PV and different changes of the parameters of the building envelope and system technology parameters have been made. For the investigation in Annex 49 the building is equipped with an air-to-water heat pump for space heating and DHW heating. Thus, electricity is the only delivered energy used for the building operation and thus the building concept corresponds to an all-electric building.

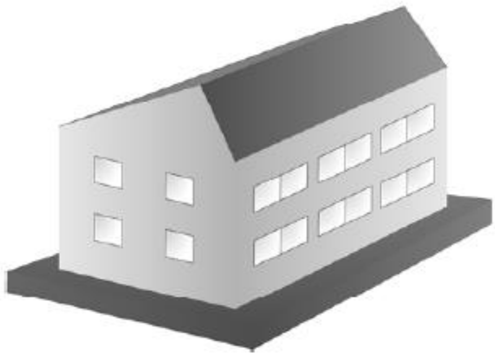


Figure 26: Reference framework building

In the framework document, the reference building is evaluated in different climates and for different building envelope qualities. As a basis for the development of the methodology the climate of Strasbourg with the envelope quality “SFH15” has been chosen, which corresponds to a single family house with a heating demand in the range of 15 kWh/(m^{2}yr) (based on IEA SHC Tas44 / HPT Annex 38). This building is called Framework building in the following.

3.1.1 Method

The methodology itself consists of different steps, which are summarised in Table 24. During the steps different criteria and parameters of the building are varied. In the table changes from step to step are marked in bold and the same parameters among the cases are colour coded in grey scales. Steps for the comparison of results are highlighted with the same colour in the column of the step number. In the following, the different criteria contained in Table 24 are explained with the options denoted in brackets and separated by a slash.

Table 24: Steps of the methodology to compare ambition levels (Wemhoener et al. 2019) (italic, if a reference building is required in national building regulations)

Step	Tool	Climate	BC	Envelope	HVAC	Renewables	Remark
1	Simulation	Strasbourg	Framework	Framework	Framework	Framework	Calibration case
2	Simulation	**National/ Site**	Framework	Framework	Framework	Framework	**Climate case**
3	***National***	*National/* Site	*National*	*National reference*	*National reference*	*National reference*	*Nat. reference building*
4	National	National/ Site	National	**National nZEB**	National nZEB	National	National nZEB
5	***Simulation***	*National*	*National*	*National reference*	*National reference*	*National reference*	*Nat. reference building*
6	Simulation	National/ Site	National	**National nZEB**	National nZEB	National	**National nZEB**
7	Simulation	National/ Site	**Framework**	National nZEB	National nZEB	National	**Comparison to No.2 / No. 11**
8	Simulation	**Strasbourg**	Framework	National nZEB	National nZEB	National	**Comparison to No.1**
9	**PHPP**	National/ Site	Framework	PH envelope	Ideal heating 20 °C	-	PHPP PH
10	*Simulation*	National/ Site	Framework	PH envelope	Ideal op. temp.20 °C	-	PHPP PH
11	*Simulation*	National/ Site	Framework	PH envelope	**Framework**	**Framework**	**National PH Comp. to No.7**

The content of each column of Table 24 is further explained by Figure 27, where:

- Tool (national/simulation) refers to the calculation method, where national refers to the national calculation tool for the approval of nZEB rating. As alternative, simulation programs are used in this investigation.
- Climate (framework/national [reference/site]) refers to the weather data as reference weather of Strasbourg or the national site or reference climate. In some standards, national weather is distinguished in a reference site of the country and the climate of the actual building site (e.g. with correction of height above sea level).
- Boundary conditions (BC) (framework/national) denote the values of the domestic hot water (DHW) tapping profile, the internal gains distinguished in persons and gains of equipment/ illumination as well as the set point of the indoor temperature. They can be set to the framework and national.
- Envelope (framework/national reference/national) denotes the building envelope type. It can be set to the original framework envelope or it is adapted to the national requirement. In some countries, a national reference building is defined and requirements are set relative to the reference building. Thus, values correspond to framework, national reference or national for the building, which exactly meets the country's nZEB requirements.

- HVAC (framework/national) denotes the installed building system technology of the different systems like the ventilation (e.g. heat recovery rate/control/volume flow), shading, heat pump, heat emission, heating and DHW control, auxiliary energy, storage etc. If there are prescriptions in the building directive for the system technology these national requirements for the building system should be taken into account for the national nZEB
- Renewables (PV/solar thermal) refers to installed renewable energies, in particular solar PV. But also solar thermal or other renewables are an option.

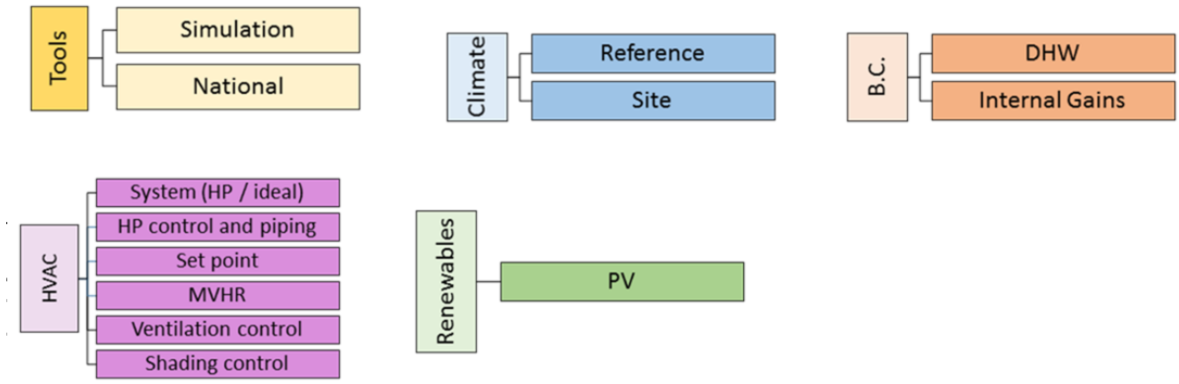


Figure 27: Allocation of values to the respective subsystem or category

3.1.1.1 Step 1: Calibration case

Since different simulation programs have been applied, the first step denoted as “calibration case” consists of the modelling of the framework building in the different programs and compare simulation results for the climate of Strasbourg. A comparison of simulated results is performed by monthly energy balances for the single energies of transmission and ventilation losses, solar and internal gains and the resulting heating demands. Furthermore, the monthly averaged operative temperature and regarding the system technology, the seasonal performance factor (SPF) of the heat pump in space heating and DHW operation and the yield of renewables are compared. Results were stepwise improved until eventually good agreement was reached.

3.1.1.2 Step 2: Climate case

Step 2 denoted as “climate case” does only consist of a simulation of the calibration case with change of the weather data to reference weather data of the respective country in order to evaluate the impact of climate data. The focus of the studies were heating dominated climates (Austria, Germany, Switzerland and Sweden (in preparation). The methodology will also be extended to climates with cooling needs (e.g. Italy).

3.1.1.3 Steps 3-8: National case

Step 3-8 are denoted as national case and consist of transforming the reference framework building to national boundary conditions (BC) which exactly fulfil the nZEB requirements in the country. Finally, the nZEB is simulated again with common boundary conditions and climate data of the reference building.

Thus, in step 3/4 the building is modelled in the national calculation tool, often Excel based, which is used to prove compliance with the national nZEB requirements.

Thereby, all boundary conditions have to be set to national values, i.e. tapping demands and internal loads, since the national nZEB requirements are defined by national calculation methods and values. In the national calculation tool, parameters of the building are modified until the building exactly meets the limit to comply with the national nZEB requirements. Depending on the national calculation, this may also include HVAC in terms of heat pump performance, control settings or ventilation or different shading levels. Step 3 is relevant for countries, which use a national reference building in order to define the national requirements.

In step 5/6 the building, HVAC and renewable parameters are transferred from the national tool to the simulation program, in case of a national reference building, both for the reference building (Step 5) and the national nZEB (Step 6). By the simulation tool, the calculation method is calibrated from different national calculation approaches to a common calculation based on the simulation model. Remaining differences between the results of the national calculation tool and the simulation shall be documented, but no detailed calibration is done for the simulation model, since the more detailed simulation necessarily delivers different results. As further normalisation, in step 7/8 boundary conditions are changed back to the framework. This is done for the internal loads, tapping demands and indoor temperature set points. For the weather data, evaluations may be performed both in national weather conditions (Step 7) and for the common Strasbourg weather of the framework (Step 8). Then, the simulation is performed and the data are compared to the results of the calibration or climate case, respectively, which thereby serves as reference for the comparison of the ambition levels. To avoid distortion of different primary energy factors and different national energy reference area definitions, the absolute electric energy input for the HVAC in terms of space heating, DHW production and ventilation is compared. This is valid for all-electric buildings such as direct electric heating or heat pump for heating dominated climates.

3.1.1.4 Step 9-11: Passive house

As a variant, also the reference building of an ultra-low energy house in terms of the internationally widespread passive house certification is investigated.

The approval of the passive house compliance is done by the planning tool Passive House Projecting Package (PHPP), www.passiv.de. Thus, the implementation of the passive house starts with the adaption of building parameters to comply with requirements in the PHPP. Since a passive house is mainly defined by the heating demand of 15 kWh/(m^2yr), the building envelope parameters are adapted. Boundary conditions in terms of internal loads are taken from the reference framework (step 9), but the PHPP calculates the heat load for ideal heating to 20 °C. In step 10 and step 11, the transfer to the simulation programs is performed like in step 7/8. For the passive house, only the national weather has been considered, i.e. the passive house serves as a local reference with high ambition level. Thereby, in order to compare the simulation, the indoor temperature is controlled to 20 °C operative temperature in step 10, while in step 11, the HVAC and boundary conditions of the framework are applied. The evaluation of the ambition level is made on the national level in terms of the difference to the high ambition level of the passive house as a common baseline. The relative difference among the countries to the local passive house serves as an indicator for the ranking of national ambition levels.

3.2 Results

3.2.1 Calibration

The calibration step of this study includes Matlab-Simulink with two different Toolboxes, the CARNOT 6.1 (Solar Institute Juelich, 2017) and carnotUIBK (Siegele; Leonardi & Ochs, 2019) as well as TRNSYS (University of Wisconsin-Madison, 2017). Figure 28 shows the comparison of the three tools reporting the monthly heating demand (a) and the electricity demand (b). After several necessary iterations, a good agreement has been reached. The relative deviation to the median value of the yearly heating demand is below 1% and of the yearly electricity demand below 3%.

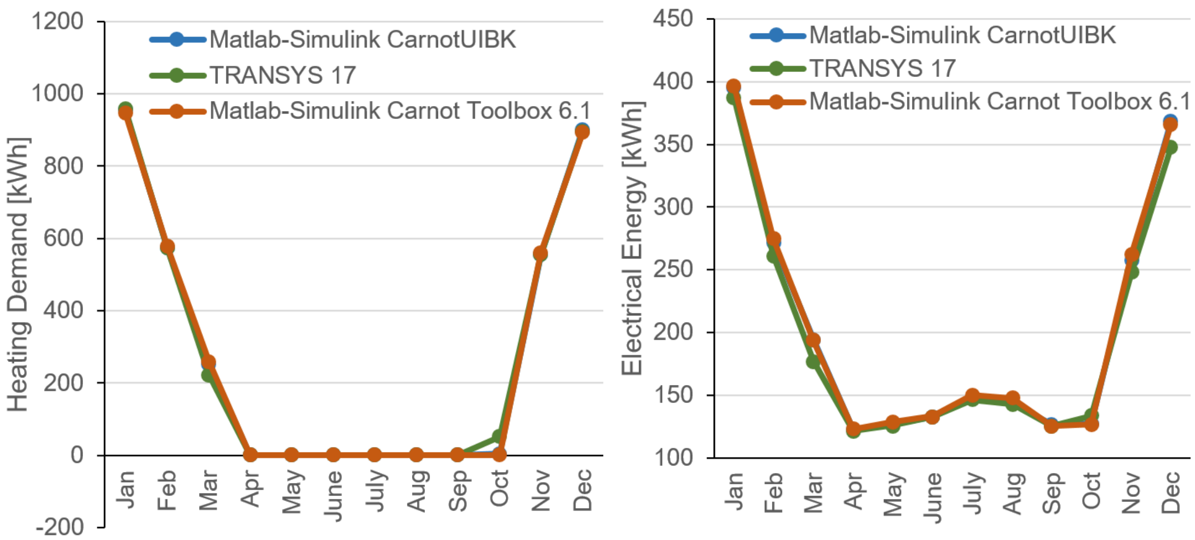


Figure 28: Heating demand (left) and total electrical energy demand (right) for the calibration case

3.2.2 Climate case

Step 2 of the climate case is just an exchange of the common Strasbourg weather data to the local weather data of the D-A-CH countries at Potsdam, Innsbruck and Zurich. Step 2 serves to compare the climate impact. Figure 29 shows the comparison of the three sites regarding the heating demand. Even though the heating demand in Zurich is lower in the core winter month of December and January, and Potsdam has the highest heating demand in every month, the values are still close, so it is confirmed the sites are in the same climate zones. Thus, from the design of the buildings, the transfer to a common climate like Strasbourg in the same climate zone should be feasible.

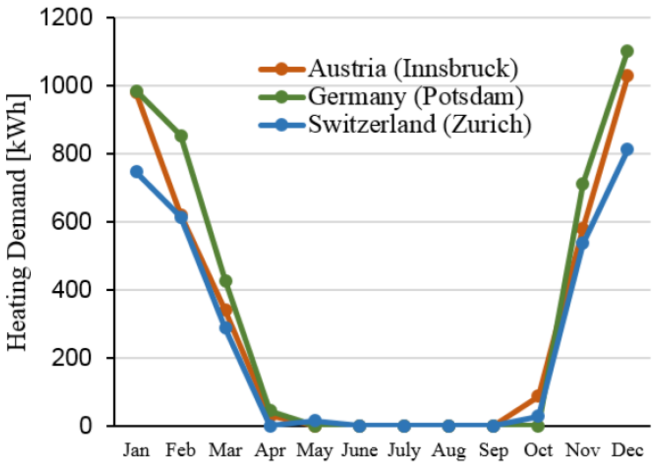


Figure 29: Climate case for the D-A-CH countries

3.2.3 National Case

Figure 30 shows the heating demand and Figure 31 shows the respective electrical energy demand for the national nZEB (step 7) and the internationally widespread passive house standard (step 11). For Switzerland the national nZEB is compared with the Swiss passive house at the site Zurich (weather data set Zurich Meteoschweiz), for Germany the KfW55 and EnEV 2016 requirements are compared with the passive house at the site of Potsdam and for Austria, the national nZEB according to OIB directive 6 (2015) and the Austrian passive house at the site of Innsbruck are considered.
The new nZEB in Germany must be built to meet the requirements of the EnEV (2016) standard, which is significantly less stringent than the KfW55 (2020).

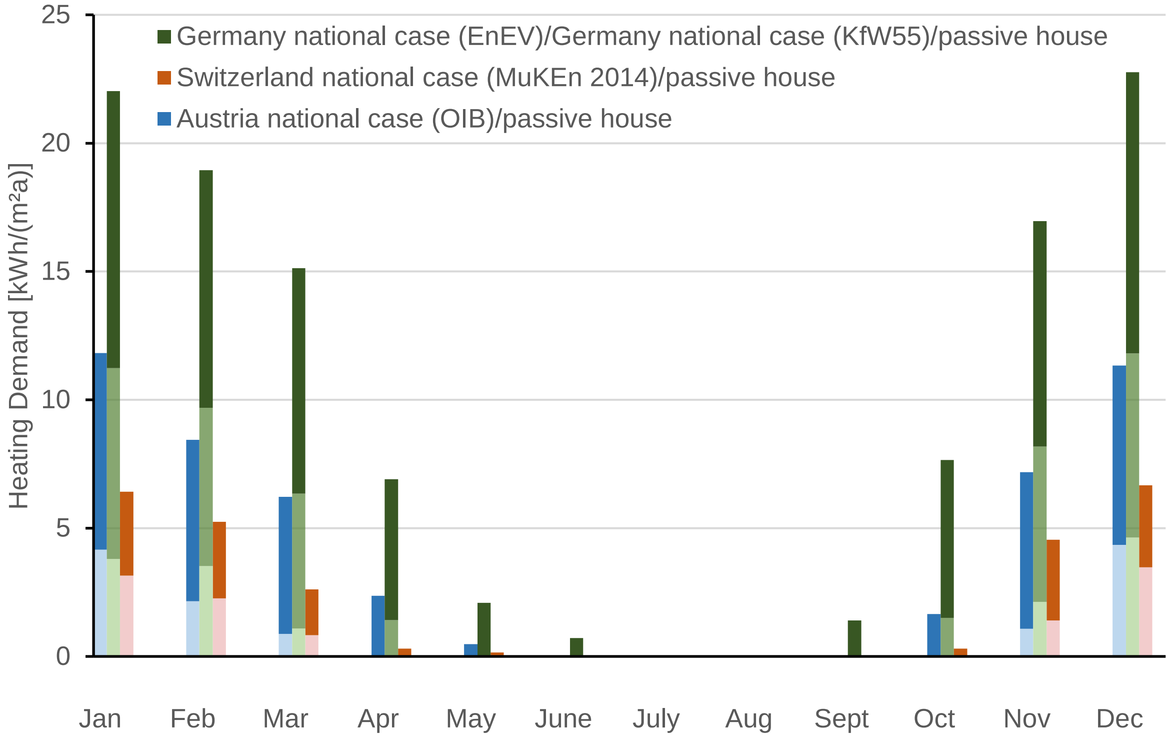


Figure 30: Comparison of space heating demand for baseline passive house (step 11 and step 7)

Compared to a passive house in local climate, the Austrian and German implementation are in the same range, but still significantly higher than the benchmark. The Swiss implementation is more ambitious and comes closer to the local passive house benchmark.

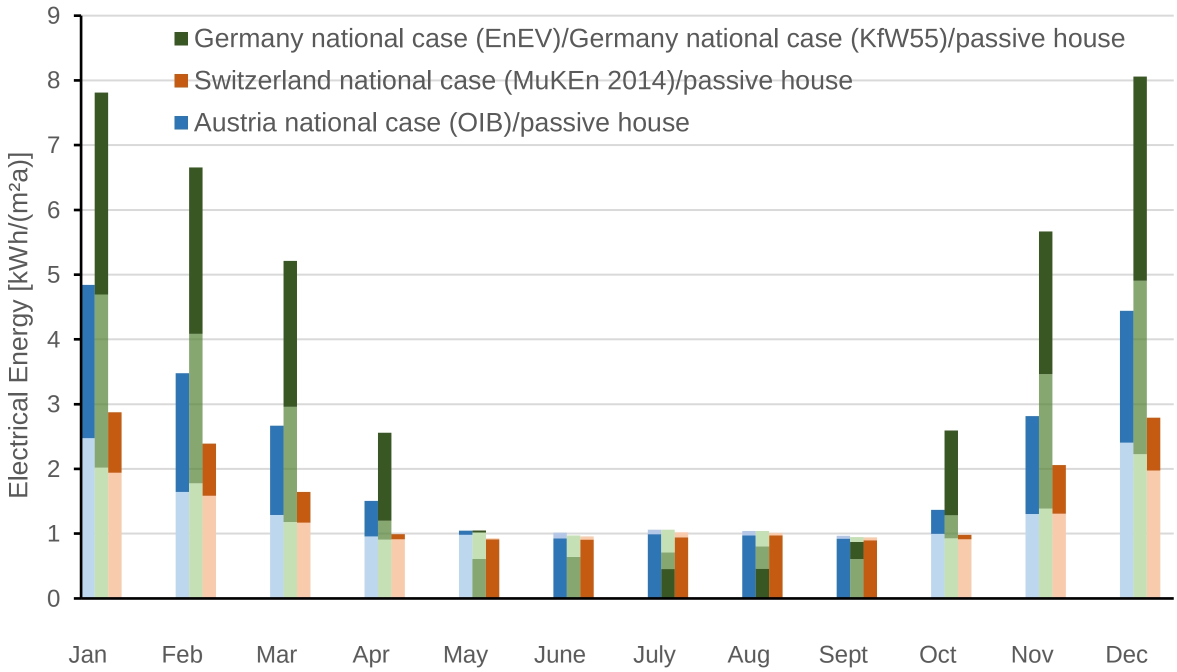


Figure 31: Comparison of electrical energy demand for baseline passive house (step 11 and step 7)

3.3 Comparison of nZEB ambition level by benchmarks

Besides the above described relative comparison among the countries either

- by common boundary conditions regarding internal loads and common weather data (in the tested case Strasbourg) or
- based on local weather data with a common high performance building benchmark as the passive house

also a comparison with other common benchmarks can characterise the ambition level of the national nZEB implementation. The passive houses is arbitrarily chosen as benchmark for a high performance building standards, but also a comparison to benchmarks can be performed to better characterise the national ambition level of the nZEB implementation. Following benchmarks have been considered.

3.3.1 Cost-optimal benchmark

According the EPBD (2018) and the cost optimality guideline (EC, 2012), the minimum ambition level for nZEB shall be the cost-optimal nZEB, see chap. 1.2.2. Thus, the cost optimal building on national level can serve as the minimum requirement for nZEB rating.

3.3.2 EU benchmarks for nZEB with residential and office use

In 2016 the European commission published benchmarks for the implementation of nZEB with residential and office use for four climate zones (EC, 2016), see chap. 1.1.5. These benchmarks were checked with typical new built building services and household electricity demands for residential single and multi-family and office buildings and form a reasonable ambition level going beyond the cost-optimal level.

3.3.3 Upper and lower boundary for nZEB implementation

As lower limit the building physics and comfort constraints for indoor wall temperatures were chosen. In order to guarantee moisture protection at indoor surfaces, minimum U-values of the outer wall in the range of 0.4 W/(m^2K) are required. Comfortable indoor wall temperatures are guaranteed in the same range. Thus, the energy demand for these U-values combined with the worst heating system of a direct electric heating are set as lower limit for the energy performance.
As upper limit a building which achieves a net Zero Energy Balance on an annual basis is defined, for which, however, only the self-consumed on-site PV electricity is accounted in the balance. Thereby, a remaining energy demand of the buildings, which has to be imported from the grid is set as upper benchmark.

3.3.4 Depiction of nZEB ambition level

From these benchmarks a diagram as conclusion of the comparison to different benchmarks, has been derived in the colour range of energy building certificate from green for high ambition level to red as lower boundary. The diagram depicts the ambition level in an energy – cost diagram, which correlates the non-renewable primary energy on the abzissa vs. the life-cycle cost on the y-axis. Figure 32 left shows the cost-optimality line for electrically-driven heating system variants of a direct electric (DE), an air-to-water (A/W-HP) and a ground-to-water heat pump (GW-HP), each with or without a mechanical ventilation system with heat recovery (MVHR). The dashed line gives the pareto front of the cost optimisation, which reaches a minimum at 20 EUR/(m^2yr) life cycle cost and 92.3 kWh/(m^2yr) non-renewable primary energy. A non-renewable primary energy factor of 2.3 for electricity has been used according the recommendation in EC (2016). Since depending on the calculation, the minimum could be quite flat, a range of ±10% around the cost optimum is defined as minimum requirement according to the EU cost-optimality guideline, see chap. 2.1.1, with is set to the yellow range.

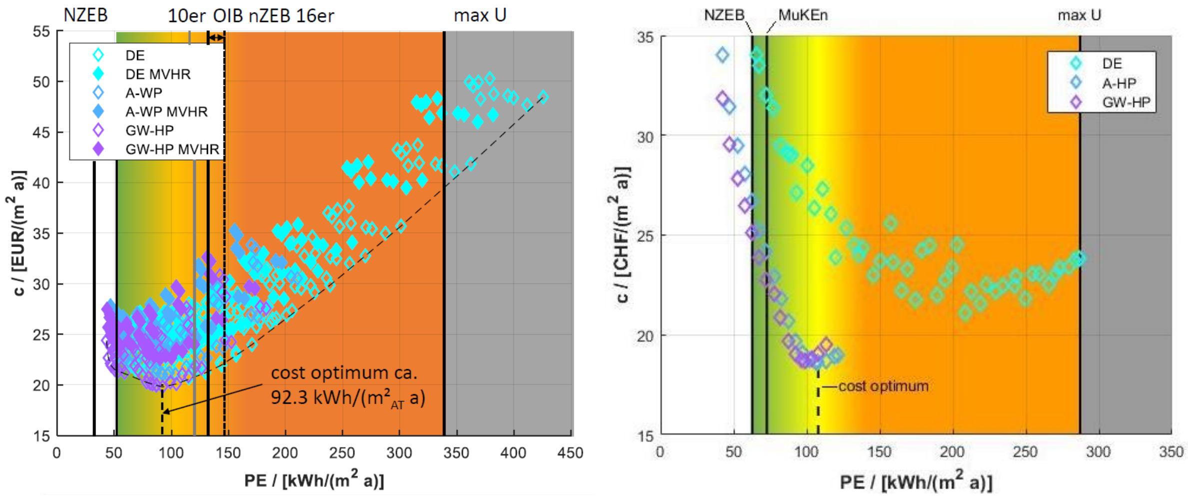


Figure 32: Comparison of the Austrian (left) and the Swiss implementation (right) of nZEB in the energy-cost diagram based on cost optimality calculations

In the diagram, also the green range is limited by the optimum of the NZEB with only self-consumed PV accounted in the balance, which is in the range of 30–50 kWh/(m^{2}yr) non-renewable primary energy. The upper boundary is derived by the max. U-value from building physics combined with the direct electric heating system and defines the highest energy consumption with 334 kWh/(m^{2}yr).

The Austrian nZEB implementation according to the 10er and 16er line of OIB-6 (2015), see chap. 2.1, is also depicted and is right of the cost-optimum, and thereby at higher energy consumption as the minimum requirement and thus in the yellow-orange range of the colour scale. It is noteworthy, that since the implementation is right of the cost-optimum, this would mean that the nZEB implementation causes higher life-cycle cost despite a worse energy performance, which would be an economic contradiction, since more money than necessary is spent for a lower energy quality. However, the contradiction can be explained by only considering investment cost, so the OIB implementation has lower investment cost than the life-cycle cost-optimum.

Figure 32 right depicts the cost-optimality calculation performed according the Swiss MuKEn 2014 for air-source heat pump. At 125 kWh/(m^{2}yr) the cost-optimum is mathematically reached and the NZEB characterising the minimum is reached at about 55 kWh/(m^{2}yr). Nevertheless, the green area transcents the NZEB a bit until the cost-optimal line, since at same life-cycle cost, a slightly better energy performance could be reached. The national implementation results in an energy performance of 75 kWh/(m^{2}yr), which is notably lower than the cost-optimal building and thus in the green area. Therefore, the required ambition level for nZEB rating in Switzerland is quite high, which is a consistent result to the comparison with the passive house benchmark. However, thereby, also a higher life-cycle cost compared to the cost-optimal level has to be accepted.

3.3.5 Discussion and conclusion

The methodology presented allows a relative comparison of the different ambition levels of the countries regarding the national implementation of the EPBD based on a reference building. Thereby, an indication is given, in how far the implementation of the EPBD recast will contribute to an increase in the energy performance in the new built sector. The comparison is useful for policy makers in order to evaluate the degree of implementation of the EPBD requirements and to set out stricter targets for the future revisions and recasts of the EPBD. Moreover, less ambitious countries can be approached to demonstrate the gap among countries and encourage them regarding the transition to a higher ambition level. It has been tested for the single family reference framework building and for the three countries Germany, Austria, Switzerland. However, the current state of the methodology has some limitations namely

- Tested only for single family buildings
- Tested only for one climate zone
- Focus on building envelope measures for reaching national nZEB requirements
- Fixed heating system of air-source heat pump
- Renewable energy production not entirely included

Thus, the methodology should be tested for a broader application range of other building uses like multi-family buildings or offices and further variants to reach nZEB requirements by building technology and renewable generation technology variants. Also other energy carriers or heating systems like wood or district heating could be included.

Moreover, the methodology shall be further improved so that it will be possible to compare also buildings and nZEB requirements of different climates (taking into account also the cooling demand).

The work on the calibration case showed, that a calibration is an absolute necessity before a comparison can be made when using different simulation programs. All the possible user input mistakes must be corrected to get rid of the user influence.

The comparison to other benchmarks based on the cost-optimality calculation required by the EU guidelines combined with benchmarks of a net Zero Energy Building a frontier to plus energy and on the other hand to the EU benchmarks can further give insight into the ambition level of the current EU MS state nZEB implementation and help for the future to achieve the objective of the EPBD of a higher performance in the built environment all over Europe.

4 Archetype nZEB building technical concepts

Table 25 provides a comparison of nZEB implementation criteria in the participating countries of Annex 49. A comparative overview on nZEB implementations across Europe is also included in BPIE (2015), JRC (2016) and IPEEC (2018). Furthermore, common building technology concepts applied in nZEB as well as building labels for high performance buildings are discussed to give an extended state-of-the-art of nZEB implementation.

4.1 Comparison of criteria for nZEB implementation

Table 25: Comparison of nZEB criteria and limit in the participating countries of Annex 49

	AT	**CH**	**DE**	**SE**
Standard	OIB 6	MuKEn 2014	EnEV 2016	BBR 29
Buildings	Residential office	12 building uses (see Table 21)	Residential Non-residential	residential
System boundary	Building technology	Building technology	Residential: building technology (SH, DHW, V, Aux) Office: also SC, L	Residential: building technology (SH, DHW, V, Aux) Office: also SC, L
Balance period	monthly	monthly	monthly	monthly
Energy reference area	gross	gross	A = 0.32*V	net
Reference building	yes	no	yes	no
Reference climate	yes	40 weather data sets	yes	yes
Criteria				
Building components	Building physics constraints	All U-values & thermal bridges acc. to Table 18 and Table 19	H_T' < reference U_{roof} ≤ 0,20 W/m²K U_w ≤1,30 W/m²K $H'_{T\ max}$ ≤ 0,4 – 0,65 W/m²K	U_m values must be met
Space heating demand	Requirement depends on characteristic length	Depending on A_{th}/A_e and site temperature acc. to Table 20	non	non
Heat load	No particular requirement	Residential < 25 W/m² Office, school < 20 W/m² acc. to Table 20	non	non
Primary energy	Requirement on delivered energy, primary energy only informative	Weighted energy Residential (office) < 35 (40) kWh/(m²yr) acc. to Table 21	Q_{PE} < 0.75 x reference building	E_{pet} SFH [90 .. 100 kWh/m²]
Thermal comfort in summer	Yes - proof of summer thermal insulation	Has to be proven by qualitative critieria, simulation or measurements	Yes - proof of summer thermal insulation	No requirement
Air tightness	No particular requirement		With (without) mech. ventilation ≤ 1.5 h^{-1} (3,0 h^{-1})	SFH 0.6 l/(sm²) at 50 Pa
Ventilation requirements	Window airing Possible Min exhaust air for internal rooms	Window airing possible	Window airing possible	– 0,35 l/(sm²)
Renewable production	Either by non RE primary energy or by offsite renewables or by on-site renewables	10 W/m² installed electric capacity required	According to EEWärmeG	Not required
Requirement for retrofitting	Similar to new buildings	1.5 x the limit of new buildings	According to EnEV 2016 for new buildings	Similar to new buildings

4.2 Archetype concepts for nZEB

Basically, there are two archetype concepts to achieve nearly Zero Energy buildings, solar electric production or solar thermal production. Depending on the ambition level and the balance boundary, requirements are stricter or more relaxed for on-site renewable energy production in order to compensate for the energy consumption. Since space for on-site production is limited, a prerequisite for the archetype concepts are reduced building loads both for the building envelope and for the appliances.

4.2.1 All-electric building concept (solar electric production)

The term all-electric building is used for a building which only uses electricity as delivered energy, i.e. electricity is used for all building technologies and appliances. Thus, the evident technology combination of all-electric buildings is a heat pump combined with solar PV on the roof and eventually in the building facade. The combination of heat pumps and PV in high performance buildings has several advantages

- High performance factors of the heat pump due to low space heating loads, which can be covered with low supply temperatures near the room temperature with adapted emission system design
- Multiple building services of SH , DHW, space cooling and dehumidification can be covered with one generator, even simultaneously, which further increases the performance
- No extra installations for fuels required, no space for storing energy carriers
- Electricity is nowadays available in every new building
- As one of the main consumers in residential buildings the heat pump can increase the self-consumption of the on-site PV production, which may be economically beneficial locally and on the larger scale by avoiding grid interaction
- By converting electricity into heating and/or cooling energy, additional storage options are unlocked by the heat pumps in terms of sector coupling (power2heat)

However, the combination is also limited by the mismatch between production and loads, where PV electricity surplus in summer cannot be easily transferred to heat pump operation in winter. Indeed, the all-electric building concept can also be characterised by a surplus electricity in summer and a deficit in winter. The electricity grid is used as virtual storage. Converting heating needs into cooling needs by very efficient building envelopes can thus create better load match and virtually higher efficiency of the heat pump/chiller in cooling operation than in heating operation.

Even though the concept principally also includes direct electric heating, it should be restricted to minor fractions for efficiency reasons, e.g. to emergency heating due to lower temperature limitations of the heat pump or to hygienic requirements of legionella protection due to the upper temperature limit of the heat pumps. However, with adapted system solutions like fresh water systems, hygienic requirements can be overcome by favourable design with lower temperature requirement (see **project Vögelebichl with fresh water system**)

Actually, the efficiency of the building technology and of the lighting and appliances also determines the on-site production necessity to meet ambitious nZE balance targets up to plus energy. Therefore, inefficiencies require extended on-site production, which may compromise cost-optimal building design at current market prices and may increase load mismatch due to larger production surplus in summer and deficit in winter. Thus, efficiency both of the building envelope and of the building system technology and appliances/plug loads is a prerequisite to achieve ambitious nZE balance targets. In particular in larger residential buildings or building with non-residential use implying increased number of devices and plug loads like highly technically equipped office buildings causing also additional cooling loads, the surface for on-site production may not be sufficient.

<u>System variants:</u>

Due to the above mentioned characteristics of the all-electric building concept, different variants are realised as extensions of the basic concept:

- Integration of additional thermal/electric storages
  Due to the beneficial self-consumption of on-site PV electricity for the homeowner or for the grid interaction the concept can be combined with on-site storages. The most evident storage would be electrical battery storages, but a current market conditions, this is not profitable in every case, yet. An alternative would be the increasing number of electric vehicles which could be extended to vehicle2grid or vehicle2building concepts with bidirectional use of the battery. However, the availability of the car and thus the battery storage is not always given and the vehicle may be off in times of highest PV production during daytime. Moreover, the lifetime of the battery may be preferably used for the mobility application.
  Thus, thermal storage is an alternative and in first place, the already integrated DHW storage and the building thermal mass activated by floor heating or thermally activated buildings systems (TABS) can be used (see project **SolSPONGEhigh** on solar fraction with storage in TABS). Moreover, also heating or cooling buffer storages may be integrated for self-consumption and demand response.
- Integration of seasonal storage
  Due to the load mismatch between the summer surplus and winter deficit, it is hard to derive a fully autarkic building operation, even though an annual zero or even plus energy balance can be reached. As an extreme of storage integration, also seasonal storage in the form of long-term chemical storage as hydrogen and power-to-X systems can be installed. However, the cost is still high and round-trip electric efficiency is limited, and thus, the technology is currently restricted to pilot and demonstration plants.
  As a variant of a seasonal source storage, regeneration of ice storage and the ground can be considered. Almost all monitoring projects use ground source, which partly uses a regeneration by free-cooling or active cooling (projects **Black&White**, **KIWI Dalgard**, **OVN**) or active regeneration by solar thermal components (in the project **Riedberg**). In the Report Annex 49 part 3 long term measurements of the ground regeneration of borehole heat exchangers (project **Berghalde**), energy piles and a horizontal agrothermal field (project **Willibald-Gluck secondary school**) and the regeneration of an ice storage with a new absorber system installed under the PV modules (project **Riedberg**) are evaluated.
- Advanced controls
  Another approach is to use advanced control strategies to unlock existing or extended storage capabilities for an energy flexible operation, which shall lead to increased self-consumption for the building owner perspective or to a grid-supportive operation from the grid operator or the electric utility perspective. Control strategies for self-consumption and grid supportive operation are applied in different projects in the monitored buildings like **Berghalde**, **Herzo-Base** and the **living lab of NTNU**, which is detailed in the Report Annex 49 part 3.

4.2.2 "Sonnenhaus" concept (solar thermal production)

The other archetype concepts use on-site solar thermal production in the building envelope combined with a seasonal thermal storage to derive solar autarky regarding space heating and DHW. This concept is linked to the solar pioneer Jenni Energietechnik located in Oberburg in Switzerland. The company has built one of the first solar thermally autarkic SFH, and in 2008 the first solar thermal autarkic MFH was commissioned. The thermal autarky for SH and DHW is achieved by a huge building integrated seasonal water storage, which is charged with solar thermal heat by summer surplus to cover the winter need. Advantages of the concept are

- Less PV-area required to reach the nZEB balance
- 100% self-consumption of the generated on-site heat
- Reduced grid interaction for the electricity grid due to restricted electric summer surplus
- Little PV installation needed for the balance boundary building technology
- Independency of future development of energy markets

However, limitations are the required space and the cost for the seasonal storage. Since a large design of the system is needed for thermal autarky, it is worthwhile to also go to the limit of the performance of the building envelope to reduce the heating demand as far as possible, so normally, the building envelope reaches ultra-low energy house level. Despite cost and space requirements, the concept has spread mainly in Germany, where quite a number of buildings according to the "Sonnenhaus" concept have been built. The disadvantage of the required space and investment for the seasonal storage can be diminished depending on the degree of autarky achieved. Thus, it is possible to combine the pure concept with back-up generators, leading to system variants:

- Integration of biomass back-up
  A decrease of the full autarky to levels for 80 – 90% autarky or lower can notably decrease the size of the components, both the solar thermal collector area as well as the storage size. Thereby, still a limited size of the back-up heater, e.g. a pellet or a biogas boiler is required, to cover the remaining 10-20% of the space heating and DHW demand.
- Combined heat and power (CHP)
  Instead of the pure biomass boiler also a CHP unit can be considered which will have good load match to PV production, since the CHP unit is operated in the heating season, where the PV production is low while during summer, when the plant is not operated the PV production is high. However, gas-engine driven CHP units, which are marketable are limited to liquid or gaseous fuels, which would require biogas or a pre-processing by wood gasification. Furthermore, CHP units require an operation time of at least 4500 hours to be profitable, which may be hard to reach with decreasing space heating demand with high performance building envelopes. At ORNL, a g**as-engine driven integrated heat pump prototype** has been developed
- Supply by district heating
  Instead of biomass imported to the building for the heat supply, also the heat can be directly supplied by district heating.

These are two archetype concepts as pure all-electric and solar thermal autarkic concepts with the respective variants. In pratical implementation in nZEB, however, also further combinations can be found. In the project **Innsbruck-Vögelebichl**, a combination with heat pump, PV and solar thermal has been realised and also variants of the solar thermal and PV share have been examined. Also in the project **SolSPONGEhigh** variants of an air-to water heat pump combined with either solar thermal or PV have been compared. Even though the concept with high solar thermal fraction above 50% is also already spread, see also chap. 4.2.2, the all-electric concept is the dominating concept in the monitoring projects in Annex 49.

4.3 Upcoming technologies applied in nZEB

Table 26 gives an overview of existing and upcoming HVAC technologies for the application in nZEB. In the following a short discussion of different technologies is given.

4.3.1 Heat pump

Heat pumps itself have the advantages already mentioned in chap. 4.2.1 for the all-electric building concept. Following upcoming issues may introduce new heat pump developments.

4.3.1.1 Refrigerants

Based on the F-gas Directive in Europe and the Kigali agreement internationally, current synthetic refrigerants are notably phased down. Thus, a change to refrigerants with low GWP is ongoing. The objective would be natural refrigerants, which are currently already partly in operation and offer interesting characteristic. Each of the natural refrigerants also brings some limitations, though, e.g. the toxicity in case of ammonia and flammability in case of propane.

Table 26: Overview of upcoming HVAC technologies for nZEB (source: Stene, Justo-Alonso, Rønneseth and Georges, 2018)

HEAT PUMPS	**Advantages**	**Disadvantages**
Heat pumps	Renewable energy Heating/cooling in one device May utilize local electricity (PV)	Costs
Natural fluids (R744, R717, R290)	low GWP, 100% eco-friendly, increased SCOP	Costs Toxicity and flammability
High quality VSD compressors, electronic expansion valves etc.	Building technology	Costs
CO_2-DHW heat pump water heaters	monthly	Costs
Grey water heat pumps	gross	Operational problems Maintenance costs
Exhaust air heat pump (CVHD)	yes	Low heating capacity
Seawater, ground water and rock	yes	Costs Maintenance
THERMAL ENERGY SYSTEMS	**Advantages**	**Disadvantages**
Solar heaters	Solar thermal energy	Costs vs. PV costs
PV/T panels	Less roof area	Reachable temperature level
Grey water heat rcovery	Heat recovery from waste source	Maintenance
Hot-fill for washing machines etc.	Reduced electricity consumption	Costs
Waste heat from computer cooling	Reduces heating demand	Operational problems, costs
Low temp. heating syst. (< 50 °C)	High SCOP for heat pumps	Costs
High temp. cooling syst. (> 12 °C)	Max. coverage from free cooling High SCOP for liquid chillers	Costs Higher SFP due to higher Δp
VENTILATION SYSTEMS	**Advantages**	**Disadvantages**
Decentralized air handling units	Short ventilation ducts, low SFP	
Demand control VAV systems	Min. el. consumption	Costs
Hybrid ventilation system design	Low SFP Lower costs, less ventilation ducts	Demand design Possible poor indoor climate
Displacement ventilation	Energy efficient ventilation	Not applicable everywhere
Space heating by ventilation air	No costs for heat distribution Increased heat pump SCOP Comb. Heating/cooling battery	Possible poor indoor climate For single-zone buildings only
Night time cross ventilation, exposed concrete and PCM	Reduced cooling loads Reduced el. demand	Costs for PCM systems
High-efficiency heat recovery units	Low vent. Air heating demand	η_{th} always lower than stated
GSHP preheating/-cooling vent. air	Renewable heating and cooling Frost protection	Costs Higher SFP due to increased Δp
Double (serial) heat recovery unit	Ultra high efficiency, $\eta_{th} \approx 92\%$	Costs Higher SFP due to increased Δp
ELECTRICITY GENERATION	**Advantages**	**Disadvantages**
PV panels	Local renewable el. Generation PV crucial for ZEB level	Moderate efficiency Costs 25-30 year pay-back time
Battery pack for PV panels	Increases local el. utilization	Limited to residential use?
PV/T panel - photovoltaic+thermal	Reduced roof airea requirement	Higher costs
Combined heat and power (CHP)	Local renewable el. generation	Costs, long pay-back time

Therefore, enhanced security measures are required. CO_2 as refrigeration offers high performance for DHW production, but has high pressure requirements and a need for higher sink-side temperature spread in order to reach high performance values. In the project **KIWI Dalgard**, a CO_2-refrigeration system is applied, which includes a heat recovery for space heating use and regeneration of the borehole thermal energy storage (BTES). Also in the **ONV project**, recharging of BTES with waste heat from cooling operation is used.

4.3.1.2 Building loads and DHW fraction

In high performance buildings, loads are shifting to increased DHW fraction and an additional space cooling demand, which may yield efficiency gains by desuperheating and simultaneous operation, if the heat can be used for DHW production. However, with decreasing heating needs in high performance buildings, also desuperheating potentials may decrease as evaluated in the project **Innsbruck-Vögelebichl.**

Another approach to increase the heat pump performance based on lower load conditions are integrated heat pumps (**ORNL prototype development**), which offer options of internal waste heat recovery for another building function, e.g. cooling/dehumidification and DHW use, require less installation space, can be equipped with more costly, but high performance components due to the use for multiple functions and can be equipped with an optimised control.

On the other hand as mentioned above higher DHW fractions are favourable for CO_2-refrigerant, which yields high performance in DHW operation with adapted system design. In the project **Justvik Skole** a particular adapted heat emission system has been designed for CO_2-heat pump application.

4.3.1.3 Capacity-controlled heat pumps

Capacity-control for heat pumps instead of on-/off-cycling for the smaller capacity range are more and more available since the mid of the years 2000 on the European market, while they have already been longer available on the American and Asian markets for air-conditioning units. Nowadays, all manufacturers offer capacity controlled heat pumps. In particular speed controlled compressors with DC inverter offer high COP in part load operation, which has the perspective of further performance increase. Thus, for nZEB with reduced heating loads a speed-controlled heat pump may have particular advantages. The evaluation of the project **Herzo-Base** confirms high performance of an SPF_{HP} of 5.6 of the two central speed-controlled heat pumps. This, however, also raises the question for the **design of speed-controlled heat pumps** for nZEB, which has been investigated by simulations by the HSR Rapperswil for a single-family nZEB and two heat pump types characterised by the performance map of the manufacturer.

4.3.1.4 Heat sources

With the use of the building envelope for renewable energy production, also the integration of the unit as heat source or heat sink is possible. A solar thermal heat source is often found in combination with an ice-storage as so-called "solar-ice systems". Ice storages, which have been more commonly used as cold storage in space cooling and air-conditioning, can be built more compact due to higher latent heat storage density as a normal water storage and provides a more or less constant heat source temperature around 0 °C in the common design temperature range of ground-source heat pumps for the heating operation in winter. Thus, this solutions is particularly interesting for building sites, where boreholes cannot be drilled. Newer developments also use uncovered solar absorber as heat source, and also photovoltaic-thermal (PV/T) collectors can be used as a heat source in such system configurations, which enable a higher area specific use by simultaneous electricity and heat production with the same collector-area. Performance values in the range of common ground-source systems can be reached, but costs may still be higher than for ground- or air-source heat pumps. In the **project Riedberg** a new system configuration, where the absorbers are installed below the PV panels on the roof and extracts the heat by convection from the ambiance without direct use of solar irradiation is applied in combination with an ice-storage. The **regeneration of the ice storage** is also considered in the project.

Also PV/T collectors with particular increased heat transfer from the ambiance are on the market, which can serve as heat source even with low or without solar irradiation. During nighttime, these unglazed solar absorbers or PV/T collectors can also be used as heat exchanger to the ambience due to a missing thermal insulation in contrast to conventional flat plate solar collectors with glass cover. **Cooling capacities of an uncovered solar absorber** for nighttime free- and re-cooling operation have been measured at the solar test rig of HSR for a prototype absorber with surface wetting. This enables integrating a highly efficient freecooling function into common system configurations of solar-ice systems, where the ice storage can be used as cold storage in summer operation.
Instead of an ice storage, uncovered solar absorbers and PV/T collector can also be used in combination with a ground-source to actively regenerate the borehole thermal heat storage (BTES) with the heat production in summer. Thus, the ground can be used as seasonal storage. For the regeneration, also waste heat from space cooling applications in summer, either from freecooling or recovered from active cooling mode, can be used. This is applied in several systems of the monitoring projects as **KIWI Dalgård**, **ONV**, **WGG** and **Herzo-Base.** The use of waste heat from the cooling operation can further increase the overall performance. In the building **Black&White**, no recooler for the cooling operation is installed, and all waste heat from active cooling is used for space heating or DHW heating or for ground regeneration. Boreholes can also be coupled to the ventilation air for preheating and precooling purpose, which has been investigated for the freecooling operation in the **twin houses in Borås and Varberg**.
For larger buildings and groups of buildings, a sewer heat recovery offers an alternate and high temperature heat source. In Brussels the water company Vivaqua intends to equip the sewers with heat exchangers in the course of retrofit works.

4.3.1.5 Low temperature lift heat pumps

In nZEB the high performance building envelope and the low heating load enable providing the remaining heating load at low supply temperatures. With good source temperature like deep or regenerated boreholes, ground-water or sewage water, the temperature lift for the heat pump can be notably decreased. There are dedicated developments of heat pumps for low temperature lift, which reach particularly high COP and SPF_{HP} values, in laboratory application up to 10 and in field monitoring up to 7 for space heating.
Especially with increasing cooling demand and with active cooling in office buildings the temperature lift can become quite low with high temperature emission systems like thermally activated buildings systems (TABS) or cooling ceilings and low temperature recooling option like the ground, which may offer high performance opportunities. In case of additional dehumidification loads, the separation of latent and sensible cooling loads is a means to cover the sensible cooling load at a higher temperature level. A system option for this separation is a dehumidification by desiccants. Systems are under development or already introduced in the market.

4.3.1.6 Ventilation systems

For the airtight building envelope of high performance buildings, a ventilation system helps to guarantee the hygienic air exchange rate. Mechanical ventilation systems have the further advantage that indoor air quality can be improved by filtering the outdoor air and offer the possibility to reduce ventilation losses by heat recovery with typical recovery rates up to 90% with counter flow heat exchangers. Demand controlled ventilation, e.g. by CO_2-sensors and hybrid ventilation as combination with window airing can reduce electricity demand. With enthalpy recovery, also the moisture of the return air can be recovered for humidification of the supply air in winter, when the air is often too dry.
For low space heating loads the exhaust air can be an interesting heat source. The original passive house concept used the ventilation air heating. For heat loads as low as 10 W/m^2, which can be reached in passive houses, the hygienic necessary air exchange rate is sufficient to heat the building.

This was implemented by so-called compact units, which combined a space heating by using ventilation air with the mechanical ventilation system, an exhaust air heat pump and the DHW heating in one packaged unit. Typical heating capacities for these ventilation air units are in the range of 1.5 kW. Units were also amended with ground-to-air heat exchangers for air pre-heating/-cooling, solar thermal DHW production and additional outdoor air source for higher capacity in the range of 4 kW. Some units incorporated an active cooling function of the supply air by reverse operation of the heat pump.

4.3.1.7 Storage and control

As mentioned already in chap. 4.2.1 for the all-electric building concept, the heat pump in combination with storages can be used for electrical load management/demand response in order to optimise PV self-consumption and grid supportive operation. In the project **Berghalde**, evaluations by simulation for the single family house both regarding control for self-consumption and grid-supportive operation have been performed. Also the design of thermal and electric storage has been evaluated. In the project **Herzo-Base**, both rule-based and model predictive control strategies have been evaluated for charging of thermal storages and electric battery. For the **ZEB Living Lab** of NTNU different control strategies have been examined using (predictive) rule-based control to evaluate energy flexibility of Norwegian residential buildings equipped with thermal storage, among them a price-based and CO_2-intensity based control. In the **solSPONGEhigh** project the solar fraction by storage in the building thermal mass by TABS have been evaluated for different control strategies.

Despite notable increase of PV self-consumption by thermal and electric storage, a larger design of the component to achieve higher self-consumption at current market conditions hardly profitable. Thermal storages are currently more economic than electric batteries, but with increasing market for electric vehicles, also battery prices may come down for stationary applications in buildings and batteries are also further developed, so new types may appear on the market. Experiences with a Vanadium Redox flow battery are given in the project **WGG**. Also for the prototype development of the **façade integrated heat pump in project COOLSKIN**, an autonomous operation with battery storage has been investigated. The façade module is covered by PV panels to supply the heat pump for cooling or heating of the adjacent room. However, also in this project, it was found, that the battery is not profitable at current market conditions.

As conclusion, using existing storage potentials of DHW and heating buffer storages as well as the building thermal mass by smart control strategies is currently most economical.

As the ice storage for the use as heat source, latent heat storage incorporating phase change materials are also introduced into the market as heat storage on use temperature level. The advantage is a higher energy storage density in the range of the phase change of the material, which enables smaller storage volumes. In the **RoCo prototype development** a PCM storage is used to store the condenser heat from the cooling operation and enable an autonomous operation without recooling for up to 8 hours. PCM integrated in building material like gypsum plate can increase the building thermal mass and dampen the temperature increase in the comfort range of the room temperature, thereby reducing the cooling load. However, the PCM has to be discharged during nighttime, which is done by cross-ventilation with cooler nighttime air. This, however, requires sufficient volume flow rates, which often coincides with windless weather in summer nights. Another option is the integration of PCM storage into the ventilation systems, where the PCM storage is discharged by nighttime ventilation air and the air is pre-cooled by passing through the PCM storage during daytime. This needs electricity for the fans, though.

4.4 International high performance building and nZEB labels

4.4.1 AT – Klimaaktiv

Klimaaktiv is the climate protection initiative of the Austrian Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology (BMK). The focus is to sustain the energy system transformation, in this context the most important starting points are construction, refurbishment, energy saving, renewable energies and mobility (Klimaaktiv, 2020). The standard klimaaktiv can be attained for residential as well as for non-residential buildings.
The Energieinstitut Vorarlberg (EIV) and the Österreichisches Institut für Bauen und Ökologie GmbH (IBO) are responsible for the development of the klimaaktiv criteria catalogues in coordination with the klimaaktiv consortium. 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 standard. These most important criteria for ensuring building quality according to klimaaktiv are summarised in the klimaaktiv basic criteria. If a building fulfils all the basic criteria of klimaaktiv, it receives the klimaaktiv BRONZE award. The news in the klimaaktiv basic criteria 2017 is the verification path for the energy parameters according to OIB-6:2015 for all building categories. Klimaaktiv criteria regard several topics, here listed and described:

- Location and assurance of quality
  - Infrastructure and facilities close to the site enhance the quality of the location, increase the user satisfaction and allow a reduction of the traffic emissions
  - For assurance of the building quality an air-tightness test according to ÖNORM EN ISO 9972 must be demonstrated for each klimaaktiv building. The requirement for new building is $n_{50} \leq 1.5$ 1/h
  - A separate recording of the relevant energy consumption in order to check the precalculated required values and detect possible defect (and if necessary eliminate)
- Energy and utilities
  - Heat demand and heat supply play a major role in klimaaktiv buildings. Therefore, stricter limits are set than those of OIB-6. The customer benefits are increased comfort and reduced energy costs. Numerous examples demonstrate that the savings shown can already be achieved economically today, especially in large-volume buildings. The additional costs compared to "normal" new buildings are lower than often assumed and can be compensated by the energy cost savings.
  - A limit is set on the externally induced cooling demand, i.e. the cooling demand that is exclusively caused by solar input and transmission, in order to optimise the solar input into the building (in accordance with the requirements of OIB-6). As for the heating demand, a low demand is a long-term effect and allows the reduction of energy input and associated pollutant emissions. Klimaaktiv buildings have lower energy input than the minimum values according to OIB-6.
  - Primary energy demand considers several factors. It depends on the length of the transport route and the energy expenditure for the production of an energy source, too.
  - CO_2 emissions are calculated according to OIB-6 (2015).
- Building material and construction:
  - It is not permitted to use several materials, which have higher global warming potential than CO_2 and which have ecological disadvantages in their production cycle. Moreover, durable materials are preferred to reduce the ecological costs.
- Comfort and indoor air quality
  - Apartments with well-insulated walls and high-quality windows can be very pleasant in winter, but may lead to overheating problems in summer. With the right planning, overheating problems in summer and in the transitional periods can be avoided. This leads to better thermal comfort in the hot season, which avoids the subsequent purchase and use of electricity-consuming room cooling units.

- Indoor air measurements allow monitoring of the air quality, in order to avoid complaints and illness. The quality of the construction work is ensured by measurements and proofs.

Further information to the klimaaktiv label is found on the following websites:
https://www.klimaaktiv.at/bauen-sanieren/gebaeudedeklaration.html
Database: http://www.klimaaktiv-gebaut.at/

4.4.2 CH – MINERGIE-A®

MINERGIE-A® was established in 2011 with the focus on a balance of energy consumption and on-site production on an annual basis expressed as a "weighted delivered" energy characteristic, i.e. a kind of primary energy metric. In accordance with the other MINERGIE®-labels, the balance boundary has first been set to the building technology, i.e. a nearly zero energy (nZEB) balance excluding the electricity consumption for plug load and appliances. With a revision in 2017 the balance has been extended to total energy consumption including appliances and plug loads and thus refers to a Net Zero Energy Balance and is thus an NZEB. Until May 2014, only residential buildings could be certified, but since then, also non-residential buildings categorized as offices and schools can be certified.

Regarding the labelling criteria mainly the following requirements must be fulfilled

- Legal requirements according to MuKEn 2014
- PV annual energy yield must balance the total annual energy consumption of the building (Net Zero Energy Building)
- MINERGIE-characteristic < 35 kWh/(m^{2}yr) (residential buildings)
- 100% fossil free for heating and DHW (30% fossil fuels for peak load and for CHP with fossil fuels with > 35% electric share is still allowed)
- Monitoring in every building

Figure 33 gives an overview of the different MINERGIE-A® features. MINERGIE-A® is one label of the MINERGIE®-label family. The MINERGIE-P®-label is an implementation of the 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 a nearly zero energy approach.
Since the introduction, more than 1042 certificates for MINERGIE-A® and MINERGIE-A-ECO® have been assigned (state August 2020). There is also a database, where basic information on the certified buildings are given and a search routine for different features of the building. An evaluation of the building technical systems installed in MINERGIE-A® buildings can be performed by the MINERGIE®-Database given below. The MINERGIE-A®-label can also be combined with the ECO-label (MINERGIE-A-ECO®), which adds requirements regarding thermal comfort, health and building materials to the certification criteria.

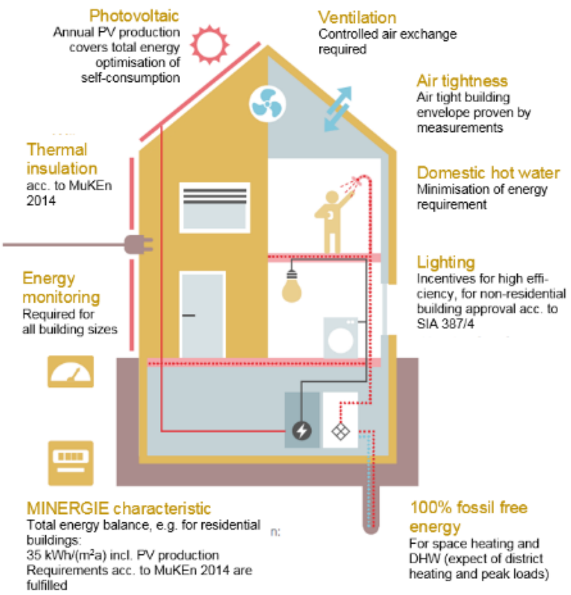


Figure 33: Characteristics of MINERGIE®-A buildings

Further information can be found on the website:

MINERGIE®-labels: https://www.minergie.ch/
Database: https://www.minergie.ch/de/gebaeude/gebaeudeliste/

4.4.3 CH/DE - Sonnenhaus

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. Regarding this high fraction of solar thermal yield extensive collector area and storage volume must be installed. Meanwhile, the database contains more than 300 of these solar houses 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 must 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^2yr). With a fossil auxiliary heating, the demand can be max. 30 kWh/(m^2yr), to get this value, usually a solar coverage of over 50% is necessary.
  - Insulation standard: The specific heat transmission losses have to be 15% lower than the German building code EnEV reference building.
- Refurbishment
  - Solar coverage: Same as for new buildings
  - Insulation standard: The specific heat transmission loss shall not be higher than 15% than the one of an EnEV reference building
  - Primary energy: The specific primary energy demand must be less than or equal to the one of an EnEV reference building
- Solar house plus
  - Solar coverage, primary energy demand according to EnEV and insulation standards are the same criteria as for normal solar houses
  - The annual primary energy demand with calculation of household electricity must be negative
- Solar house self-sufficient
  - Solar house self-sufficient: Criteria of solar house plus a self-sufficiency degree of at least 50%
  - Solar house plus autarkic: Additional to solar house autarkic, the annual primary energy demand criteria must fulfil the requirement of the solar house plus

Homepage: http://www.sonnenhaus-institut.de/
Criteria: http://www.sonnenhaus-institut.de/wp-content/uploads/1-Sonnenhauskriterien-2014.pdf
Database: https://www.sonnenhaus-institut.de/solararchitektur/solarhaeuser.html

4.4.4 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.

The exact definition is according to the Passive house institute (PHI)

A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air.

This very low space heating demand is expressed in the required space heating demand lower than 15 kWh/(m^2yr). For air heating with the hygienic necessary air flow rate, a heat load lower than 10 W/m^2 is required, which is also typical for passive houses.

Moreover, the renewable primary energy demand (PER) must not exceed 60 kWh/(m²yr). These requirements refer to a so-called classic passive house standard without renewable electricity production on-site. Two further categories of passive house certification have been introduced, denoted as passive house plus and passive house premium, where also requirements for an on-site electricity production are set as depicted in Figure 34.
The Renewable Primary Energy Demand (PER) (Passipedia, 2015) is the total energy to be used for all domestic applications (heating, hot water and domestic electricity) evaluated with the PER factors. PER factors represent how much more renewable energy must be supplied in order to cover the final energy consumed at the building, including all losses incurred along the way. They are evaluated with the following formula:

$$PER = \frac{Energy\ supply\ from\ renewable\ sources}{Final\ energy\ demand\ at\ the\ building}$$

and considering an hourly resolution in load profiles of the energy demand simulated in the context of a future scenario (Passipedia, 2015). As renewable sources only photovoltaics, wind turbines and hydropower are considered. Biomass and all systems based on secondary energy (e.g. district heat) are taken into account directly in the passive house projecting package (PHPP), with appropriate parameters for the respective system.
Further information about the criteria is found on the passive house homepage.

Homepage: http://www.passiv.de/
Passipedia: http://passipedia.org

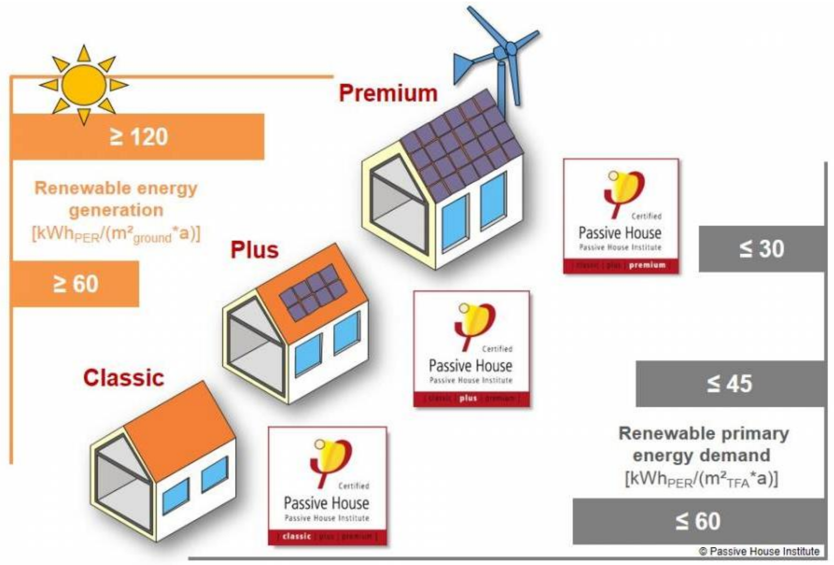


Figure 34: Requirements for different types of passive houses (source: Passive House Institute)

4.4.5 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 at the usage shall be considered and promoted.

The ActivPlus initiative is linked to the Danish Activehouse Alliance, see chap. 4.4.8, which itself is also linked to initiatives in other European countries, e.g. the Activehouse NL initiative in the Netherlands.

Homepage: https://aktivplusev.de
Database: https://aktivplusev.de/aktivplus-haeuser/

4.4.6 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 EnEV (see chap. 2.2). Note, that the Effizienzhaus plus is not an official certification, yet. This is just a program of the 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.

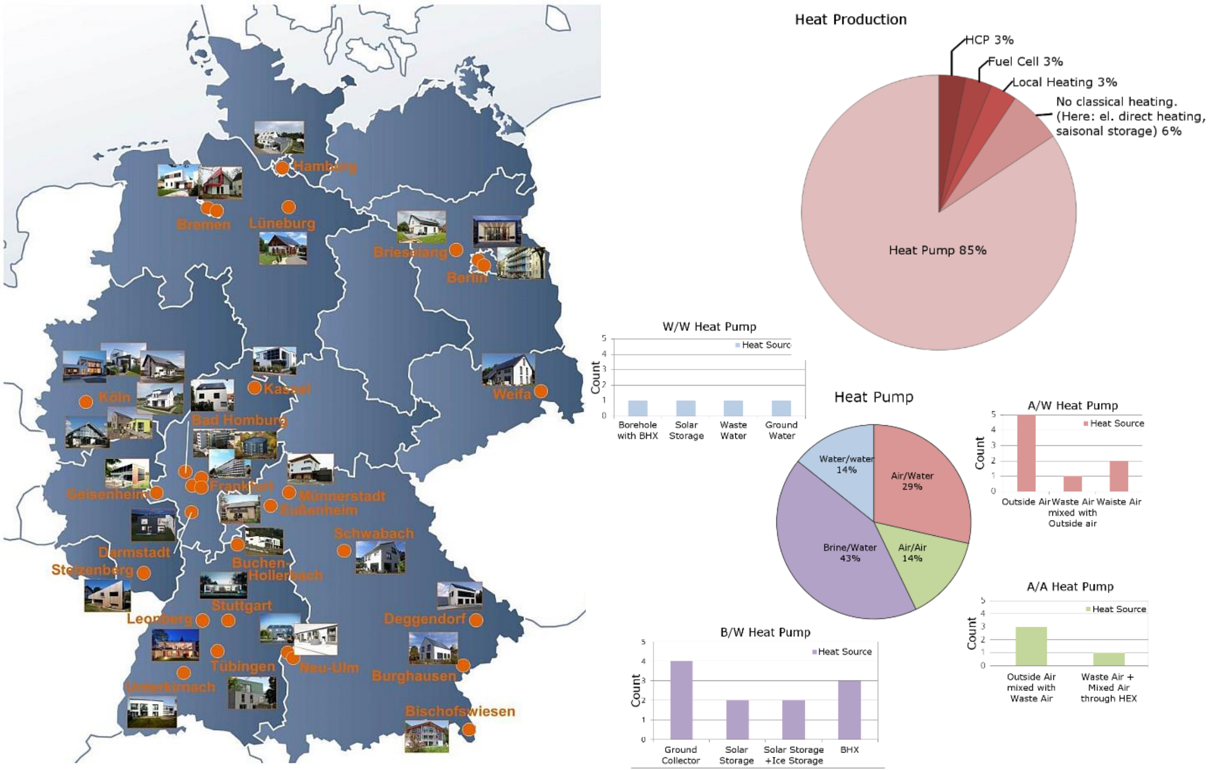


Figure 35: Building sites (left) and applied system technologies (upper right) and heat pump (lower right) in the Effizienzhaus Plus accompanying research (source: Erhorn et al., 2015)

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

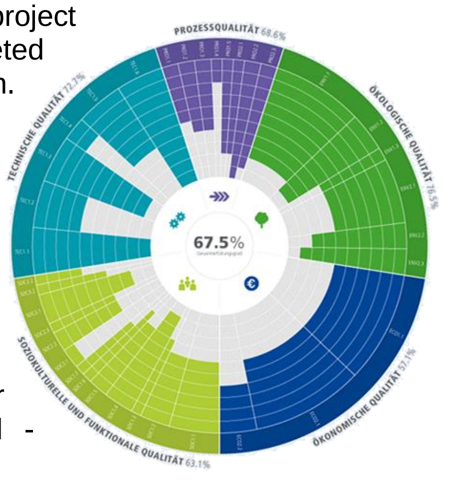
Balance Boundary: The building footprint is set as the balance boundary. In case of more than one building on the estate, the on-site generated renewable energy is accounted by the energy reference area of the buildings.

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

Model buildings and field testing:
https://www.zukunftbau.de/projekte/modellvorhaben/modellvorhaben-effizienzhaus-plus

4.4.7 DE/AT/CH - DGNB/SGNI/ÖGNB/I Gütesiegel für Nachhaltiges Bauen

DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council)) is a certification system for sustainable buildings, which can be applied internationally. It provides an objective description and assessment of the sustainability of buildings and urban districts (DGNB System, 2020).
It is crucial that the DGNB does not assess individual measures but instead the overall performance of a building or urban district (DGNB System, 2020).
DGNB criteria change based on the end-use of the building and based on the case of a new construction or existing building. DNGB provides points for six assessment categories. The final scale (based on the compliance of minimum performance) ranges from “Bronze” to “Platinum”.
Some of the DGNB platforms refer to the German Institute for Standardisation (DIN) and the Association of German Engineers (VDI).
The DGNB model provides a full certificate after the project realisation. Prior to that, a pre-check that sets the targeted level of quality and a preliminary certificate can be given. The assessment process is led by a DGNB accredited accessor. Once the project has been completed, the documents are submitted to the certification institute, which evaluates them and subsequently awards the certificate (Kosanović, Klein, Konstantinou, Radivojević, & Hildebrand, 2018).



ÖGNB the Austrian Society for Sustainable Building (*Österreichische Gesellschaft für Nachhaltiges Bauen*) originated from an initiative of the Austrian Institute for Building Biology and Ecology (IBO (Baubiologie und -ökologie)) and the Austrian Institute of Ecology (ÖÖI (Österreichischen Ökologie-Instituts)) (ÖGNB, 2020).
The ÖGNB addresses companies, institutions and also individuals who are interested in a higher qualification of the Austrian building industry in the sense of sustainable building.
ÖGNI (Austrian Society for Sustainable Real Estate Management (Österreichische Gesellschaft für Nachhaltige Immobilienwirtschaft)) is the Austrian sister label of the German DGNB. In 2013 the cooperation between ÖGNB and ÖGNI started, forming the Austrian Sustainable Building Platform (ASBP), Austria's representative in the international environment. For the duration of the cooperation agreement, the ÖGNI represents the newly founded ASBP in the World Green Building Council (WGBC), while ÖGNB represents the newly founded ASBP in the Sustainable Building Alliance (SBA) and in (International Initiative for a Sustainable Built Environment) IISBE (ÖGNB, ÖGNB Österreichische Gesellschaft für Nachhaltiges Bauen - Partnerschaften, 2020).
SGNI ("Schweizerische Gesellschaft für nachhaltige Immobilienwirtschaft" – Swiss society for sustainable real estate management) is as the Austrian ÖGNI a sister label of the German DGNB, which is in operation for 10 years in the Swiss market.

4.4.8 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 third version of the Active House specifications 3.0 is currently in use. Besides the key principles, the technical specification can also be used as a tool for designing nearly Zero Energy Buildings (Eriksen et al., 2013).

Figure 36 left shows the three basic evaluation criteria comfort, energy and environment, which can be further divided as depicted in an “active house radar” in Figure 36 left.

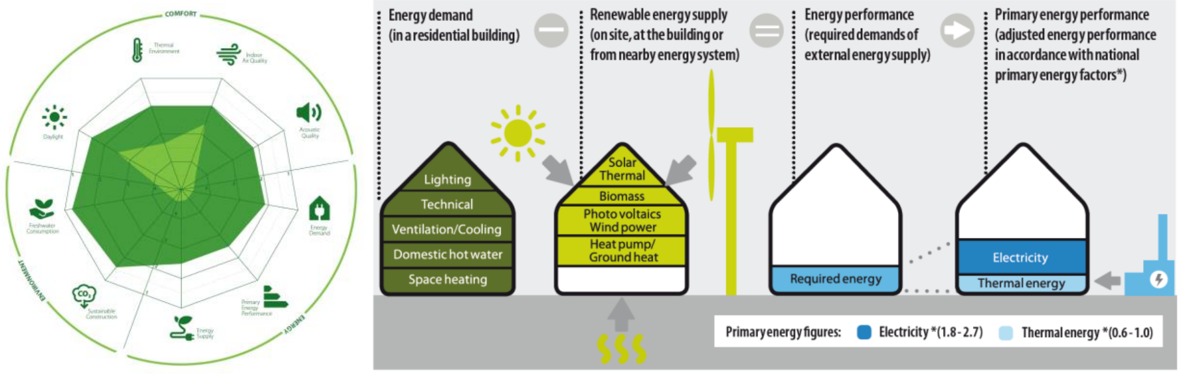


Figure 36: Energy principles for active house (source: Eriksen, Rode and Gillet, 2013)

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.
Figure 36 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 and good comfort with the 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:
Homepage: http://www.activehouse.info
Database: https://www.activehouse.info/active-house-cases/

4.4.9 UK BREEAM

BREEAM or Building Research Establishment Environmental Assessment Method is used to masterplan projects, infrastructure and buildings (McPartland, 2016). Five levels of the BREEAM project are possible (from “pass” to “outstanding”), based on the achieved score (BREEAM International New Construction 2016 – Technical Manual, 2016). The considered topic-areas are:

- Responsible construction practices
- Commissioning and handover
- Aftercare
- Visual comfort
- Indoor air quality
- Accessibility
- Private space
- Water quality
- Reduction of energy use and carbon emissions
- Energy monitoring
- Water consumption
- Water monitoring
- Responsible sourcing of construction products
- Construction waste management
- Operational waste

Among them, only five have to be fulfilled in order to reach the minimum level (“pass”). Among the latter five, it is not included in the building energy requirement. Indeed, it is required only

for the last two levels “Excellent” and “Outstanding”. In these cases, the requirement regards the Energy Performance Ratio.
In the BREEAM International New Construction 2016 it is highlighted that these are minimum acceptable levels of performance and in that respect, they should not necessarily be viewed as levels that are representative of best practice for a BREEAM rating level. Moreover, the assessment and certification process is aligned with the Royal Institute of British Architects (RIBA) Plan of Work, and consists of five stages: preassessment; design stage assessment; interim (design) certification; construction stage assessment/review; and final (post-construction) certification (BREEAM 2017).
Assessment and certification are guided by the independent, trained, and licenced assessor. Upon successful completion of the procedure, a certificate indicating the level of achieved quality of a building is issued.

4.4.10 US LEED

LEED (Leadership in Energy and Environmental Design) is a green building rating system. It is available for several types of buildings, community and home projects. LEED provides a framework to create healthy, highly efficient and cost-saving green buildings (LEED). To reach the LEED standard, a set of minimum requirements has to be met, namely:

- LEED project must be in a permanent location
- LEED project boundary must include all contiguous land that is associated with the project and supports its typical operations
- Size requirements must be satisfied. Size requirements change with the LEED certification

Different LEED rating levels are based on the amount of points. Points are reachable proving credits, which are based on how the building is planned, constructed, maintained and operated. The LEED version 4 platform uses a four-stage rating scale, from “Certified” to “Platinum” (TerraCast, 2016).
Some of the LEED platforms refer to the standards of the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). Moreover, LEED allows for variety in providing proof of performance, e.g. for the criterion Thermal Comfort, the project team can choose between two options: to meet the requirements of the American ASHRAE standard or to meet the requirements of the ISO and CEN standards, which are more commonly used in Europe.

In LEED for Homes, the certification process accounts: registration, on-site verification throughout the design and construction, review of documentation and award of the certificate.
In the LEED v4 commercial platform, the rating process consists of the following major steps: registration, application, review and certification.

4.4.11 US – DOE Zero Energy Ready Home

”A DOE Zero Energy Ready Home is a high performance home that is so energy-efficient a renewable energy system can offset most or all annual energy consumption.“
The DOE Zero Energy Ready Home offers leading builders and architects/ designers a timely solution for differentiating their product from existing homes

as well as minimum code new homes. It 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. (U.S. Energy Star Homes Program, "ENERGY STAR Qualified Homes, Version 3 Savings & Cost Estimate summary," June 2013)

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.

DOE ZERH website:
https://www.energy.gov/eere/buildings/doe-zero-energy-ready-home-partner-central
DOE ZERH Resource website:
https://www.energy.gov/eere/buildings/doe-zero-energy-ready-home-resources
U.S. Energy Star home program ENERGY STAR Qualified Homes
https://www.energystar.gov/newhomes?s=mega

5 Conclusions

The following conclusions and perspectives can be derived from the Annex 49 work regarding the state of the art of heat pumps in nZEB:

State-of-the-art and implementation of nZEB

- At current state of the implementation of the EPBD in EU member states different implementations and ambition levels of nZEB prevail in EU member states, which differ both in system boundaries, requirement and linked metrics and limits.
- Some EU member states implement a step to higher efficiency in the new built sector, while others virtually remain at the state that existed before the introduction of nZEB
- In the US a similar definition of nZEB as the REHVA definition in Europe has been outline in a report
- Some EU member state's implementations seem not ambitious enough and remain below the EU benchmark requirements, which have been published as recommendations for the required nZEB energy performance
- Due to the different implementations of the EPBD in the EU member states a comparison of ambition levels in different countries is hindered and sophisticated.
- Thus, a common methodology for comparison of ambition levels would be useful to motivate less ambitious countries to set higher performance requirements as intended by the EPBD. The developed methodology in Annex 49 shall thus be further tested and developed to enable a harmonised comparison.
- The all electric building concept, as a combination of heat pump and PV, is an archetype for nZEB implementation, which is found often in realised nZEB and is a market driver for heat pumps with the introduction of nZEB requirements in the new built sector.

Perspectives

- With the background of rapidly progressing climate change, ambitious energy performance targets shall be a pursuit for the built environment as intended by the EPBD recast.
- Thus, a further harmonisation of nZEB implementations among the EU countries is recommended to support high ambition levels and facilitate standardised system solutions and technologies across European countries, which can further reinforce the good market position of heat pumps for nZEB applications
- From a general perspective the nZEB concept on annual energy balancing may be misleading due to load mismatch and seasonal effects (intermittent renewable energy production, overproduction in summer and lack of production in winter). Adequate Key Performance Indicators shall be further developed to entirely assess these concepts including grid-interaction effects in order to optimise local consumption and grid operation.
- Limitations to reach nZEB requirements, particularly in larger buildings, may be overcome by moving the nZEB assessment boundary from one to groups of buildings and neighbourhoods. Thereby, the ambition levels for single buildings shall still be high, but load and on-site production profiles and balancing, both for thermal and electric loads, can be facilitated to reach ambitious targets. Research shall thus be extended to groups of nZEB and neighbourhoods

6 Acknowledgment

IEA HPT Annex 49 is a co-operative research project on heat pump application in nearly Zero Energy Buildings in the framework of the Heat Pumping Technologies (HPT) Technology Collaboration Programme (TCP) of the International Energy Agency (IEA). This report is based on the contributions of all participants in the Annex 49 and the constructive and co-operative discussions during the project as well as the contributed results are highly appreciated.

The support and funding of the IEA HPT Annex 49 by the Swiss Federal Office of Energy (SFOE) is highly appreciated and gratitude is expressed to the programme managers of the SFOE heat pump research Dr. Carina Alles and Stephan Renz for advice and support in the IEA HPT Annex 49 and the Swiss national contributions.

The financial supports from the Austrian Ministry for Transport, Innovation and Technology and the Austrian Research Promotion Agency (FFG Project Nr. 864143) through the IEA Research Cooperation to this work are gratefully acknowledged.

The project COOLSKIN (FFG Project-Nr. 848871) was funded by the Austrian Climate and Energy Fund and was carried out as part of the Energy Research Programme 2014.

The project solSPONGEhigh (FFG Project-Nr. 845182) was funded by the Austrian Ministry for Transport, Innovation and Technology (bmvit).

The participation in the IEA Annex 49 as well as this research and the monitoring of the buildings was funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) and the research initiative ZukunftBau and the Federal Institute for Research on Building, Urban and Spatial Development (the BMVBS and BMUB). Thanks to all building owners and operators for their help and support as well as for providing measurement data and information about the monitored buildings.

The Norwegian authors would like to thank the Norwegian Research Center on Zero Emission Neighborhoods in Smart Cities (FME ZEN) as well as ENOVA for their support

The Swedish Energy Agency, through the research program Effsys Expand, Bosch Thermoteknik, Danfoss Heat Pumps, NIBE, Skanska and TMF companies

Grateful acknowledgment to Antonio Bouza of DOE BTO for his support of the US participation in IEA HPT Annex 49 and the ORNL technical activities under Contract No. DE-AC05-00OR22725 with UT-Battelle LLC.

7 Abbreviations

Abbreviation	Meaning	Remark
A/W-HP	Air-to-water heat pump	
AS	Air source	
ASBP	Austrian Sustainable Building Platform	
BBR	Swedish Building regulation	
BC	Boundary condition	
BGF	Gross floor area	Bruttogeschossfläche
BMK	Austrian Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology	Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie
BPIE	Buildings Performance Institute Europe	
BREEAM	Building Research Establishment Environmental Assessment Method	UK sustainable Building label
BRI	gross volume	Brutto Rauminhalt
BSB	electric energy demand (non-residential sector)	Betriebsstrombedarf
BelEB	lighting energy demand	Beleuchtungsenergiebedarf
BTES	Borehole Thermal Energy Storage	
BTO	Building technology office	Office of DOE
CEN	Committee Europeen des Normalisation	EU Standardisation Organisation
CHP	Combined Heat and Power	
COP	Coefficient Of Performance	
CVHD	Compact ventilation and heating device	Kompaktgerät
DC	Direct Current	
DGNB	German Sustainable Building Council	Deutsches Gütesiegel für nachhaltiges Bauen
DHW	Domestic hot water	
DIN	German Institute for Standardisation	Deutsches Institut für Normung
DOE	US Department of Energy	
DSH	Desuperheater	
DSM	Demand Side Management	
EC	European Commission	
ECBCS	Energy conservation in Buildings and community systems	iEA TCP, now called EBC
EEB	final energy demand	Endenergiebedarf
EIV	Energy-Institute Voralberg	
EnEV	German Energy saving directive	EnergieEinsparVerordnung
EPBD	Energy Performance of Buildings	EU Directive
EPC	Energy Performance Certificate	
ErP	Energy related Products	EU Directive also call Ecodesign Directive
EU	European Union	
GFA	gross floor area	
GSHP	Ground source heat pump	
GWP	Global warming potential	
HD	Heat demand	
HEB	Final energy demand for HVAC	
HERS	Home Energy Rating System	
HHSB	Household electricity demand	
HP	Heat pump	
HPP	Heat Pump Programme	
HPT	Heat Pumping Technologies	IEA TCP
HTEB	Maximum allowed final energy demand	
HVAC	Heating, Ventilation and Air-conditioning	
HWB	Space heating demand	Heizwärmebedarf

Abbreviation	Meaning	Remark
IBO	Building Biology and Ecology	Baubiologie und -ökologie
IEA	International Energy Agency	
IISBE	International Initiative for a Sustainable Built Environment	
IPEEC	International Partnership for Energy Efficiency Cooperation	
ISO	International Standardisation Organisation	
JRC	Joint Research Centre	
KEB	Space cooling demand	Kühlenergiebedarf
KfW	Kreditanstalt für Wiederaufbau	German bank for funding high performance buildings
LCA	Life cycle assessment	
LEED	Leadership in Energy and Environmental Design	US sustainable building label
MFH	Multi-family house	
MS	(EU) member state	
MuKEn	Model ordinance of the cantons in Energy	
MVHR	mechanical ventilation heat recovery	
NREL	National Renewable Energy Laboratory	
NS	Norge Standard	
nZE		
nZEB		
NZEB	Net Zero Energy Builiding	
ÖGNB	Österreichische Gesellschaft für Nachhaltiges Bauen	Austrian Society for Sustainable Building
ÖGNI	Austrian Society for Sustainable Real Estate Management	Österreichische Gesellschaft für Nachhaltige Immobilienwirtschaft
OIB	Austrian Institute of Construction Engineering	Österreichisches Institut für Bautechnik
ÖÖI	Austrian Institute of Ecology	Österreichischen Ökologie-Instituts
ORNL	Oak Ridge National Laboratory	
OVN	Otto Nielsens vei	Monitoring Building in NO
PCM	Phase change materials	
PE	Primary energy	
PEB	Primary energy demand	
PER	Primary Energy Renewable	
PH	Passive house	
PHPP	Passive House Planning Package	Passivhaus-Projektierungs-Paket
PV	Photovoltaic	
PV/T	photovoltaic/thermal	
RE	Renewable energy	
RED	Renewable energy Directive	EU-Directive
REHVA	Federation of European HVAC associations	
RES	Renewable Energy Sources	EU Directive
RIBA	Royal Institute of British Architects	
RK	Reference climate	
SBA	Sustainable Building Alliance	
SC	Space cooling	
SCOP	Seasonal coefficient of performance	
SFH	Single family house	
SFP	Specific Fan Power	
SGNI	Swiss Society for Sustainable Real Estate Management	Schweizerisches Gütesiegel für nachhaltige Immobilienwirtschaft
SH	Space heating	
SHC	Solar heating and cooling	IEA TCP

Abbreviation	Meaning	Remark
SIA	Swiss society of engineers and architects	
SK	Site climate	
SMHI	Swedish Meteorological and Hydrological Institute	
SPF	Seasonal performance factor	
SS	Swedish standard	
ST	Solar thermal	
TA	treated area	Konditionierte Fläche
TABS	Thermally activated building system	
VAV	Variable air volume	
VDI	Association of German Engineers	Verein Deutscher Ingenieure
VSD	Variable speed drive	
WBGC	World green building council	
WGG	Willibald Gluck Gymnasium	School of monitoring project DE
WWWB	domestic hot water demand	Warmwasserwärmebedarf
ZEB	Zero Energy Building	

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A Appendix

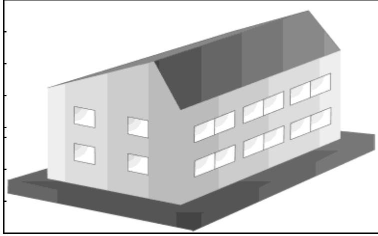
A.1 Austrian residential and office buildings case study

A single-family house (SFH) and a multi-family house (MFH) are considered as case studies, to investigate in detail the nZEB requirements, considering several scenarios for each building regarding the thermal envelope and system. Results are obtained using the tool GEQ, version 2020.4 (GEQ Zehentmayer Energieausweis Software, 2020), where the OIB-6:2015 is implemented. The National Plan 2018 is considered. Therefore, U-values, primary energy factors (non-renewable, renewable and total), the renewable share and the percentage of electricity demand shares that can be covered by photovoltaics are slightly different than those shown in Section 2.1.5. (Compare tables Table A 12 and Table A 13 for the maximum share of electricity covered by PV, Table A 14 and Table A 15 for U-values, Table A 16 and Table A 17 for primary energy conversion factors).

A.1.1 Single-family house description

The single-family house described in the Reference Framework of IEA SHC Task44/ HPP Annex 38 (Dott et al., 2013) is considered as case study. Geometric and energetic properties of the house are depicted in Table A 1.

Table A 1: Geometric and energetic properties of the single-family house (Dott et al., 2013)

		U [W/(m²K)]	d [cm]
	External wall	0.182	42.8
	Basement	0.135	50.5
	Roof	0.162	25.5
	Windows	1.00	g = 0.46
	Gross floor area BGF [m²]	171	
	Gross Volume BRI [m³]	558	
	Characteristic length ℓ_c [m]	1.35	

Three variants of the SFH are created to meet the minimum envelope requirement (U-values and heating demand (HWB)) according to the "f_{GEE} path", the "EEB path" and the Passive House standard. Properties of walls and windows of the three variants are shown in Table A 2. The geometrical properties of the building change for the different variants because of the different insulation thickness.

Table A 2: Geometric and energetic properties of the SFH for the three considered envelopes ("f_{GEE} path", "EEB path" and Passive House)

	f_{GEE} path		EEB path		Passive House	
	U [W/(m²K)]	d [cm]	U [W/(m²K)]	d [cm]	U [W/(m²K)]	d [cm]
External wall	0.248	38.3	0.148	47.8	0.148	47.8
Basement	0.356	33.5	0.135	50.5	0.135	50.5
Roof	0.176	23.5	0.122	32.5	0.111	35.5
Windows	1.00	g = 0.46	0.73	g = 0.42	0.73	g = 0.42
Gross floor area BGF [m²]	167		175		175	
Gross Volume BRI [m³]	546		572		572	
Characteristic length ℓ_c [m]	1.38		1.41		1.41	

The envelope presented in Table A 2 leads to the HWB shown in Table A 3.
The calculations are performed with GEQ, an Austrian energy certificate software and with the Passive House Planning Package (PHPP)(Feist, 2007), which allows the verification of the Passive House standard. In the case of GEQ, the heating demand (HWB) is shown for both, the reference climate (HWB_{RK}) and the standard climate (HWB_{SK}). As explained in Section

2.1.5, the HWB requirement refers to the reference climate without considering the mechanical ventilation heat recovery ($HWB_{Ref,RK}$).

The minimum requirements are the following:

$$HWB_{max,2020,fGEE} = 16 \cdot \left(1 + \frac{3}{l_c}\right) = 50.78 \frac{\mathrm{kWh}}{\mathrm{m}^2_{GFA}\, a}$$

$$HWB_{max,2020,EEB} = 10 \cdot \left(1 + \frac{3}{l_c}\right) = 31.28 \frac{\mathrm{kWh}}{\mathrm{m}^2_{\mathrm{GFA}}\, a}$$

$$HWB_{max,PHPP} = 15 \frac{\mathrm{kWh}}{\mathrm{m}^2_{\mathrm{AT}}\, a}$$

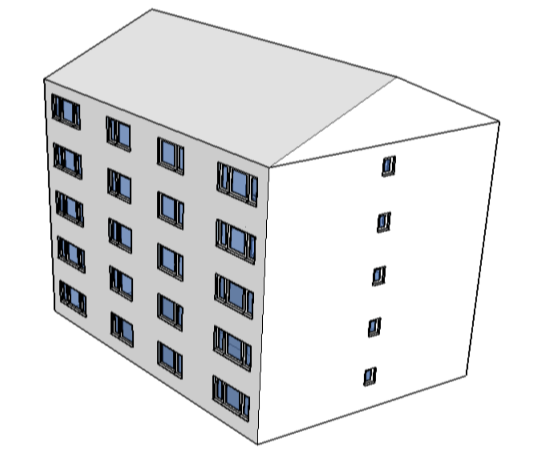
Table A 3: Heating demand (HWB) for the three considered envelopes of the single-family house. Comparison between GEQ calculation results (reference and site climate) and PHPP

			f_{GEE} path	EEB path	Passive House
GEQ	$HWB_{REF,RK}$	[kWh/(m^2_{GFA}yr)]	50.7	31.2	30.7
	$HWB_{REF,SK}$	[kWh/(m^2_{GFA}yr)]	59.2	36.8	36.2
PHPP	HD	[kWh/(m^2_{AT}yr)]	53	36*	15*
* In spite of similar envelopes of "EEB path" and Passive House, they have different HD because MVHR is only required in case of the Passive House and $HWB_{REF,RK}$ and $HWB_{REF,SK}$ exclude MVHR					

A.1.2 Multi-family house description

Similarly, the multi-family house described in the FFG project SaLüH! (Ochs et al., 2020) (see properties in Table A 4) is considered with three different variants to investigate the minimum envelope quality to meet the requirements according to the "f_{GEE} path", the "EEB path" and the Passive House standard (see Table A 5).

Table A 4: Geometric and energetic properties of the multi-family house (Ochs, et al., 2020)



		U [W/(m²K)]	d [cm]
	External wall	0.143	45.0
	Basement	0.342	30.0
	Roof	0.111	55.0
Windows	East, West	0.93	g_{value} = 0.53
Windows	North, South (Type1)	0.88	g_{value} = 0.53
Windows	North, South (Type1)	0.77	g_{value} = 0.53
	Gross floor area BGF [m²]	1012	
	Gross Volume BRI [m³]	2923	
	Characteristic length ℓ_c [m]	2.37	

The resulting heating demands (HWB) are shown in Table A 6.

The minimum requirements are the following:

$$HWB_{max,2020,fGEE} = 16 \cdot \left(1 + \frac{3}{l_c}\right) = 36.51 \frac{\mathrm{kWh}}{\mathrm{m}^2_{GFA}\, a}$$

$$HWB_{max,2020,EEB} = 10 \cdot \left(1 + \frac{3}{l_c}\right) = 22.40 \frac{\mathrm{kWh}}{\mathrm{m}^2_{\mathrm{GFA}}\, a}$$

$$HWB_{max,PHPP} = 15 \frac{\mathrm{kWh}}{\mathrm{m}^2_{\mathrm{AT}}\, a}$$

Table A 5: Geometric and energetic properties of the MFH in the three considered envelopes ("f_{GEE} path", "EEB path" and Passive House)

		f_{GEE} path		**EEB path**		**Passive House**	
		U [W/(m²K)]	d [cm]	U [W/(m²K)]	d [cm]	U [W/(m²K)]	d [cm]
External wall		0.266	35.0	0.143	45.0	0.116	50.0
Basement		0.342	30.0	0.184	40.0	0.203	38.0
Roof		0.189	40.0	0.111	55.0	0.111	55.0
Windows	East, West	1.39	g=0.46	0.93	g=0.53	0.93	g =0.53
Windows	North, South (Type1)	1.27	g=0.46	0.88	g=0.53	0.88	g =0.53
Windows	North, South (Type2)	1.04	g=0.46	0.77	g=0.53	0.77	g =0.53
Gross floor area BGF [m²]		983		1012		1026	
Gross Volume BRI [m³]		2811		3085		3129	
Characteristic length ℓ_c [m]		2.34		2.42		2.43	

Table A 6: Heating demand for the three considered envelopes of the multi-family house. Comparison between GEQ (reference and site climate) and PHPP results

			f_{GEE} path	**EEB path**	**Passive House**
GEQ	$HWB_{REF,RK}$	[kWh/(m²$_{GFA}$yr)]	36.4	22.3	20.8
GEQ	$HWB_{REF,SK}$	[kWh/(m²$_{GFA}$yr)]	43.0	26.8	25.1
PHPP	HD	[kWh/(m²$_{AT}$yr)]	54	35*	15*
* In spite of similar envelopes of "EEB path" and Passive House ,the HD differs because MVHR is necessary only in the Passive House (see also the SFH example)					

A.1.3 Results for SFH and MFH

The single-family house described in the Reference Framework of IEA SHC Task44 / HPP Annex 38 (Dott et al., 2013) and the multifamily house of the FFG project SaLüH! (Ochs et al., 2020) are used as a basis for the investigations. In both, the single and the multi-family houses, the envelope according to the "f_{GEE} path" presents poorer envelope quality compared to the original building (Table A 1, Table A 4). On the contrary, envelopes for "EEB path" and Passive House standard are nearly the same and they present improved U-values compared to the original building (only slightly improved in case of MFH). The main difference between the "EEB path" building and the PH is the implementation of the mechanical ventilation heat recovery (MVHR) in the latter one.
In all case studies, a system with air/water HP and DHW storage (outside of the heated space) is considered. Various modifications are applied in order to meet the minimum nZEB requirements.
In the case of "f_{GEE} path" envelope in both cases, the SFH and the MFH, a photovoltaic (PV) system is required to fulfil the f_{GEE} requirement ($f_{GEE,RK,zul} \leq 0.75$). Furthermore, in the SFH it is necessary to consider the DHW storage inside the heated space and with loss coefficient of 1.2 kWh/d (instead of the standard value of 2.4 kWh/d).
In the case of the "EEB path" envelope, no further modifications of the system are required because the EEB requirement is already more than fulfilled.
The achieved EEB and the maximum limit are shown in Table A 7 for both cases:

Table A 7: Comparison between the achieved EEB (RK) and the maximum EEB limit (zul,RK) for the SFH and MFH [GEQ]

	EEB_{RK} [kWh/(m²yr)]	**$EEB_{zul,RK}$ [kWh/(m²yr)]**
SFH	35.7	39.1
MFH	35.9	40.4

Table A 7 shows that in order to meet the minimum EEB requirement, a HVAC system with lower efficiency would be possible, especially in case of MFH or in other words, with a standard HVAC system it is easy to fulfil the EEB requirements.
In the cases following the "EEB path" the choice of the heating technology has minor importance in order to fulfil the nZEB requirements, thanks to high-quality envelope. The EEB and PEB are fulfilled in almost all cases of the investigated systems and configurations. However, if the "f_{GEE} path" is chosen, the requirements on the system efficiency (heating, DHW, ventilation and renewable) have major importance, due to the lower envelope quality. However, only moderately improved HVAC efficiency, MVHR, or a relatively small PV (or ST) system is sufficient in order to fulfil the f_{GEE} requirement.
The primary energy (PEB) is a requirement to reach the nZEB level according to EPBD but seems to be not mandatory anymore from 2019 on (as it is only one option out of three that can be chosen to fulfil the renewable source of energy requirement, see above). According to the National Plan (2018), the limit of 41 kWh/(m^{2}yr) refers to the evaluation without appliances and with the non-renewable primary energy conversion factor of $f_{PE,non-RE}$ = 1.02 for electricity. It is remarkable that the previous version of the OIB-6 and National Plan indicated the total primary energy limit of 160 kWh/(m^{2}yr) considering appliances. The total primary energy conversion factor for electricity was $f_{PE,non-RE}$ = 1.91. Table A 8 shows the resulting PE for the case studies with different primary energy factors and with or without appliances.

Table A 8: Primary energy for the three considered cases of SFH, evaluated with and without appliances and with total and non-renewable primary energy conversion factors of 2014 and 2018

		Limit values on PE	f_{GEE} path	EEB path	Passive House
PE [kWh/(m^{2}yr)]	f_{PE} (= 1.91) with appliances	PE_{max} (2014) = 160 kWh/(m^{2}yr)	68.7	75.3	65.9
	f_{PE} (= 1.91) w/o appliances		37.4	43.9	34.5
	$f_{PE,n.ern.}$ (=1.32) w/o appliances	PE_{max} (2018) = 41 kWh/(m^{2}yr)	25.8	30.4	23.8

A sensitivity study has been carried out for each of the three envelope qualities changing

- the HVAC system (direct electric heating and heat pump, with and without MVHR)
- the type and performances of heat pumps (HP)
- the heat emission system
- the DHW system
- and the PV system

The discussion of the results is presented for the SFH building, results with respect to the trends apply also for the MFH.
The use of a direct electric system doesn't allow to achieve the nZEB requirements through the "f_{GEE} path" because f_{GEE} =1.96 while $f_{GEE,RK,zul}$ = 0.75. Even the implementation of MVHR and/or photovoltaic or solar thermal system is not sufficient to fulfil the f_{GEE} requirements (f_{GEE} with MVHR = 1.68, f_{GEE} with 5kWp of PV panels = 1.65, f_{GEE} with MVHR and 5kWp of PV panels = 1.38). Direct electric heating is theoretically possible in combination with the "EEB-path" envelope. However, it remains unclear how the constraint of the system expenditure coefficient (e_{AWZ} = 1/SPF_{sys}) that is mentioned in OIB-6 will be implemented by the local authorities. Further clarification is required, here.
In several cases with heat pumps with standard settings, f_{GEE} is only slightly higher than the maximum limit of 0.75 (e.g. 0.76). In these variants, minor improvements of the envelope or changes in the system will allow achieving the nZEB requirements.

Some examples are:

- Change from a modulating heat pump to a start/stop heat pump [sic!][3]

[3] Due to the improved definition of f_{GEE} in H5056:2019 the contradiction should be removed.

- Add photovoltaic modules
- Increase the nominal power of the heat pump (while the change in the COP does not have any influence)
- Increase the insulation of the building envelope (few centimetres are enough)
- Add a MVHR or increase the efficiency of the MVHR

Assuming a system based on air/water heat pump or ground/water heat pump, the choice among monovalent, bivalent alternative or bivalent parallel mode (considering a second electric system in case of bivalent) has only a minor influence on the results with respect to achieving the nZEB requirements. The same applies for the choice of the bivalent temperature and the nominal power of the heat pump. Through the "f_{GEE} path", the main parameter results to be the modulating or start/stop operation. In several cases the start/stop operation allowed to fulfil the f_{GEE} requirement, while the modulating heat pump led to $f_{GEE} > 0.75$. This trend is confirmed by the following example: two air/water heat pumps from the product list given in GEQ are considered. Their properties are:

1. Nominal power = 20.6 kW; COP (A7/W35) = 3.4; not modulating
2. Nominal power = 8.7 kW; COP (A7/W35) = 5.5; modulating

When all other parameters are kept equal, the first heat pump leads to $f_{GEE} = 0.75$ (i.e. nZEB level reached), while the second one (although the COP is higher and HP is a modulating one) leads to $f_{GEE} = 0.76$ (nZEB level not reached).

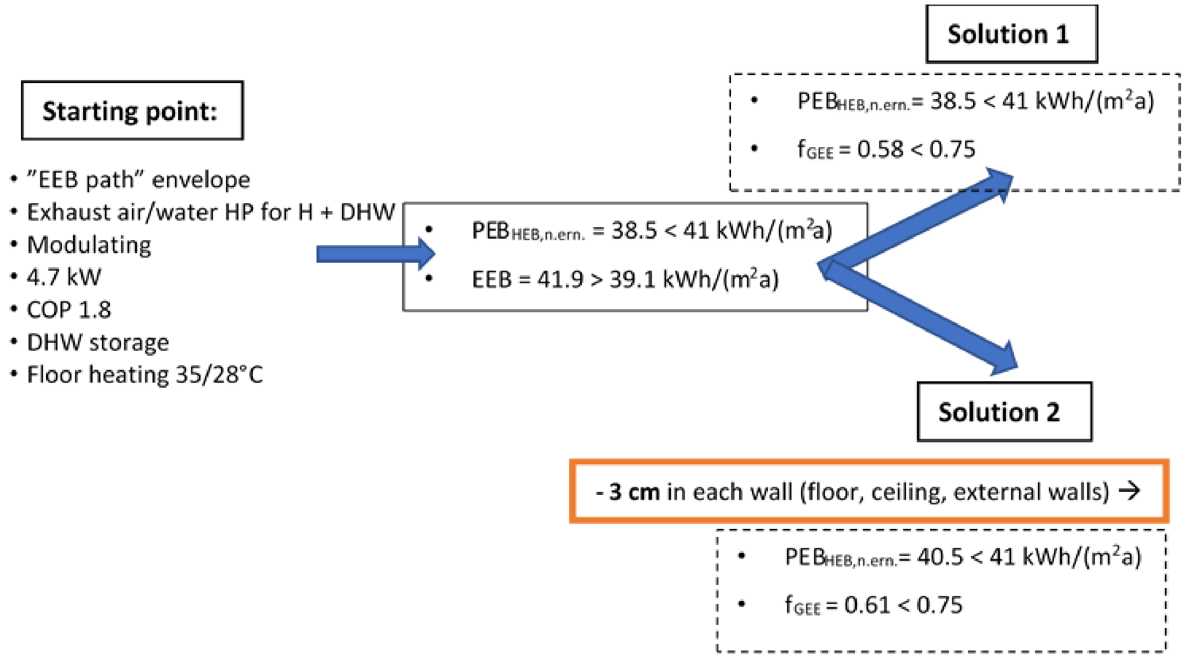


Figure A 1: Representation of achieving nZEB through the "fGEE path" instead of the "EEB path" (nZEB not achieved

In the case of "EEB path" with high insulating envelope, the heating demand is already so low that also systems with moderate efficiency allow to reach the nZEB level. As a matter of fact, the critical point in the "EEB path" is the HWB limit. In some particular cases when EEB > EEB_{max}, it is theoretically possible to switch the path and achieve the nZEB level through the "f_{GEE} path" (i.e. the HWB limit is already fulfilled and reaching f_{GEE} lower than $f_{GEE,RK,zul}$ is relative easy to achieve). An example is shown in Figure A 1 for the SFH where it is even possible to reduce the envelope quality because following the "EEB path" the HWB is already so low that the limit of f_{GEE} lower than 0.75 is already reached.

It has been noted that for every case where nZEB was achieved through the "EEB path", the "f_{GEE} path" was fulfilled, too. While the opposite is not true, as proven by the example in Figure 5. This means that the "EEB path" will very likely never be chosen because it requires a higher investment effort than the "f_{GEE} path". When the same system technology is considered, the "f_{GEE} path" allows achieving nZEB with lower quality envelopes and thus with lower investment costs.

Consequently, the building with the minimum requirements according the “EEB path” presents a lower EEB than the building with the minimum requirements according to the “f_{GEE} path”. Nevertheless, results show that the EEB according to the two paths are in many cases of the same order of magnitude. Furthermore, it is noteworthy that, when different system technologies are compared such as heat pumps, MVHR or PV, the “f_{GEE} path” might lead to lower EEB. For example, the minimum building according to the “EEB path” can have higher EEB than a building following the “f_{GEE} path” having a less performant envelope and a PV system.
Alternatively, a reduction of the HWB in the “f_{GEE} path” building allows lower quality HVAC systems and/or reduced PV system size. Table A 9 shows different ways to achieve nZEB level by reducing the HWB with respect to the maximum possible of (around) 50 kWh/(m² yr) by 5 kWh/(m²yr) or 10 kWh/(m²yr), respectively. The required HVAC configuration and the required size of PV to reach $f_{GEE} \leq 0.75$ are also shown in Table A 9.

Table A 9: Example of different ways to achieve nZEB level through the improvement of the building envelope and consequently possible reduction of the HVAC system quality and PV system size

Name	HWB [kWh/(m²yr)]	Possible reduction of the HVAC system quality / PV area		f_{GEE}	EEB [kWh/(m²yr)]
		DHW system	PV		
f_{GEE} path (HWB45)	45	DHW storage outside + $Q_{loss,DHW}$ = 2.4 kWh/d	2 kWp	0.75	32.1
f_{GEE} path (HWB40 a)	40	DHW storage outside + $Q_{loss,DHW}$ = 2.4 kWh/d	1 kWp	0.72	33.0
f_{GEE} path (HWB40 b)	40	-	no PV	0.73	36.9

The second case (f_{GEE} path (HWB40 a)) shows the great influence of the PV system on the f_{GEE}: a PV system of only 1 kWp allows to pass from a f_{GEE} = 0.77 (reached with reduced quality of the DHW system without PV) to 0.72 (reduce quality of the DHW system and 1 kWp PV). It is remarkable that there is no correlation between f_{GEE} and EEB and thus PEB.
Similar results, but less pronounced, are reflected in the MFH case study. In the MFH case study, more systems (especially the heat pump-based) allow to fulfil the f_{GEE} requirement, reaching the nZEB level. In these cases, the difference between modulating and start/stop heat pumps has an insignificant influence.
The limit on the primary energy excluding household electricity and considering the non-renewable primary energy factor (equal to 41 kWh/(m²yr)) was rarely reached in the several considered case studies. Exceptions are cases with direct electric heating.

A.1.4 Conclusions

From the studies described in sections A 2.1 and A 2.2 it can be understood that the “f_{GEE} path” is usually the easiest way to reach the nZEB level. As a matter of fact, when the “EEB path” is fulfilled, the “f_{GEE} path” is fulfilled too, while the opposite does not apply.
The choice of the system technology (heating system, DHW storage, ventilation, PV system) is relevant in the case of the “f_{GEE} path”. Contrarily, the “EEB path” requires a high quality envelope, so that the system is of minor importance.
When the same system technology is considered, the “EEB path” leads to a lower EEB than the “f_{GEE} path”, nevertheless the two are in the same order of magnitude and are not where “real” nZEB should be. Inerestingly, an opposite trend can be verified when different system technology is considered (e.g. implementation of PV system in the building following the “f_{GEE} path”).
The two ways to reach nZEB (Dual Path) together with a simplified weighting of the effort are shown in Figure A 2. It is noteworthy, that the HVAC system requirements of the f_{GEE} path are tighter, but still moderately performing HVAC systems are sufficient to reach the nZEB requirement and thus both paths are not sufficient with respect to the ambitious climate protection goals.

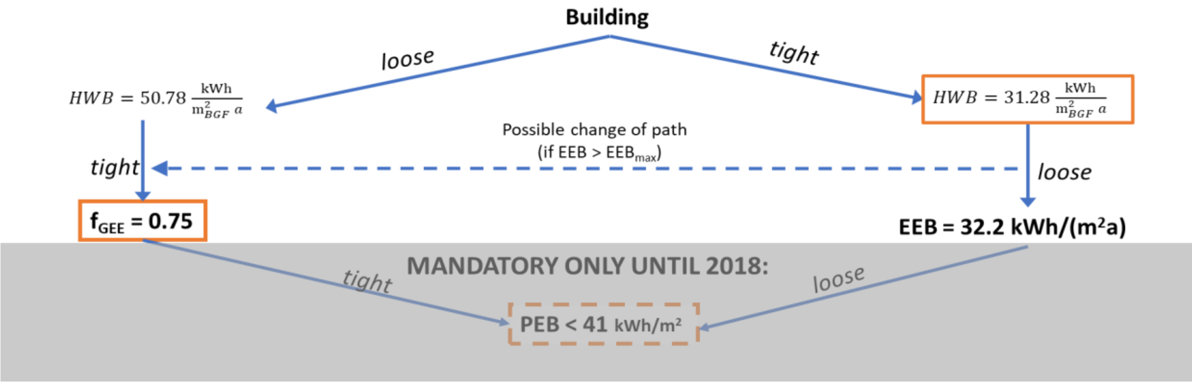


Figure A 2: Schematic of "f_{GEE} path" and "EEB path" with the required effort, values refer to the SFH case study (according to OIB-6:2019).

The possible change of path (described in Figure A 1, too) is possible only in one direction. Figure A 3 shows a simplified representation of possible ways of improving either the envelope, applying MVHR or using PV in order to achieve the nZEB requirements according to the two paths. To reach nZEB level following the f_{GEE} path with the maximum allowed heating demand of around 50 kWh/(m² yr), either MVHR is required or a 1.4 kWp PV system. With improved envelope quality with around 35 kWh/(m² yr) f_{GEE} requirements are met without MVHR or PV. A further improved envelope, which results in a heating demand of 30 kWh/(m² yr) fulfils the requirement of both paths. Interesting: below 20 kWh/(m² yr) for the reference heating demand (HWB_{ref}, i.e. without MVHR) is only theory and will not appear in reality (see discussion of classes above). Note: Values are only approximated referring to the SFH case study with standard air/water HP.

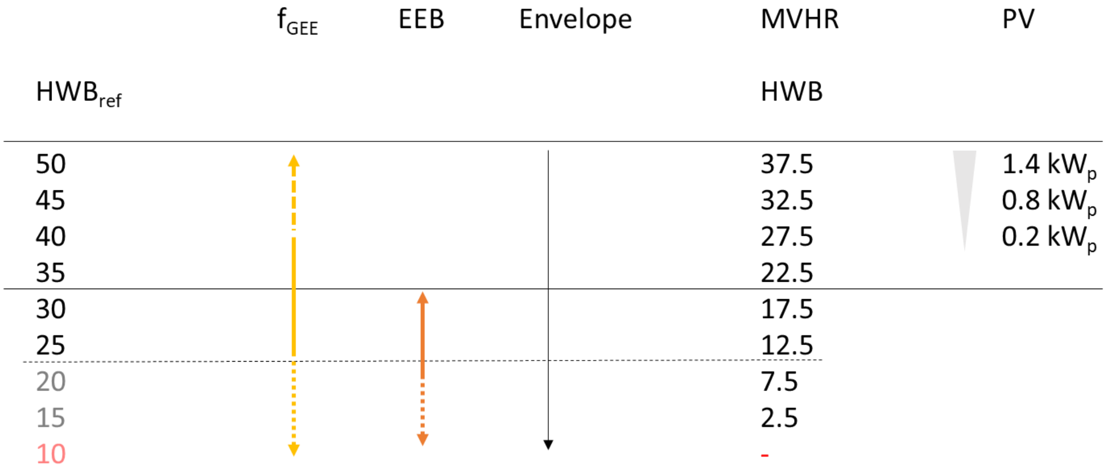


Figure A 3: Representation of the PV peak power required in correlation with the HD (and the possible path). Values (approximated) refer to the SFH case study

The MVHR allows to decrease the heating demand (acc. to OIB-6 by some 12.5 kW/(m² a)) and therefore it allows HVAC systems with lower efficiency. Better envelope qualities require less PV peak power to reach the limit of 0.75 for f_{GEE}. Envelope qualities that allow nZEB according to the "EEB path" do not require any PV. This relationship between heating demand and PV power is shown in Figure A 4. Only buildings with $f_{GEE} = 0.75$ (maximum allowed value) are shown in the diagram. Increasing the HD (x-axis), the EEB increases, too (left y-axis) when no PV is required. For higher values of HD, the implementation of PV system is needed in order to fulfil the f_{GEE} limit. The PV peak power increases with the HD, while the EEB decreases. It can be seen that there is no direct correlation between EEB and f_{GEE}. Remark: the PV own-consumption is overestimated according to OIB-6.

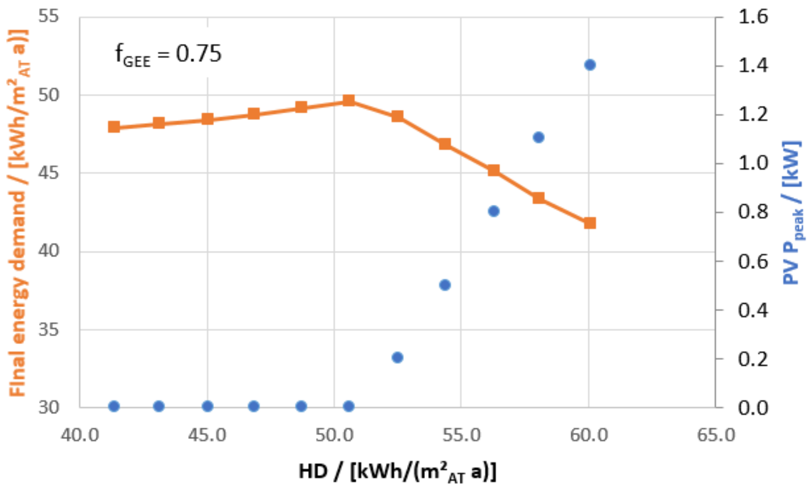


Figure A 4: Correlation between HD and EEB (left y-axis) and between HD and PV peak power (right y-axis) for building with fGEE = 0.75 (maximum allowed value).

A.1.5 Office buildings case study

For office buildings a case study was performed based on a virtual building, that was originally used as a reference building in a research project (Heimrath, Lerch, Mach, Ramschak, & Fink, 2018). The three-storey building consists of 18 office rooms with a useful floor area of 30 m² each (see Figure A 5). The gross floor area is 806 m² and the gross heated volume, which is indicated by a red frame in the figure, is 2880 m³.

As for the case study for residential buildings, the building was implemented into the software tool GEQ (Zehentmayer Energieausweis Software, version 2019.1), which was used to perform calculations for different variants of the building envelope and the HVAC system. It has to be noted, that the last version of the standard that was implemented in this software is the OIB-6:2015. In the meantime, primary energy factors (non-renewable, renewable and total), the renewable share and the percentage of electricity demand shares that can be covered by photovoltaics have been changed in the latest version of the OIB (OIB-6:2019). Therefore, the presented results here are not based on the latest values (see section above).

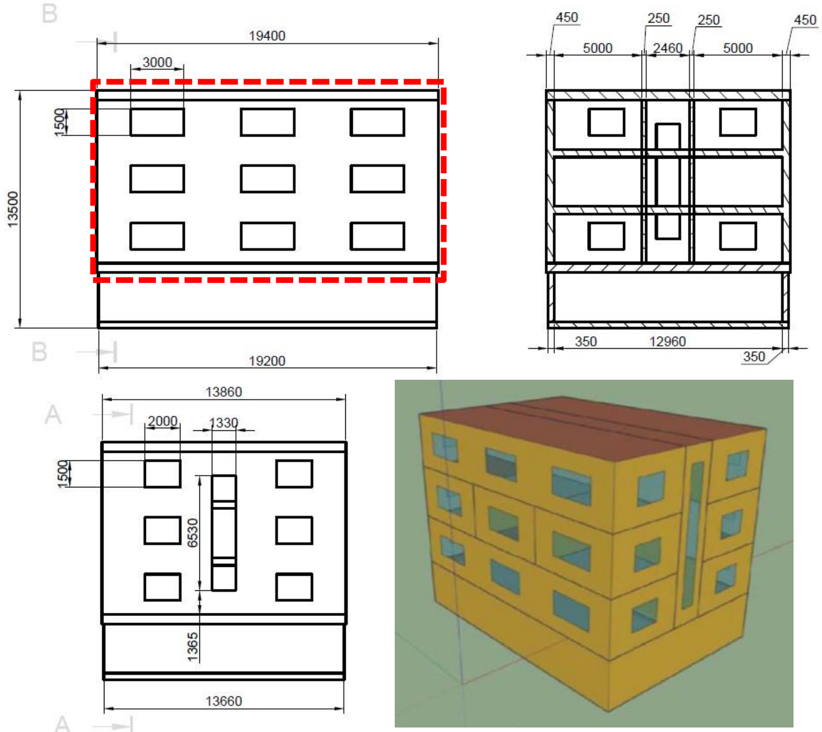


Figure A 5: Office Building used for the case study

In the first step, the building was used in its original state concerning the building's envelope, as it was available from the previous project. With these assumptions, the building has a characteristic length of $l_c = 2.27$. The average room height (gross volume divided by gross floor area) is 3.45, therefore the HWB limit according to the National Plan (which is related to a room height of 3 m) can be corrected by a factor of 1.15. This results in the following limits for $HWB_{Ref,RK}$:

i. EEB- path: $HWB_{Ref,RK,zul}$ = 26.67 kWh/(m²a)
ii. f_{GEE}- path: $HWB_{Ref,RK,zul}$ = 42.68 kWh/(m²a)

The calculated $HWB_{Ref,RK}$ is 29.8 kWh/(m²a), therefore the nZEB-requirements cannot be fulfilled following the "EEB- path" with this configuration of the building. Table A 10 shows the results of different variants of HVAC systems that were calculated in order to assess the possibility to fulfil the requirements of the f_{GEE}-path. The preparation of domestic hot water (DHW) was chosen to be done with decentralized electrical boilers, which is quite common in this type of buildings.
The first variant A uses a gas boiler for heating the building, resulting in a f_{GEE} = 0.72, which already meets the limit of 0.75. However, the building does just barely not meet the non-renewable primary energy limit of 84 kWh/(m²a) (acc. to National Plan 2018) and is therefore not a nZEB according to the definition. It has to be noted, that with the new values of the (non-renewable) primary energy conversion factors, which were published with the latest OIB-6:2019, also the PEB requirement would be fulfilled for this system ($f_{PE,n.ern}$ for gas was reduced from 1.16 to 1.10).
An interesting aspect is that the resulting f_{GEE} is improved if the building is equipped with an additional cooling system. For example, f_{GEE} is reduced from 0.72 to 0.69 from variant A to B by adding cooling. Here this even leads to a fulfilment of the nZEB-definition, as also $PEB_{HEB+BelEB,n.ern}$ drops below the limit (which can be increased by 16 kWh/(m²a), if cooling technology is used, see Table 4). The building has a calculated cooling demand of 20 kWh/(m²a).

Table A 10: Selection of variants for the office building, original building envelope

Variant	Heating	DHW	Additional system	$HWB_{Ref,RK}$ [kWh/m²a]	f_{GEE}	$PEB_{HEB+BelEB,n.ern.}$ [kWh/m²a]	nZEB?
A	Gas	El. decentral		29.8	0.72	84.31	👎
B	Gas	El. decentral	Cooling	29.8	0.69	92.61 (1)	👍
C	Pellets	El. decentral		29.8	0.72	53.61	👍
D	Air/water-HP	El. decentral		29.8	0.72	61.51	👍
E	Air/water-HP	El. decentral	Cooling	29.8	0.70	69.7 (1)	👍

(1) limit can be increased due to cooling

If the building is heated with a pellet boiler (variant C) or an air/water heat pump (D) both the f_{GEE} and the PEB limit can be met. Also if a heat pump is used, additional cooling improves the f_{GEE} (E compared to D).
With the considered HVAC systems and a better building envelope that would fulfil the requirements of the "EEB- path", it is quite obvious that also the "f_{GEE}- path" would be fulfilled. Thus it can be stated, as already mentioned for the residential buildings, that the "f_{GEE}- path" is probably the one that is easier to achieve.
An interesting question is, how the fulfilment of the nZEB requirements is influenced if the HWB requirement of the "f_{GEE}- path" is only just met. For this purpose the building envelope was changed accordingly, resulting in a $l_c = 2.24$ and a $HWB_{Ref,RK}$ of 42.6 kWh/(m²a), which is exactly the limit according to the "f_{GEE}- path". The results for this configuration are shown in Table A 11 for different systems using an air/water heat pump, again with decentralized electrical boilers for DHW.
In variant F it can be seen that the nZEB requirements cannot be met just by applying an air/water heat pump, as the f_{GEE} limit of 0.75 is exceeded. In variant G a photovoltaic plant with 7 kW_p is added, which is a size that should easily fit onto the available roof space of the considered building.

The calculation procedure considers the use of PV with a percentage of the electricity demand that can be covered by PV, therefore reducing both f_{GEE} and PEB, making the building a nZEB according to the definition.
As shown before, if cooling is added, f_{GEE} is reduced in variant H compared to F. However, the limit of 0.75 is still not reached in this case, which could for example be achieved by adding additional PV (variant I).

Table A 11: Considered variants for the office, building envelope fulfilling the limit acc. to the "f_{GEE}- path"

Variant	**Heating**	**DHW**	**Additional system**	**$HWB_{Ref,RK}$ [kWh/m²a]**	**f_{GEE}**	**$PEB_{HEB+BelEB,n.ern.}$ [kWh/m²a]**	**nZEB?**
F	Air/water-HP	El. decentral		42.6	0.82	66.4	👎
G	Air/water-HP	El. decentral	PV 7 kW_p	42.6	0.73	52.04	👍
H	Air/water-HP	El. decentral	Cooling	42.6	0.78	73.26 (1)	👎
I	Air/water-HP	El. decentral	Cooling, PV 7 kW_p	42.6	0.72	61.81 (1)	👍

(1) limit can be increased due to cooling

A.2 Tables for the application of OIB-6

Table A 12 and Table A 13 show the maximum share of the electricity demand that can be considered covered by photovoltaic energy according OIB-6:2019 and OIB-6:2015, respectively.

Table A 12: Maximal accountable PV energy [OIB-6:2019]

Components	Coverable share without battery
Lighting energy demand	25 %
Humidification energy demand	25 %
Space heating energy demand	25 %
Cooling energy demand	50 %
Hot water energy demand	50 %
Household and operating electricity requirements	75 %
Auxiliary energy demand for space heating and hot water	75 %
Auxiliary energy demand for solar thermal energy	100 %

Table A 13: Maximal accountable PV energy [OIB-6:2015]

Components	Coverable share without battery
Space heating, heat supply energy demand	25 %
Space heating, auxiliary energy demand	75 %
Hot water, heat supply energy demand	50 %
Hot water, auxiliary energy demand	75 %
Cooling energy demand	25 %
Household and operating electricity demand	75 %
Solar thermal, auxiliary energy	100 %
Lighting energy demand	0 %
Humidification energy demand	0 %

Table A 14 and Table A 15 show the maximum U-values according OIB-6:2019 and OIB-6:2015, respectively:

Table A 14: Limits of U-values for each type of wall [OIB-6:2019]

	Component	U [W/(m^{2}K)]
1	Wall against outside air	0.35
2	Wall against unheated or not developed attic rooms	0.35
3	Wall against unheated, frost-free parts of building (except lofts) and against garages	0.60
4	Walls against the ground	0.40
5	Walls (partition walls) between residential or operating units or conditioned staircase	1.30
6	Walls against other structures or neighbouring land or building site boundaries	0.50
7	Walls (partition walls) within residential and business units	-
8	Windows, window doors, glazed doors in residential buildings towards outside air	1.40
9	Windows, window doors, glazed doors in non-residential buildings towards outside air	1.70
10	Other transparent vertical components towards outside air	1.70
11	Other transparent horizontal or inclined components towards outside air	2.00
12	Other transparent components vertical against unheated building parts	2.50
13	Roof window towards outside air	1.70
14	Doors unglazed, towards outside air	1.70
15	Doors unglazed, against unheated building parts	2.50
16	Gates Rolling doors, sectional doors like towards outside air	2.50
17	Inner doors	-
18	Ceilings and roofs in each case towards outside air and against roof areas (ventilated or uninsulated)	0.20
19	Ceilings against unheated building parts	0.40
20	Ceilings against separate living and operating units	0.90
21	Ceilings within residential and operational units	-
22	Ceilings over outdoor air (for example over passages, parking decks)	0.20
23	Ceilings against garages	0.30
24	Floors touching the ground	0.40

Table A 15: Limits of U-values for each type of wall [OIB-6:2015]

	Component	U [W/(m²K)]
1	Wall against outside air	0.35
2	Wall against unheated or not developed attic rooms	0.35
3	Wall against unheated, frost-free parts of building (except lofts)	0.60
4	Walls earth touched	0.40
5	Walls (partition walls) between residential or operating units or conditioned staircase	0.90
6	Walls against other structures at land or building site boundaries	0.50
7	Walls on small surfaces against outside air	0.70
8	Walls (partition walls) within residential and business units	-
9	Windows, window doors, glazed doors each in residential buildings against outside air	1.40
10	Windows, window doors, glazed doors each in non-residential buildings against outside	1.70
12	Other transparent components vertical against outside air	1.70
13	Other transparent components horizontal or inclined to outside air	2.00
14	Other transparent components vertical against unheated building parts	2.50
15	Roof window against outside air	1.70
16	Doors unglazed, against outside air	1.70
17	Doors unglazed, against unheated building parts	2.50
18	Gates Rolling doors, sectional doors like against outside air	2.50
18	Inner doors	-
19	Ceilings and roofs in each case against outside air and against roof areas (ventilated or uninsulated)	0.20
20	Ceilings against unheated building parts	0.40
21	Ceilings against separate living and operating units	0.90
22	Ceilings within residential and operational units	-
23	Ceilings over outdoor air (for example over passages, parking decks)	0.20
24	Ceilings against garages	0.30
25	Floors touched the ground	0.40

The conversion factors for the primary energy (f_{PE}), the non-renewable and renewable parts (respectively $f_{PE,n.ern.}$ and $f_{PE,ern.}$) and the conversion factor for the CO_2 (f_{CO2eq}) from OIB-6:2019 are shown in Table A 16, while Table A 17 show the values according OIB-6:2015.

Table A 16: Austrian conversion factors [OIB-6:2019]

	Energy source	f_{PE} [-]	$f_{PE,n.ern}$[-]	$f_{PE,ern}$ [-]	f_{CO2eq} [g/kWh]
1	Coal	1,46	1,46	0,00	375
2	Fuel oil	1,20	1,20	0,00	310
3	Natural gas	1,10	1,10	0,00	247
4	Solid biomass	1,13	0,10	1,03	17
5	Liquid biofuels (island operation)	1,50	0,50	1,00	70
6	Gaseous biofuels (island operation)	1,40	0,40	1,00	100
7	Electricity (Delivery mix)	1,63	1,02	0,61	227
8	District heating from heating plant (renewable)	1,60	0,28	1,32	59
9	District heating from heating plant (non-renewable)	1,51	1,37	0,14	310
10	District heating from high-efficiency cogeneration	0,88	0,00	0,88	75
11	Waste heat	1,00	1,00	0,00	22

Table A 17: Austrian conversion factors [OIB-6:2015]

	Energy source	f_{PE} [-]	$f_{PE,n.ern}$ [-]	$f_{PE,ern}$ [-]	f_{CO2eq} [g/kWh]
1	Coal	1,46	1,46	0,00	337
2	Fuel oil	1,23	1,23	0,01	311
3	Natural gas	1,17	1,16	0,00	236
4	Biomass	1,08	0,06	1,02	4
5	Electricity (Delivery mix)	1,91	1,32	0,59	276
6	District heating from heating plant (renewable)	1,60	0,28	1,32	51
7	District heating from heating plant (non-renewable)	1,52	1,38	0,14	291
8	District heating from high-efficiency cogeneration (default value)	0,94	0,19	0,75	28
9	District heating from high-efficiency cogeneration (best value)	≥ 0,30	acc. to itemization		≥ 20
10	Waste heat (default value)	1,00	1,00	0,00	20
11	Waste heat (best value)	≥ 0,30	Acc. to itemization		≥ 20

A.3 Swedish implementation of EPBD – Tables

Table A 18: Geographical adjustment factors F_{geo}

County	Geographical location Municipality	F_{geo}
Blekinge	All municipalities	0.9
Dalarna	Avesta, Hedemora and Säter	1.1
	Borlänge, Falun, Gagnef, Leksand, Ludvika, Mora, Orsa, Rättvik, Smedjebacken and Vansbro	1.2
	Malung-Sälen and Älvdalen	1.4
Gotland	Gotland	0.9
Gävleborg	Gävle, Ockelbo and Sandviken	1.1
	Bollnäs, Hofors, Hudiksvall, Nordanstig and Söderhamn	1.2
	Ljusdal and Ovanåker	1.3
Halland	All except Hylte	0.9
	Hylte	1.0
Jämtland	Berg, Bräcke, Ragunda and Östersund	1.4
	Härjedalen, Krokom and Strömsund	1.5
	Åre	1.6
Jönköping	Aneby, Gislaved, Gnosjö, Habo, Jönköping, Mullsjö, Tranås, Vaggeryd, Vetlanda and Värnamo	1.0
	Eksjö, Nässjö and Sävsjö	1.1
Kalmar	Borgholm, Emmaboda, Kalmar, Mönsterås, Mörbylånga, Nybro, Oskarshamn, Torsås and Västervik	0.9
	Hultsfred, Högsby and Vimmerby	1.0
Kronoberg	All municipalities	1.0
Norrbotten	Piteå	1.4
	Boden, Haparanda, Kalix, Luleå and Älvsbyn	1.5
	Arvidsjaur, Överkalix and Övertorneå	1.6
	Arjeplog and Pajala	1.7
	Jokkmokk	1.8
	Gällivare and Kiruna	1.9
Skåne	Höganäs, Landskrona, Lomma, Malmö and Vellinge	0.8
	Bjuv, Bromölla, Burlöv, Båstad, Eslöv, Helsingborg, Hässleholm, Hörby, Höör, Klippan, Kristianstad, Kävlinge, Lund, Perstorp, Simrishamn, Sjöbo, Skurup, Staffanstorp, Svalöv, Svedala, Tomelilla, Trelleborg, Ystad, Åstorp, Ängelholm and Östra Göinge	0.9
	Osby and Örkelljunga	1.0
Stockholm	All municipalities	1.0
Södermanland	All municipalities	1.0
Uppsala	Enköping, Håbo, Knivsta and Uppsala	1.0
	Heby, Tierp, Älvkarleby and Östhammar	1.1
Värmland	Grums and Säffle	1.0
	Arvika, Eda, Filipstad, Forshaga, Hammarö, Karlstad, Kil, Kristinehamn, Munkfors, Storfors, Sunne and Årjäng	1.1
	Hagfors and Torsby	1.2
Västerbotten	Nordmaling and Umeå,	1.3
	Bjurholm, Robertsfors, Skellefteå and Vännäs	1.4
	Dorotea, Lycksele, Vindeln and Åsele	1.5
	Malå, Norsjö and Vilhelmina	1.6
	Sorsele	1.7
	Storuman	1.8
Västernorrland	Härnösand, Kramfors, Sundsvall, Timrå and Örnsköldsvik	1.3
	Sollefteå and Ånge	1.4
Västmanland	Arboga, Hallstahammar, Kungsör, Köping, Surahammar and Västerås	1.0
	Fagersta, Norberg, Sala and Skinnskatteberg,	1.1
Västra Götaland	Göteborg, Härryda, Kungälv, Lerum, Lysekil, Mölndal, Orust, Partille, Sotenäs, Stenungsund, Strömstad, Tanum, Tjörn, Uddevalla and Öckerö	0.9
	Ale, Alingsås, Bengtsfors, Bollebygd, Borås, Dals-Ed, Essunga, Falköping, Färgelanda, Grästorp, Gullspång, Götene, Herrljunga, Hjo, Karlsborg, Lidköping, Lilla Edet, Mariestad, Mark, Mellerud, Munkedal, Skara, Skövde, Svenljunga, Tibro, Tidaholm, Trollhättan, Töreboda, Vara, Vårgårda, Vänersborg and Åmål	1.0
	Tranemo and Ulricehamn	1.1
Örebro	Hallsberg, Kumla, Laxå, Lekeberg and Örebro	1.0
	Askersund, Degerfors, Hällefors, Karlskoga, Lindesberg and Nora	1.1
	Ljusnarberg	1.2
Östergötland	All municipalities	1.0

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