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Laurent Georges

State-of-the-Art Analysis of Nearly Zero Energy Buildings

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Country report IEA HPT Annex 49 Task 1 – NORWAY

SINTEF Academic Press

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IEA HPT Annex 49

Design and Integration of Heat pumps for nearly Zero Energy Buildings

49 Country Report NO Task 1

State-of-the-Art Analysis of Nearly Zero Energy Buildings

Country report IEA HPT Annex 49 **Task 1 – NORWAY**

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IEA HPT Annex 49 is a corporate research project on heat pump application in Nearly Zero Energy Buildings
The project is accomplished in the Heat Pump Technologies (HPT) Technology 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 design and integration of heat pumps as core component of the HVAC system for Nearly or Net Zero energy buildings (NZEB). The IEA HPT Annex 49 has been structured into four tasks which comprise the following investigations:

Task 1: State-of-the-art analysis

Task 1 – this report – is to give an overview on NZEB on the national level of the participating countries. In more detail, the political framework in terms of NZEB (e.g. building codes, legislation, definition(s) of NZEB), the state of market introduction and applied technologies both on the building envelope and the bldg. HVAC system shall be characterized. The compiled technical concepts shall be analysed regarding the heat pump application. Technologies can be classified in a technology matrix and evaluated regarding specific advantages of single technologies for dedicated applications like new bldgs., retrofit, office, residential, etc. Technologies shall also be considered regarding different aspects of the definitions, e.g. characteristics regarding load match and grid interaction, the necessity of a grid connection or the capability to integrate local storage. This information can be updated from IEA HPT Annex 40. Information shall be extended regarding the technologies for groups of bldgs. and neighbourhoods as well as for current market conditions for renewable energy.

Task 2: Integration options of system technology

Task 2 is dedicated to identifying promising integration options in order to increase the performance. This can be done for single buildings, i.e. simultaneous operation modes or storage integration, but the investigations shall also be extended to groups of buildings or neighbourhoods, which may offer collective heat source/heat sink and a load balancing in case of different use of buildings. Concepts and technologies can be analysed by simulations wrt. the benefits in performance or cost of the system integration options, but also wrt. further aspects like self-consumption of energy, load match and grid interaction. Evaluation can also be linked to Task 4 regarding the design and control of system configurations.

Task 3: Technology development and field monitoring

Task 3 is dedicated to technology developments on the component and system level as well as to gather field experiences of system solutions in field monitoring projects. Marketable and prototype technologies could be lab-tested or investigated in field monitoring. Task 3 is accomplished in parallel to Task 2.

Task 4: Design and control of nZEB technical building systems

Task 4 is also to be accomplished in parallel and deals with the design and control of building systems in nZEB. On the one hand, this is related to the integration option investigated in Task 2 and also include the design for groups of buildings and neighbourhoods. Besides the function of the components control, it also addresses strategies for demand response in order to enhance the flexibility of the building technology, either for higher self-consumption or for a grid-supportive operation, e.g. based on price signals. Thus, a holistic evaluation of the design and control of the building technology based on the criteria performance, cost and flexibility shall be derived.

This report gives the results with the **State-of-the-Art Analysis (Task 1)** for **NORWAY**.

The Norwegian activities in IEA HPT Annex 49 are organized and carried out by SINTEF Building and Infrastructure (http://www.sintef.no/home/building-and-infrastructure), while NTNU (http://www.ntnu.edu) and COWI AS (www.cowi.no) are subcontracting partners. The project is funded by the governmental organization Enova SF (www.enova.no) and the Norwegian Research Centre on Zero Emission Neighbourhoods, FME ZEN (http://fmezen.com/).

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1 Policy Framework and Definition

In this chapter, the current and future political boundary conditions for the introduction of nZEB are summarized by means of the following chapters.

1.1 Political Framework

Klimameldingen (Report on Climate Policies) – A White Paper on environment and energy (KLD 2017) from the Norwegian Ministry of the Environment. It describes the government's strategy for achieving Norway's climate commitment for 2030. Norway will also cooperate with EU to fulfil the commitments from The Paris Agreement. Some of the relevant goals are:

- Banning mineral oil as base load and peak load for heating of all kinds buildings. Review possibilities for reducing the use of mineral oil for heating buildings in agriculture and temporary buildings, construction sites and district heating systems.
- Reduce emissions from HFCs, by revising the product regulation while implementing the Kigali Amendment to the Montreal Protocol.

Bygningsmeldingen (Report on Future Buildings) – A White Paper on future building policies (MD 2012) from the Norwegian Ministry of the Environment. The main goals include:

- Introduce nearly passive house level as the building code standard in 2017
- Reach nearly zero emission/energy buildings (nZEB) in 2020

The revision of the Norwegian building code from TEK10 to TEK17 in 2017 was a part of this national strategy. TEK17, which is implemented with a transition period until 31st December 2018, has become a modified passive house standard partly based on the Norwegian passive house standards NS 3700 (residential buildings) and NS 3701 (non-residential buildings):

- Minimum requirements for building elements: U-value outer wall ≤ 0.22 W/(m²K), U-value roof and walls on the ground ≤ 0.18 W/(m²K), U-value windows/doors ≤ 1.2 W/(m²K) and leakage rate at 50 Pa pressure difference ≤ 1.5 air change per hour.
- Prohibition of fossil fuelled boilers (mineral oil, natural gas and propane/LPG)
- Buildings with < 1000 m² heated area
  - No special requirements regarding the thermal energy supply – e.g. electric heating systems can be used (electric baseboard heaters, electric boilers etc.)
- Buildings with > 1000 m² heated area
  - Energy flexible and low-temperature hydronic heating systems should cover minimum 60 % of the total heating demand. Possible heating systems include heat pumps, biomass-fired boilers and solar heaters. Electric boilers and other electric heating systems can be used as peak load (auxiliary heating).

In addition to the passive house standards and a step further than the zero energy buildings are the **Plus-houses. "***Plus-energy implies that the building during its lifetime shall produce and export energy that compensates for energy use for other life cycle stages. This must be compensated with self-produced and exported energy based on renewable energy (solar, wind and heating and cooling from the sea, air or the ground via heat pump ". (Powerhouse 2016)*

The main goal of "Powerhouse", which is a collaboration between Entra Eiendom, Skanska, Snøhetta, Zero, Hydro, Sapa and Asplan Viak, is to build energy-positive buildings.

The future building strategy includes implementation and compliance with the EU directives "Energy Performance of Buildings Directive", EPBD (European Parliament and Council 2010), "Renewable Energy Sources, RES" (EC 2009) and "Eco Design, ErP" (EC 2009). This cover strategies regarding e.g. energy labelling of buildings ("Energimerking"), increased use of renewable energy sources for heating/cooling of buildings, and improved energy efficiency for energy related products (ErP) including heating/cooling systems for buildings.

BREEAM-NOR is an eco-certification tool developed by the Norwegian Green Building Council (NGBC), to adapt BREEAM to Norwegian conditions. Its purpose is to motivate sustainable design and construction of buildings. Projects are awarded points for choosing low and zero carbon technologies, like heat pumps, and may achieve additional points for choosing natural working fluids or low-charge systems. (NGBC 2016)

Enova SF is a public enterprise owned by the Norwegian Ministry of Petroleum and Energy, https://www.enova.no/about-enova/about-enova/259/0/. Enova SF was established in 2002 to take a leading role in promoting environmentally friendly restructuring of energy consumption and energy generation in Norway. Enova SF has since the start-up established a large number of different funding programmes to promote the evaluation, design and construction of low-energy and passive house buildings as well as installation of high-efficiency heating/cooling systems based on renewable energy sources, including heat pump and liquid hiller systems with various heat sources/sinks. Relevant programmes for heat pumps:

- *Heating plants in buildings* – standard/simple subsidy schemes for air-to-water (A/W), water-to-water (W/W) and brine-to-water (B/W) heat pump systems, solar heating systems (solar collectors), biomass-fired boilers etc.
- *Innovative technologies for the next generation of advanced buildings*. Subsidies for full-scale demonstration projects with considerable innovation. High-efficiency heat pump and cooling systems with natural working fluids (CO_2, ammonia, propane), innovative system design, high-efficiency PV systems (building integrated or roof-top mounted) and exchange of thermal and electrical energy between buildings (neighbourhoods) are examples of innovative technologies/design/operation. This Enova-programme is a step towards an effective market introduction of near Zero Energy Buildings (nZEB).
- *Concept evaluation of innovative energy and climate solutions in buildings, neighbourhoods and energy systems.* Subsidy scheme which purpose is to ensure that good innovative projects are not stranded at an early stage.

Enova SF as well as The Research Programme on Zero Emission Neighbourhoods in Smart Cities, *ZEN*, http://fmezen.no/, are the main financial contributors to the Norwegian activity in IEA HPT Annex 49. ZEN is presented in another part of this report.

There are currently no governmental strategies for retrofitting existing buildings to nZEB or ZEB in Norway. In one of the field measurement projects of IEA HPT Annex 40, an existing office building from 1989 (Powerhouse Kjørbo, Sandvika – Norway) was retrofitted to ZEB standard by refurbishing the entire building envelope, installing a high-efficiency ventilation system, upgrading the lighting systems etc. and installing a high-efficiency ground-source heat pump system for heating and cooling of the building (*Chapter 4.3*).

1.2 Definition(s) of ZEB and nZEB

ZEB is a grid-connected, energy-efficient building that balances its total annual energy consumption by on-site generation of electricity and associated feed-in credits. The term NET has been introduced to mark the balance concept – in contrast to an autonomous building. Based on the definitions of Rehva (Kurnitski, Allard et al. 2013), we can define ZEB and nZEB as follows.

- **Net Zero Energy Building (net ZEB)** – A net ZEB is defined as a building having a primary energy use lower or equal to zero [kWh/(m^2a)]. The term “net” refers to the <u>annual</u> balance of primary energy calculated based on delivered/supplied and exported thermal and electric energy. A net ZEB is normally defined as a grid connected building with very high energy performance. A net ZEB implies that the building produces the same amount of energy from renewable sources as the energy needed for its operation (Sartori, Napolitano et al. 2012). Therefore, a net ZEB produces energy when conditions are suitable and uses delivered energy otherwise (Kurnitski, Allard et al. 2013). A good example is referred by (Dar, Georges et al. 2012) for the Norwegian case. A net ZEB definition can be expanded by using primary energy used (PEU) and life cycle perspective, in that case the PEU used for building operation, embodied energy and end of life energy would be accounted for. (Fufa, Schlanbusch et al. 2016)

- **Nearly Zero Energy Building (nZEB)** – nZEB stands for a technically and reasonable achievable primary energy use higher than zero kWh/(m^2a). This would be achieved with a combination of best practice energy efficiency measures and renewable energy technologies which may or may not be cost optimal. "Reasonably achievable" is assumed by comparison with national energy use benchmarks appropriate to the activities served by the building. Renewable energy technologies needed in nearly Zero Energy Buildings may or may not be cost-effective, depending on available national incentives (Kurnitski, Allard et al. 2013). A Norwegian definition of nZEB is still under development and should be published soon.

1.2.1 Norwegian Definition of Zero Emission Buildings

A revised Norwegian definition of ZEB (Note: in the Norwegian definition ZEB = Zero <u>Emission</u> Buildings) 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 equivalents (CO_2-eq.), still compensated by on-site renewable energy generation. 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.

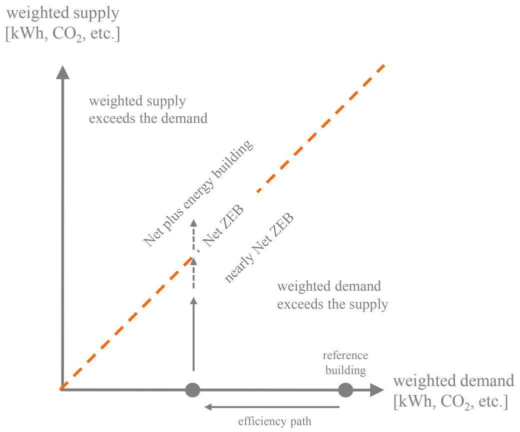


Figure 1 Graph representing the path towards a Net Zero Energy Building (Net ZEB), with the nearly and plus variants. (Sartori, Napolitano et al. 2012)

Figure 2 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.

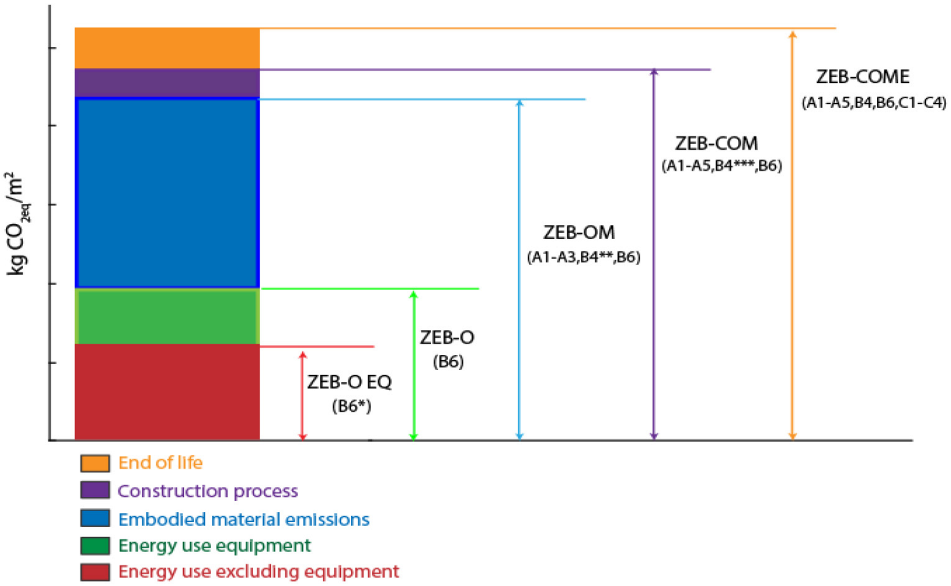


Figure 2 Illustration of five of the six ambition levels for Zero Emission Buildings (ZEB). (Fufa, Schlanbusch et al. 2016)

All the calculations regarding emissions and energy balances are to be done based on the Norwegian standard NS 3031:2014. Export to the electricity grid will be considered by NS-EN-ISO 13790:2008, but also by NS 3701:2012. 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.

1.2.2 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. SN/TS 3031:2016 is a supplement to NS 3031:2014, which is more suitable for advanced technical installations, and can be used for documentation regarding nZEB and plus-houses. The greenhouse gas emissions from operational energy has to be calculated according to delivered energy using CO_2-eq. conversions factors for each energy carrier. (Fufa, Schlanbusch et al. 2016)

1.3 Proposal of Definition of a nZEB for the Work in IEA HPT Annex 49

A Low-Energy Commission delivered a number of suggestions for increasing energy efficiency of all sectors in Norway in 2009. The report also included suggestions of future net energy frame values (kWh/m²a) for new buildings, as well as for major renovations. TEK 07 was published in 1st February 2007. This was the first Norwegian building code with an energy performance approach. Afterwards, the TEK 10 was published in 2010, and the TEK 17 was published in 2017. The energy requirements in TEK 10 were although revised in 2015. A new version of the TEK is expected to be published every fifth year with stricter constrains.

The total net specific energy use in the energy frame includes space heating, heating of ventilation air, space cooling (ventilation air cooling and local cooling), heating of domestic hot water (DHW), ventilation, lighting systems and electric appliances. The energy requirements proposed for the different bldg. codes are summarized in *Table 1*.

Table 1 Net specific energy frames for new buildings in Norway (kWh/m²a) vs. building code. TEK17 is the prevailing Norwegian building code. (DIBK 2017)

		Energy frame [kWh/(m²a)]				
Building Code	**TEK07**	**TEK10**	**TEK17**	**TEK20**	**TEK25**	**TEK30**
Res. – detached house	135	130	100 + 1600/m²	nearly ZEB (nZEB)	Intermediate nZEB – ZEB	ZEB
Res. – block of flats	120	115	95			
Non-res. – office bldg.	165	150	115			

The floor area used for these calculations is *the heated floor area* measured inside the external walls (BRA). Norway has four different climate zones. Among them, the values given in *Table 1* are valid for the “standard” climate zone around the capital Oslo (DOT -20 °C, t_m 5,9 °C), which is in the South-eastern part of the country. The annual energy use of the proposed building is first calculated for the considered climate zone and then for the “standard” climate zone. The results for the standard climate zone must fulfil the required energy frame. The current energy frames are specified for single-family houses, multi-family houses and eleven types of non-residential buildings (Kurnitski, Allard et al. 2013).

Regarding the building restrictions for the building envelope, *Table 2* shows the requirements for a possible nZEB (Dokka, Kristjansdottir et al. 2013) that enable a zero-energy balance. The right-hand column shows *examples* of possible construction types to comply with the required U-values and other requirements. These designs are not standardized but only a proposal.

Table 2 Minimum values for the building envelope required for a ZEB. (Dokka, Kristjansdottir et al. 2013)

		Technical Solution
External walls	U = 0.12 W/m²K	Timber frame wall with 350 mm mineral wool insulation
External roof	U = 0.09 W/m²K	Compact roof with approximately 450 mm mineral wool 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 with insulation
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, superior quality assurance in craftsmanship and pressure testing of the building in two stages, i.e. when the wind barrier is mounted and when the building is completed).
Heat loss factor cellar	0.78	Taking into account the increased thermal resistance of the unheated basement

Requirements for the **HVAC components** in ZEB are shown in *Table 3*. Again, these values are not standardized but minimum requirements to enable zero annual energy balance. The requirements regarding e.g. heat recovery are enforced but no requirements regarding latent recovery are implemented (conversely to USA or Canada where one should always talk about "total heat recovery").

Table 3 Specifications for HVAC installations in ZEB. (Dokka, Kristjansdottir et al. 2013)

	Values	**Technical solution**
Heat recovery	η = 90 %	Single rotary wheel heat exchanger. Temperature efficiency, not enthalpy efficiency. I.e. 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)	Ultra-low pressure drop (Δp) in air handling unit (AHU) and ultra-low pressure drop (Δp) in ducting system.
Installed cooling capacity	Q"cool = 10 W/m²	Low installed capacity, so it can be covered entirely by free cooling from a vertical ground-source system (boreholes in bedrock), alternatively seawater or groundwater systems
Installed heating capacity, alt. 1	Q"heat = 30 W/m²	Installed capacity to preheat and reheat the supply air, i.e. no separate room heating system is required
Installed heating capacity, alt. 2	Q"heat = 15 W/m²	Installed capacity for radiators installed in a hydronic heat distribution system

1.4 System Boundary for Operational Energy

In order to calculate or measure the delivered and/or exported energy to or from the building, the system boundary needs to be defined. Marszal, Heiselberg et al. (2011) have defined 5 different levels, which are illustrated in *Figure 3*.

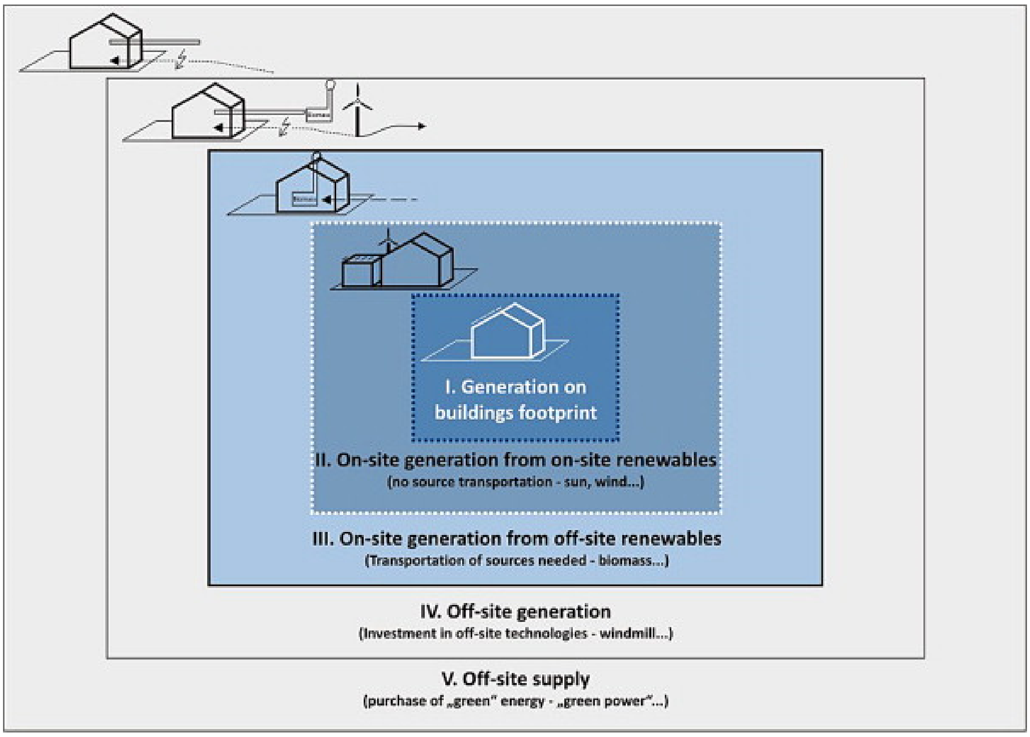


Figure 3 **Illustration of the 5 different levels of possible system boundaries when calculating/measuring delivered and/or exported energy to or from the bldg. (Marszal, Bourelle et al. 2010)**

Based on these levels, the Norwegian ZEB Research Centre has defined the following boundaries for local renewable production of electricity and thermal energy:

- **Electricity production:** Level III in *Figure 3* has been chosen. This means that the production unit of electricity must be located on-site, while off-site renewables (e.g. biomass) may be used.

- **Thermal production:** Level IV in *Figure 3* has been chosen. The thermal energy production for the building may thus be either on- or off-site, but emissions from the actual energy mix shall be used, and total system losses from the productions site to the building shall be included. Due to this consideration, near heating and import/export from/to district heating grids can be considered. (Fufa, Schlanbusch et al. 2016)

CO2-eq Factor for Electricity

The ZEB centre expects the realization of what it has defined as *ultra-green scenario* in the coming years, and it's assumed that Norway will be an integral part of a single European electricity grid. Based on green scenario simulations it's expected a 90 % reduction of CO_2 emissions by 2050 (Graabak and Feilberg 2011). This is "verified" by the EU's *A roadmap for moving to a competitive low-carbon economy in 2050*. The average specific CO_2 emissions over a building lifetime of 60 years is extrapolated to be approximately 132 g CO_2/kWh, and this is the specific CO_2-factor for electricity employed by the ZEB Research centre (Fufa, Schlanbusch et al. 2016).

The authors (Fufa, Schlanbusch et al. 2016) support a common calculation method that may avoid different calculation methods that include different shares of the energy losses when calculating the embodied energy and CO_2 emissions. Not using a common methodology may imply that one might over-or underestimate values that complicates the correct comparison of factors. For instance, EN 15603 includes losses from the fuel extraction, the building and demolition of a power plant, whereas Graabak and Feilberg (2011) in their green scenario do not include the building operation and demolition. This might also be a little bit too positive regarding the increase in energy efficiency within the next 40 years. Therefore, it could be useful to use the two values – optimistic and pessimistic – so that one could get a range for the real value of each technology until a standardized calculation method has been approved for the entire EU. Our suggestion is to use *EU average values and compare them with the ultra-green profile*.

1.5 Temporary Energy Match Characteristics

One of the biggest challenges of the nZEB/ZEB is the mismatch between demand and generation of electrical and thermal power/energy. Given that the majority of the energy provided to this type of buildings has renewable nature, generation is very dependent on the availability of the source. Example, solar energy in Norway – during the winter when a large demand of space heating is required, the sun radiates with the least intensity. Therefore, the match between demand and generation is complicated, and this type of building must normally be connected to the grid.

Figure 4 illustrates one common mismatch problem addressed in ZEBs. The diagram shows the monthly average electric energy demand and generation of energy from PV. There is a mismatch between generation and demand the entire year, and therefore the system in this case would need to be connected to the electricity grid.

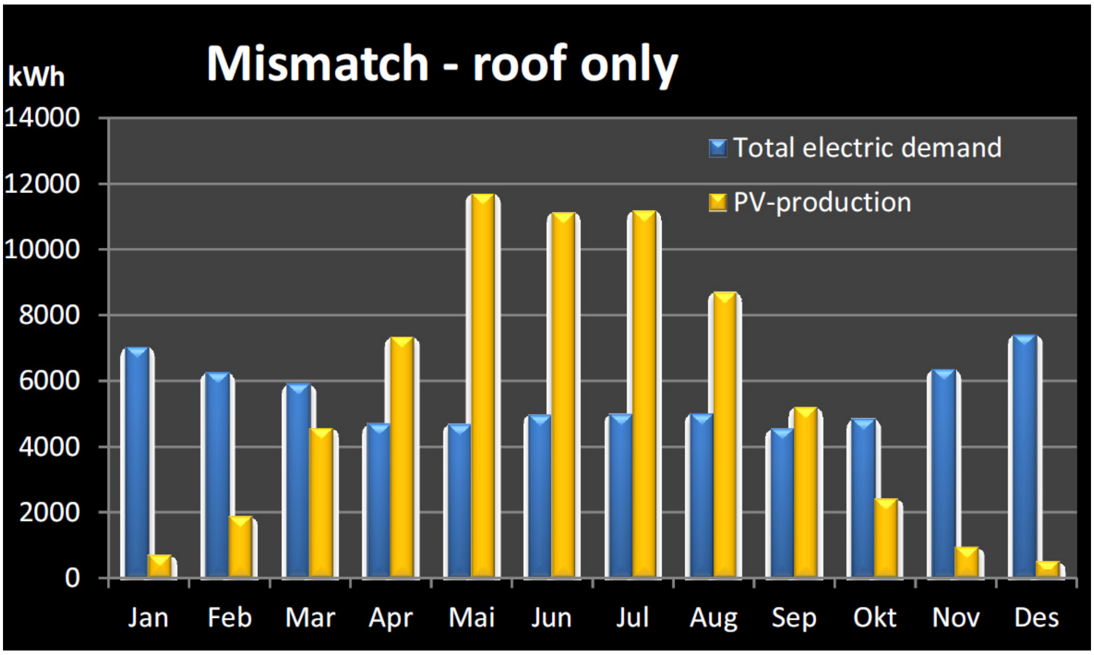


Figure 4 Mismatch between electricity demand and PV production. (Dokka, Kristjansdottir et al. 2013)

As for the temporal basis, *Figure 5* shows that the problem increases when the time frame is reduced. From coverage of almost 50 % when analysing at the monthly horizon, this value drops to about 15 % when considering 5 minutes' periods.

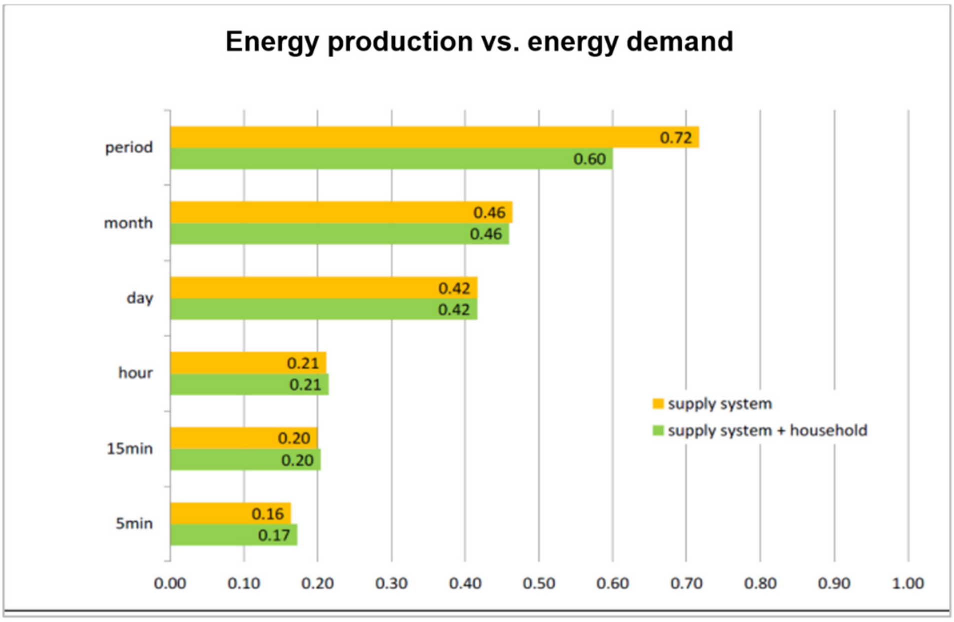


Figure 5 **Mismatch between generation and demand for different time periods. (Dokka 2012)**

The Norwegian ZEB Research Centre has chosen an approach called *symmetric weighting* (Dokka, Sartori et al. 2013), where the same factor for CO_2-equivalents is used for both import and export of electricity from the building(s). There will thus be no daily, weekly or annual variation, and the CO_2 factor is considered constant. This approach limits the complexity of the calculations, but it is still recommended by Fufa, Schlanbusch et al. (2016) to calculate the mismatch between energy demand and on-site energy production during different seasons according to NS-EN 15603:2008 *Energy performance of buildings – Overall energy use and definition of energy ratings*.

1.6 Minimum Energy Efficiency

To achieve a ZEB, there are two main design strategies; first to minimize the energy need through energy efficiency measures, and then to meet the remaining energy demand through use of renewable energy and other technologies. The strategies could either be passive or active, whereas passive strategies relate to the location, shape and design of the building, while active strategies involve technical systems or machinery to provide services to the building, ex heat pumps.

The minimum requirements for energy efficiency in ZEBs are represented by the passive house level. With passive house level, it's meant that these buildings comply with the requirements in the Norwegian passive house standard **NS 3700:2013** (residential buildings) and **NS 3701:2012** (non-residential buildings). These standards set requirements for maximum heating and cooling demands and energy demand for lighting (non-residential). Furthermore, they set requirements for maximum heat loss, component requirements for windows and doors, thermal bridges, infiltration rate and specific fan power (SFP). This minimum energy efficiency level ensures that the buildings are constructed with robust and long-living energy measures that minimize energy consumption. (Dokka, Kristjansdottir et al. 2013)

1.7 Requirements for Indoor Air Quality (IAQ)

ZEBs does not only make requirements regarding energy consumption but also regarding the indoor air quality in the building, as it needs to fulfil the requirements in the Norwegian building regulations. (Dokka, Kristjansdottir et al. 2013) Such requirements can be summarized as:

- Max air speed – winter: 0.15 m/s
- Max operating temperature dim. Summer: 26 °C (may be higher for a maximum of 50 hours in a normal year)
- Min operating temperature – dim. winter: 20 °C
- Max CO_2 levels winter (temp below 22 °C): 1000 ppm
- Minimum floor temperature: 19 °C
- Minimum average daylight factor: 2 %

In addition, the requirements regarding local discomfort for category B in appendix A of ISO 7730:2005 should also be met.

1.8 Verification

To define a ZEB verification is needed – the calculations of energy use represent a good starting point that must be further followed up. The calculated values must be verified by monitoring and evaluation, and lessons learned during this process could prove useful for new projects. According to Fufa, Schlanbusch et al. (2016) 4 levels of verification of ZEB are recommended:

- *Verification of annual energy performance and the ZEB balance*. Measurement of the delivered and exported energy to/from the building to evaluate if the designed performance is achieved. The ZEB balance is calculated from the specific CO_2-factors for each energy carrier.
- *Verification of energy performance level.* Comparing simulated and measured energy use for different purposes (heating, domestic hot water, fans, lighting, appliances) according to NS 3031:2014. A method for verification of buildings energy use is proposed by (Dokka and Grini 2013).
- *Monitoring if indoor climate parameters are obtained*. Measurement of temperatures, air velocities, CO_2 levels, noise levels, light levels (natural/artificial), etc. are required. They must be carried out at both summer and winter conditions.
- *AS-BUILT assessment of embodied emissions.* Verification whether the materials, products and processes used in the construction of the building are the same as what was assumed in the design phase. The actual materials used in the construction should be included in an AS-BUILT analysis.

The LCA made for ZEBs should also be verified and quality assured by an independent, qualified third party (Kristjansdottir, Fjeldheim et al. 2014).

2 Market State of Nearly and Net Zero Energy Buildings

In this chapter, the market state and the introduction of nZEB on the national level as well as building envelope strategies are summarised.

2.1 Thermal Loads and Boundary Conditions for Buildings

In passive houses and ZEBs the demand for space heating and heating of ventilation air has been drastically reduced due to heavily insulated and air-tight walls as well as the utilization of high-efficiency heat recovery units (heat exchangers) in the ventilation system. In high performance buildings with a demand for domestic hot water (DHW), including single-family houses, multi-family houses, row-houses, block of flats, apartment buildings, hotels, nursery homes, hospitals, commercial buildings and sport centers, the annual space heating demand is lower than the annual energy demand for DHW. The ratio between the annual energy demand for DHW heating and the total annual heating demand typically range from 0.5 to 0.8, and the ratio is to a large extent determined by the type of building and the climate zone (coastal climate, inland climate latitude).

Figure 6 to *Figure 9* show examples of simulated thermal power duration (load) curves for a 128 m² single-family house, a 3240 m² block of flats, a 2400 m² nursery home and a 3600 m² office building design according to the Norwegian passive house standard NS 3700/3701 (Standard Norge 2012, Standard Norge 2013). The simulations have been made for Oslo climate (DOT -20 °C, t_m 5.9 °C). P_{dim} is the gross power heating demand (W/m²) and DOT is the design outdoor temperature (°C). The red continuous curve shows the total power demand duration curve for space heating, heating of ventilation air and DHW heating while the red dotted line indicates the average power demand for DHW heating only. The grey dotted curve shows the energy distribution at different design points. (Stene and Smedegård 2013)

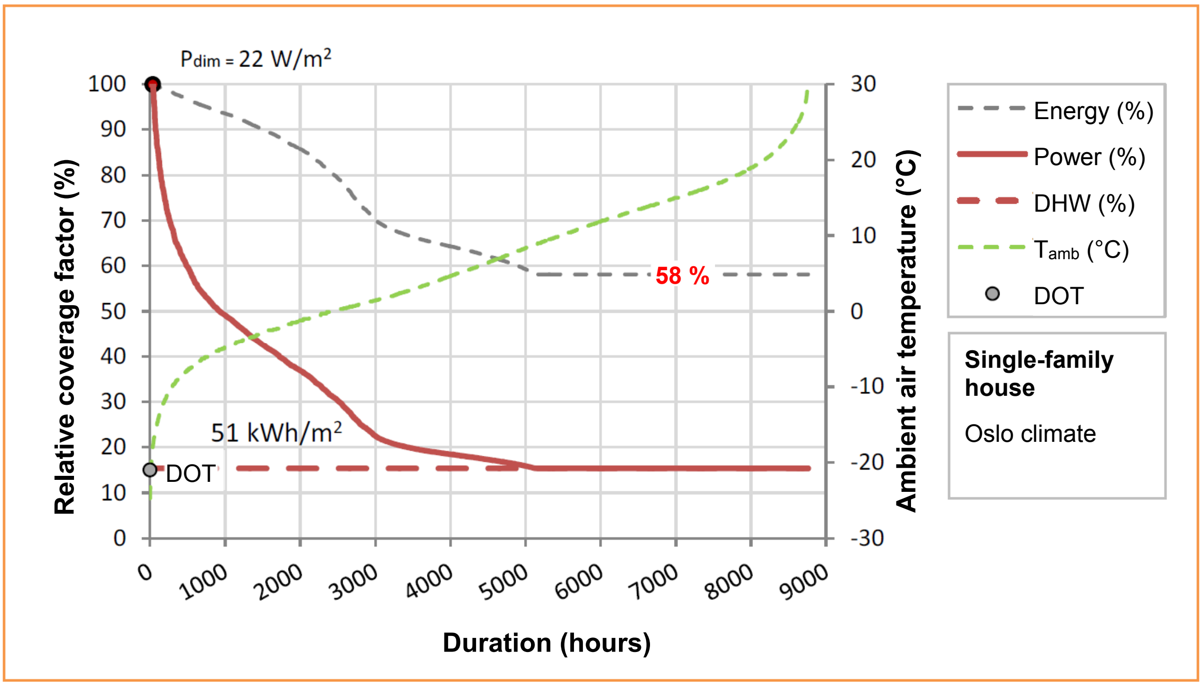


Figure 6 **Example A – calculated thermal power duration curve for a 2-storey 128 m² residential building of passive house standard in Oslo climate. (Stene and Smedegård 2013)**

The gross/net heating demand for the single-family house is approx. *22 / 20 W/m²*, and the specific annual heating demand is approx. *51 kWh/(m²a)*. The DHW heating demand constitutes approx. *58 %* of the total annual heating demand of the building.

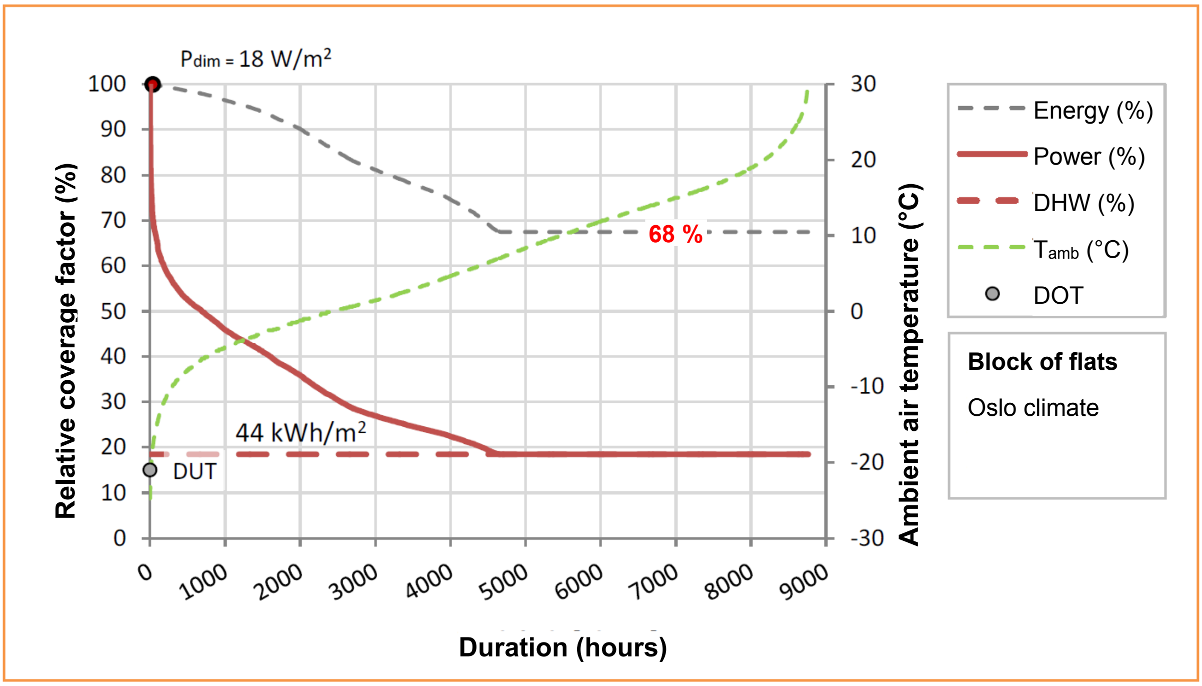


Figure 7 Example B – calculated thermal power duration curve for a 4-storey 2240 m² block of flats of passive house standard in Oslo climate. (Stene and Smedegård 2013)

The gross/net heating demand for the block of flats is approx. *18 / 17 W/m²*, and the specific annual heating demand is approx. *44 kWh/(m²a)*. The DHW heating demand constitutes approx. *68 %* of the total annual heating demand of the building.

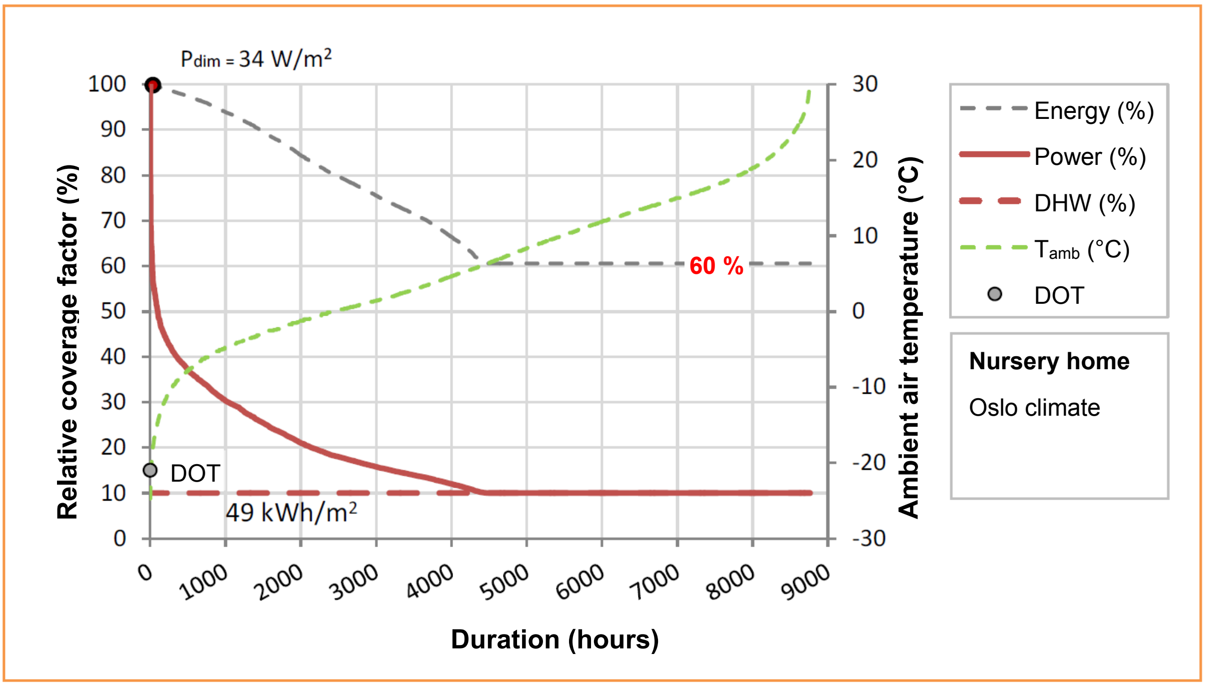


Figure 8 Example C – calculated thermal power duration curve for a 2-storey 2400 m² nursery home of passive house standard in Oslo climate. (Stene and Smedegård 2013)

The gross/net heating demand for the nursery home is approx. *34 / 23 W/m²*, and the specific annual heating demand is approx. *49 kWh/(m²a)*. The DHW heating demand constitutes approx. *60 %* of the total annual heating demand of the building.

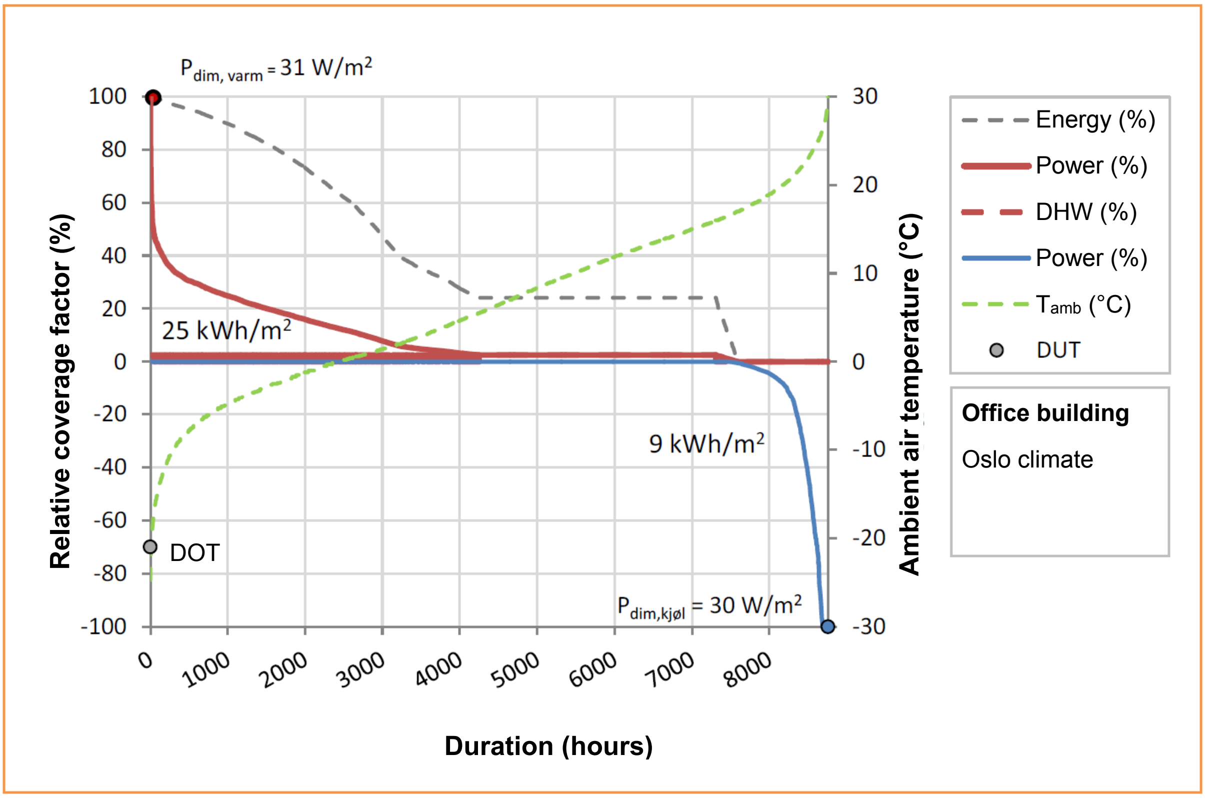


Figure 9 Example D – calculated thermal power duration curves (red-heating, blue-cooling) for a 3-storey 3600 m² office building of passive house standard in Oslo climate. (Stene and Smedegård 2013)

The gross/net heating demand for the office building is approx. *31 / 21 W/m²*, and the specific annual heating demand is approx. *25 kWh/(m²a)*. The maximum power demand and the specific annual energy demand for space cooling is approx. *30 W/m²* and *9 kWh/(m²a)*, respectively. The DHW heating demand is negligible.

Accurate/detailed modelling and simulation of the building is crucial for the design of the thermal energy system as well as for the LCC calculations. Heat pump and chiller systems for heating and cooling of different passive house buildings and ZEBs should be designed in accordance with the power duration curves of the building.

An optimized design will lead to the lowest possible energy consumption through maximum utilization of excess heat as well as maximum SCOP and energy coverage factor for the heat pump system. An optimized design also leads to the lowest possible annual costs (€/a) and the highest possible present value (PV, €) for the heating/cooling system as well as long lifetime for the equipment.

2.2 Market State of Nearly or Net Zero Energy Buildings

Table 4 and 5 show some existing and upcoming Norwegian nZEB/ZEB with heat pumps. Some are completed projects that have been monitored and analysed (*Section 4.1* and *Section 4.2)* and some are upcoming projects (*Section 4.3*). Powerhouse Kjørbo is one of the completed pilot projects in the Norwegian ZEB Centre. It was presented in *the task 3 report for Annex 40 (Stene and Justo-Alonso 2015)*. Kjørbo is an unique office building from 1985 refurbished to plus energy standard and Breeam-Nor Outstanding (eco-classification).

Table 4 **Overview of Norwegian ZEB. HP=heat pump unit, LCS=liquid chiller, space cooling, LCP=liquid chiller, process cooling, SH=space heating, VH=ventilation air heating, DHW=domestic hot water, SC=space cooling, PC=process cooling, BN=Breeam-Nor, m=measured, c=calculated**

	Powerhouse Kjørbo (Nordang 2014)	**GK Miljøhuset (Orvik 2014-2015)**	**Vulkan Energi-sentral (Rohde, Bantle et al. 2015)**	**Scandic Lerkendal Hotel (Aashammer 2015-2016)**
Place	Sandvika	Oslo	Oslo	Trondheim
Bldg. type	Office building	Office building	Several bldgs. incl. office bld. and hotel	Hotel
Bldg. standard and certification	Plus energy bldg. BN "Outstanding"	Passive house (A+) BN "Good"	Various bldgs. incl. passive houses	Passive house Energy class A++
Constructed	1985/2014 (refurb.)	2012	2013	2014
Heated area (m^2)	5,180	13,650	55,000	11,434
Thermal energy demand (kWh/m^{2}a)	SH-VH: 19.1 (m) DHW: 1.9 (m) SC: 1.8 (m)	SH-VH: 17.6 (m) DHW: 3.4 (m) SC: 6.9 (m) PC: 15.8 (m)	SH-DHW: 48.3 (m) SC: 25.3 (m) PC: 15.8 (m) SM: 5.5 (c)	SH-VH: 33.5 (m) DHW: 24.5 (m) SC: 0 (m)
HP function	HP1: SH + VAH HP2: DHW	HP: SH/VH, SM, SC: PC separ. unit	SH, VH, preheating DHW, cooling	SH and SC
Working fluid	HP1: R410A HP2: R407C	R410A	HP1-3: R134a HP4-5: R410A	R410A
Heat source/sink	Bedrock (10)	Ambient air	Bedrock/waste heat	Ambient air
Cooling design	Free cooling (100%)	Liq. chiller (100 %)	HP/LCS/LCP	HP/LCS
Installed power	HP1: 65 kW HP2: 8.5 kW	HP1-2: 520 kW LCS1-2: 500 kW LCP1-2: 25 kW	SH: 1.5 MW SC/PC: 1.3 MW Ice bank-system	SH: 200 kW
Energy coverage factor – HP	HP1: 100 % (m) HP2 100 % (m)	HP1-2: 70 % (m) LCS1-2: 100 % (m) LCP1-2: 100 % (m)	*	80 %
Seasonal COP (SCOP, SPF)	HP1: 3.9 (m) HP2: 2.9 (m)	Tot: 2.3 (m) SH: 2.1 (m) SC: 3.3 (m)	Tot: 1.7-3.4 (m)	SH: 2.2
Heat distribution	Radiators + heater batteries ventilation	Ventilation air only	Small-scale district heating system	Ventilation air
Temp. levels	SH: 50/40 °C VH: 50/25 °C	SH: max. 30 °C SC: min. 10 °C	SH: 50 °C SC/PC: 8/-8 °C	SH: 40 °C
Compressor type	HP1: Scroll HP2: Piston	Scroll (2 x 4)	HP1-3: Screw HP4-5: Scroll	Scroll (x4)
Control methods	HP1: On/off HP2: On/off	On/off	HP1-3: Slide valve HP4-5: On/off	On/off
Accumulator tanks	HP1: 2 x 900 l HP2: 2 x 550 l	DHW: 3 x 400 l	Heating: 5 x 2000 l Cooling: 2 x 1500 l	*
Peak load system	District heating Back- up only	Electro boiler El. heating rods	District heating	District heating

Table 5 Overview of Norwegian ZEB. HP=heat pump unit, LCS=liquid chiller, space cooling, LCP=liquid chiller, process cooling, SH=space heating, VH=ventilation air heating, DHW=domestic hot water, SC=space cooling, PC=process cooling, BN=Breeam-Nor, m=measured, c=calculated.

	Tveita borettslag (Stene and Justo-Alonso 2015)	**Otto Nielsens vei 12E**	**Akuttpsykiatri Østmarka**	**Psykiatriløftet Levanger**
Place	Oslo	Trondheim	Trondheim	Levanger
Bldg. type	Block of flats (x 3)	Office building	Psychiatric nursing home	Psychiatric nursing home
Bldg. standard and certification	Refurbished to TEK10 standard	Passive house (A+) BN "Excellent"	Passive house (A) Green heating label	Passive house (A) Green heating label
Year of construction	1967/2011 (refurb.)	2017	2017	2018
Heated area (m^2)	3 x 16,330	9,100	4,600	2,500
Thermal energy demand (kWh/m^{2}a)	DHW: 36,2 (c) SH: *	SH-VH: 20.2 (c) DHW: 5.0 (c) SC: 11.4 (c) PC: 14.4 (c)	SH-VH: 14.5 (c) DHW: 29.5 (c) SC: 10.0 (c)	SH-VH: 35.2 (c) DHW: 29.5 (c) SC: ? (c)
HP function	HP1: SH HP2: DHW	SH, VH, SM, SC and PC	HP1: SH-VH, SC HP2: DHW	SH-VH, SC, DHW
Working fluid	HP1: R134a HP2: CO$_2$ (R744)	R134a	HP1: R410A HP2: CO$_2$ (R744)	CO$_2$ (R744)
Heat source/sink	Exhaust air (22 °C)	Bedrock (25)	Seawater – indirect	Waste heat (15 °C)
Cooling design	*	Free cooling+chiller	Free cooling+chiller	Chiller operation
Installed power	HP1: 285 kW x 3 HP2: 100 kW x 3	HP: 290 kW in cooling mode (10/15-35 °C)	HP1: 80 kW HP2: 20 kW	SH: 75 kW SC: 40 kW
Energy coverage factor – heat pump	HP1: * HP2 100 % (m)	SH/VH: 100 % (c) DHW: 100 % (c) SC/PC: 100 % (c)	HP1: 95 % HP2: 100 %	SH-VH: 90 % DHW: 100 %
Seasonal COP (SCOP, SPF)	HP1: * HP2: 4.0 (m)	Tot: >4.0 (c)	HP1: 5.0 (c) HP2: 4.0 (c)	SH: 3.4-5.0
Heat distribution	SH: Radiators	Radiators	Small-scale district heating system	SH: Radiators
Temp. levels	SH: 50/40 °C DHW: 73 °C	SH: 60/50 °C SC: 10/15 °C	SH-VH: 45 °C DHW: 70 °C	SH: 50/35 °C
Compressor type	HP1: Scroll HP2: Piston	Piston x 3	HP1: Scroll HP2: Piston	Piston
Control methods	HP1: On/off HP2: On/off	Variable speed drive and on/off	HP1: On/off HP2: On/off	Variable speed drive (VSD)
Accumulator tanks	HP2: 18 x 400 l + 200 l (DHW)	DHW: *	SH-VH: 500 l DHW: 4 x 550 l	DHW: 3 x 400 l
Peak load system	Biogas-fired boiler El. boiler (DHW)	District heating (back-up only)	District heating	Electro boiler

2.3 Market state of heat pumps in Norway

This chapter is based on (Macic and Birkeland 2017), and the figures are based on statistical data from the Norwegian Heat Pump Association (NOVAP). Heat pumps represent a well-established technology in Norway, especially air-to-air heat pumps in residential buildings. *Figure 10* provides an overview of the annual heat pump unit sales rates during the past 22 years. The left axis shows their contribution to renewable energy production.

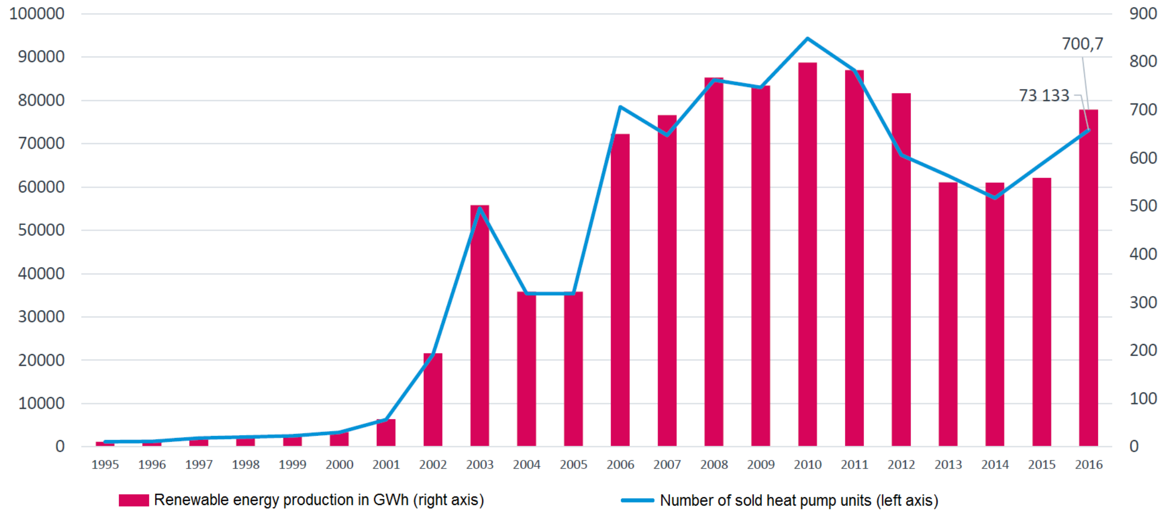


Figure 10 **The Norwegian heat pump market for 1995-2016. The left axis shows the annual sales rates, while the right axis is shows the renewable energy production [GWh/annum]. (Macic and Birkeland 2017)**

The annual heat pump sales in Norway escalated around 2002, and in 2016 there were sold more than 73 000 heat pump units in Norway, contributing to a renewable energy production of roughly 700 GWh. The bulk of the heat pump units are residential air-to-air heat pumps, contributing to 63 % of the energy savings as shown in *Figure 11*. Heat pumps are installed in approx. 700 000-750 000 dwellings, covering 42 % of the estimated potential of 1 660 000 dwellings. The total energy savings by heat pump units are approximately 7 500 GWh.

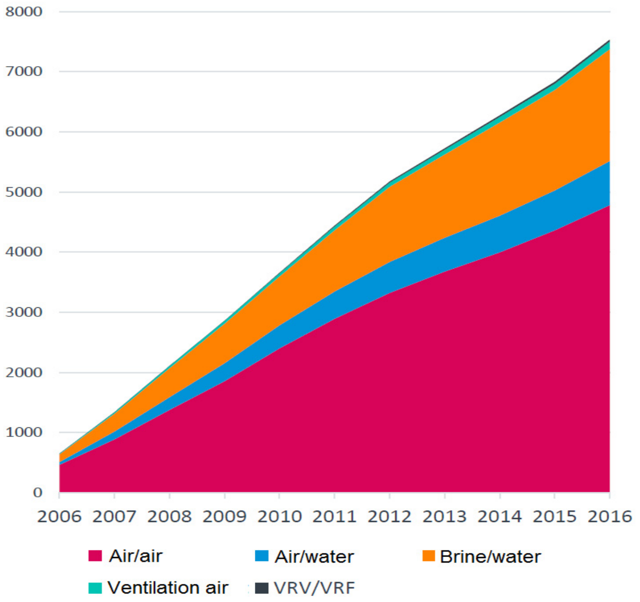


Figure 11 **Renewable energy production/energy saved by heat pumps [GWh] for the period 2006-2016. (Macic and Birkeland 2017)**

Figure 12 illustrates the predicted development of annual heat pump sales in existing dwellings. The number of new heat pump installations peaked in 2011 and have decreased during the past years. This trend is expected to continue, as there will rather be a need for replacing the existing heat pump installations.

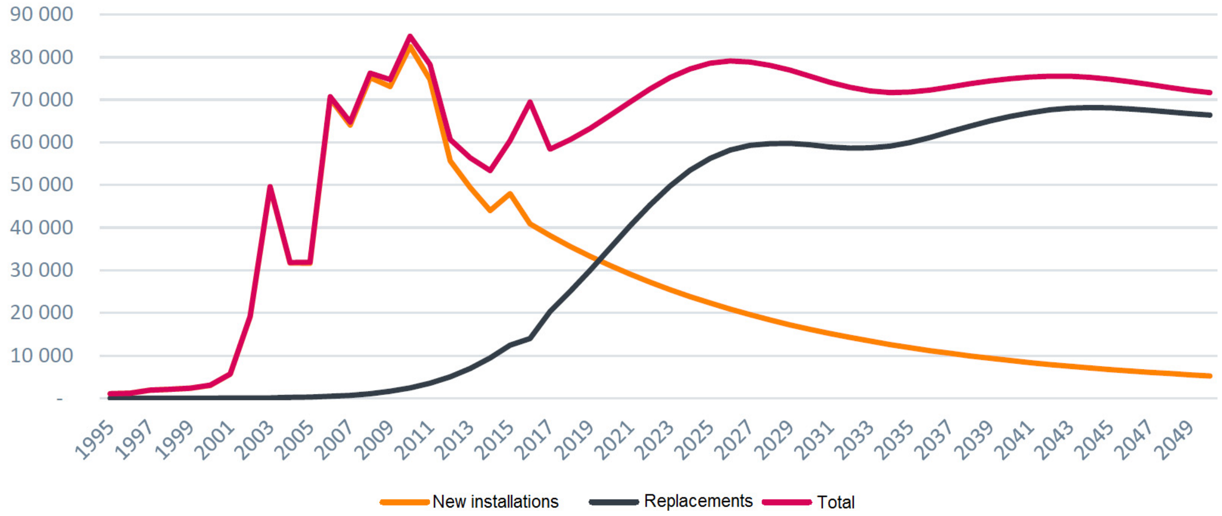


Figure 12 **Annual number of installed heat pumps in existing dwellings, both statistics and future predictions. (Macic and Birkeland 2017)**

Figure 13 outlines the expected total annual sales up until 2020. It is expected an increase of 6 %, compared to 2016.

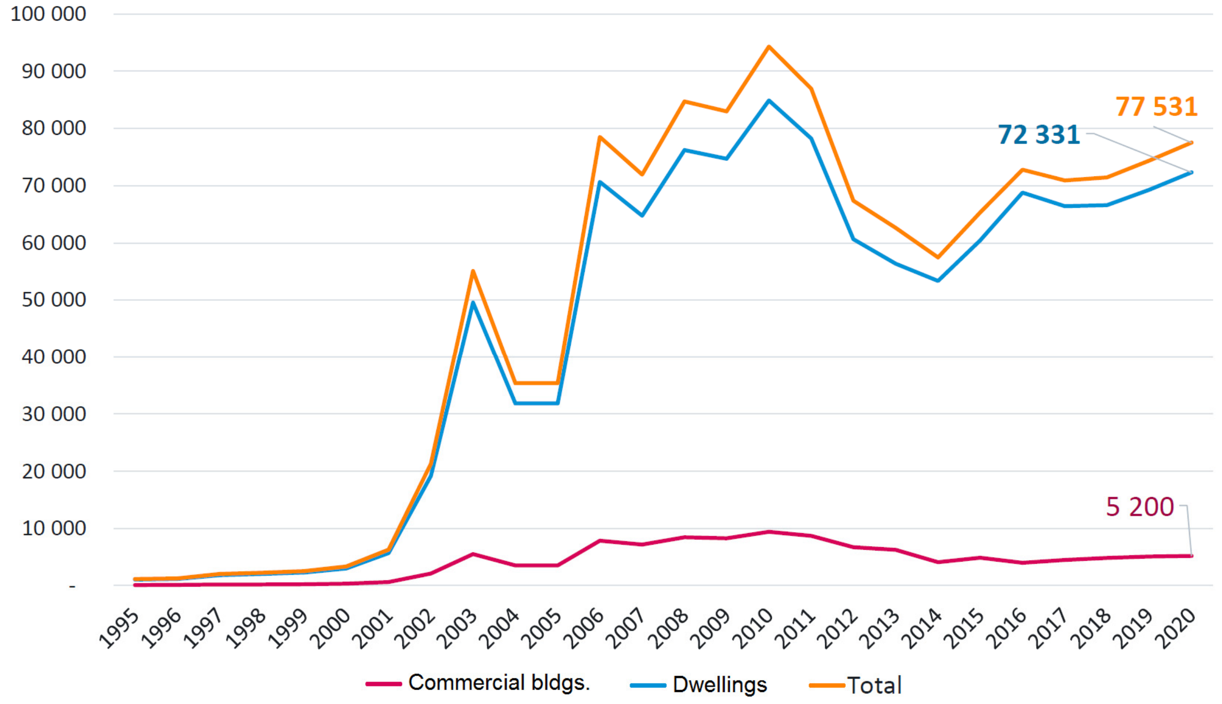


Figure 13 **Expected development of the Norwegian heat pump market. (Macic and Birkeland 2017)**

The market development for the coming years is expected to maintain at a high and stable level, which renders a more predictable development. Business prospects and activity in the building sector are becoming increasingly important as market drivers, temperature variations, energy costs and other external factors at the same time are becoming less significant. 31st December 2016, there were 919 875 operational heat pump units in Norway, and the total number is soon expected to pass 1 million units.

Figure 14 shows the share of the markets for heat pumps. Most of the new heat pumps are installed in existing buildings or they replace existing units. These two cases represent 41% of the renewable production. Non-residential buildings, though they are less, represent 37% of the total renewable production related to heat pumps.

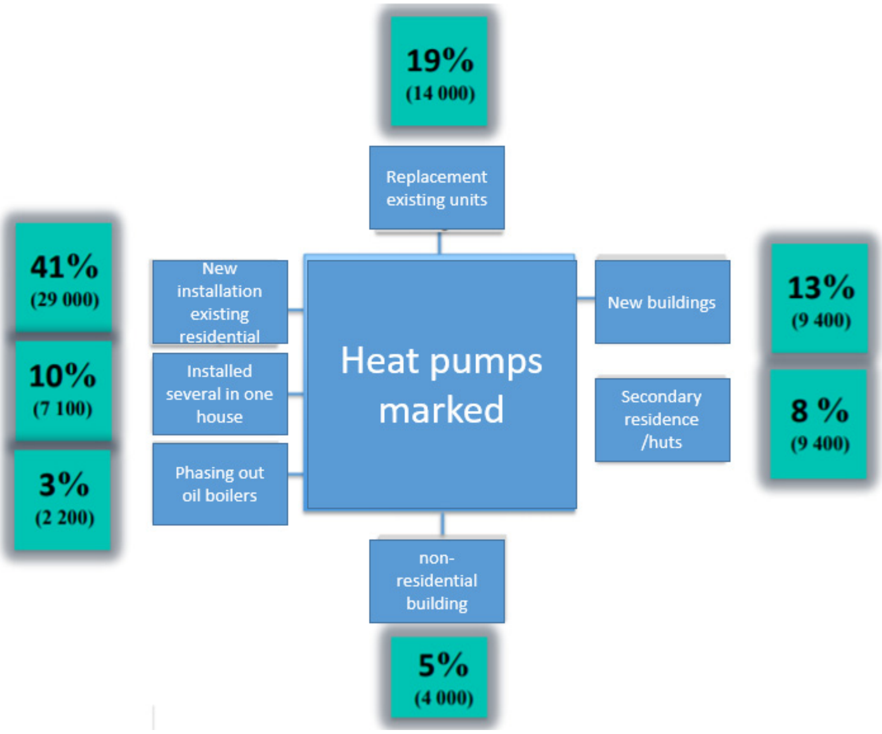


Figure 14 Share of the sales of heat pumps in Norway. (Macic and Birkeland 2017)

To summarize: heat pumps are often the selected technology for accomplishment of ZEB as they are related to lower CO_2 emissions and high efficiency as long as they are correctly designed and operated. We also see this trend in many passive and low-energy houses in Norway, both in new and renovated buildings.

However, and related to the low cost of electricity in Norway, it is still a widespread practice to use electric baseboard radiators or other electric resistance heaters in buildings. According to the new building code (TEK17), the heating demand in new buildings can be covered by direct electric heating systems as long as they are smaller than 1000 m². Direct electric heating is probably the strongest competitor to heat pumps in Norway today.

2.4 R&D Centre, Zero Emission Neighbourhoods in Smart Cities

Centres for Environment-friendly Energy Research (FME) is a national research scheme funded by the Norwegian Research Council. "The Research Centre on Zero Emission Neighbourhoods in Smart Cities" (**FME ZEN**) at NTNU/SINTEF is the successor of the former "The Research Centre on Zero Emission Buildings", (**FME ZEB**) (2009-2016).

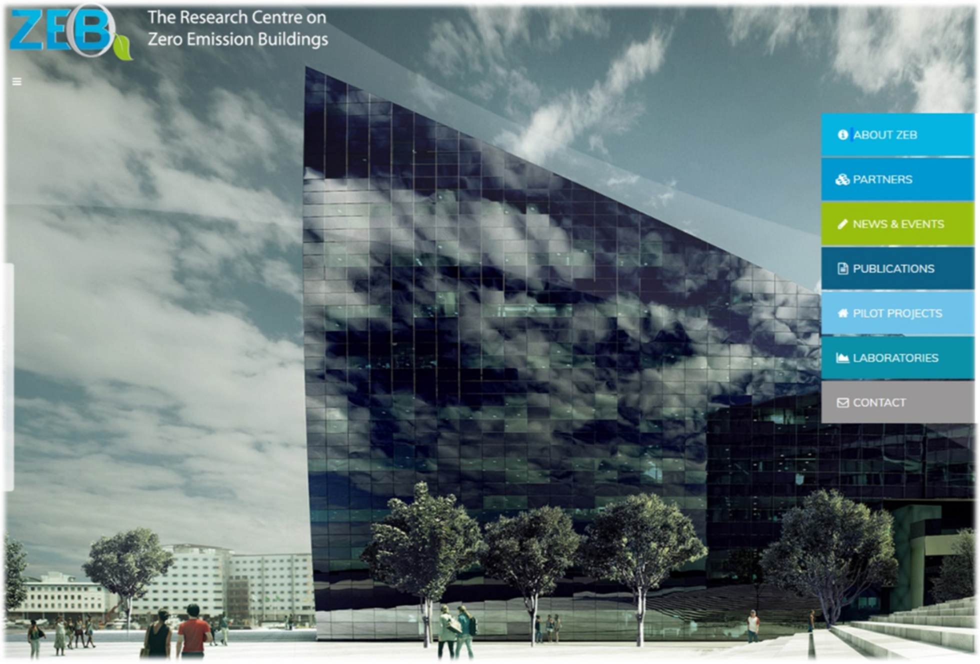
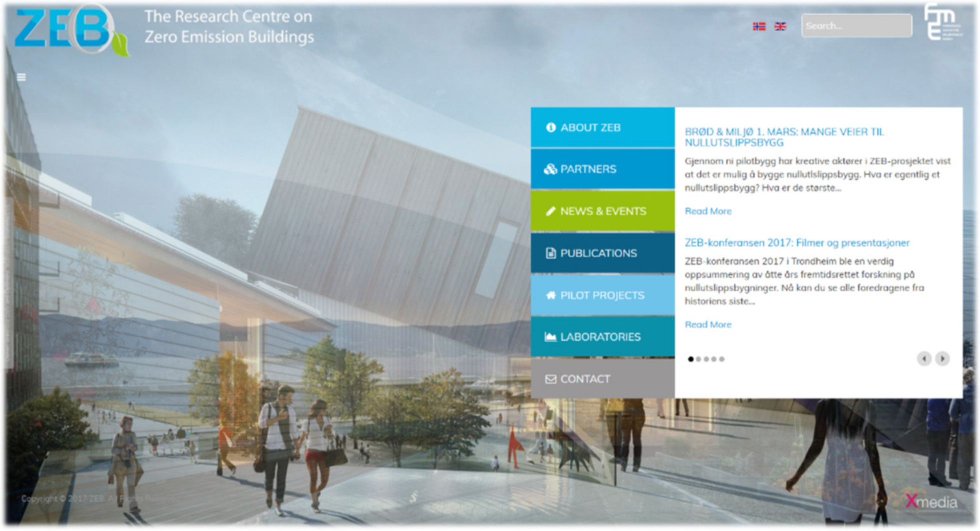


Figure 15 Powerhouse Brattøra, Trondheim – a plus energy office building under construction, January, 2018. (ZEB 2017)

2.4.1 FME ZEB (2009-2016)

For *FME ZEB*, The Norwegian University of Science and Technology, NTNU (www.ntnu.edu) has been the host, while the Norwegian research organisations SINTEF Buildings and Infrastructure and SINTEF Energy (www.sintef.no) have been research partners.



BRØD & MILJØ 1. MARS: MANGE VEIER TIL NULLUTSLIPPSBYGG

Gjennom ni pilotbygg har kreative aktører i ZEB-prosjektet vist at det er mulig å bygge nullutlslippsbygg. Hva er egentlig et nullutslippsbygg? Hva er de største...

ZEB-konferansen 2017: Filmer og presentasjoner

ZEB-konferansen 2017 i Trondheim ble en verdig oppsummering av åtte års fremtidsrettet forskning på nullutslippsbygninger. Nå kan du se alle foredragene fra historiens siste...

Figure 16 Homepage for the FME ZEB, www.zeb.no. (ZEB 2017)

The vision of ZEB has been to reduce and balance to zero the greenhouse gas emissions caused by buildings. This national research centre has placed Norway in the forefront with respect to research, innovation and implementation within the field of energy efficient zero-emission buildings. *The main objective of ZEB* has been to develop competitive products/-solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition (ZEB). The Centre has encompassed both residential and commercial buildings, as well as public buildings.

8 pilot buildings have been developed in ZEB: **1)** Heimdal videregående skole (new high school), **2)** Campus Evenstad (new office building), **3)** Multicomfort Larvik (new single-family house), **4)** Powerhouse Brattørkaia (new office building, to be constructed), **5)** Skarpnes residential development (new detached houses), **6)** Zero Village Bergen (new dwellings homes), **7)** Powerhouse Kjørbo (refurbished office bldg.) and **8)** Visund Haakonsvern, Bergen (new office building), *Figure 17*. *Section 3.1.1* provides a presentation of these pilot projects with the main focus on technical installations incl. HVAC.

Figure 17 Overview of the pilot projects in NTNU-SINTEF FME ZEB. (ZEB 2017)

2.4.2 FME ZEN (2017-2024)

For the new FME research centre, *ZEN*, NTNU is, as for the FME ZEB, the host of the project while SINTEF Buildings and Infrastructure and SINTEF Energy will be the research partners. The start date was *March 2017*, and the total budget for the programme period (2017-2024) is 380 mill. NOK (approx. 40 mill. € or 45 USD).

FME ZEN has *10 public partners* including several municipalities, The Norwegian Construction and Property Management Department (Statsbygg), The Norwegian Water Resources and Energy Directorate (NVE) and The Directorate for Building Quality (DiBK) as well as *21 industry partners* including various manufacturers of building materials, housing cooperatives, energy utilities, architect companies, contractors and consultant companies.

Figure 18 Homepage for the FME ZEN, http://fmezen.no/ (ZEN 2018)

The main objective of ZEN is to develop knowledge, competitive products and solutions that will lead to realization of sustainable neighbourhoods (groups of buildings) that have zero emissions of greenhouse gases related to their production, operation and transformation.

- By looking at several buildings at the same time, synergies can be accomplished between the power/energy demand profiles of the individual buildings (incl. ZEB). When one or several buildings have a surplus of thermal and/or electric power/energy, other buildings can utilize the available energy.
- Not all buildings can be built/refurbished into zero emission buildings, e.g. protected/listed buildings or buildings on a challenging site
- Optimizing at the neighbourhood scale can reduce the strain on the electric grid (synergies between buildings, PV, charging stations for electrical vehicles, etc.)
- The neighbourhood dimension is large enough to have an impact, but small enough to allow demonstration of technologies and interaction with users.

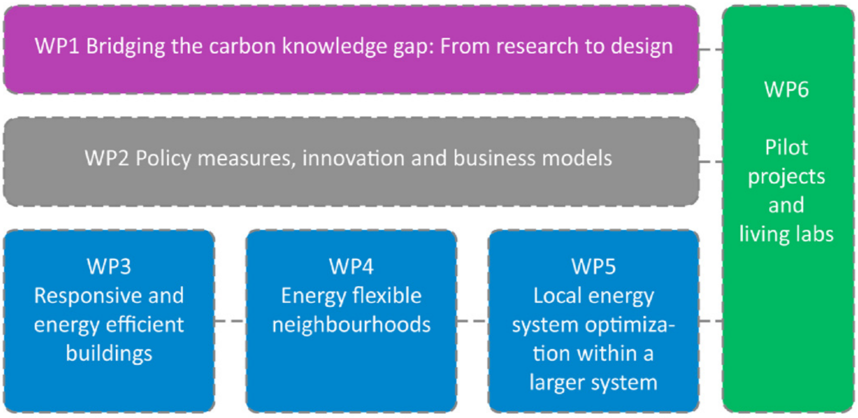


Figure 19 Working packages for the NTNU-SINTEF FME ZEN, 2017-2024. (ZEN 2018)

2.5 The FutureBuilt Programme (2010-2020)

FutureBuilt is a ten-year programme with an aim of developing 50 pilot projects including individual buildings and city areas. FutureBuilt runs from 2010 to 2020, and the pilot projects will be carried out throughout this period.

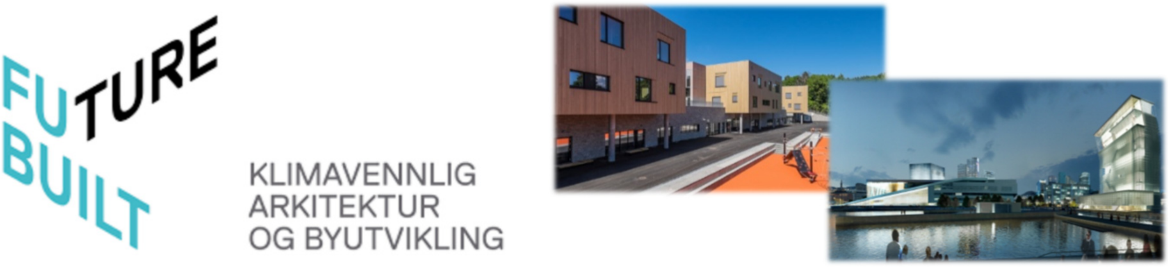


Figure 20 Homepage for the FutureBuilt: http://www.futurebuilt.no/English (photos: Future Built)

The pilot projects are set to reduce greenhouse gas emissions from transport, energy and material consumption by at least 50 %. Pilot building will involve high quality architecture and contribute to a better environment for urban dwellers. Many of the buildings are and will be passive houses and near Zero Energy Buildings (nZEB).

By January 2018 the FutureBuilt includes 45 pilot projects dealing with e.g.:

- Urban areas
- Schools
- Kindergartens
- Office buildings
- Cultural centres
- Sport centres
- Housing projects/developments

FutureBuilt is a collaboration between 10 partners including the municipal authorities of Oslo, Bærum, Asker and Drammen, the Ministry of Local Government and Modernisation, the Norwegian State Housing Bank (Husbanken), Enova SF (Norwegian energy national fund), the Directorate of Building Quality (DiBK), the Green Building Alliance (Grønn Byggallianse) and the National Association of Norwegian Architects.

The nZEB buildings belonging to the FutureBuilt with relevant technologies including HVAC systems are presented in *Section 3.1.2*.

3 HVAC Technologies Applied in nZEB

3.1 HVAC System (active) Technologies on the National Level

This chapter presents typical system configurations in Norwegian nZEB/ZEB and experience with different technology options. In Norway, there are no standard solutions for nZEB/ZEB. The R&D programme for dedicated developments for ZEB are presented in *Section 2.4*.

3.1.1 The Research Programme on Zero Emission Buildings – Pilot projects

Table 6 provides an overview of the 8 completed and 1 ongoing pilot projects in the Norwegian R&D programme on Zero Emission Buildings (FME ZEB, NTNU/SINTEF).

Table 6 Pilot projects in the Norwegian R&D program on Zero Emission Buildings (NTNU/SINTEF).

ZEB PILOT PROJECT	TYPE OF BUILDING	ZEB LEVEL	LOCATION
Heimdal VGS	New school and sports hall	ZEB-O20%M	Trondheim
Campus Evenstad	New educational and office bldg.	ZEB-COM	Hedemark
Multicomfort	New single-family house	ZEB-OM	Larvik
Powerhouse Brattøra	New office building – to be constructed	ZEB-OM÷EQ	Trondheim
Skarpnes	Residential development area	ZEB-O	Arendal
Zero Village Bergen	800 new residences	ZEB-O	Bergen
Powerhouse Kjørbo	Renovated office building	ZEB-OM÷EQ	Sandvika
Visund Haakonsvern	New office building	ZEB-O-EQ	Bergen
Living Laboratory	New single-family house	ZEB-OM	Trondheim

These 9 pilot buildings are described below. In summary; 8 out of 9 have installed heat pumps to cover the largest share of the heating demands. Most of the systems have or are projected to have low temperature distribution systems and balanced mechanical ventilation. Regarding electricity production PV and combined heat and power are the chosen solutions.

1) Heimdal Videregående Skole – to be completed 2018

- The building
    - New high school and sports hall – separate buildings
    - Heated area: 17,500 m^2 + 7,100 m^2 = 24,600 m^2
- Level of ambition
    - ZEB-O20%M
    - Passive house standard for all components according to NS 3701
    - Energy Performance Contracting for energy generation and energy saving
- Building envelope
    - Low U-values, low average thermal bridge value
    - Extremely low air leakage rate (0.2-0.3 h^{-1} at 50 Pa pressure difference)
    - Indoor exposed concrete as thermal energy storage – reduces demands
    - Solar shading – windows with electrochromic glass (first building in Norway)
- Building materials
    - Low-carbon concrete
    - Indoor low-emitting materials to reduce ventilation demand – EPD

- Lighting system
    - Maximum utilization of daylight
    - Energy efficient lighting systems (LED technology)
- Ventilation system
    - Several decentralized air handling units (AHU) with short ventilation ducts and low pressure loss – ultra-low SFP systems (0.5-0.7 kW/m^3/s)
    - High-efficiency heat recovery – rotary wheel units (85-87 %)
    - Displacement ventilation for excellent indoor climate and minimum energy use
- Thermal energy supply system
    - Different sources, focus on renewable energy
    - Combined Heat and Power plant (CHP) with biogas fuel for domestic hot water (DHW) heating – possible heat export to swimming pool
    - Grey water heat pump for preheating of DHW – 50 % coverage factor
- Electricity generation
    - Combined Heat and Power plant (CHP) with biogas fuel for electricity generation – possible electricity export to adjacent buildings
    - PV – high-efficiency solar cells at the roof-top and possibly parts of the façade
- Other technologies to minimize energy consumption
    - Advanced BEMS (Building Energy Management System)
        - Extensive electric and thermal power/energy measurements
- Calculated/estimated total net energy demand – thermal + electric
    - Total 24,700 m^2 1,285,000 kWh/a 52 kWh/(m^{2}a)
- Thermal energy production
    - CHP 460,000 kWh/a (65 %) + 520,000 kWh/a export
    - Heat pump 195,000 kWh/a (30 %)
    - District heating 40,000 kWh/a (5 %)
- Electricity generation
    - CHP 630,000 kWh/a (85 %)
    - PV 120,000 kWh/a (15 %)

Figure 21 ZEB pilot building – Heimdal videregående skole, high school and sports hall (photos: Skanska Norway).

2) Campus Evenstad (completed 2016)

- The building
  - New educational building and offices
  - Heated area: 1,100 m^2
- Level of ambition
  - ZEB-COM – first building in Norway
- Building envelope
  - Low U-values, low average thermal bridge value
  - Very compact geometry
  - Low air leakage rate (0.5 h^{-1} at 50 Pa pressure difference)
- Building materials
  - Solid wood construction
  - Low carbon concrete for the base plate
  - Tree fibre insulation
  - Indoor low-emitting materials to reduce ventilation demand
- Lighting system
  - Maximum utilization of daylight
  - Energy efficient lighting systems (LED technology)
- Ventilation system
  - Hybrid ventilation system
  - High-efficiency heat recovery system
- Thermal energy supply – different sources, focus on renewable energy
  - Combined Heat and Power plant (CHP) with biomass for heating
  - Pellet boiler (peak load) + 10.000 litres accumulation tank
  - Electro boiler
- Electricity generation
  - Combined Heat and Power plant (CHP) with biomass fuel for el. generation with maximum 70 % total efficiency – 20 % to electricity and 50 % to heat
  - PV – high-efficiency solar cells at the roof-top and possibly parts of the façade
- Other technologies to minimize energy consumption
  - Advanced BEMS (Building Energy Management System)
    - Extensive electric and thermal power/energy measurements
- Calculated/estimated total net heating demand – thermal + electric

Heating	1,100 m^2	46,000 kWh/a	46 kWh/(m^2a)
Total	1,100 m^2	85,000 kWh/a	77 kWh/(m^2a)

- Thermal energy production

CHP	500,000 kWh/a
Pellet boiler	Peak load/back-up
Electro boiler	Peak load/back-up

- Electricity generation

CHP	200,000 kWh/a
PV	64,000 kWh/a

Figure 22 ZEB pilot building – Campus Evenstad, educational bldg. and offices (photos: Statsbygg).

3) ZEB Multicomfort Larvik – completed 2014

- The building
    - New single-family house + swimming pool – test facility with extensive options
    - Heated area: 200 m²
- Level of ambition
    - ZEB-OM
    - Passive house standard for all components according to NS 3700
- Building envelope
    - Low U-values, low average thermal bridge value
    - Low air leakage rate
    - Indoor exposed concrete as thermal energy storage – reduces demands
    - Efficient solar shading systems
- Building materials
    - Low-carbon construction materials (wood, low-carbon concrete etc.)
    - Indoor low-emitting materials to reduce ventilation demand
- Lighting system
    - Utilization of daylight
    - Energy efficient lighting systems (LED technology)
    - Demand control of lighting system
- Ventilation system
    - Compact Ventilation and Heating Device (CVHD)
        - Heat exchanger vs. borehole – preheating and free cooling
    - High-efficiency heat recovery – plate heat exchanger (85 %)
    - Low SPF – corrugated plastic ducts with smooth surface
- Thermal energy supply – different sources, focus on renewable energy
    - 3 kW (low-capacity) brine-to-water heat pump – space and DHW heating
        - 100 m vertical borehole heat exchanger or
        - 150 horizontal ground-heat exchanger

  - Exhaust air heat pump integrated in CVHD – DHW and air heating
  - Solar heaters 16 m² – space and DHW heating
  - Low-temperature heat distribution – floor heating and large radiators

- Electricity generation
  - PV – 150 m² high-efficiency solar cells at the roof-top, PV roof-angle 17 °
  - Battery pack – 600 Ah
  - Excess electricity exported to the electricity grid

- Other technologies to reduce energy consumption
  - Grey water heat recovery
  - Hot fill system for washing machine and dishwashing machine
  - Advanced BEMS (Building Energy Management System)
    - Extensive electric and thermal power/energy measurements

- Calculated/estimated total net energy demand – thermal + electric
  - 16,000 kWh/a 80 kWh/(m²a)

- Thermal energy production
  - Heat pumps 4,800 kWh/a
  - Solar heater 1,200 kWh/a
  - Grey water 3,000 kWh/a

- Electricity generation
  - PV 19,000 kWh/a

Figure 23 ZEB pilot building – ZEB Multicomfort Larvik, new single-family house (photos: ZEB Centre NTNU-SINTEF).

4) Powerhouse Brattørkaia – design phase, to be constructed (2017/19)

- The building
    - New office building
    - Heated area: 14,000 m²
- Level of ambition
    - ZEB-COM÷EQ
    - Passive house standard for all components according to NS 3701
    - Breeam-Nor Outstanding
- Building envelope
    - Low U-values, low average thermal bridge value
    - Low air leakage rate
    - Indoor exposed concrete as thermal energy storage – reduces demands
    - Efficient solar shading systems
- Building materials
    - Low-carbon construction materials (wood, low-carbon concrete etc.)
    - Indoor low-emitting materials
- Lighting system
    - Utilization of daylight
    - Energy efficient lighting systems (LED technology) – demand control
- Ventilation system
    - System with decentralized air handling units (AHU), ultra-low SFP
        - Return air by overflow from cell offices via landscape and stairways
        - Demand control VAV system
        - High-efficiency heat recovery – by-passed when not in use
    - Air distribution via raised installation floor
    - Displacement ventilation for excellent indoor climate and minimum energy use
- Thermal energy supply – different sources, focus on renewable energy
    - 140 kW seawater heat pump system – space and DHW heating
    - Seawater – preheating of ventilation air (direct heat exchange)
    - Seawater – free cooling (100 % coverage)
    - Low-temperature heat distribution – floor heating and large radiators
- Electricity generation
    - PV – 3000 m² high-efficiency solar cells – roof-angle 26 °
    - Excess electricity exported to the electricity grid
- Other technologies to reduce energy consumption
    - Advanced BEMS (Building Energy Management System)
        - Extensive electric and thermal power/energy measurements
- Calculated/estimated total net energy demand – thermal + electric
    - 650,000 kWh/a 46 kWh/(m²a)
- Thermal energy production
    - Heat pump 185,000 kWh/a – 100 % space heating, 50 % DHW heating
    - Free cooling?
- Electricity generation
    - PV 500,000 kWh/a – considerable export of electricity

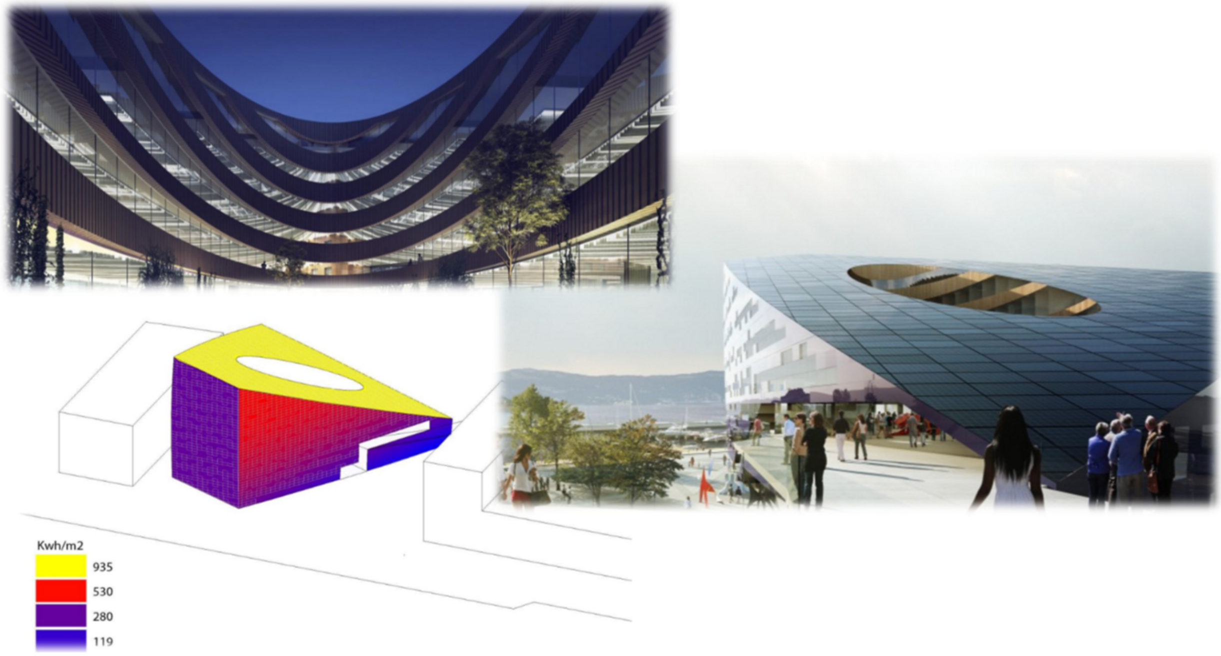


Figure 24 ZEB pilot building – Powerhouse Brattøra, new office building (photos: Snøhetta and MIR).

5) Skarpnes residential development area (first residences 2015 – under development)

- The buildings
  - Zero energy homes – 17 single-family houses, 21 apartments in low-rise buildings and 3 undetached homes (row houses)
  - Total heated area: 4,100 m²
- Level of ambition
  - ZEB-O
  - Passive house standard for all components according to NS 3700
- Building envelope
  - Low U-values, low average thermal bridge value and low air leakage rate
  - Concrete in interior walls and ceiling
  - Automatic solar shading systems
- Building materials
  - Low-carbon construction materials (concrete and wooden constructions)
  - Indoor low-emitting materials to reduce ventilation demand
- Lighting system
  - Utilization of daylight
  - Energy efficient lighting systems (LED technology)
- Ventilation system
  - High-efficiency air handling units (AHU) – low SFP design for AHU and ducts
  - High-efficiency heat recovery (90 %) – plate heat exchanger
  - Preheating and cooling of ventilation air from boreholes (renewable energy)
- Thermal energy supply – different sources, focus on renewable energy
  - Brine-to-water heat pumps – space and DHW heating
    - 100 m vertical borehole heat exchanger for single-fam. houses
    - Common boreholes for the apartment buildings

  - No solar heaters – PV + GS heat pump regarded more profitable
  - No grey water heat recovery – too much maintenance
  - Low-temperature heat distribution – floor heating and large radiators
  - Cooling with cross ventilation
- Electricity generation
  - PV – high-efficiency solar cells at the roof-top and vertical façades
  - No battery pack – export to the electricity grid (April-September)
- Other technologies to reduce energy consumption
  - Advanced BEMS (Building Energy Management System)
  - Hot fill system for washing machine and dishwashing machine
- Calculated/estimated total net energy demand – thermal + electric
  - 330,000 kWh/a   80 kWh/(m^{2}a)
- Thermal energy production
  - Heat pumps?
- Electricity generation
  - PV 6,700 kWh/a per residence

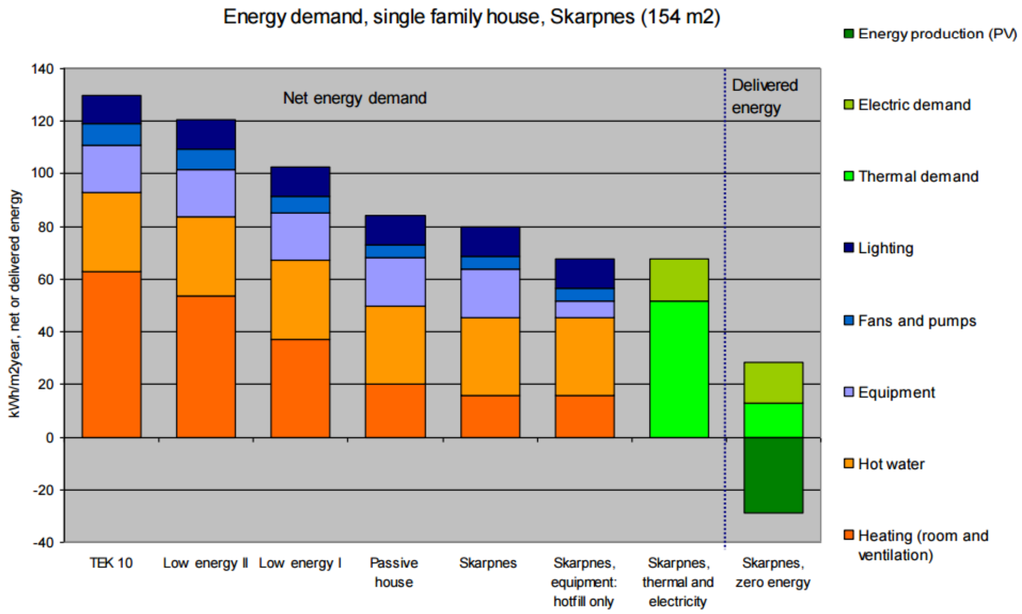


Figure 25 The Skarpnes residential development area (photos and illustrations: Skanska Norway).

6) Zero Village Bergen (early stage – under development)

- The buildings
    - Zero energy homes – 800 apartments in low-rise buildings
    - Total heated area: 80,000-100,000 m²
- Level of ambition
    - Average level ZEB-O and some ZEB-OM and ZEB-COM
    - Passive house standard for all components according to NS 3700

Figure 26 Zero Village Bergen – residential development area (photos: ZEN Centre NTNU-SINTEF).

7) Powerhouse Kjørbo (refurbished office building – 2014)

The renovated plus energy building is presented in *Chapter 4.1.3*.

- Level of ambition
    - ZEB-COM÷EQ
    - Passive house standard for all components according to NS 3701
    - Breeam-Nor Outstanding

8) Visund Haakonsvern, Bergen – completed 2016

- The building
    - New office building
    - Heated area: 2,200 m²
- Level of ambition
    - ZEB-O÷EQ
    - Passive house standard for all components according to NS 3701

- Building envelope
    - Ultra-compact building shape (i.e. very low area/volume ratio)
    - Low U-values, low average thermal bridge value
    - Low air leakage rate
    - Indoor exposed concrete and exposed PCM panels as thermal energy storage
    - Efficient automatic solar shading systems
- Building materials
    - Low-carbon construction materials
    - Indoor low-emitting materials
- Lighting system
    - Maximum utilization of daylight
    - Energy efficient lighting systems (LED technology) – demand control
- Ventilation system
    - High-efficiency air handling units (AHU), ultra-low SFP
        - Demand control VAV system
    - High-efficiency heat recovery (85 %)
    - Night time cross ventilation to minimize cooling loads
    - Active air supply diffusers – heated ventilation air, no radiator system
- Thermal energy supply – different sources, focus on renewable energy
    - Seawater heat pump system – space and DHW heating
    - Seawater – free cooling (100 % coverage)
    - Heating by ventilation air only – no heat distribution system (radiators etc.)
- Electricity generation
    - PV – 310 m² high-efficiency solar cells on the rooftop
    - Excess electricity exported to the electricity grid
- Other technologies to reduce energy consumption
    - Advanced BEMS (Building Energy Management System)
- Calculated/estimated total net energy demand – thermal + electric
    - 120,000 kWh/a   54 kWh/(m²a)
    - 38,000 kWh/a   17 kWh/(m²a) – measured annual net energy demand (2016)
- Thermal energy production
    - Heat pump? No monitoring data available
- Electricity generation
    - PV   55,000 kWh/a

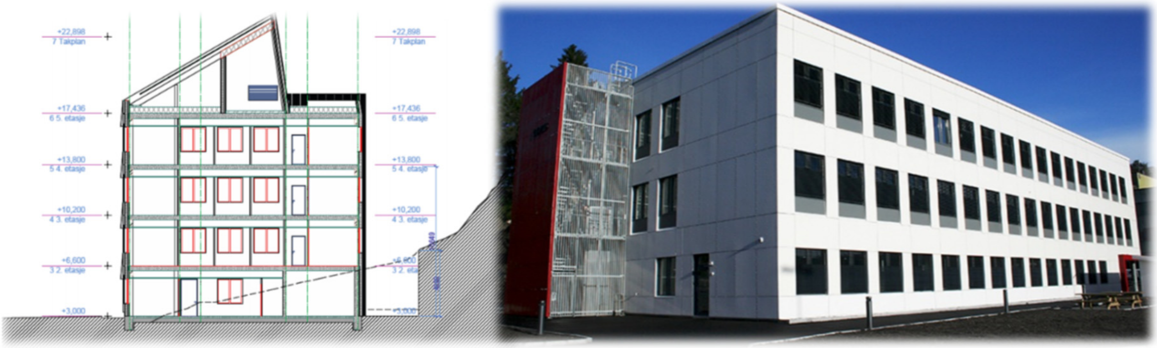


Figure 27 Visund, Haakonsvern, office building (photos: Forsvarsbygg and Link Arkitektur).

9) Living lab – completed 2015

The Living Laboratory (Lab) is presented in Section 4.2, "Completed nZEB field monitoring".

3.1.2 The FutureBuilt programme (2010-2020)

The minimum level in the Norwegian FutureBuilt programme (2010-2020, *Section 2.5*) is passive house standard (NS 3701). Some of the buildings are **nZEB** or **plus energy bldgs.** since they have considerable on-site generation of thermal and electric (PV) energy.

Frydenhaug skole

- nZEB – school incl. sport centre – 5,170 m² – 2014
- Heating, DHW
  - Ground source heat pump
  - Solar heaters – 150 m²
  - Electro boiler – peak load

Photo: Svanhild Blakstad/Byggeindustrien

Brynseng skole

- nZEB – school – 9,800 m² – under construction
- PV 1100 m² – building integrated
  - 135,000 kWh/a – covers 25 % of el. demand
- Heating, DHW
  - Ground source heat pump – base load (90 %)
  - Electro boiler – peak load

Photo: Lauluten, FutureBuilt

Gullhaug Torg 2A

- nZEB – 16 floor office building – under construction
- PV – building integrated
- Ventilation system
  - Natural and hybrid
- Heating, DHW, cooling
  - Ground source heat pump – base load
    - Heating/cooling distribution floor/walls

Illustration: Snøhetta

Kilden barnehage

- Plus energy building – kindergarten – under construction
- Breeam-Nor certification
- PV – roof-mounted, optimum angle – 70,000 kWh/a
- Ventilation system
  - Hybrid
  - Preheating/-cooling of air via concrete culvert
- Heating, DHW, cooling
  - Ground source heat pump – base load

Illustration: Link Arkitektur

Kringsjå studentby

Photo: Lauluten, FutureBuilt

- nZEB – block of flats for students – completed 2018
- 11,715 m² heated area
- PV – roof-mounted
- Heating, DHW
    - Ground source heat pump – base load
    - Electro boiler – peak load

OsloSolar

Illustration: Entra ASA

- Plus energy building – office bldg. – completed 2020
- Breeam-Nor Outstanding (highest level)
- PV – 8300 m² on slanting roof towards south
- Heating
    - Air heating with "Solar walls" (solar heating syst.)

The **passive house projects** (cf. NS 3701) in FutureBuilt include:

Bellonahuset	office building	3,100 m²	2010
Fjell barnehage	kindergarten	755 m²	2010
Papirbedden 2-3	office buildings	19,000 m²	2012
Østensjøveien	office building	13,500 m²	2013
Bjørnsletta skole	school	8,200 m²	2014
Marienlyst skole	school	6,450 m²	2014
Veitvedt skole	school	9,930 m²	2015
Dechmanske hovedbibliotek	library	19,260 m²	2018
Munch-museet	museum	22,100 m²	2020
New National museum for art	museum	51,900 m²	2019

The selection/design of the HVAC system can be summarised as follows:

- **Ventilation**
    - Decentralised air handling units (AHA)
    - Natural and/or hybrid ventilation
    - Displacement ventilation
    - Air supply via floor ducts – thermal mass due to concrete
- **Heating base load – cooling**
    - Ground-source heat pump (base load)
        - Free cooling from boreholes + liquid chiller operation
    - Seawater heat pump (base load)
        - Free cooling from seawater + liquid chiller operation

  - Solar heaters – building integrated or roof-mounted
  - District heating
  - Waste heat from industry (uncommon)

- **Heating – peak load**
  - Electro boiler
  - District heating

- **Heat distribution systems**
  - Low-temperature radiators
  - Low-temperature floor heating
  - Thermally Active Building Systems (TABS)
  - Heating of ventilation air – no heat distribution system

Figure 28 shows an overview of important factors to achieve eco-friendly and energy efficient buildings including nZEB and ZEB.

Diagram: Andreas Eggertsen

Figure 28 Important elements for an eco-friendly and energy efficient building. Factors related to energy use incl. HVAC systems are market with red circles. (Andresen 2015)

Selected HVAC technologies in Norwegian nZEB, ZEB and plus energy bldgs. are summarized in Table 7.

.

Table 7 Overview of selected HVAC technologies in Norwegian nZEB, ZEB and plus energy bldgs.

HEAT PUMPS	**Advantages**	**Disadvantages**
Heat pumps	Renewable energy Heating/cooling in one device May utilize local electricity (PV)	Costs
Natural fluids (R744, R717, R290)	Zero GWP, 100 % eco-friendly Increased SCOP	Costs Toxicity and flammability
High-quality comp. – VSD compressors, electronic expansion valves etc.	Increased SCOP Superior controllability	Costs
CO$_2$ DHW heat pumps	60-90 °C DHW – no reheating High SCOP Independent of heating system	Costs
Grey water heat pumps	Utilize available heat source High temperature heat source	Operational problems Maintenance costs
Exhaust air heat pumps (CVHD)	Utilizes local heat source	Low heating capacity
Seawater, ground water and rock	Provides free cooling Minimum energy use for cooling	Costs Maintenance
THERMAL ENERGY SYSTEMS	**Advantages**	**Disadvantages**
Solar heaters	Thermal solar energy	Costs vs. PV costs
PVT panels	Less roof area	
Grey water heat recovery	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	Demanding 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 system etc.
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 units	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?
PVT panel – photovoltaic + thermal	Reduced roof area requirement	Higher costs
Combined heat and power (CHP)	Local renewable el. generation	Costs, long pay-back time

3.2 Design of the HVAC System Technology

3.2.1 Design Methods for nZEB Technologies

Previous Norwegian standards for energy design focused mainly on the building envelope and did not focus in detail about the energy supply and HVAC system. The same is the case for the Norwegian simulation tool SIMIEN, which is applied both for evaluation of building codes, energy labelling, calculation of power and energy demands and validation of indoor climate. Due to the advanced building envelope in passive houses and nZEBs, the technical installations including heating and cooling systems, should be on the same technical level in order to minimize energy consumption.

SN/TS 3031:2016 *Energy performance of buildings – Calculation of energy needs and energy supply* is a supplement to NS 3031:2014 and provides a common tool for the industry for designing technical plants and energy supply with the same accuracy as for solutions regarding the building envelope. The calculation method considers interaction between the building envelope and technical installations for heating, cooling and energy production. The methods in this standard can be used for documentation regarding nZEB and plus-houses. (Standard Norge 2017) The standard may however be subject to change based on ISO 52000-1:2017 and the revised NS-EN 15265.

More and more Norwegian consultants and constructors are now turning towards more advanced simulation tools, such as IDA ICE (IDA ICE 2017). This is a dynamic multi-zone building simulation software which allows the user to introduce a CAD model or IFC-file and use it as a base for the simulation. The user can introduce the information available regarding walls, thermal bridges and thermal solutions. The more detailed the input data, the higher the level of details in the simulation. The application of IDA ICE requires more time for achieving relevant results but is considered a very powerful tool when simulating and optimizing high-performance ZEBs with advanced energy solutions.

The Research Centre on Zero Emission Buildings developed a tool for energy system analysis and cost optimality for the early design of ZEB (Sartori, Løtveit et al. 2017). The current implementation is based on post-processing hour-based simulation results from the software IDA ICE, and provides the opportunity to utilize a more detailed energy system analysis and cost optimality than current software. Supplementary tools include COP curve fitting for heat pumps, optimal sizing of solar thermal collectors and analysis of global cost (investment, operation and maintenance). Also, within the Centre a more detailed tool based on Carnot/Simulink was developed and report on the Task 2 report (Justo Alonso, Stene et al. 2015) was developed to optimize controls and heat pump choice.

At the time of the writing, there was no accepted or public definition of nZEB in Norway.

3.3 "Smart" Technology Application in Buildings

The Norwegian Water Resources and Energy Directorate (NVE) is responsible for the introduction of Smart metering in Norway. In their website (NVE 2017) it is stated that all electricity consumers will receive smart meters by 1 January 2019. The distribution system operator (DSO) will have the responsibility for installing smart meters, and many DSOs have started this task already before the end of 2015. The goal of smart metering is to provide consumers with better information about their electricity consumption and prices and facilitate opportunities for new energy related services. AMS will enable to implement active demand response (ADM) strategies (Ellinggard, Hallenstvedt et al. 2015, Ellinggard and Krogsrud 2015).

In addition, in Norway, Elhub is being developed with the goal to modernise the power industry. NVE has mandated Statnett the development this IT solution for information exchange between actors in the power market. In addition, Elhub will enable the use of AMS by means of more efficient communication and data management. Elhub will be implemented by 23 October 2017. Elhub is expected to lead to a more efficient organisation of the power market. This can enable clearer split between monopoly regulated companies and competitive retailers. The use of smart metering is expected to increase market competition and innovation.

The expected result of using AMS is an hourly basis collection of metering values (that may be reduced to every 15 minutes), and a fairer basis for billing consumers. The installed meters will communicate the metering point and the DSO. Based such communication the consumer can receive “time-of-use information about consumption and prices”. This is expected to enable consumers to use electricity more efficiently.

Among the main Norwegian motivations to perform AMS for the heating loads is the power in the distribution grid. The overall electricity demand is expected to increase and more decentralized electricity production will have to be installed unless the situation is improved. Flexible operation of the heat pump, storage, etc. could be used to reduce the network peak loads thus delaying the need to expand the electricity distribution grid.

In the context of ZEB with large on-site generation, the heat pump and storage controls can maximize self-consumption. This is expected to be beneficial from the user’s economical point of view, but also to avoid voltage problems locally.

3.3.1 Storage Technologies

The energy demands in buildings are dependent on both user activity and outdoor conditions. Fluctuations in energy demand and generation yield a need for flexibility, and energy storage will in many cases be convenient for the total system solution to keep the balance between supply and demand. Both thermal and electric physical storage technologies at the building site, and virtual storage utilizing the grids the buildings are connected to, are viable options. For this report the focus will be on physical storage technologies at the building site, including solutions such as:

- BTES – Borehole Thermal Energy Storage (seasonal storage in bedrock)
- Accumulator tanks with water
- Thermal mass of building materials
- PCM – Phase Changing Materials
- Electric batteries

Norway has an estimated number of 50 000 ground-source heat pump installations, where more than 400 of the installations are medium to large-size or BTES systems with more than 10 borehole heat exchangers. (Midttømme, Ramstad et al. 2015) There will be an increased demand for thermal energy storage in buildings, especially nZEBs, to balance uneven supply and demand and to reduce the necessary installed capacity. Systems can be operated at an integral improved efficiency by avoiding extended periods of part load operation thus contributing to increased energy efficiency and reduced emissions. BTES can best demonstrate their advantages in larger installations where both heating and cooling are required. In addition, they are dependent on local ground conditions, as the possibility for storage requires no water flow through the borehole area and high thermal conduction for the ground material.

Accumulator tanks with water as the storage fluid is a common solution for DHW systems. They may also be used in hydronic heating systems to ensure that the heat generation system is operated on long production cycles, i.e. not starting and stopping too frequently (typically, cycles of minimum 20 minutes for heat pumps). Long operation cycles will also lead to better performance and less wear-and-tear for heat pumps. In the case of floor heating, the thermal inertia of the emissions system may also be exploited. When using these storage solutions, it is however important to minimize the thermal losses from the system. (Hestnes and Eik-Nes 2017) The use of compressors with variable speed drive (VSD) and with that stepless capacity control will reduce or eliminate the need for accumulator tanks in the heat distribution system, unless the tanks are used to store heat during periods with e.g. low electricity prices.

Thermal energy storage systems could also be in the form of passive systems for shorter timespans, for example by utilizing the thermal mass of building materials. The operation time of the space heating system may thus be increased, if the indoor temperature can vary by a few °C around the set-point temperature. Phase changing materials (PCM) is another opportunity for short-term thermal storage. An example is the campus for Western Norway University of Applied Sciences in Bergen, which utilizes a ground-source heat pump system with 81 boreholes (BTES) in combination with a large PCM cold storage. The PCM storage capacity of 11 200 kWh reduces the peak load for cooling by as much as 50 %. (Midttømme, Henne et al. 2016)

Batteries may store electricity produced by for example PV in periods where the production is larger than the energy consumption for the building. The excess energy may also be sold to the grid. However, battery solutions could prove profitable, as the building owner receives less money for the energy sold to the grid than the costs for buying electricity from the grid. This is especially relevant during the summer when the PV production is at its highest. As of today, batteries are however not used in combination with heat pumps in the Norwegian market.

Storage in electric vehicles is another opportunity which may be relevant for stabilizing the power grid. The solution is called "vehicle to grid", and the idea is that fully loaded electric vehicles should assist in balancing the electric power grid in periods of high demand. Norway does not have the same challenges as other European countries in this area, as nearly all the electricity production comes from hydropower. Water reservoirs serve as an energy storage solution and are easy to control and thus balance the generation to the demand. The development in this field may still prove useful for Norway as well, for balancing the local grids and thus reduce the need for investments in local grids, in addition to as a storage possibility for electricity produced from PV. (Heer, Allan et al. 2015)

4 Case Studies and Sample Projects of Realised NZEB

4.1 Completed nZEB Field Monitoring – IEA HPT Annex 40

In IEA HPT Annex 40 "Heat Pump Concepts for Nearly Zero Energy Buildings" (2012-15) the following nZEB/ZEB buildings/projects were extensively monitored and analysed:

- Tveita borettslag – block of flats
- Miljøhuset GK – office building
- Powerhouse Kjørbo – office building

Figure 29 Tveitta borettslag. (Tekniske Nyheter 2015)

4.1.1 Tveita borettslag – block of flats – Oslo

- 3 block of flats x 268 flats – renovated buildings (2011)
- Monitored/analysed – 2014
- 3 x 100 kW CO_2 heat pump water heater
    - Exhaust air as heat source
    - 73 °C DHW temperature
    - Measured SCOP = approx. 4.4

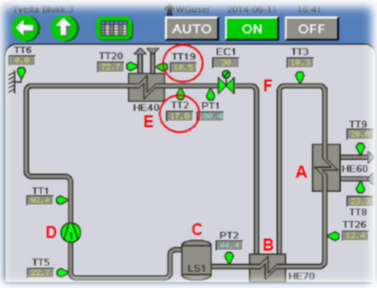


Illustration: Kuldeteknisk AS

Figure 30 Miljøhuset GK. (*GK Inneklima AS*)

4.1.2 Miljøhuset GK – office building – Oslo

- 13,650 m² – new building (2012)
- Passive house building – Bream-Nor "Very Good"
- Monitored/analysed – 2014/2015
- Measured heating/cooling demands
  - Space heating/ventilation – 18 kWh/year
  - DHW heating – 3.5 kWh/year
  - Space cooling – 5.5 kWh/year
- Hydronic systems for heating/cooling distribution
  - Heating max. 30 °C – heating of vent. air
  - Cooling min. 10 °C – cooling of vent. air
- Air-source heat pump/chiller – 2 identical units
  - Heating – max. 320 kW (-15/35 °C)
  - Cooling – max. 500 kW (+7/35 °C)
  - Measured SCOP = approx. 2.3

Photo: GK Inneklima AS

Figure 31 Powerhouse Kjørbo. (Illustration: Snøhetta and MIR).

4.1.3 Powerhouse Kjørbo – office building – Sandvika/Oslo

- 5,200 m² – refurbished building from 1985 (2014)
- Plus energy standard – Bream-Nor "Outstanding"
- Monitored/analysed – 2014/2015
- Hydronic systems for heating/cooling distribution
  - Heating 50/40 °C – low-temperature radiators
  - Cooling 12/17 °C – cooling of ventilation air
- Measured heating/cooling demands
  - Space/vent. heating – 24.6 kWh/year, 14.4 W/m²
  - DHW heating – 3.5 kWh/year
  - Space cooling – 2.0 kWh/year, 13.5 W/m²
- Space heating/cooling – ground-source heat pump unit
  - Heating capacity – 65 kW unit (0/45 °C)
  - Measured SCOP = approx. 3.9
- DHW heating – ground-source heat pump unit

Photos: Ivar Nordang

    - Heating capacity – 8.5 kW (0/45 °C)
    - Measured SCOP = approx. 2.9

4.2 Completed nZEB Field Monitoring – IEA HPT Annex 49

In IEA Heat Pumping Technologies Annex 49 "Design and Integration of Heat pumps for Nearly Zero Energy Buildings" (2015-2019) the following nZEB/ZEB buildings have been monitored and analysed by Master students at NTNU in 2015/2016:

- Scandic Lerkendal – hotel – Trondheim
- Living Lab – single-family house – Trondheim

The monitoring results and analysis will be presented in a separate Annex 49 report (**Task 3**)

Figure 32 Scandic Lerkendal. (Ezzex 2015)

4.2.1 Scandic Lerkendal – hotel – Trondheim

- 11,430 m² – new building (2014)
- Passive house standard – Energy Label A^{++}
- Monitored/analysed – 2015/2016
  (Master thesis Aashammer)
- Measured heating and cooling demands
    - Space heating – 32.1 kWh/year
    - DHW heating – 25.7 kWh/year
    - Space cooling – no cooling demand
- DHW heating – thermal solar system
    - Average heating capacity – 13 kW
    - Combined with heat recovery system for freezing/cooling installations for food
    - Poor design/operation – to be rebuilt
- Space heating – air-source heat pump unit
    - Heating capacity – 200 kW (+7/45 °C)

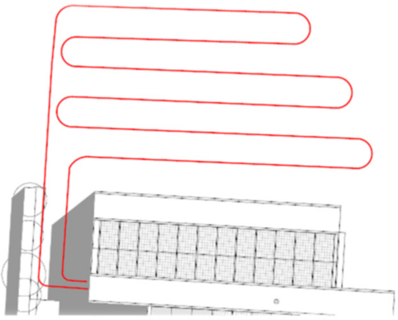
Photos: Henrikke Aashammer

  - Measured SCOP = approx. 2.2
  - 80 % energy coverage factor

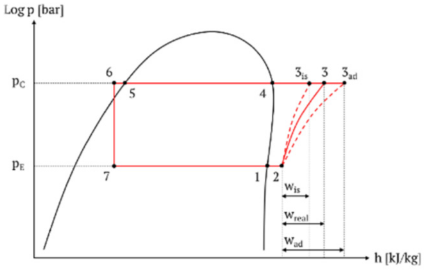
Photo: ZEB Centre NTNU-SINTEF

4.2.2 Living Lab – single-family house – Trondheim

- 100 m² – new building (2014)
- Passive house standard (cf. NS-EN3700)
- Test facility for "The Research Centre on Zero Emission Buildings" (NTNU-SINTEF) http://www.zeb.no/index.php/pilot-projects/13-laboratories/158-living-lab-trondheim
- Monitored/analysed – 2016 (Master thesis Lillevåg)
- Measured heating demands
  - Space/ventilation heating – 35.7 kWh/year
  - DHW heating – 29.8 kWh/year
  - Total net thermal power – 58 W/m²
- Space/ventilation/DHW heating – ground-source heat pump unit
  - Horizontal ground collector system
  - Heating capacity – 3.2 kW (0/35 °C)
  - Measured SCOP = approx. 2.45 incl. pumps
  - Poor design/operation – to be rebuilt
- Solar heating system – 4.2 m²
  - No performance analysis carried out



Illustrations: Stian J. Lillevåg



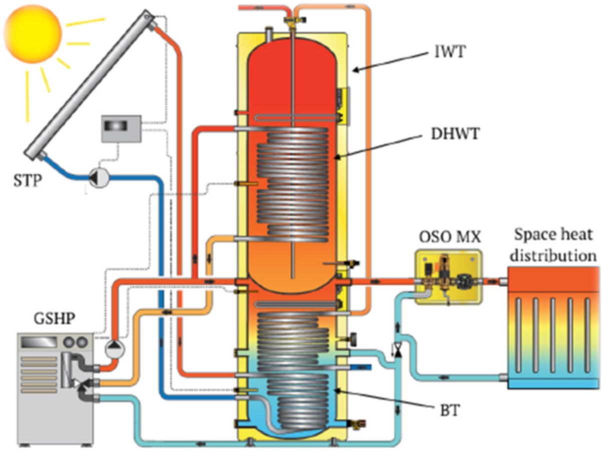


Illustration: OSO Hotwater

4.3 Upcoming nZEB Field Monitoring – IEA HPT Annex 49

Upcoming nZEB field monitoring projects in IEA HPT Annex 49 include the following buildings and projects (not complete, may be changed):

1. Medbroen Gårdsbarnehage – kindergarten – Stjørdal (2017)
2. Otto Nielsens vei 12 E – office building – Trondheim (2017/2018)
3. Akuttpsykiatrisk Østmarka – psychiatric nursing home – Trondheim (2018)
4. Levanger akuttpsykiatriske sykehus – psychiatric nursing home – Levanger

Photo: Marit Thyholt

4.3.1 Medbroen gårdsbarnehage – kindergarten – Stjørdal

- 900 m² – refurbished 100 years old farm building / barn (2015)
- Passive house standard (cf. NS-EN3700)
- Low-temperature heating system (35/30 °C)
  - Floor heating
  - Reheating of ventilation air
- 13 kW ground-source heat pump system
  - Space/ventilation heating + preheating DHW
  - Horizontal ground collector system

Photo: COWI AS

4.3.2 Otto Nielsens vei 12E – office building – Trondheim

- 9,500 m² – new building under construction (2017)
- Passive house standard (cf. NS-EN3701) – Breem-Nor "Excellent"
- Heating and cooling demands
  - Space heating, heating of ventilation air, DHW heating
  - Process cooling (dominating load) and space cooling
  - Heating demand in adjacent existing building
- Ground-source heat pump and liquid chiller system
  - 25 boreholes – thermal energy storage under the building
  - 290 kW high-quality heat pump and liquid chiller unit
    - Designed according to max. cooling load
    - Variable speed drive reciprocating compressors

Photo: Nordic Office of Architecture

4.3.3 Akuttpsykiatrisk Østmarka – psychiatric nursing home – Trondheim

- 4,450 m² – new building under construction (2016/2017)
- Passive house standard (cf. NS-EN 3701) – Energy Label A
- Heating and cooling demands
  - Space heating, heating of ventilation air, DHW heating
  - Space cooling
- Water-source heat pump and liquid chiller system
  - Indirect seawater heat source/sink system shared with two other installations, 1) Nidaros DPS" (7,000 m² regional psychiatric centre 2007) and "Sikkerhets-psykiatrisk Østmarka" (10,000 m² high-security mental institution, 2024)
    - Free cooling from centralized seawater system
  - 15 kW CO_2 heat pump water heater unit – DHW heating only
  - 70 kW heat pump and liquid chiller unit
  - Electric boiler – peak load (auxiliary heating)

4.3.4 Levanger akuttpsykiatriske sykehus – psychiatric nursing home – Levanger

- 2,500 m² – new building under construction (2017)
- Passive house standard (cf. NS-EN3701) – Energy Label "Green"
- Heating and cooling demands
    - Space heating, heating of ventilation air, DHW heating
    - Space cooling
- Low-temperature space heating system (50/35 °C)
- Water-source heat pump and liquid chiller system
    - Waste heat from low-temperature fridge installation (blood bank)
    - Electric boiler – peak load (auxiliary heating)
    - Unique CO_2 heat pump unit
        - DHW heating (70 °C)
        - Space/ventilation heating
        - Space cooling
    - Dry-cooler for rejection of excess heat from space cooling

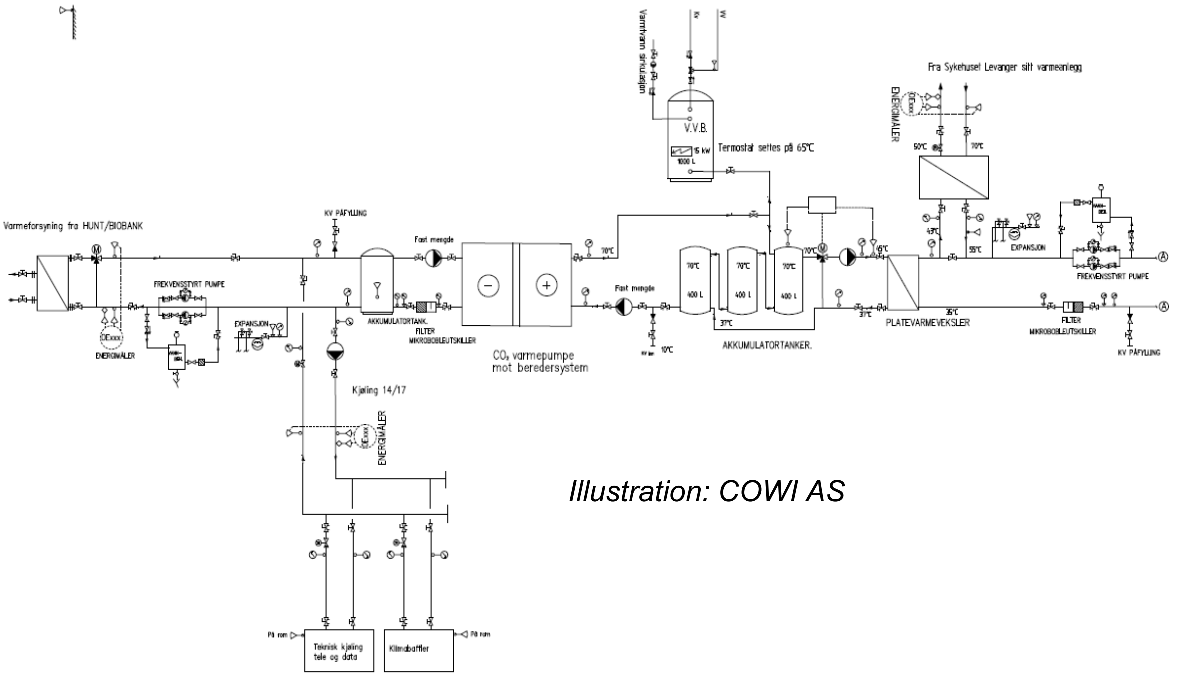


Illustration: COWI AS

5 Conclusions

Heat pumps are often the selected technology for accomplishment of ZEB as they are related to lower CO_2 emissions and high efficiency if correctly designed. We see this trend also in many passive and low energy houses in Norway, both in new and renovated buildings.

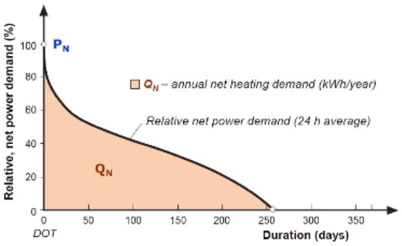
In general, they are installed in 42% of the dwellings in Norway and air to air heat pumps are the preferred solution. The sales of heat pumps are increasing and seem to stabilize for the coming years.

8 of 9 pilot buildings of the ZEB centre use heat pumps. Most of the systems have or are projected to have low temperature distribution systems and balanced mechanical ventilation. Regarding electricity production PV and combined heat and power are the chosen solutions.

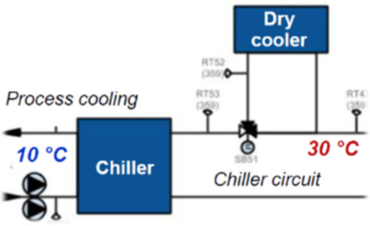
Heat pumps are the chosen solution mostly for base load covering, and the cases where there are cooling demands, the chosen solution is often seawater or groundwater heat pumps.

The main conclusions from completed field monitoring of 5 realized Norwegian nZEB and ZEB buildings/projects are as follows:

1. *Realistic heating/cooling demands* – There is a considerable deviation for some buildings between measured power/ energy demands for heating/cooling and calculated values.
    - Accurate/detailed modelling/simulation of the building is crucial for the design of the thermal energy system as well as for the LCC calculations.



2. *Utilization of waste heat source* – Waste heat from cooling of e.g. computers and telecom equipment represents an excellent heat source during the entire year and should always be utilized.
    - Condenser heat from the liquid chiller should be utilized to cover low-temperature heating demands (< 40 °C) including preheating of domestic hot water (DHW).
    - A desuperheater or oil cooler (screw compressors) for the liquid chiller is very suitable for DHW heating since the heat pump and liquid chiller is running 8760 hours/annum.



Illustrations: COWI AS

3. *Design of heat pumps and liquid chillers* – Heat pumps are normally designed as a base load for space heating and heating of ventilation air in buildings (70-100 % energy coverage factor).
    - In buildings with a dominating space cooling demand the heat pump will have sufficient capacity to cover the entire heating demand (i.e. 100 % energy coverage factor).

Heating ↔ cooling

4. *Domestic hot water (DHW) heating* – heat pump water heaters with CO_2 as the working fluid (CO_2 HPWH) supply

heat at 65 to 90 °C (no reheating required) and achieve superior SCOP.

Photo: *Eptec Energi AS*

- The CO_2 HPWH are designed to cover the entire DHW heating demand. They can also be used as combined HPWH and liquid chillers if the demands are in the same order of magnitude.
- The DHW system (storage tanks, piping system etc.) should be designed/operated according to the unique properties of the CO_2 cycle. Reference is made to "IEA HPT Annex 40 – Task 3" for further information.

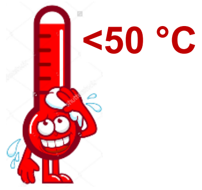
5. *Variable speed drive (VSD) compressors* have much better controllability, higher average energy efficiency and longer lifetime than compressors with intermittent operation (on/off).
    - Apply heat pump and liquid chiller units with VSD scroll, reciprocating or screw compressors.

Photo: GEA Bock GmBH

6. *VSD high-efficiency pumps* for hydronic distribution systems for heating and cooling, ground-source systems, sea-/groundwater systems etc. will minimize the parasitic losses (el. demand).
    - Apply pumps that are at least as energy efficient as the minimum requirement in the Eco-Design Directive (ErP).

Photo: Grundfos

7. *Low-temperature heat distribution systems* (< 50 °C) leads to high SCOP, excellent operating conditions and no temperature limitation for heat pumps with a max. outlet water temperature of 50 °C (standard units with ammonia/R717 and propane/R290).
    - Use hydronic heat distribution systems with maximum 50 °C set-point (supply) temperature and apply outdoor temperature compensation of the set-point temperature.



8. *High-temperature cooling distribution systems* (> 12 °C) make best use of free cooling sources and maximizes the COP of the heat pump installation in overall cooling mode.
    - Use cooling distribution systems with minimum 12 °C set-point (supply) temperature and apply outdoor temperature compensation of the set-point temperature.

9. *Only natural working fluids* should be used in heat pump and liquid chillers. The fluids are 100 % eco-friendly working with zero/negligible GWP and excellent thermophysical properties that leads to high SCOP. HFO1234ze does not represent a 100 % environmentally benign alternative to the HFCs.
    - *CO_2 (R744)* – heat pump water heaters (DHW heating in hotels, hospitals, nursing homes, sport centres etc.) and heat pumps for combined DHW

R744

and space heating for low temperature heat distribution systems.

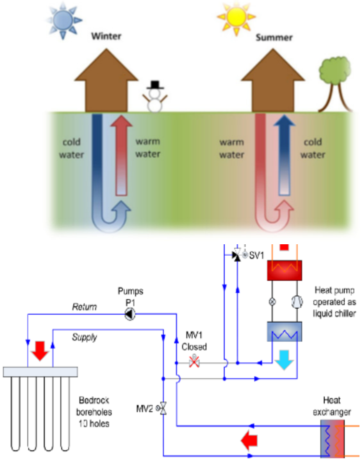
- *Ammonia (R717)* – heat pump and liquid chillers for space heating and heating of ventilation air as well as space cooling and process cooling. Capacity range from 150 – 200 kW and max. temperature 50-55 °C.

R717

- *Propane (R290)* – heat pump and liquid chillers for lower capacities, < 150 – 200 kW and max. temp. 60-65 °C.

R290

10. *Ground- and water-source heat pump systems* represent a better technological alternative than air-source systems. They have higher annual energy saving due to higher SCOP (average COP) and higher energy coverage factor (α). They also cover a large share of annual cooling demands with free cooling and have much less operational problems and longer lifetime.
    - Air-source: SCOP = 2.2, α = 70 – 80 %
        - Relative energy saving **38 – 44 %**
    - Ground-source: SCOP = 3.5-4.0, α = 90 to 100 %
        - Relative energy saving **65 – 75 %**
11. *Free cooling from the boreholes* in ground-source heat pump systems cannot meet the peak load cooling demand unless they are greatly over-sized (i.e. expensive and unprofitable design).



Illustrations: Ivar Nordang

The heat pump should be utilized for peak load cooling – requires tubing, three-way valve and one extra heat exchanger for rejection of condenser heat to the borehole system and several valves to connect the evaporator to the chilled water (cooling) circuit.

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STATE-OF-THE-ART ANALYSIS OF NEARLY ZERO ENERGY BUILDINGS

This report is a state-of-the-art analysis for nearly zero energy buildings in Norway. It provides an overview of applied HVAC technologies in energy efficient buildings. In addition to political framework, definitions and market state of heat pumps in Norway, it also includes an overview of relevant research projects, such as FME ZEB, FME ZEN and Futurebuilt and some of their pilot buildings.

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