Country Report NO Task 1

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

Country Report IEA HPP Annex 40 Task 1 – **NORWAY**

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Abstract

The IEA Heat Pump Programme (HPP) Annex 40 "Heat Pump Concepts for Nearly Zero Energy Buildings" deals with the application of heat pumps as core component of the HVAC system for Nearly or Net Zero energy buildings (NZEB).

Annex 40 has been structured into four tasks which comprise the following activities:

Task 1 – State-of-the-art analysis

The Task 1 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, definitions of NZEB), the state of market introduction and applied technologies both on the building envelope and the building HVAC system shall be characterised. The compiled technical concepts shall be analysed regarding the heat pump application. Moreover, technologies shall be classified in a technology matrix and evaluated regarding specific advantages of single technologies for dedicated applications like new buildings, 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.

Task 2 – Assessment of system technology

Task 2 is dedicated to identify promising concepts for the further development of system configurations and in-depth analysis of technologies and system configurations suitable for different applications in NZEB. Concepts shall be optimised by simulations regarding design, integration options and control, but also regarding further aspects like self-consumption of energy, load match and grid interaction, which shall be considered in Task 4. Evaluation is made based on energy performance and cost.

Task 3 – Technology development and field monitoring

Task 3 is dedicated to technology developments on the component and system level as well 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 – Integration of NZEB into the energy system

Task 4 is also to be accomplished in parallel and deals with the integration of NZEB into the energy system. An NZEB should be designed in a way not to produce additional stress for the grid. In this respect, load match profiles and grid interaction shall be investigated in order to maximize self-consumption and minimize grid interaction. Thus, local storage options shall be evaluated. On the other hand, the ability of NZEB to react to signals from the grid (“smart grid”), i.e. demand response technology options shall be examined. Heat pumps are also a unique system in this respect due to the option of a transformation electrical surplus to storable heating or cooling energy, as well in simultaneity, and due to the connection to source and sink systems which may be used as short-term storage like the ground. Control issues play an important role for these investigations, as well.

This report gives the results with the state-of-the-art analysis of Task 1 for **NORWAY**.

The Norwegian activities in Annex 40 are organized and carried out by SINTEF Energy Research (www.sintef.no/home/SINTEF-Energy-Research), while COWI AS (www.cowi.no) and The Norwegian University of Science and Technology (NTNU) are subcontracting partners. The project is funded by the governmental organization Enova SF (www.enova.no) and the Norwegian Research Centre on Zero Emission Buildings, ZEB (www.zeb.no).

Contents

1 Policy Framework and Definition

1.1 Political Framework – Summary

- "Klimameldingen", i.e. white paper on environment and energy (MD, 2012-1) from the Norwegian Ministry of the Environment. The main superior goal is that Norway should become carbon neutral by 2050 by reduction of domestic greenhouse gas emissions (e.g. energy efficiency measures and conversion to renewable energy sources in buildings) and purchase of climate quotas abroad.

- "Bygningsmeldingen" i.e. white paper on future building policies (MD, 2012-2) from the Norwegian Ministry of the Environment. The goal is to introduce Norwegian passive house level as the building standard in 2015 and nearly zero emission/energy buildings in 2020. The revision of the Norwegian building code from TEK10 to TEK15 in 2015 is a part of this national strategy. TEK15 will be a modified passive house standard partly based on the Norwegian passive house standards NS 3700 (residences) and NS 3701 (non-residential buildings).

- Implementation of and compliance with the EU directives "Energy Performance of Buildings, EPBD (EC, 2002/2010), "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 and cooling of buildings, and improved energy efficiency for energy related products including heating and cooling systems for buildings.

- Enova SF, which is owned by the Ministry of Petroleum and Energy (MPE), 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 established a number of funding programmes to promote the evaluation, design and construction of low-energy and passive house buildings as well as heating and cooling based on renewable energy sources, including heat pumps (www.enova.no).

1.2 Definition(s) of NZEB

ZEB is a grid-connected, energy-efficient building that balances its total annual energy consumption by on-site generation 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, 2013), we can define ZEB and nZEB as follows.

- **Net zero energy building (ZEB).** A net ZEB is defined as a building having a primary energy use lower or equal to zero kWh/(m^{2}a). The “net” makes reference to the annual balance of primary energy calculated based on delivered and exported energy. A net ZEB is normally defined as a grid connected building with very high energy performance. A net ZEB achieves equality between its primary energy use, so that the primary energy feed-in to the grid or other energy network equals the primary energy delivered to ZEB from energy networks. Therefore a net ZEB produces energy when conditions are suitable and uses delivered energy otherwise (Kurnitski, 2013). A good example is referred by Dar (2012) for the Norwegian case.

- **Nearly zero energy building (nZEB).** nZEB stands for a technically and reasonable achievable primary energy use higher than zero kWh/(m^{2}a). 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, 2013).

1.2.1 Criteria Included in Norwegian Definition, Criteria Neglected

For the time being, a revised Norwegian definition of ZEB is being developed. The current definition of the Norwegian Research Centre for ZEB (ZEB, 2013) is based on nine criteria:

1. Ambition level
2. Basis for calculation
3. System boundaries
4. CO_2 factors
5. Energy quality
6. Mismatch production and demand
7. Minimum requirements energy efficiency
8. Requirements indoor climate
9. Verification in use

Figure 1 shows a graph representing the path towards a Net Zero Energy Building.

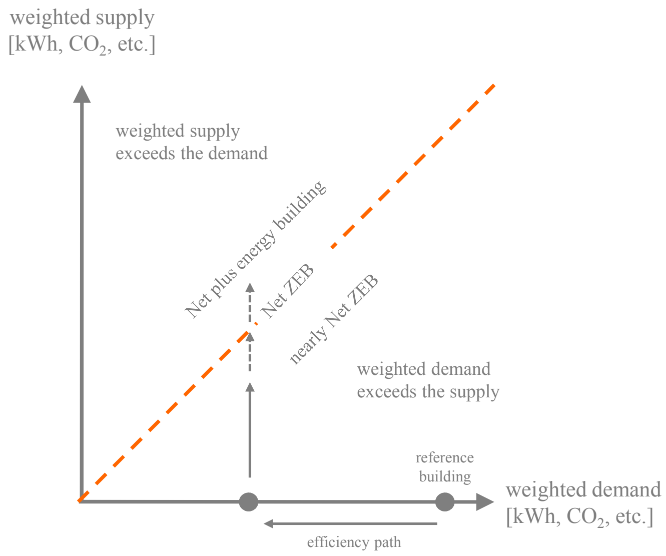


Figure 1 Graph representing the path towards a Net Zero Energy Building (Net ZEB), with the nearly and plus variants. Source: University Wuppertal, btga.

Figure 2 illustrates how the different levels take into account different emission items based on these criteria. According to Dokka (2012), the four ZEB levels are at the moment defined based on different boundaries for balance as:

1. **ZEB-O÷EQ** – Net emission related to all operational 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 emission related to all operational energy use shall be zero, also including energy use for equipment.
3. **ZEB-OM** – Net emission 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 taking into account emissions related to the construction process of the building. At the moment we don't have the data and methods to quantify these emissions in an accurate way.

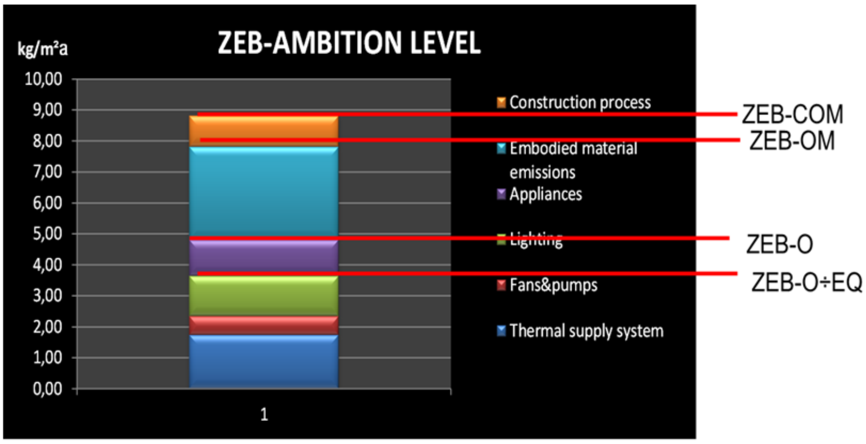


Figure 2 Definition of the ZEB ambition levels – ZEB-O÷EQ, ZEB-O, ZEB-OM, ZEB-COM (Dokka, 2012)

All the calculations regarding emissions and energy balances are to be done based on the Norwegian standard NS 3031 (2007). Export to the electricity grid will be taken into account by NS-EN-ISO 13790 (2008), but also by NS 3701 (2012). The normal use and operation times used are those defined in NS 3031 and then, the Net ZEB energy balance is calculated over a year, using "normalized" climate data (Oslo climate).

1.2.2 Physical and Balance Boundaries

This chapter is based on the definitions proposed in Voss (2012). The building codes are based on calculations for a single building where the energy services are metered. However, it is possible to distinguish between a *physical boundary* and a *balance boundary*. The combination of both boundaries defines the building system boundary, *Figure 3*.

- The *physical boundary* isolates the building (as opposed to a cluster or a neighbourhood). The energy analysis addresses energy flows at the connection point to supply grids (power, heating, cooling, gas, fuel delivery chain). The physical boundary is the interface between the building and the grids including up to the meters (or delivery points). This boundary is useful to identify “on-site generation” systems. Given a system within the building distribution grid before the meter it is considered to be on-site, otherwise it is off-site.

  Examples of on-site generation systems are PV and micro CHP, which allow energy to be exported beyond the physical boundary. Solar thermal energy is classically consumed entirely on-site, therefore solar thermal systems are treated as demand-reduction technology (efficiency path, x-axis in *Figure 1*). A typical off-site option is a wind energy park which is financed by a share of the building budget. Yet, the EU Directive "Energy Performance of Buildings, EPBD" (EC, 2002/2010) only addresses energy generated on-site or nearby. Therefore, of-site production falls out of the scope of this report.

- The *balance boundary* identifies the energy services considered. In the EPBD, energy balance calculations take into account the technical services for heating, cooling, ventilation and domestic hot water (and lighting in the case of non-domestic buildings). Plug loads and central services are not included, but are typically included when metering energy use at the point of delivery. Other forms of energy consumption that do not appear in the annual operational phase but belong to the life cycle of a building may be considered within the balance boundary, such as embodied energy/emissions related to construction materials and installations. Norwegian definition under development addresses this issue (Voss, 2011).

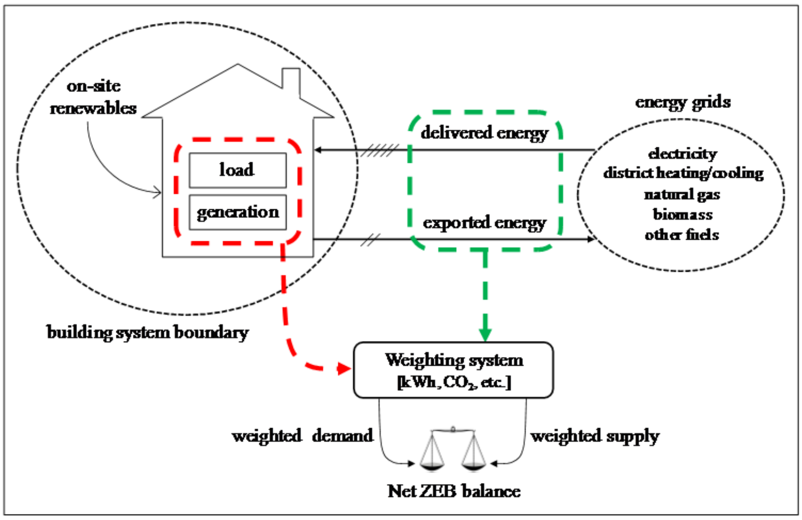


Figure 3 **Sketch of the connection between buildings and energy grids showing the relevant terminology (Sartori et al, 2012).**

1.2.3 Weighting Systems – Primary Energy, Carbon Emissions etc.

This chapter is based on the weighting system proposed in Voss (2012). The EPBD states that a weighting system is needed for new buildings. According to the EPBD recast (EC, 2002/2010), the balance weighting system for a nearly ZEB is *primary energy*. Still, some countries prefer *carbon emissions* as the primary metric. A common definition of the calculation is already under development in different IEA tasks (Stang, 2010) and standardization groups. Examples of weighting factors are documented in EU standards, such as EN 15603. Yet many different factors are used in national building practice, reflecting the specific national or local power grid structure (Annex 1 in Sartori, 2011, Dokka, 2012). Most countries apply factors taking into account barely the non-renewable component of the primary energy. Norway (Graabak, 2011) and Denmark (Bygningsklasse, 2020), fight for using politically adjusted (decreased) factors to electricity in order to include the expected "greening" of the power sector in accordance with national and EU road maps. Such "discounting" of electricity favours all-electric solutions such as systems based on heat pumps, facilitating achieving the Net ZEB target in connection with decarbonized power grids (with a high share of renewable energy). Similarly, discounted values for the district heating/ cooling grid (such as The Power Bonus method) would make the Net ZEB target more feasible in connection with thermal grids based on large shares of renewable energy and/or waste as fuel. The allocation method to be used is under development. The most probable methods to be used as standardized are the Power Bonus, the Best alternative Technology and the Dresden methods for allocation of losses. Additives and ashes are also a matter of concern when calculating primary energy factors (Berner,2009).

1.2.4 Balance Types

This chapter is based on the balance types proposed in Voss (2012). Nowadays, building designers lack an indicator of the synergy between buildings and grid. The Net ZEB's annual balance between weighted demand and weighted supply is implicitly understood as the import/export balance, indicated with the green line in *Figure 4*. Weighted delivered and exported energy can be used to calculate the balance when monitoring a building, as long as all consumptions are included.

Self-consumption differs based on the type of generating technology, building, climate and user behaviour because it depends on the simultaneity between generation and consumption. Presently, scarce knowledge about self-consumption hampers the establishment of standardised self-consumption fractions. As the EPBD recast mainly addresses building performance requirements in the planning phase, it focuses on the balance between weighted on-site generation and the calculated energy demand, the load/generation balance (red line in *Figure 4*). These quantities do not cross the building system boundary, so the grid interaction is disregarded. The load/generation balance refers to the generation by renewable sources only. As most national energy codes apply calculations on a monthly basis, generation and consumption may be calculated and compared on a monthly level.

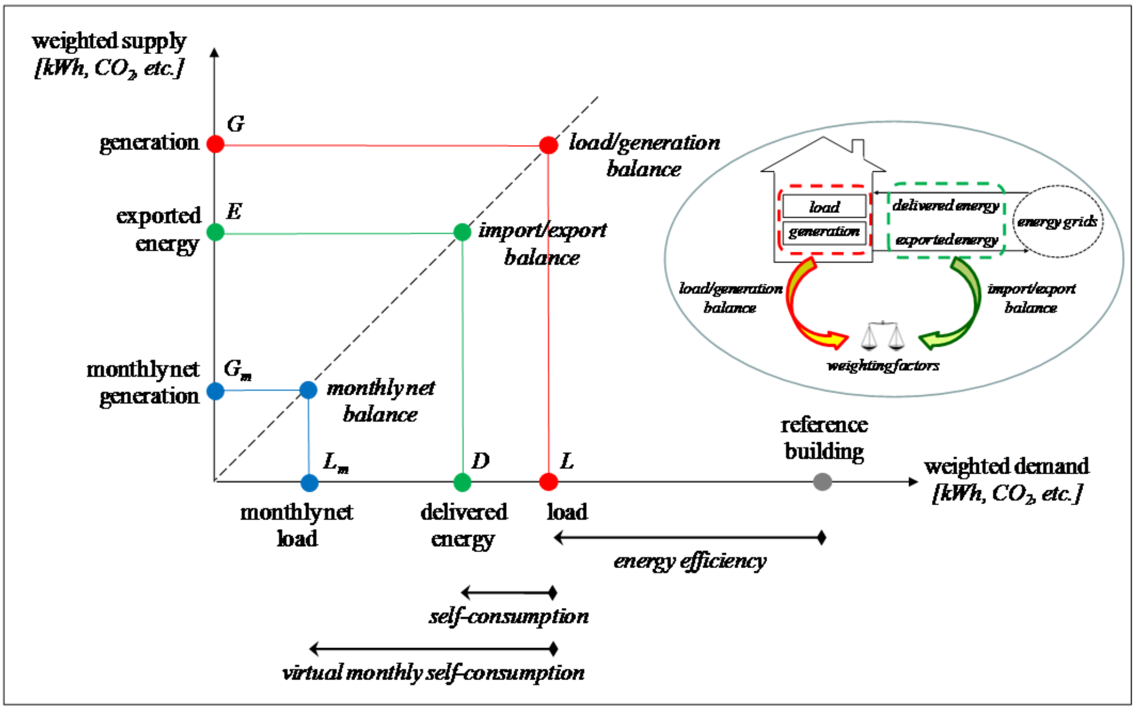


Figure 4 Graphical representation of the three types of balance – import/export balance between weighted exported and delivered energy, load/generation balance between weighted generation and load, and monthly net balance between weighted monthly net values of generation and load (Sartori, 2011).

1.3 Proposal of Definition of an NZEB for the Work in Annex 40

A Low Energy Commission delivered a number of suggestions for increasing energy efficiency of all sectors in Norway in the summer of 2009. The report also included suggestions of future net energy frame values for new buildings, as well as for major renovations. The Norwegian Building Code, TEK is proposed to be sharpened every fifth year with more stricter constrains.. TEK 07 was published in 1 February 2007; this was the first in Norway with an energy performance approach. Afterwards, the TEK 10 has been published in 2010, and the TEK 15 is expected to be published in the coming years.

The net energy use in the energy frame consists of heating, ventilation, cooling, domestic/service hot water, as well as tenants' or users' electricity. The net energy includes cooling supplied to air-cooling coils or fan coils in the rooms. The energy requirements proposed for the different standards are summarized in *Table 1*.

Table 1 Proposed future net energy frames for new buildings in Norway.

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

The floor area used for these calculations is the heated floor area measured inside the external walls. Norway has four different climate zones. Among them, the values given in *Table 1* are valid for the "standard" climate zone around the capital Oslo, 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, 2013).

Regarding the building restrictions in U value, *Table 2* shows the requirements for a possible NZEB, so that balance zero can be achieved. The last column shows examples of construction type enabling achieving the U-values described. These values are not standardized but only a proposal of maximum leakages.

Table 2 Minimum U-values required for a ZEB (Dokka et al., 2012).

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

As for the HVAC system, requirements for the HVAC components in ZEB are shown in *Table 3*. Again these values are not standardized but minimum requirements to make it possible to achieve balance zero. The restrictions for example for heat recovery are enhanced but still no requirements regarding latent recovery are introduced (conversely to USA or Canada where one should always talk about total heat recovery).

Table 3 Specifications for HVAC installations in ZEB (Dokka et al, 2012).

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

1.4 System Limits

As for the zero calculation, the building balance limits have to be defined. These limits are different for electricity and thermal production, and they are defined as follows:

- **Electricity production:** As a first approach, the Norwegian definition of NZEB proposes that the production unit of electricity for a building has to be constructed on the site of the building, or the site of a ZEB-development area (Dokka, 2012).

- **Thermal production:** Regarding the thermal production, the limits can be selected for the cases of outside and inside generation the system boundary. The losses have to be taken into account consistently, in district and near heating, using the same CO_2 equivalent factors in both cases. Due to this consideration, near heating and import / export from/to district heating grids can be considered. (Dokka, 2012).

1.4.1 CO_2 EQ factor Electricity

The ZEB centre expects the realization of what it is defined as ultra-green scenario in the coming years. For that, it is assumed that Norway is an integral part of a single European electricity grid. Based on the green scenario simulations from Graabak and Feilberg, it is 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". In that it is expected that the average over 60 years will be approximately 130 g / kWh.

The authors however support a common calculation method that may avoid different calculation methods which 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/under estimate values which complicates the correct comparison between factors. For instance EN 15603 includes losses from the extraction of the fuel, the building and demolition of a power plant whereas Graabak and Feilberg in their green scenario do not include the building operation and demolition. This might also be a little bit too positive regarding the increase on 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 an standardized calculation method has been approved for the whole EU.

Our suggestion is to use *EU average values and compare them with the ultra-green profile*.

In addition another argument to point out is that the ultra-green scenario assumes coal plants to be phased out in favour of atomic power plants. With the recent accident in Fukushima, this change is not so likely to happen, affecting the actuality of the green scenario. Another economic/political issue that is affecting the expectations for the ultra-green scenario is the economic crisis that prevents investors to finance as much as expected in renewable energies.

1.5 Temporary Energy Match Characteristics

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

Figure 5 shows the mismatch problems that have to be addressed in ZEBs. In the diagram on the left it is shown the monthly average production and demand of electricity. There is a mismatch between production and demand the entire year, and therefore the system in this case would need to be connected to the electricity grid.

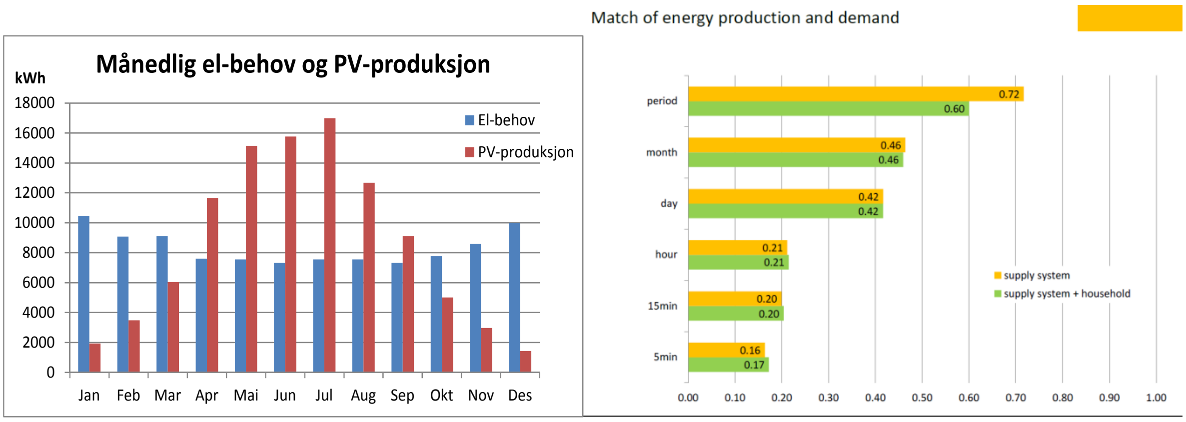


Figure 5 Left: Mismatch production and demand for different time periods (Dokka et al, 2012). Right: Mismatch between electricity demand (blue lines) and photovoltaic production (red lines) (Candanedo, 2011)

As for the temporal basis, we can see in *Figure 5* on the right 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 a 16% when considering 5 minute periods.

1.6 Minimum Energy Efficiency

The minimum requirements for energy efficiency in ZEBs are represented by the passive house level. With passive house level it is meant that these buildings comply with the requirements in the Norwegian passive house standard NS 3700 (residential) and NS 3701 (non-residential).These standards settle requirements for maximum heating demand, cooling demand and energy demand for lighting (non-residential). Furthermore, they fix requirements for maximal heating consumption, component requirements for windows and doors, thermal bridges, air leakage figures 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, 2012).

1.7 Requirements for Indoor Air Quality

ZEB buildings not only make requirements regarding energy consumption but also regarding the indoor air quality in the building. (Dokka et al, 2012). Such requirements can be summarized as:

- Max air speed winter: 0.15 m / s
- Max operating temperature dim. Summer: 26 °C
- 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%

1.8 Verification

In order to define a ZEB verification is needed – the calculations of energy use represent a good start point that must be further followed up. The verification of the calculated values has to be done. According to Dokka (2012) four levels of verification of ZEB-buildings can be considered:

- *Verification of annual energy and CO_2 balance*. This requires measurement of the provided (and exported) energy to the building / area for different energy products. The CO_2 balance is calculated from the specific CO_2-factors.

- *Verification of energy post level.* This one is done by comparing simulated and measured energy use down to record-level energy (heating, hot water, fans, lighting ...) according to NS3031 (2007).

- *Verification / evaluation of the energy mismatch.* Measurement of mismatch between production and demand, i.e. exported and imported energy on hourly, monthly and annual basis.

- *Verification of indoor climate parameters obtained*. Measurement of temperatures, velocities, CO_2 levels, noise levels, light levels (natural / artificial), etc. are required. They must be carried out in both summer and winter situation.

2 Market State of Nearly and Net Zero Energy Bldgs.

2.1 Buildings Labels for Different Kinds of Buildings

Table 4 provides an overview of the requirements for houses built according to the Norwegian building code of 2010, TEK10 ("Normal house", NH) as well as low-energy house, passive house built according to the Norwegian passive house standard NS3700 (2010) and Zero Emission Building (ZEB).

Table 4 General requirements for the building envelope, the ventilation system as well as heating power and annual heating demands for "normal houses" (TEK10, 2007), low-energy houses and passive houses according to the Norwegian passive house standard NS3700 (2010).

General requirements	**Normal house**	**Low-energy house**	**Passive house**	**ZEB center**
Bldg. envelope insulation	TEK10	Stricter than TEK10	NS3700	Better than NS 3700
Bldg. envelope – air tightness	TEK10	4 times better than TEK10	8 times better than NH	Better than NS 3700
Balanced vent. – heat recovery efficiency	70–80%	70–80%	80–90%	90%
Heating power demand	**Normal house**	**Low-energy house**	**Passive house**	**ZEB**
Space heating	55 W/m^2	38 W/m²	22 W/m²	Max. 18 W/m^2
Space heating – 150 m²	8.3 kW	5.7 kW	3.3 kW	Max. 2.7 kW
DHW demand – average	500 W	500 W	500 W	500 W
Total heating dem. – 150 m²	8.8 kW	6.2 kW	3.8 kW	Max. 3.2 kW
Annual heating demand	**Normal house**	**Low-energy house**	**Passive house**	**ZEB**
Space heating (SH)	80 kWh/m^2	58 kWh/m^2	22 kWh/m^2	18 kWh/m^2
DHW heating	25-35 kWh/m^2	25-35 kWh/m^2	25-35 kWh/m^2	25-35 kWh/m^2
Ratio DHW and SH	0.27	0.34	0.58	0.63
Total annual energy demand	110 kWh/m^2	88 kWh/m^2	52 kWh/m^2	48 kWh/m^2

When the ZEB building is not using constant heating but intermittent, the factor of consumption would be multiplied by a factor 2 since it must cover for the reloading of the thermal mass. Given that ZEB are defined as that based on the balance, the fact that they are using more energy will not move them from ZEB given enough production.

As a consequence of the EU Directive on the Energy Performance of Buildings (EC, 2002/-2010), Norway has implemented a national system for energy labelling of residential and non-residential buildings (NVE, 2013). All residences, non-residential buildings and vacation properties that are sold or hired out as well as well all non-residential buildings with more than 1000 m² heated area should have an *energy certificate*. The certificate comprises an *Energy Label* and a *Heating label*.

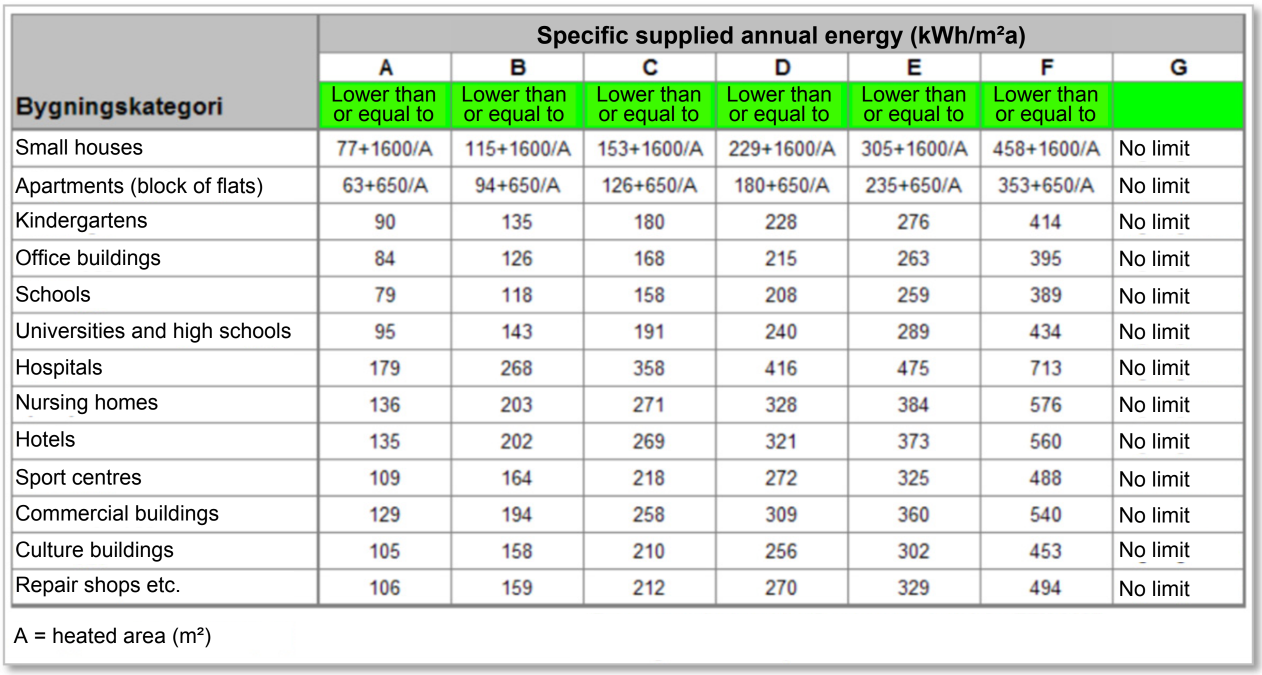
2.1.1 Energy Certificate – Energy Label

The Energy Label, which ranges from A to G, is based on calculated *total annual supplied energy* to the building (kWh/m²a) according to the Norwegian standard NS3031 (2007). A building that is constructed according to the prevailing building code TEK10 will the get energy label **C**. In order to receive energy label B or A, the thermal properties of the building envelope have to be improved and/or a heat pump or solar heating system, that reduce the supplied energy to the building, has to be installed (NVE, 2013).

Table 5 shows the present scale for the Norwegian energy labelling of residential and non-residential buildings (NVE, 2013).

The scale for the Energy Label will come into force in July 2013. The new reference values are A (passive house), C (TEK10) and F (TEK69 + 7 %), *Table 6*.

Table 5 Current scale for energy labelling of Norwegian buildings – the Energy Label (NVE, 2013).



Bygningskategori	Specific supplied annual energy (kWh/m²a)						
	A	B	C	D	E	F	G
	Lower than or equal to	Lower than or equal to	Lower than or equal to	Lower than or equal to	Lower than or equal to	Lower than or equal to	
Small houses	77+1600/A	115+1600/A	153+1600/A	229+1600/A	305+1600/A	458+1600/A	No limit
Apartments (block of flats)	63+650/A	94+650/A	126+650/A	180+650/A	235+650/A	353+650/A	No limit
Kindergartens	90	135	180	228	276	414	No limit
Office buildings	84	126	168	215	263	395	No limit
Schools	79	118	158	208	259	389	No limit
Universities and high schools	95	143	191	240	289	434	No limit
Hospitals	179	268	358	416	475	713	No limit
Nursing homes	136	203	271	328	384	576	No limit
Hotels	135	202	269	321	373	560	No limit
Sport centres	109	164	218	272	325	488	No limit
Commercial buildings	129	194	258	309	360	540	No limit
Culture buildings	105	158	210	256	302	453	No limit
Repair shops etc.	106	159	212	270	329	494	No limit

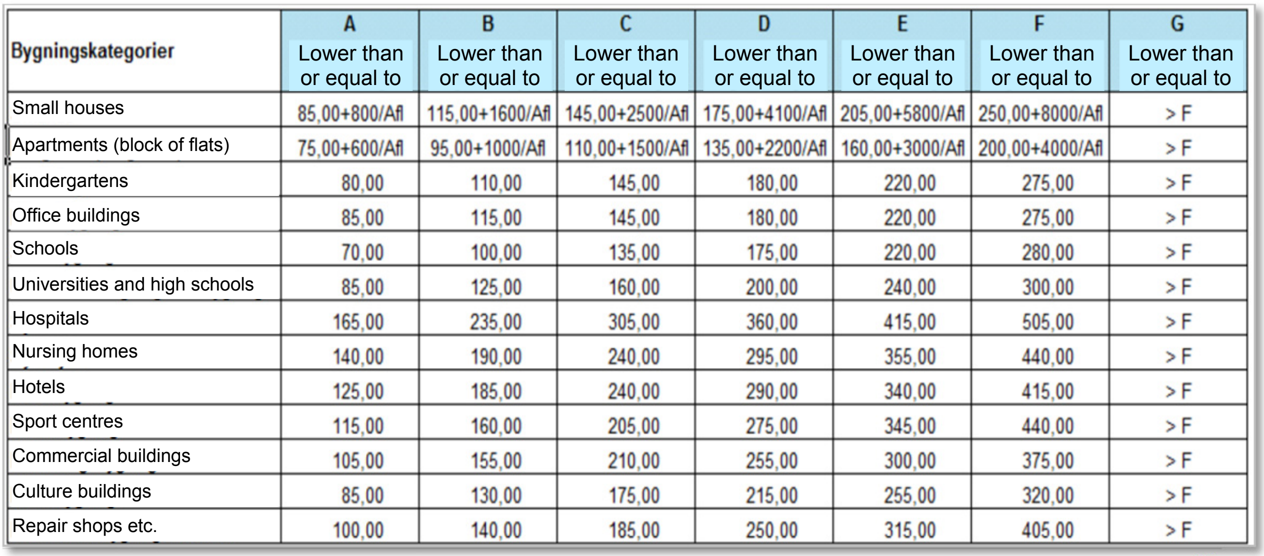
A = heated area (m²)

Table 6 Reference values from 07.13 for the Energy label in the energy labelling system (NVE, 2013).

Levels for supplied energy – Norwegian energy labelling system for buildings						
A	B	C	D	E	F	G
Passive house	(A+C)·½	TEK10	(2C+TEK69)/3	(2·TEK69+C)/3	TEK69·1,07	>F

Table 7 shows the updated scale for the Energy Label for energy labelling of Norwegian buildings which will come into force July 2013.

Table 7 The scale for energy labelling of buildings (Energy mark) which will come into force July 2013 – A-G, total supplied annual energy kWh/(m²a) (NVE, 2013). Afl = heated area (m²).



Bygningskategorier	A Lower than or equal to	B Lower than or equal to	C Lower than or equal to	D Lower than or equal to	E Lower than or equal to	F Lower than or equal to	G Lower than or equal to
Small houses	85,00+800/Afl	115,00+1600/Afl	145,00+2500/Afl	175,00+4100/Afl	205,00+5800/Afl	250,00+8000/Afl	> F
Apartments (block of flats)	75,00+600/Afl	95,00+1000/Afl	110,00+1500/Afl	135,00+2200/Afl	160,00+3000/Afl	200,00+4000/Afl	> F
Kindergartens	80,00	110,00	145,00	180,00	220,00	275,00	> F
Office buildings	85,00	115,00	145,00	180,00	220,00	275,00	> F
Schools	70,00	100,00	135,00	175,00	220,00	280,00	> F
Universities and high schools	85,00	125,00	160,00	200,00	240,00	300,00	> F
Hospitals	165,00	235,00	305,00	360,00	415,00	505,00	> F
Nursing homes	140,00	190,00	240,00	295,00	355,00	440,00	> F
Hotels	125,00	185,00	240,00	290,00	340,00	415,00	> F
Sport centres	115,00	160,00	205,00	275,00	345,00	440,00	> F
Commercial buildings	105,00	155,00	210,00	255,00	300,00	375,00	> F
Culture buildings	85,00	130,00	175,00	215,00	255,00	320,00	> F
Repair shops etc.	100,00	140,00	185,00	250,00	315,00	405,00	> F

2.1.2 Energy Certificate – Heating Label

The Heating Label for the energy certificate was implemented in order to favour heating systems based on renewable energy sources with minimal greenhouse gas emissions.

The Heating Label, which is independent of the Energy Label, ranks the building according to the type of heating system and the energy carriers that are being used. The scale ranges from dark green, light green, yellow, orange to dark red. Dark green represents systems with a large share of renewable energy sources, such as biomass, solar heat and ambient heat. Red represents direct electric and/or fossil-fuelled heating systems. The share of electricity and fossil fuels for heating of the building should be less than the values shown in *Table 8* in order to achieve the different Heating Labels. The annual efficiency for boilers and the Seasonal Performance Factor (SPF, average COP) for different types of heat pumps may be according to the table values in the Norwegian standard NS3031 (2007) or calculated according to the type and size of equipment, operating conditions etc.

Table 8 Energy certificate, Heating label – grading scale from dark green to dark red (NVE, 2013).

🟩	🟩	🟨	🟧	🟥
30,0 %	47,5 %	65,0 %	82,5 %	100,0 %

Heating Labels for different types of heat pump systems may be as follows:

- < 30,0-47,5 % – dark green or light green label – brine-to-water or water-to-water heat pump systems + solar collectors + electric boiler as peak load
- < 47,5-65,0 % – light green or yellow label – brine-to-water or water-to-water heat pump systems + electric boiler as peak load
- < 65-82,5 % – yellow or orange label – air-to-water heat pump + el. boiler as peak load
- Orange or red label – air-to-air heat pump combined + wood burning stove or electric heating systems as peak load

Figure 6 shows, as an example, the Energy Certificate of a high-performance passive house building or ZEB with Energy Label **A** and the best possible Heating Label, **dark green**.

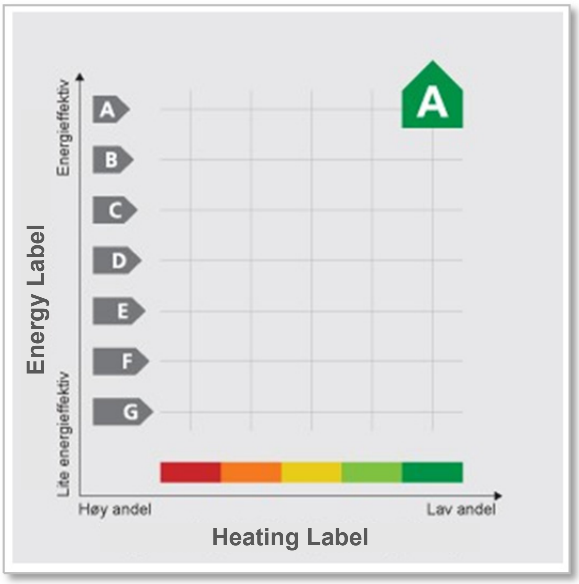


Figure 6 Example – energy certificate of a passive house or ZEB using an environmentally benign heating system. Energy Label – A, Heating Label – dark green (NVE, 2013).

2.1.3 Renewable Energy Sources for Heating and Cooling

The Norwegian building code (TEK10, 2007) and the Norwegian passive house standards NS 3700 (2010) and NS 3701 (2012) have minimum requirements regarding the share of renewable energy for the heating system. The minimum limits are as follows:

- TEK10 – buildings with a heated area < 500 m² – **40 %** of the annual heating demands should be covered by a renewable heat source
- TEK10 – buildings with a heated area > 500 m² – **60 %** renewable energy
- NS 3700 – residential buildings – minimum **50 %** of the annual energy demand for hot water heating should be covered by a renewable heat source
- NS 3701 – **60 %** renewable energy (as TEK10)

The Norwegian building code will be updated in 2015 (TEK15), and the minimum limits regarding the use of renewable energy for heating of the buildings may be increased from the current level.

2.2 Market State of High-Performance Buildings

There is a rapidly increasing interest in low-energy, passive houses and ZEB in Norway. Together with The National Directorate for Building Quality (Direktoratet for byggkvalitet,), a number of stakeholders play an important role in developing the future Norwegian market and technology for passive houses/buildings including The Norwegian University of Science and Technology (Faculty of Architecture and Fine Art), SINTEF (Buildings and Infrastructure, Energy), The Directorate for Public Construction and Property (Statsbygg), The Norwegian Defense Estates Agency (Forvarsbygg), The Norwegian Housing Bank (Husbanken), Entra Eiendom (state-owned), housing construction companies, contractors (e.g. Skanska) as well as co-operative building societies and development companies for housing constructions.

The National Association of Norwegian Architects (NAL) also deals with low-energy and passive buildings through the programme "Ecobox" [1]. Their objectives are to strengthen the environmental competence of architects as well as interdisciplinary cooperation within the overall construction trade. NAL/Ecobox plays a major role in order to implement NAL’s strategy on sustainable development within architecture. This project brings a wide database of low-energy and passive houses examples.

Only 2% of the Norwegian single-family houses, 3 % of the apartment buildings (block of flats) and 4 % of the office buildings have currently achieved the **A** and **B** category/label, which is more or less equivalent to the Norwegian passive house standard (NS3700/01) or better.

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[1] *www. arkitektur.no/?nid=5699*

Table 9 Number of constructed buildings by Dec. 2012 classified based on their energy labelling

Type of building	A	B	C	D	E	F	G	Total examined bldgs.
Small houses	*286*	*2,482*	12,047	36,345	32,316	38,003	18,053	139,532
Apartments	*219*	*2,792*	9,302	24,912	16,534	26,293	20,928	100,980
Kinder gardens	*17*	*50*	76	89	68	62	5	367
Hotels	*8*	*55*	108	128	81	138	26	544
Offices	*24*	*169*	901	1,635	1,004	860	208	4,801
Light industry, workshops	*15*	*168*	456	601	487	549	215	2,491
Nursing homes and hospitals	*1*	*46*	132	143	73	43	7	445
Schools and universities	*9*	*84*	327	576	391	296	60	1,819

2.2.1 Statistics of Energy-Efficient Buildings

The Norwegian statistics office has worked out the following graphs regarding energy performance in buildings. The data has been mostly obtained from the information given in finn.no (website where people advertise buildings for sale). For that, the sample is not representative as statistic sample, but is the only existing statistic including high performance buildings.

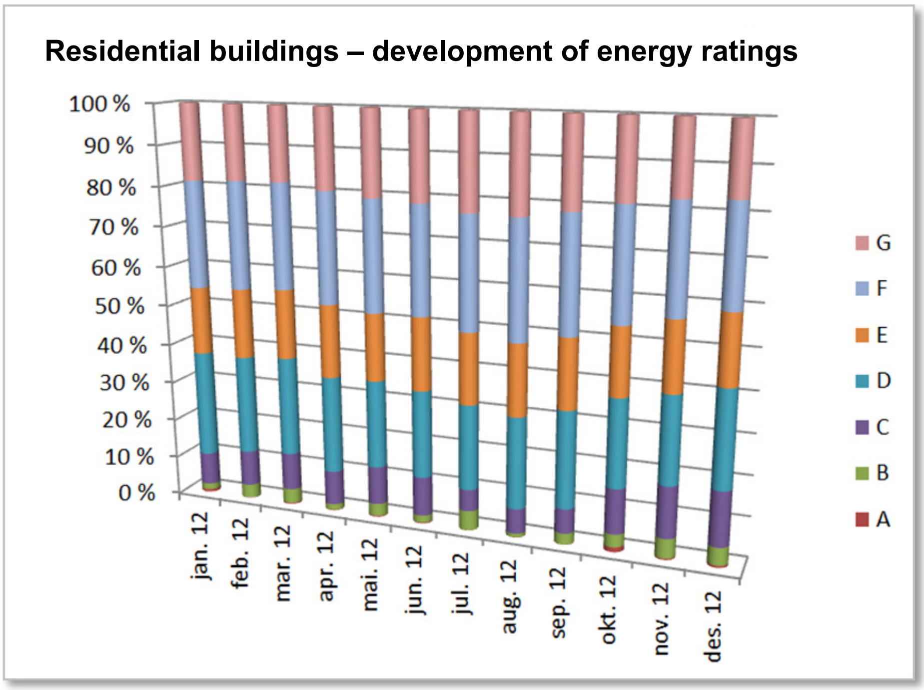


Figure 7 Development of energy ratings for Norwegian residential buildings (NVE, 2013).

For residential buildings, the Norwegian building stock is old and the previous standards were not as strict as the current. Consequently, a large share of the buildings achieves Energy Mark F or G. Buildings that are not officially rated are given label G by default.

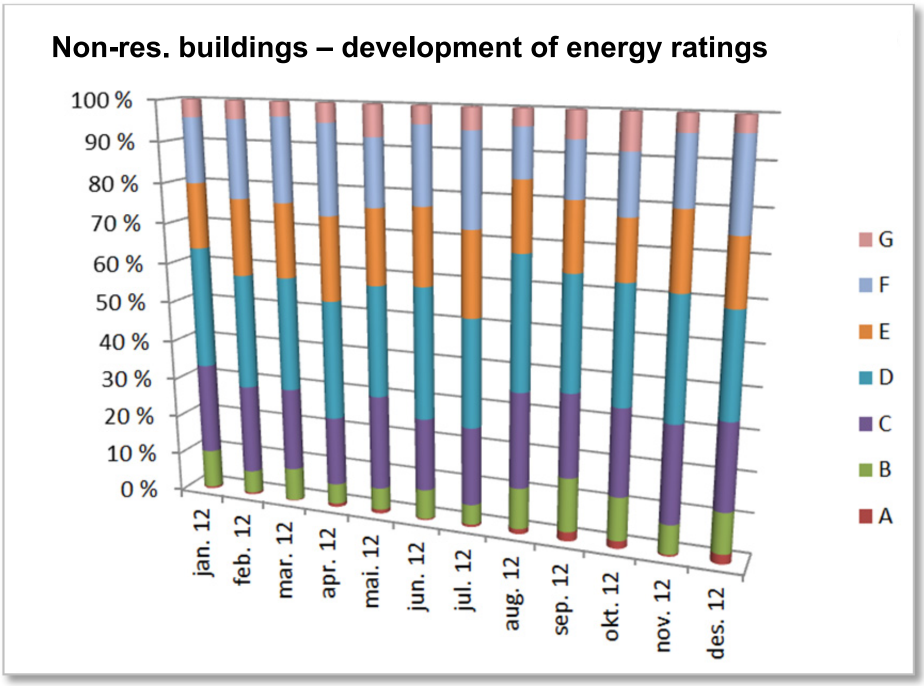


Figure 8 Development of energy ratings for Norwegian non-residential buildings (NVE, 2013).

Non-residential buildings are normally rated by professionals. That justifies the increased share of "D" buildings which are more corresponding to the normal age of non-residential buildings and their energy performance.

2.2.2 Available Performance Data and Monitoring Results from ZEB

So far no data regarding ZEB is available as monitoring results since all the prototype buildings are under development.

2.3 Market state of Nearly or Net Zero energy buildings

2.3.1 Annual Installation Rates of Heat Pumps 1991-2011

At present, 650,000 to 700,000 heat pumps have been installed in Norway from the 1900ies (Novap, 2013). The estimated annual heat supply from Norwegian heat pumps is assessed at 8-9 TWh/a. It is not clear if the number of heat pumps includes or excludes heat pumps that have broken down and are no longer operative.

Figure 9 shows the annual installation rate for heat pumps in Norway during the period 1991 to 2011 residential and non residential (Novap, 2013). *Figure 10* shows the percentage distribution in terms of heat source and sink – ventilation air, brine-to-water, air-to-water and air-to-air heat pumps.

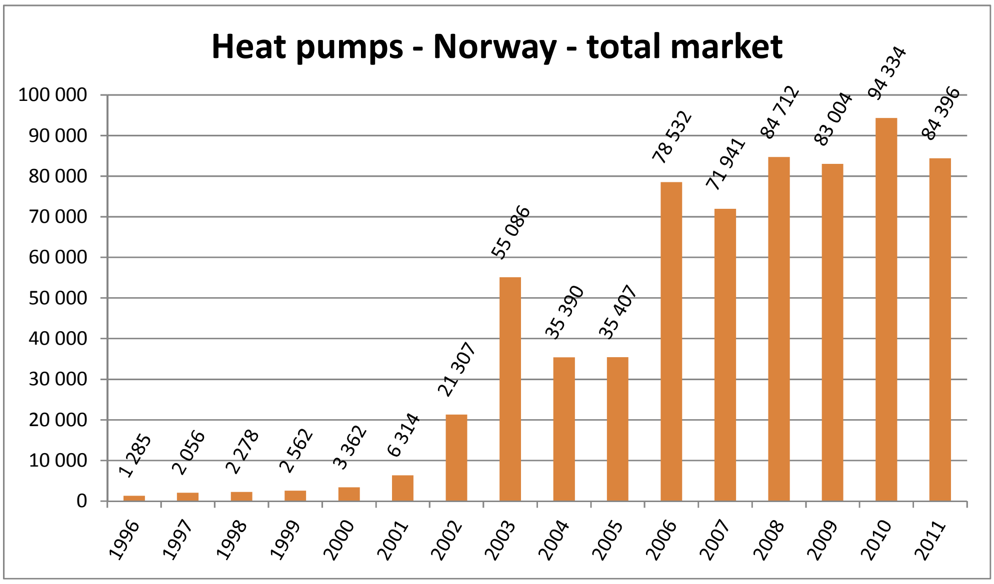


Figure 9 Number of annual installation rate for Norwegian heat pumps, 1991-2011 (Novap, 2013).

Heat pumps have become one of the main renewable options for heating/cooling in residential and non-residential passive houses/buildings. However, there exists no detailed statistics on the number and types of heat pumps installed in this market segment. Reference is made to *Section 4* for information about best practice examples of realised residential and non-residential ZEBs with heat pump systems.

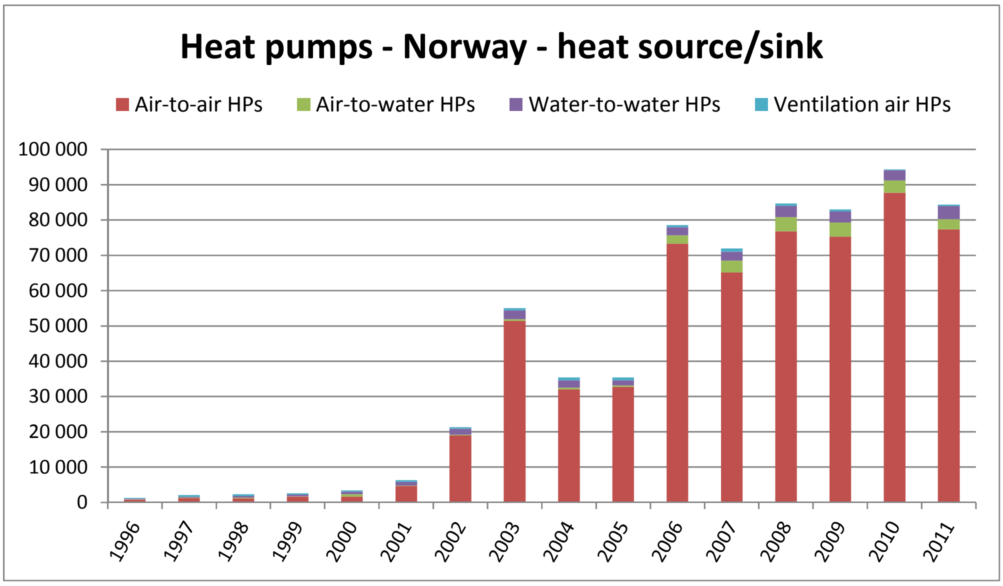


Figure 10 Number shares of the annual installation rate for heat pumps in Norway during the period 1996-2011 sorted by heat sink and/or heat source (Novap, 2013).

After a minimal Norwegian heat pump market during the 1990'ies, the annual installation rate has now stabilized at 80,000-85,000 installations per annum. The main reasons for this are:

- Increasing energy prices – strengthens the competitive power of heat pumps vs. conventional heating systems, e.g. el. heating systems and oil-/gas-/pellet-fired boilers.

- Relatively low interest rate – favourable for capital intensive installations such as heat pump systems.
- Establishment of Enova SF, The main mission of Enova SF is to contribute to environmentally sound and rational end-use and production of energy relying on financial instruments and incentives to stimulate market actors and mechanisms to achieve national energy policy goals. The main objectives are improved energy efficiency, more flexibility in the energy supply (decreased dependence on direct electricity for heating), and an increased share of renewable energy sources. – e.g. more focus on hydronic heat distribution systems in buildings, small- and large-scale district heating systems and heat pumps.

  Enova is subsidising the construction of innovative demonstration projects in full size under real operation. These projects must show high energy efficiency or increase the production of renewable energies. The goal is to introduce new energy saving technologies that otherwise would require excessive investments.

  Enova offers subsidies to building owners and industrial companies that want to install heating plants for heating of buildings and manufacturing purposes based on renewable energy sources. The renewable sources include biomass-fired systems based on wood chips, briquettes or pellets, solar heating systems and different types of heat pumps (water-to-water, brine-to-water, air-to-water). The maximum support level is NOK 100 000 per project (approx. 15.000 €). Enova uses predefined funding rates to calculate the maximum support level. The rates are only based on the installed thermal power of the biomass-fired boiler or heat pump. The application should only affect the base load source included. The maximum support levels in NOK per kW are – wood 1700, briquettes 1700, pellets 1700, heat pumps (air-to-water) 1100, and heat pump (water/brine-to-water) 1600.
- Hydronic floor heating systems, which are installed in many residential and non-residential buildings, facilitates the installation of air-to-water, water-to-water and brine-to-water heat pumps.
- Implementation of the Norwegian Standard NS 3700 and NS3701. In order to implement NS3700 and NS3701, Oslo municipality has worked out a new mandate where all the new municipality buildings from 2014 must meet the passive house standard. Moreover, the Ministry of Local Government and Regional Development wants to reduce the energy demand for new future buildings to passive house level by 2020.

2.3.2 Field Experience with the Operated NZEB

So far no data regarding ZEB is available as monitoring results since all the prototype buildings are under development to be finished by the end of this year 2013.

2.3.3 Strategies According to Building Standards (New Buildings, Retrofitting) and Application (Residential, Commercial, Education etc.)

Presently, only a few NZEBs have been constructed or are under construction in Norway. A summary of the most important projects is shown in *Table 10* pointing out some details of the building and its location, some information regarding their strategies for the ventilation system (in several cases used also as cooling system), selected heating systems and electricity generation. Most of the Norwegian ZEB buildings utilize heat pumps for heating and cooling, and the systems cover the entire or a large share of the cooling demand by free cooling from the heat source.

Table 10 Information about the most important Norwegian NZEB. HP=heat pump, ground-source heat pump=GSHP, Air-to-water heat pump=AWHP, seawater HP=SWHP

Building – location	Bldg. info	Ventilation	Util. of thermal mass	Heating system	El. production
Powerhouse1, Trondheim (Thyholt, 2012)	Large office building, Plus house.	DCV + control recovery	Yes	SWHP	PV
Marienlyst skole, Drammen (Dokka, 2012)	School 6450m^2 Passive house	Exposed thermal mass and natural ventilation	Yes	Local district heating based on HP	n/a
Haakonsvern, Bergen (Andresen, 2012)	Office bldg. 2000m^2 ZEB-O	Window night ventilation. Recovery (VAV) active supply diffuser	PCM	SWHP	PV
Statnett, Trondheim (Smiths, 2012)	Office bldg. 2025 m^2 Passive house	VAV SPF<1,5. Heat recovery 0.8 Central and extract in atrium	N/A	AWHP Cooling of exhaust air	n/a
Skarpnes, Arendal (Thyholt et al, 2012)	37 dwellings ZEB-O (passive house standard NS 3700)	High-efficient heat recovery (more than 90 % for the small houses) Pre-heating and –cooling of ventilation air via energy wells in the small houses Local ventilation plants in the flats	Yes	GSHP Solar collectors Possible heat recovery from grey water	PV
Powerhouse #2, Oslo	Renovation of 2 office blocks Plus energy.	DCV incl. heat recovery	Yes	GSHP Simple hydronic heating system	PV
Mulitkomfort, Larvik	Single family house ZEB-COM	CAV incl. heat recovery	To some extent	GSHP Simple hydronic heating system	PV
Depotbygget Haakonsvern, Bergen	Small office building ZEB-O÷EQ	DCV incl. heat recovery	Yes	SWHP coupled to system for whole of Håkonsvern) Simple hydronic heating system with radiators.	PV

2.4 Building envelope (passive) technologies

2.4.1 Extent of investment in the building envelope

So far no data regarding real investment costs for NZEB in Norway are available since only some prototype buildings have been developed where the costs were not the major concern due to governmental subsidies.

2.4.2 Application of passive operation of source and sink systems

Passive operation of source and sink systems include passive cooling like natural ventilation with cross flow, cooling towers, ground-source heat exchangers, utilization of "cold" seawater or groundwater and strategies for using solar gains for heating purposes.

One of the major challenges of NZEB is the requirement for space cooling. This cooling need is due to the high insulation and airtightness of the buildings combined with solar gains and internal heat gains. This is particularly a challenge in office buildings due to the increased internal heat gains. Cooling and overheating in residences have traditionally not been considered as a design challenge and therefore the available cooling solutions are very limited and often too simplified. Many house owners when challenged by overheating install an air conditioning system that increase the energy use instead of looking at energy efficient solutions such as Ventilative cooling and passive cooling techniques (Heiselberg, 2012).

In office buildings sometimes the chosen solution comes from using outdoor air into the mechanical ventilation system. This, due to the risk of draught and to damage the thermal comfort, leads to and reduction of the cooling capacity and increase of air flow rates, increasing therefore the energy use. For natural ventilated buildings these limitations may not apply and the use of Ventilative cooling together with natural ventilation could lead to a significant energy reduction.

Being the NZEB heavily insulated, the load from occupancy and solar irradiation may vary dramatically between occupied and unoccupied rooms and the use of thermal mass as heat storage for reduction of cooling demand in combination with night cooling will gain importance in the coming years.

Therefore in Norway three are the trends for cooling:

1. Cooling by use of treated air, supplied at a temperature lower than the room temperature via the ventilation system of the building
2. Cooling of the room by use of cold surfaces such as cooling baffles, convectors, chilled beams, fan-coils etc.
3. Night cooling. Whenever having available thermal mass, the walls/ceilings/floor can be cooled down with chill night-air and by that reduce the cooling demand during daytime. Depending on the type of material, thermal capacity and thermal emissivity, the thermal mass will be cooled more or less releasing the cooling at a different speed.

Passive cooling methods use the natural convection such as chilled ceiling. Active cooling methods use force convection with cooling baffles of fan coils. The normal used secondary fluid is water. The water temperature should be above the dew point of the air in order to avoid condensation of the air on the surface of the cooling system. The cooling capacity from some cooling baffles can cover a big share of the cooling demand. Both cooling baffles and chilled beams are produced by several Norwegian manufacturers including Trox, Swegon, Yyt and Fläktwoods.

Solar shading is a very important measure for maintaining an acceptable indoor air temperature and reducing cooling loads in residential and non-residential passive houses and ZEBs. However in buildings with considerable internal heat gains, e.g. in office buildings, solar shading is not sufficient to maintain the required indoor air temperature, and some kind of external cooling is required.

3 HVAC Technologies Applied in Realised NZEB

3.1 Introduction

Norway has not yet developed a standard for Near Zero Emission/Energy Buildings (NZEBs). *Table 11* shows a summary regarding the demands for ventilation and air-tightness in ZEB. It is expected that these values will be "tightened up" in the coming standards.

Table 11 Guidelines and requirements for ZEB.

Ventilation requirements	**Norway**
Kitchen	10(30)l/s
Bad/shower room with opening possibilities	15l/s
Bad/shower room without opening possibilities	30l/s
Toilet	10l/s
Room	7l/(s·p)
Minimum sensible heat recovery	80 %
Minimum latent heat recovery	N/A
Minimum total heat recovery	N/A
ACH	0.6
Ventilation specific fan power[kW/(m³/s)]	>1.5
Air tightness in NZEB. Tested at a pressure difference of 50 Pa [l/s per m²]	0.6

** for ventilation systems in single dwellings*

Table 12 shows the development of the building code and building standards from TEK 1997 to the new Norwegian passive house standard NS 3700 (2010).

Table 12 ***Comparison of important requirements in the Norwegian building codes of 1997 (TEK97) and 2007/10 (TEK07/10) and the new passive house standard NS 3700 (residences). LEH=low-energy house, PH=passive house, res.=residential, non-res.=non-residential, fl.=floors***

Measure	**TEK97**	**TEK07/10**	**LEH1**	**LEH2**	**PH**	**Comments**
U-value – wall *W/(m²K)*	0.22	0.18	0.18	0.22	0.15	From 20 to 25 cm insulation thickness
U-value – ceiling *W/(m²K)*	0.15	0.13	0.13	0.18	0.13	From 20-30 to 30-35 cm insulation thickness
U-value – floor *W/(m²K)*	0.15	0.15	0.15	0.18	0.15	Unchanged
U-value – windows *W/(m²K)*	1.60	1.20	1.20	1.60	0.80	Double-glazed windows, argon charged, low emission coating, insulated frame
Air tightness and resulting air change rate of building envelope	4.0 1/h – res. 3.0 1/h – 2 fl. 1.5 1/h – > 2 fl.	1.5 1/h	0.33l/h	0.33l/h	0.33l/h	Stricter requirements regarding air-tightness for res. and non-res. bldgs..max.2 floors
Ventilation – Specific Fan Power *kW/(m³/s)*	No req.	Non-res. – 2.0/1.0 Res. – 2.5	< 2.0	-	< 1.5	50% reduced SPF during night for non-res. buildings
Ventilation – temperature efficiency, heat recovery	Non-res. 60% Res. – no req.	70%	70%	-	80%	The same requirements in res. and non-res. bldgs. in TEK07

The trend of further constrains to the technical requirements for the building envelope and ventilation and heating system and heat losses is expected to continue in order to achieve further reduction in energy use. A big discussion has started in Norway regarding which strategy is the most profitable way of reducing the energy use in buildings. The constant improvement of the building envelope by e.g. increasing the insulation thickness is no longer regarded the only measure, and increasing energy-efficiency and cost-efficiency for heating and cooling of the buildings is getting more attention.

3.2 Loads of High Performance Buildings in Norway

3.2.1 Short Characterisation of Loads in Norway (Residential/light Commercial)

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 11 to *Figure 14* shows 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 NS3700/3701 (2010, 2012). 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 (Smedegård and Stene, 2013).

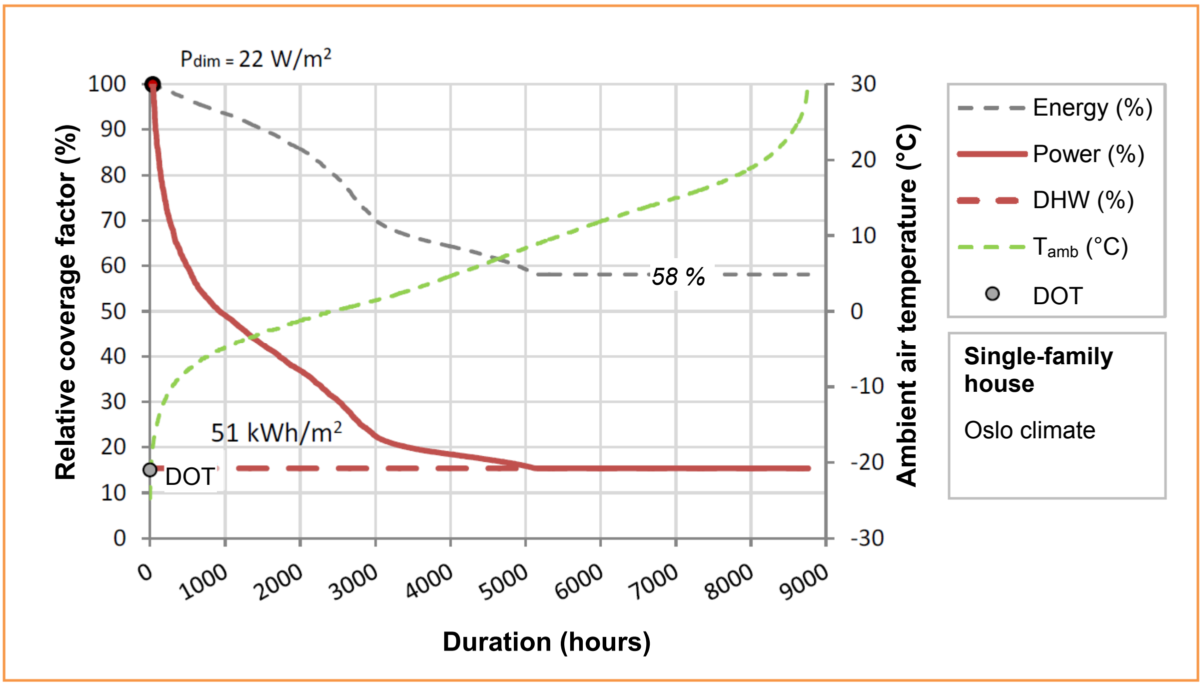


Figure 11 Example A – calculated thermal power duration curve for a 2-storey 128 m² residential building of passive house standard. Oslo climate (Smedegård and Stene, 2013).

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.

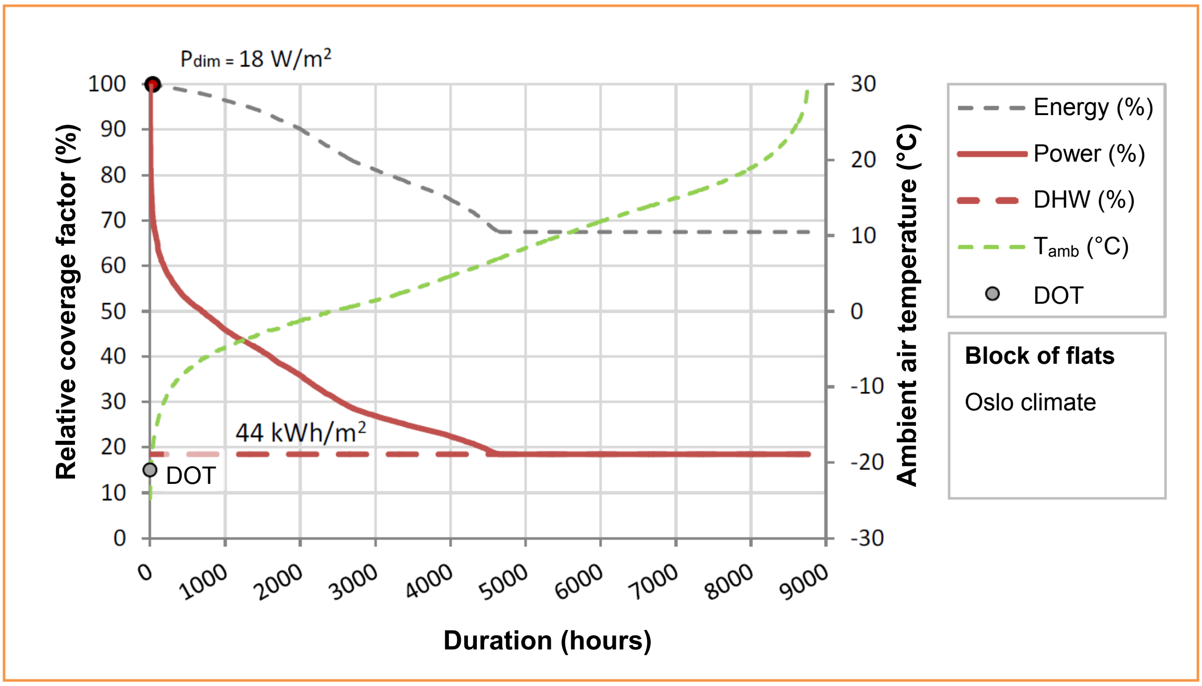


Figure 12 Example B – calculated thermal power duration curve for a 4-storey 2240 m² block of flats of passive house standard. Oslo climate (Smedegård and Stene, 2013).

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.

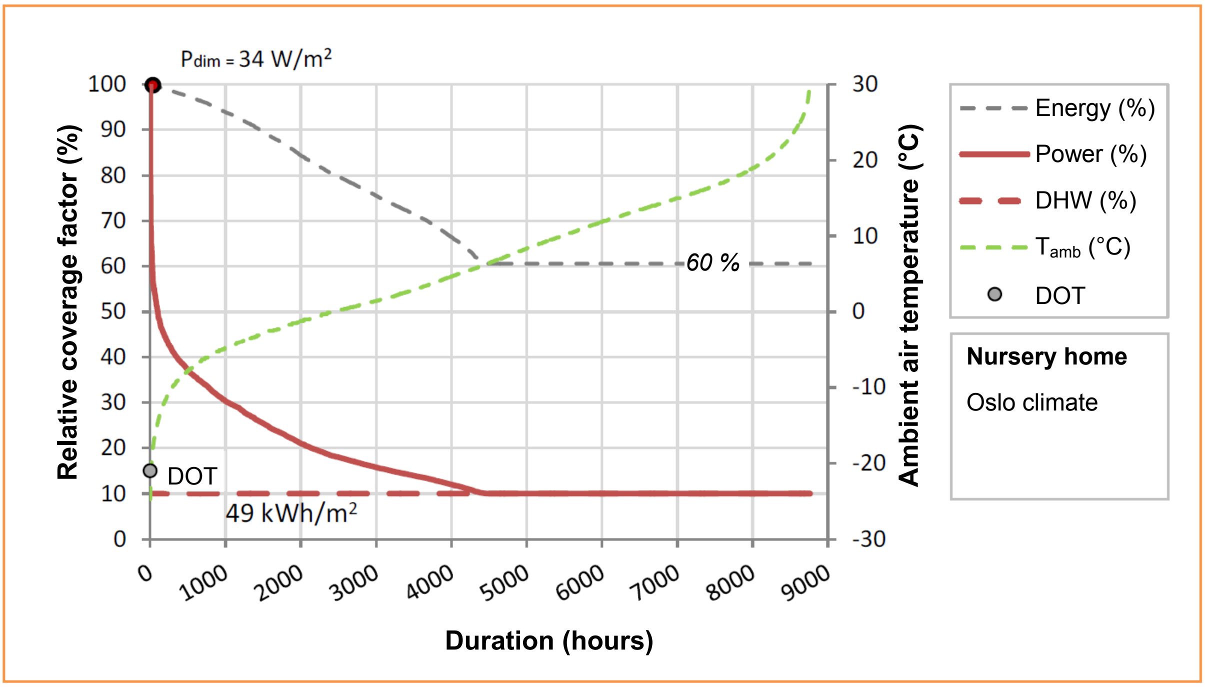


Figure 13 Example C – calculated thermal power duration curve for a 2-storey 2400 m² nursery home of passive house standard. Oslo climate (Smedegård and Stene, 2013).

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.

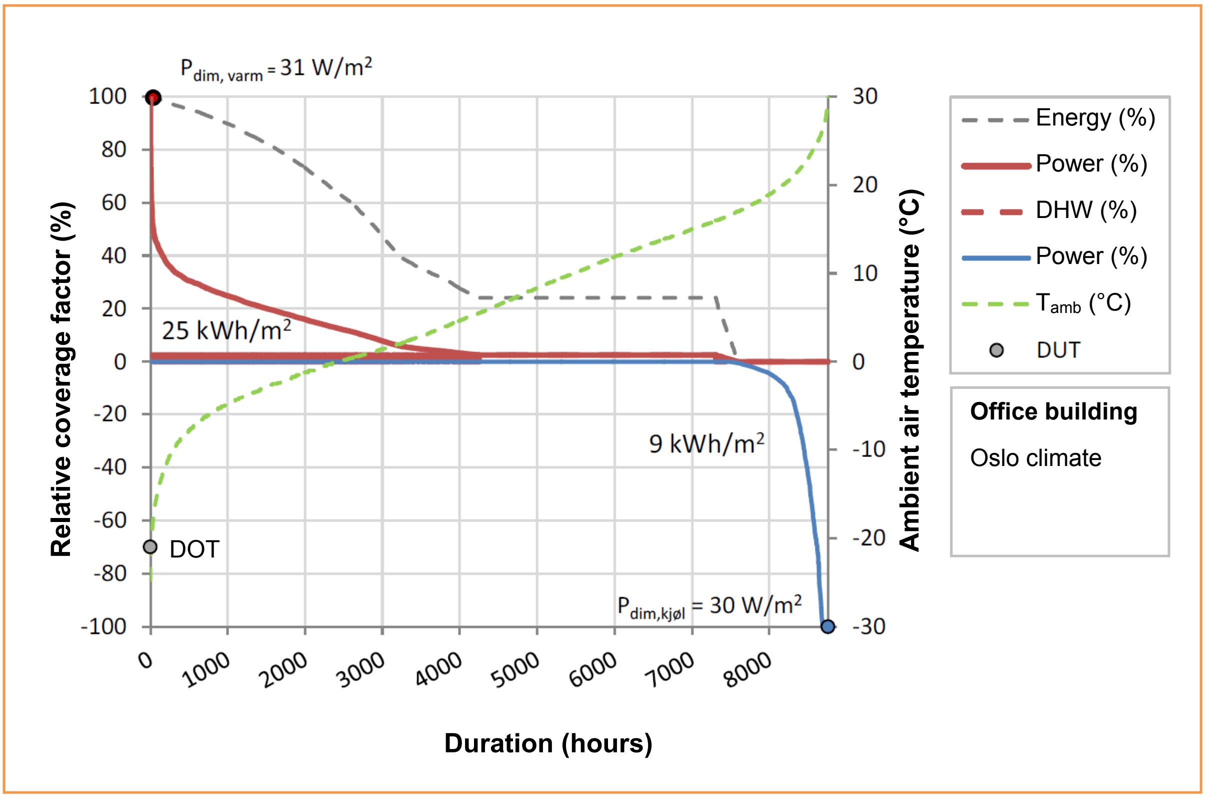


Figure 14 Example D – calculated thermal power duration curves (red-heating, blue-cooling) for a 3-storey 3600 m² office building of passive house standard. Oslo climate (Smedegård and Stene, 2013).

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 approx. *9 kWh/(m²a)*, respectively. The DHW heating demand is negligible.

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 curve of the building. An optimized design will lead to the lowest possible annual costs (€/a) for the heating and cooling system as well as long lifetime for the equipment.

3.3 Active HVAC Technologies – Heat Pumps and Heat Exchangers

The presentation on heat pumps has been divided into heat pump systems for residential applications and non-residential applications since due to the large differences in heating and cooling loads, heat distribution systems, heat pump equipment, dimensioning of the systems, control strategies and system complexity.

3.3.1 Heat Pumps – Residential Systems

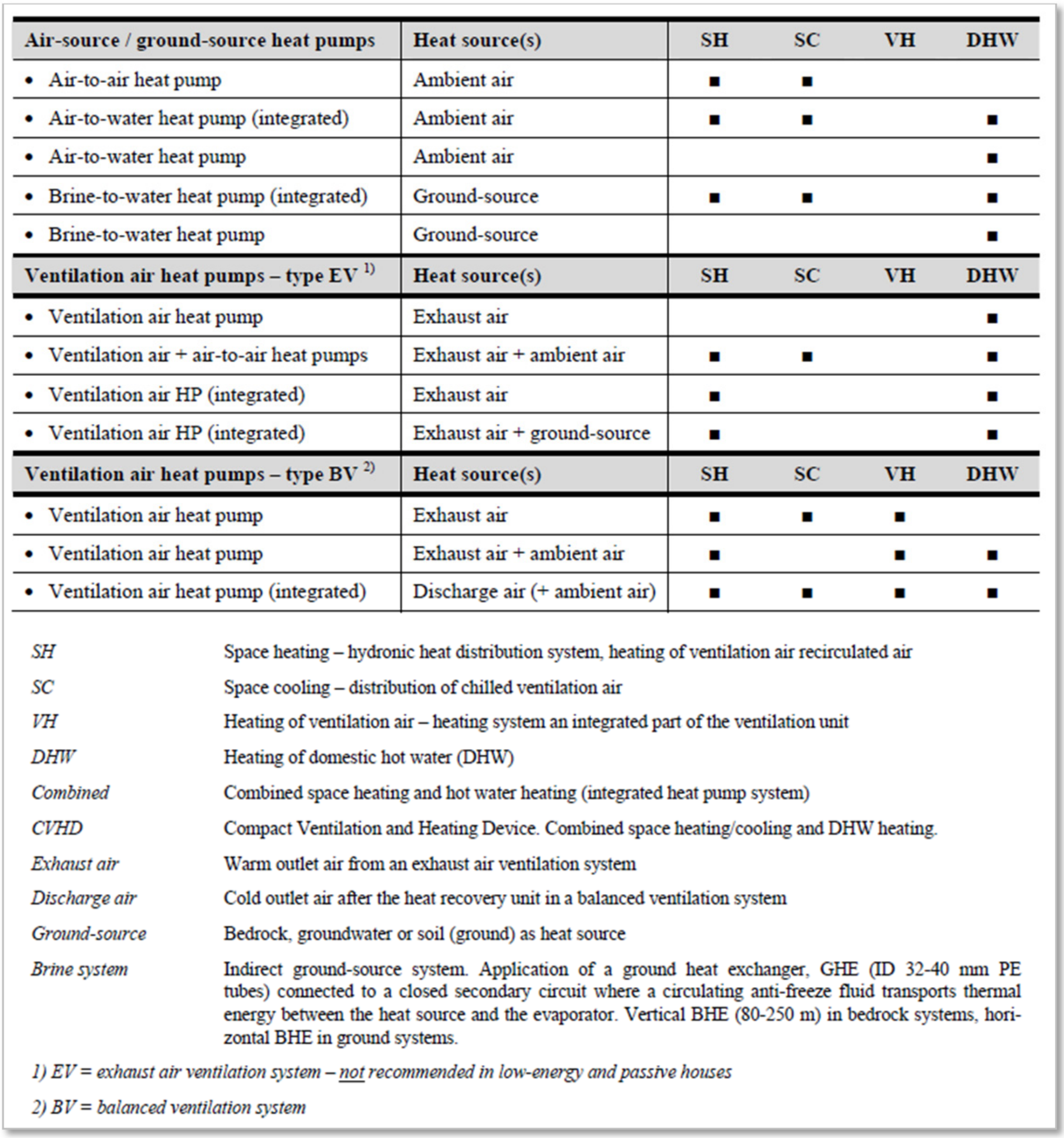
Residential buildings include single- and multi-family houses, row houses, block of flats and apartment buildings. For passive house buildings and ZEBs the annual heating demand for hot water heating typically constitutes 50 to 80 % of the total annual heating demand.

The different heat pump systems/types for heating (and cooling) of residential passive houses can be classified as follows:

- Available heat source(s)
    - Ambient air
    - Ventilation air (exhaust ventilation system or balanced ventilation system),
    - Ground/soil (horizontal system) and bedrock (vertical system)
    - Water source (sea water, ground water, lake water, grey water)
- Heating modes – system complexity
    - Integrated systems – space heating and domestic hot water (DHW) heating
        - Air-to-water, brine-to-water and water-to-water heat pumps
    - Space heating systems
        - Air-to-air heat pumps
    - Heat pump water heater (HPWH) systems – as a separate installation in e.g. block of flats and apartment buildings
        - Air-to-water, brine-to-water and water-to-water heat pumps
- Type of heat distribution system – space heating
    - Heating of ventilation air through centralized balanced ventilation system
        - Integrated/compact unit
    - Hydronic heat distribution system with floor heating, radiators, convectors
        - Air-to-water, brine-to-water and water-to-water heat pumps
    - Recirculation and heating of air directly in the rooms
        - Air-to-air heat pumps
- Type of cooling distribution systems
    - Cooling of ventilation air
        - Mechanical cooling by heat pump unit in e.g. DHW mode
    - Space cooling
        - Convectors connected to free cooling source (ground, bedrock)
- Preheating and precooling of air and/or ventilation air
    - Ground heat exchanger (GHE)

Heat pump types of current interest for residential passive houses have been described in the extensive Norwegian IEA HPP Annex 32 report (Alonso and Stene, 2010), *Table 13.*

Table 13 Classification of residential heat pumps for passive houses (Alonso and Stene, 2010).



Air-source / ground-source heat pumps	**Heat source(s)**	**SH**	**SC**	**VH**	**DHW**
• Air-to-air heat pump	Ambient air	■	■		
• Air-to-water heat pump (integrated)	Ambient air	■	■		■
• Air-to-water heat pump	Ambient air				■
• Brine-to-water heat pump (integrated)	Ground-source	■	■		■
• Brine-to-water heat pump	Ground-source				■
Ventilation air heat pumps – type EV 1)	**Heat source(s)**	**SH**	**SC**	**VH**	**DHW**
• Ventilation air heat pump	Exhaust air				■
• Ventilation air + air-to-air heat pumps	Exhaust air + ambient air	■	■		■
• Ventilation air HP (integrated)	Exhaust air	■			■
• Ventilation air HP (integrated)	Exhaust air + ground-source	■			■
Ventilation air heat pumps – type BV 2)	**Heat source(s)**	**SH**	**SC**	**VH**	**DHW**
• Ventilation air heat pump	Exhaust air	■	■	■	
• Ventilation air heat pump	Exhaust air + ambient air	■		■	■
• Ventilation air heat pump (integrated)	Discharge air (+ ambient air)	■	■	■	■

SH	Space heating – hydronic heat distribution system, heating of ventilation air recirculated air
SC	Space cooling – distribution of chilled ventilation air
VH	Heating of ventilation air – heating system an integrated part of the ventilation unit
DHW	Heating of domestic hot water (DHW)
Combined	Combined space heating and hot water heating (integrated heat pump system)
CVHD	Compact Ventilation and Heating Device. Combined space heating/cooling and DHW heating.
Exhaust air	Warm outlet air from an exhaust air ventilation system
Discharge air	Cold outlet air after the heat recovery unit in a balanced ventilation system
Ground-source	Bedrock, groundwater or soil (ground) as heat source
Brine system	Indirect ground-source system. Application of a ground heat exchanger, GHE (ID 32-40 mm PE tubes) connected to a closed secondary circuit where a circulating anti-freeze fluid transports thermal energy between the heat source and the evaporator. Vertical BHE (80-250 m) in bedrock systems, horizontal BHE in ground systems.

1) EV = exhaust air ventilation system – not recommended in low-energy and passive houses

2) BV = balanced ventilation system

European, Asian and American heat pump and HVAC equipment manufacturers are to an increasing degree developing products for the residential passive house marked including:

- Integrated air-to-water heat pumps for combined space heating and DHW heating – nominal heating capacity from 3-4 kW
- Integrated brine-to-water and water-to-water heat pumps for combined space heating and DHW heating – nominal heating capacity from 3-4 kW
- Compact heating and ventilation devices (CVHD[2]) with one or two integrated heat pump units with ventilation air and possible one or two additional heat source (ambient air, ground) – some units have been passive house approved, *Figure 16*, *Figure* 17

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[2] *CVHD – comprises a complete ventilation unit (fans, filters, heat recovery heat exchanger etc.), domestic hot water (DHW) storage tank, electric immersion heaters and one or two integrated heat pump units.*

- Air-to-water and brine-to-water CO_2 heat pump water heaters (carbon dioxide as the working fluid) – nominal heating capacity from 6 kW to several hundred kW, *Figure 15*
- Integrated air-to-water and brine-to-water CO_2 heat pumps for combined space heating and DHW heating – nominal heating capacity from about 5 kW to 35 kW
- Prefabricated grey water heat exchanger systems
- Prefabricated components for ground heat exchangers for preheating and precooling of ventilation air or ambient air for air-source heat pumps, *Figure 17*
- Permanent magnet motors for compressors, fans and pumps – achieves a very high efficiency and can be operated over a wide rpm range (Fahlén, 2012), *Figure 18*
- Inverter controlled compressors – superior controllability and higher COP compared to intermittent operation – applied in many air-to-water heat pumps as well as some CVHD units and water/brine-to-water heat pump units. *Figure 19* shows examples of measured COPs for heat pumps with three different motor topologies (Fahlén, 2012)
- Inverter controlled pumps and fans – improved controllability and reduced energy use

Figure 15 Air-to-water and brine-to-water CO_2 heat HPWH from Asian and European manufacturers.

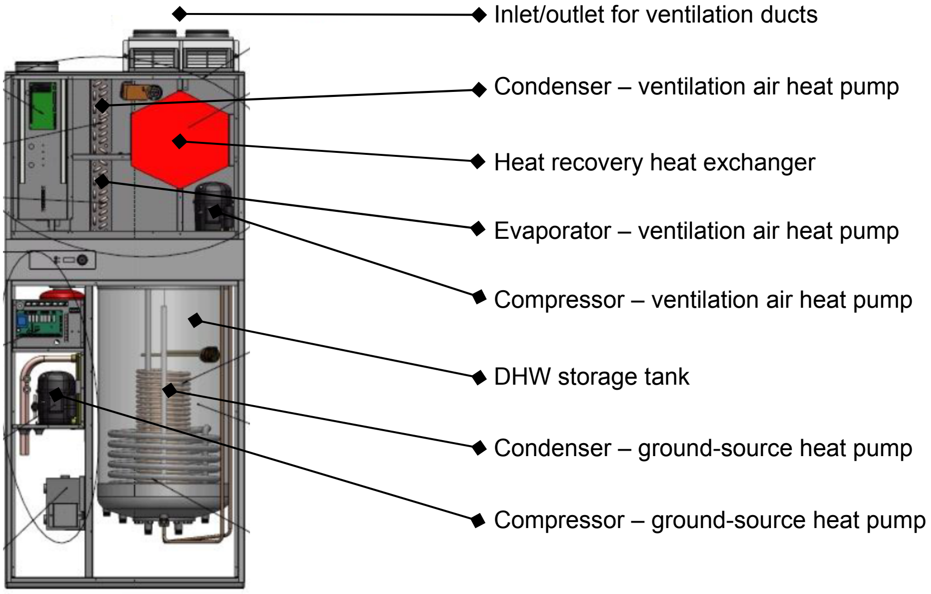


Figure 16 Passive house approved compact heating and ventilation device (CVHD) with two integrated heat pump units utilizing ventilation air and ground (soil) as heat sources (2013).

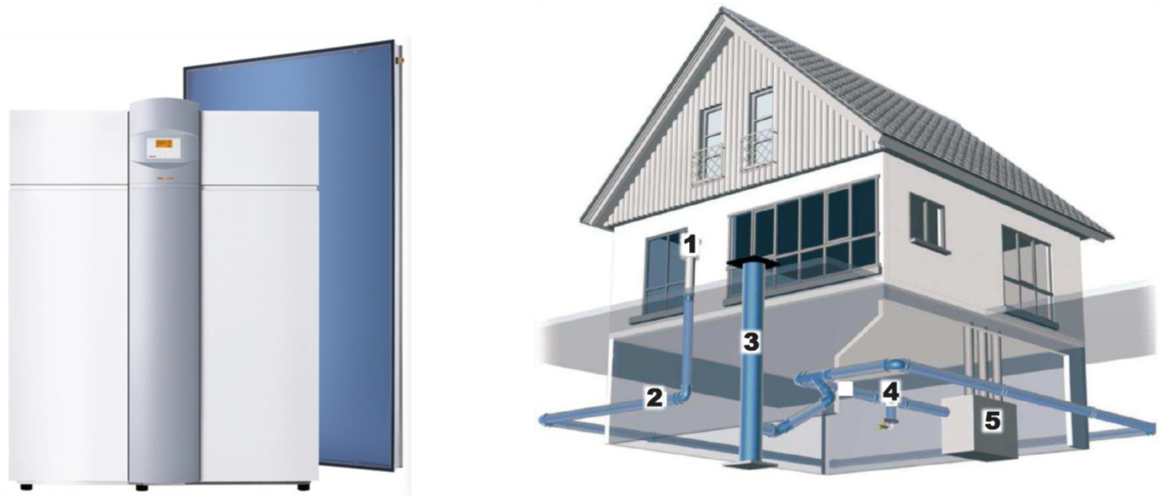


Figure 17 Left – passive house approved compact heating and ventilation device (CVHD) with integrated heat pump unit utilizing ventilation air and ambient air as heat sources (2013). Right – prefabricated ground heat exchanger system for preheating/precooling of amb. air.

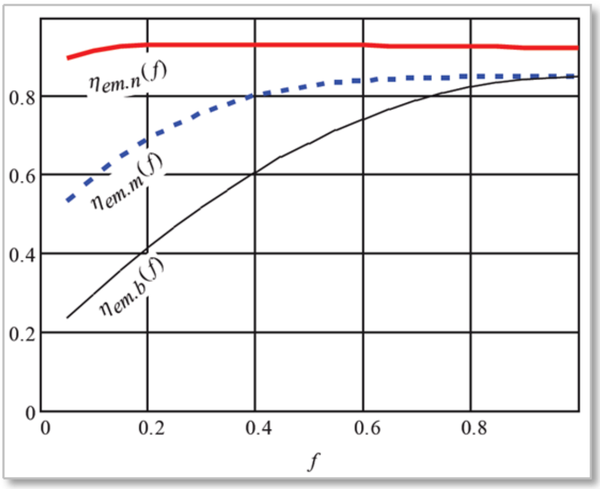


Figure 18 motor efficiency (η_{em}) as a function of the fractional capacity/rpm ($0 \leq f \leq 1$). Index *b* represents a base case with today's standard motor, *m* corresponds to modern, state-of-the-art motors and *n* is a newly developed 1 kW motor (Fahlén, 2012).

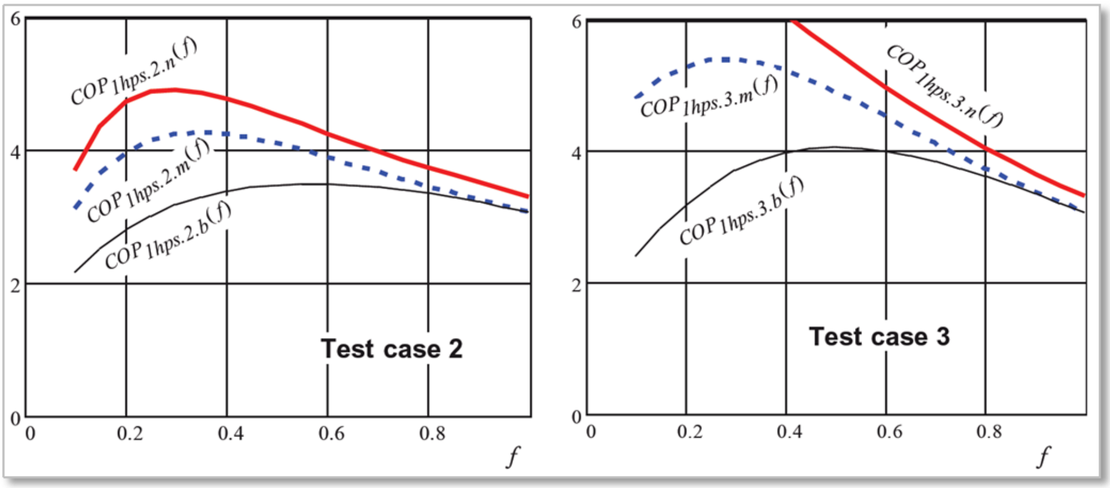


Figure 19 COP for an air-to-air heat pump system (COP_{hps}) as function of the fractional heating capacity ($0 \leq f \leq 1$) for 3 alternative motor types, ref. Figure 18. Input power to the evaporator and condenser fans are constant and variable in Test Case 2 and 3, resp. (Fahlén, 2012).

3.3.2 Heat Pumps – Non-residential Systems

For office buildings and commercial buildings the annual heating demand for hot water heating constitutes less than 5 % of the total annual heating demand, and the heat pump system is designed according to the space heating/cooling demand. In hotels, nursery homes, hospitals and sport centers, heating of hot water is the dominating thermal load. In these kinds of buildings a possible design is to use two separate heat pump systems, one for space heating and space cooling, and one heat pump water heater e.g. with CO_2 as the working flud.

In most cases the heat pump systems is designed as the base load for space heating, and boilers (el.boiler, gas/oil-fired boiler, pellet boiler) or district heating is used as peak load. If the heat pump is utilizing seawater, ground water or bedrock as heat source, the system should be designed to maximize free cooling. Ambient air can during parts of the year be used for free cooling via the ventilation system of the building. The electricity driving energy for the heat pump/chillers and auxiliary equipment should preferably come from renewable sources including hydro power, windpower and/or solar cell modules.

Due to the advanced building envelope in passive houses and NZEBs, the technical installations incl. heating and cooling systems, should be on the same technical level in order to minimize energy consumption. For heat pump and chillers the main focus should be on optimum load management and energy efficient operation. General design recommendations for heat pump units/chillers in passive house buildings and NZEBs include:

- Energy efficient working fluids
  - Ammonia (R717, NH_3)
  - Hydrocarbons, e.g. propane (R290, C_3H_8)
  - Carbon dioxide (R744, CO_2)
  - R134a (GPW=1300)
- Evaporator and condensers with large UA-value
  - High-efficiency heat exchangers with large surfaces
- Energy efficient compressors
  - Reciprocating – inverter control (*Figure 20*) or suction valve control
  - Screw – inverter control, v_i-control recommended (*Figure 20*)
  - Scroll – inverter control or intermittent control (buffer tank)
- Energy efficient evaporators
  - Direct expansion system with electronic expansion valves (*Figure 21*)
  - Flooded evaporator with float valve
- Energy efficient pumps and fans
  - Permanent magnet motors, inverter control

Design recommendations for distribution systems for heating and cooling:

- Heating – low temperature systems (<60 °C) – large heat exchanger surfaces
  - Radiators – traditional system (*Figure 24 A*), simplified system (Figure 24, *B*)
  - Floor heating systems – simplified systems
  - Ceiling heating (radiation panels)
  - Heater batteries – heating of ventilation air only using active air valves for air flow and temperature control (*Figure 25*, *Chapter 4.1.3*)
- Cooling – high-temperature systems (>10 °C) – large heat exchanger surfaces
  - Ventilation – cooling batteries

Figure 20 A high-efficiency semi-hermetic reciprocating compressor (left) and screw compressor (right) with integrated frequency inverter for R134a (2013).

Figure 21 Electronic expansion valves for energy efficient control of HFC evaporators (2013).

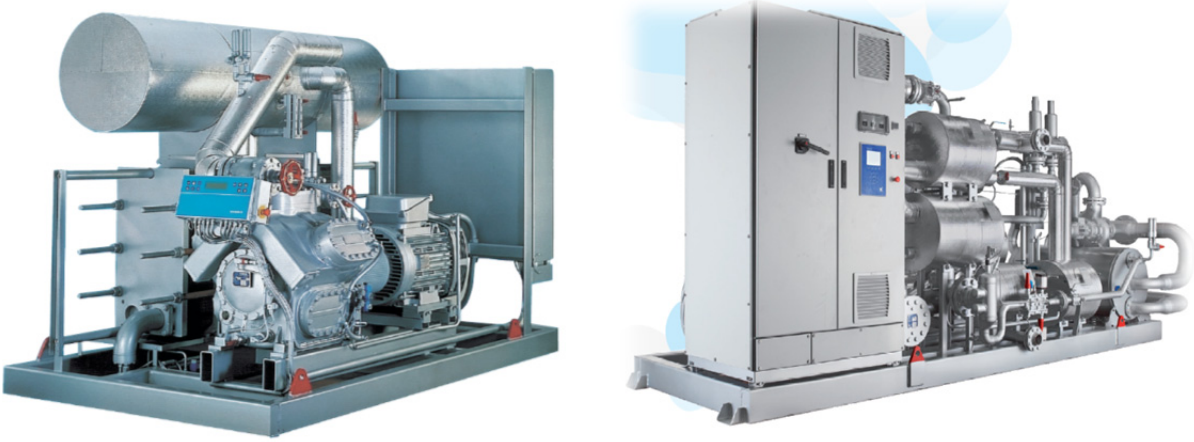


Figure 22 Low-capacity single-stage ammonia heat pump/chiller units with flooded evaporator and reciprocating compressor (2013). Maximum outlet water temperature 48 °C.

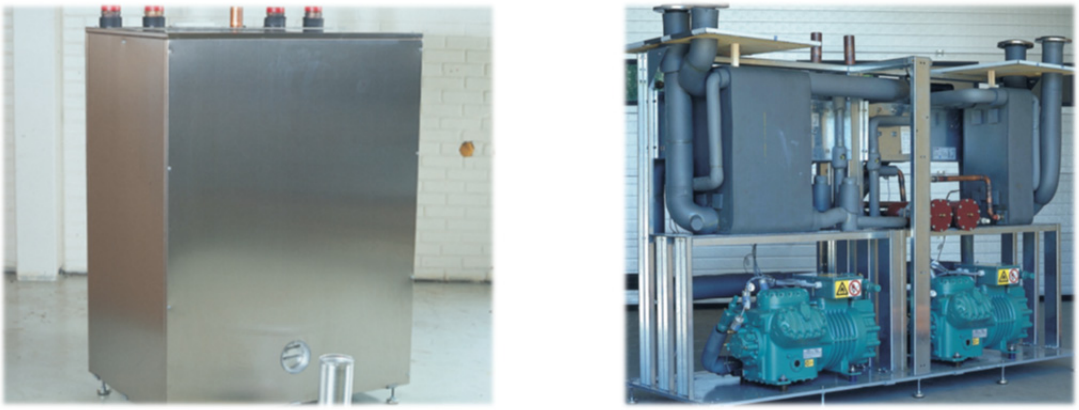
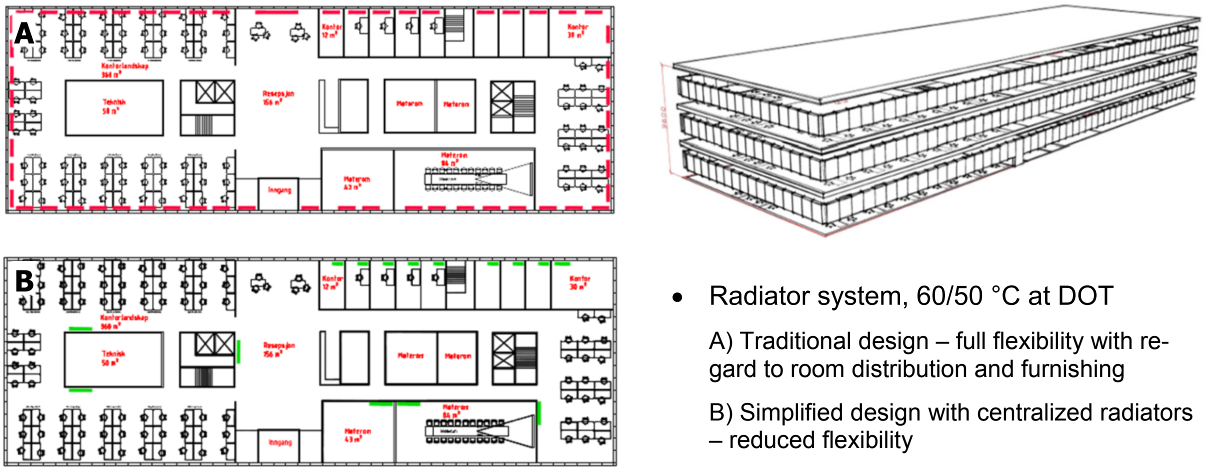


Figure 23 Low-capacity single-stage propane heat pump/chiller units with DX evaporators and reciprocating compressors (2013). Maximum outlet water temperature 50-55 °C.



- Radiator system, 60/50 °C at DOT

A) Traditional design – full flexibility with regard to room distribution and furnishing

B) Simplified design with centralized radiators – reduced flexibility

Figure 24 **Example – traditional design (A) and simplified design (B) for a radiator system for space heating in a 3200 m² office building of passive house standard (Smedegård et al., 2012).**

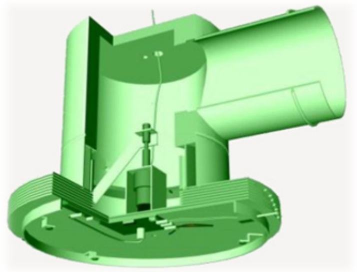


Figure 25 **Active air valve with constant air throw for installation in VAV ventilation systems. The warm inlet air is used to cover the entire transmission loss of the building.**

3.3.3 Ventilation Air Heat Exchangers

New Norwegian buildings must comply as well with the standard TEK 10 (current building code, 2010) or NS 3700 (passive house standard, 2010). These standards set a minimum requirement for the heat recovery efficiency. In new residential buildings the most common heat exchanger type is rotary heat exchangers, since they can achieve high temperature efficiency and, at the same time, are relatively cheap. The ZEB Centre in Trondheim, Norway is developing "membrane energy exchangers" (MEE) for this purpose. These are suitable for use in single-family houses and apartment buildings, since they do not transfer odours as the rotary heat exchangers. The membrane energy exchangers are, however, under development and yet the preliminary results are very promising (Alonso, 2013).

When retrofitting residential buildings to a passive house standard, the goal is to make the minimum possible changes in the building. Mixed mode ventilation (hybrid ventilation) with or without exhaust fan represents the state-of-the-art installation in Norway as they combine natural and little physical rebuilding of the ventilation duct network. In addition, Norway started early requiring exhaust ventilation in bathrooms. Therefore this solution is easy to implement.

A challenge in the use of rotating heat exchangers ("heat wheels") is that, due to the requirement of physical contact between exhaust and supply air, they require a higher degree of refurbishment.

A second solution under development is the use of "run around membrane energy exchangers" (RAMEE). Since they use a refrigerant as transferring medium, do not need the exhaust and supply air to be in contact, easing their installation.

Table 14 **Overview of ventilation concepts and heat recovery systems for residential and non-residential passive house buildings – new buildings and retrofitting.**

	Residential		**Non-Residential**	
New buildings	• Natural ventilation • Exhaust ventilation • Balanced ventilation	• Heat wheel • Plate HX • ETAHE	• DCV • CAV • LPDD	• Exhaust air HP • Heat wheel • PHX
Retrofitting	• Natural ventilation • Exhaust ventilation	• RAMEE • ETAHE	• Mix mode • DCV • LPDD	• RAMEE

In non-residential (commercial) buildings the ventilation system is more complex and sophisticated than that of residential buildings. Non-residential buildings normally use demand control ventilation (DCV) which adapts the airflow rate to the user demands. In buildings such as office buildings, the occupancy factor may reach values as low as 20% (Halvarsson, 2012), meaning that only 20% of the designed occupancy is reached. In these type cases, DCV systems will reduce energy consumption compared with continuous air volume (CAV) system, the other state-of-the-art ventilation method.

A new trend for ventilation in new high-performance buildings is the use of low pressure drop distribution (LPDD).The lowest pressure drop is achieved by exploiting building-integrated conduits for air transport, such as corridors or under floor air supply plenums. This ensures a high degree of thermal coupling with heavy weight building structures. However, ductwork systems are normal for other practical reasons such as good control of distribution. Very low pressure ductwork poses particular challenges, such as space provision and easier transmission of fan noise and cross-talk between rooms.

3.4 Design of the HVAC System Technology

3.4.1 Design Methods for NZEB Technologies

A study among Norwegian consultants and constructors (Berner, 2012) revealed a need for more detailed calculation/simulation tools that introduce the new challenges related to NZEB. The Norwegian simulation tool *Simien* (Simien, 2013), which is applied both for evaluation of building codes (NS3031, TEK10), energy labelling, calculation of power and energy demands and validation of indoor climate, is not suitable for calculating natural ventilation and has not yet introduced the modifications to adapt to the requirements in EPBD.

More and more Norwegian consultants and constructors are now turning towards more advanced simulation tools, such as Ida ICE (Ida Ice, 2013). This is dynamic multi-zone building simulation software which allows the user for introducing a CAD model and uses it as a base for the simulation. The user can introduce the information available regarding walls, thermal bridges and thermo solutions. The more detailed the input data, the higher the level of details in the simulation. The application of Ida ICE requires longer time for achieving relevant results, but is seen as a very powerful tool when simulating and optimizing high-performance ZEBs with advances energy solutions.

3.5 "Smart" Technology Application in Buildings

3.5.1 Info-Communication Technologies in Bldgs. (Smart-Metering, Smart-Home)

For achieving this information-communication the use of smart meters, smart appliances (that could communicate for example on priority modes and deadlines where external signal make decision), smart hot water storage tank (communicate level of charge level with external agent that decide when to operate heating device) is expected to be introduced. In addition agents could be optimizing cost or other objectives

3.5.2 Demand Response Technologies (Smart-Grid, Smart-city, etc.)

Mid- to long-term storage technologies as well as combined heat and power plants (CHP). These technologies could be partly centralized in districts/small cities and enable demand response and increase the use of renewable energy sources.

3.5.3 Higher Level Concept on Level of Groups of Buildings, City Quarters

Smart grids and self-supporting Zero Emission Buildings (ZEB) require reliable methods and tools in order to develop sustainable, energy efficient solutions for heating/cooling and electricity generation. As stand-alone buildings or in clusters (depending on the definition of the system boundary), there will be an increased demand for energy storage in order to balance uneven supply and demand. There is a need to focus on enablers, frame conditions and practical consequences of realizing such systems, and this knowledge is not yet developed for Norway. Tools capable of predicting supply and demand and routines securing operational flexibility are essential (Østegard, 2012). Knowledge on interactions between building and thermal storage is needed (Streckiene, 2009). The shift from electric heating systems towards hydronic heating systems opens up for energy interactions. Knowledge on efficient integration of technologies in larger system solutions needs to be developed (Blanke, 2008, *Berner, 2013).* Smart grids and an increasing number of plus-houses will demand more reliable interaction tools in order to optimize utilization of surplus heating/cooling.

3.5.4 Technologies to Improve Load Match

The combination of heat pump systems together with photovoltaic (PV) electricity generation is about to become a standard solution in near-term net-ZEBs (Dar, 2012). Nevertheless, a large part of onsite production in such buildings is exported to the grid due to strong variability in onsite electricity production (related to diurnal and seasonal solar effects) and building heating, cooling and electricity loads (due to stochasticity and behaviour).

Different concepts to improve the consumption of onsite production have been under investigation internationally including following:

- Use of electric batteries	(Kathan, 2010)
- User of building thermal mass	(Gerhard, work under development on AIT)
- Use of thermal energy storage(s)	(Dar, 2013)

Standard controls of heat pump consider only the thermal comfort of the resident as only constraint leading to operating of heat pump strictly following the building heating needs. Introduction of thermal energy storage (TES) could decouple the interaction between the heating system and the building heating needs and offer flexibility to operate the heat pump to improve building self-consumption as well as ensuring comfort of the occupants. Investigation of different control strategies along with thermal energy storage concepts have revealed that introduction of TES along with proper control of heat pump results into nearly 150% increase in building self-consumption compared to the reference case (Dar, 2013).

In order to shave peak power production during daytime and increase energy efficiency, a thermal energy storage system can be implemented as an integral part of systems for supply of heating and cooling in passive houses and NZEB. The thermal energy storage can be water tanks, vertical ground-source storages in bedrock, TABS or PCM storages. A thermal energy storage accumulates more energy than needed, and distributes it over a longer period of time in order to achieve a more optimal operation. The size of the thermal storage has to be calculated for every case. Over-dimensioning leads to higher investment costs and larger thermal losses while under-dimensioning reduces the thermal benefit of the storage. Many of the current systems represent a sub-optimization. Consequently, future research should focus on overall solutions for Norwegian climate and building characteristics in order to obtain optimum system integration and minimize energy use and total investment costs.

- *Borehole thermal energy storages* (BTES, vertical boreholes in bedrock) is currently being used in buildings and district heating/cooling system all around the world as a seasonal thermal energy storage in combination with heat pump and chillers. Due to the slow temperature response of the ground, the ground-source heat pump/chiller system operates with higher heat source temperatures and lower sink temperatures than that of a system without seasonal storage. If the temperature level of the hydronic cooling distribution system is relatively high (>10 °C), a rather large share of the annual cooling demand can be covered by free cooling from the boreholes as well as from the heat pump evaporator during winter operation.

- *The Dynamic Thermal Energy Storage* (DTES) concept developed by Gether et al. (2009), represents a novel, short-term energy water storage concept for heating and cooling of buildings. During the winter the DTES keeps the surplus heat from the building/heat pump at an optimal temperature level before it's reused and upgraded by the heat pump to a higher temperature level whenever needed. At summer conditions the DTES keeps hold on the surplus free cooling from the cold air at night, and covers some of or the entire cooling demand during daytime.

- *A PCM thermal energy storage* can be used to reduce the maximum peak cooling power for combined ground-source heat pump/chillers systems. The storage comprises a large number of elements charged with a salt hydrate (PCM) which has a freezing/melting point that is adapted to the minimum set-point in the hydronic cooling system. The elements are installed in large storage tanks and connected to the hydronic cooling system in the building be means of a closed loop with circulating antifreeze fluid (brine). During night-time the heat pumps/chillers cools down and freezes the elements, and the excess heat from the condensers is rejected to the boreholes (BTES). During daytime the considerable volume of the frozen PCM elements is used to cover the space cooling demand together with the heat pumps/chillers.

  A PCM thermal energy storage is now being implemented by the consultant company SWECO AS at The University of Bergen, Norway (Nielsen, 2012). The storage systems comprises 60,000 PCM elements that freezes/melts at approx. 10 °C, and the elements are installed in 4 large storage tanks with a total volume of 250 m³. The maximum cooling capacity is 1600 kW, while the maximum cooling capacity of the ground-source heat pump/chiller system is 1400 kW. By utilizing the PCM concept the number of boreholes has been reduced from 180 to 80 (220 m deep), and the heat pump/chiller could be designed for a much lower cooling capacity.

  Due to the reduced heating/cooling capacity of the heat pump/chiller system and the favourable operating conditions in cooling mode, the system obtains excellent controllability even at low heating and cooling loads and achieves a high Seasonal Performance Factor (SPF). The system concept is regarded as very promising in the next generation high-performance buildings, i.e. passive houses and NZEBs.

4 Best Practise Examples of Realised NZEB

4.1 NZEB Heat Pump Installations in Norway

4.1.1 The Nor-One Residence – A/W Heat Pump

The NorOne residence in Sørum, Southern Norway, was the first single-family house in Norway to be certified by the German Passivhaus-Institut in Darmstadt in 2007. The 340 m² passive house is equipped with a number of heat recovery and heating systems including:

- High-efficiency plate heat recovery unit in the ventilation system (η=85%)
- Heat recovery unit for grey water (preheating of domestic hot water, DHW)
- Horizontal ground heat exchanger for preheating/precooling of air (ID 250 mm, 50 m)
- 6 m² vacuum-type solar heater/collector
- 5 kW air-to-water heat pump system for combined space heating and preheating of DHW, approx. 2 kW heating capacity at -15 °C
- Electric heater for reheating in the space heating and DHW systems
- Wood stove

Figure 26 shows a principle sketch of the heating system including the 5 kW air-to-water heat pump, the grey water heat recovery unit and 6 m² solar collector (www.norone.info).

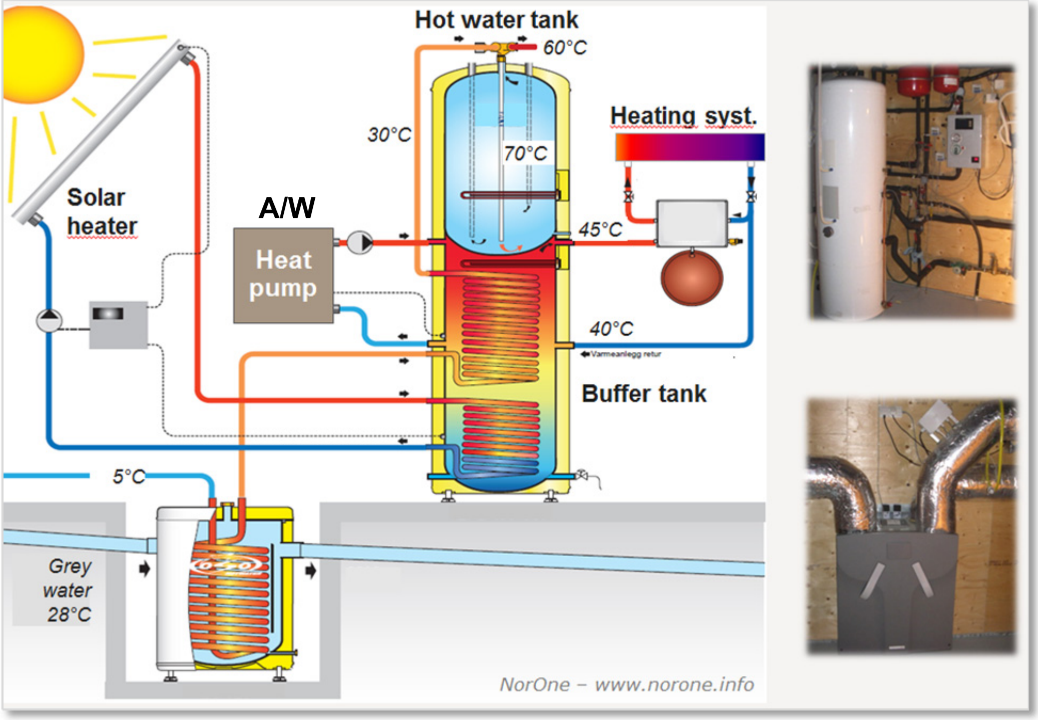


Figure 26 Principle sketch of the heating system in the NorOne passive house (www.norone.info).

At the design outdoor temperature (-25 °C), the ground heat exchanger preheats the inlet air by as much as 20 °C. It has been reported that the heat exchanger has no negative effect on the air quality in the house which proves that there is no bacterial growth inside the tubes.

In 2011 the heat supply from the grey water heat exchanger and the solar heater system was 600 kWh (*1,000 kWh*) and 1,400 kWh (*3,400 kWh*), respectively. The numbers in the brackets show the calculated (expected) heat supply. The measured total annual energy use was 60 kWh/m², while the annual space heating demand was 7,200 kWh (21 kWh/m²).

Figure 27 NorOne ground heat exchanger, ID 250 mm, 50 m (www.norone.info)

The city water, which circulates in a coil heat exchanger inside a double-shell buffer tank, is preheated to about 35-40 °C by the heat pump unit. An electric immersion heater in the hot water tank reheats the water to the required temperature (min. 65 °C). This kind of integrated heat pump design is not recommended in passive houses since it only covers approx. 50 % of the annual DHW heating demand, and the supply water temperature from the condenser is maintained at 40-45 °C the entire year. A much more energy efficient heat pump design is presented in Chapter 4.1.2 where the maximum temperature in the floor heating system has been reduced to about 35 °C, and the heat pump covers the entire DHW heating demand at a relatively low condensation temperature.

Project	2007 – NorOne (www.norone.info)
Building – type, area	Single-family house, 340 m², Sørum/Norway
Building – standard, certification	Passive house, sertified by the Passivhaus-Institut, DE
Heating demand	Space heating, domestic hot water (DHW) heating
Cooling demand	No
Heat source/sink for heat pump	Ambient air
Heat pump specification	5 kW, air-to-water heat pump unit – standard design
Working fluid (refrigerant)	R407C
Average COP – heat pump	No available measurements for the heat pump

4.1.2 The Zijdemans Residence – W/W Heat Pump

A 2.9 kW prototype water-to-water heat pump for combined space heating and hot water heating was installed in a single-family passive house in Flekkefjord (Southern Norway) in 2007. The main goal when designing the heat pump unit was to utilize an environmentally benign working fluid, cover the entire annual DHW heating demand by the heat pump unit (i.e. no reheating) and achieve a good Seasonal Performance Factor (SFF, average COP).

The heat pump unit utilizes lake water as heat source, and propane (R290) is used as working fluid. The heat pump is optimized for energy-efficient DHW and low-temperature space heating. Regarding the DHW heating the heat pump is equipped with a suction gas heat exchanger that increases the heating capacity and temperature of the suction gas as well as a desuperheater for reheating of DHW. Since DHW is preheated by the condenser and reheated by a desuperheater, the system design is denoted "two-stage DHW heating". The main advantage of this system is that the heat pump can cover the entire DHW heating demand at the required temperature (65 °C) without reheating by electric immersion heaters, and still maintain a relatively low condensation temperature. The heat pump is operated in "space heating mode", "DHW heating mode" or "combined heating mode". *Figure 28* shows a principle sketch of the heat pump system including heat pump unit and two buffer tanks.

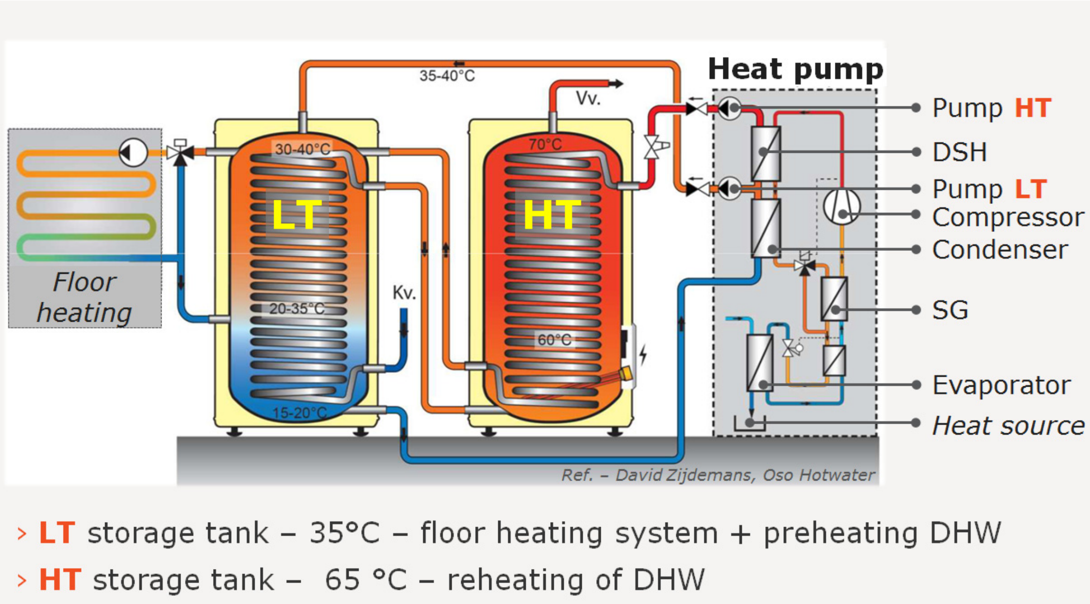


Figure 28 **Principle sketch of the 2.9 propane water-to-water heat pump system comprising a 2-stage DHW system with two storage/buffer tanks (ref. David Zijdemans, Oso Hotwater).**

The heat pump system was monitored during 2 ½ year of operation, and the average COP (i.e. SPF) including energy to circulation pumps was about 3.1. No peak load heat was required during the monitoring period. It was discovered that the heat flow meters for the DHW system had a malfunction at low DHW demands, which means that the measured annual heat supply was too low. In an optimized system with correct heat flow measurements the heat pump is expected to achieve an SPF of about 4, which corresponds to about *75 %* energy saving compared to a direct electric heating system (Alonso and Stene, 2010).

Table 15 **Project summary – prototype water-to-water heat pump system for a single-family house.**

Project	2007 – Zijdemans residence
Building – type, area	Single-family house, 170 m², Flekkefjord/Norway
Building – standard, certification	Passive house
Heating demand	Space heating, domestic hot water (DHW) heating
Cooling demand	No
Heat source/sink for heat pump	Lake water
Heat pump specification	2.9 kW, water-to-water heat pump unit – prototype
Working fluid (refrigerant)	R290 (propane)
Average COP – heat pump	3.1 for the entire system – no peak load required

4.1.3 Miljøhuset GK (Office Bldg.) – A/W Heat Pump & Chiller

Miljøhuset GK is a passive house office building which was completed in 2012. The 14,300 m² building has a passive house design, and the estimated net energy demand and annual supplied energy are 67 kWh/(m²a) and 52 kWh/(m²a), respectively. The estimated total annual heating demand is approx. 45,000 kWh/a (GK Norway, 2013).

Two reversible R410A air-to-water heat pump units, each comprising 4 scroll compressors, are connected to a common secondary circuit (distribution system) charged with anti-freeze fluid for heating and cooling of the ventilation air. The system provides either space heating or space cooling. Peak load for heating is covered by an electro boiler and by 200 W electric heating rods located in the offices. *Figure 29* shows a principle sketch of the system.

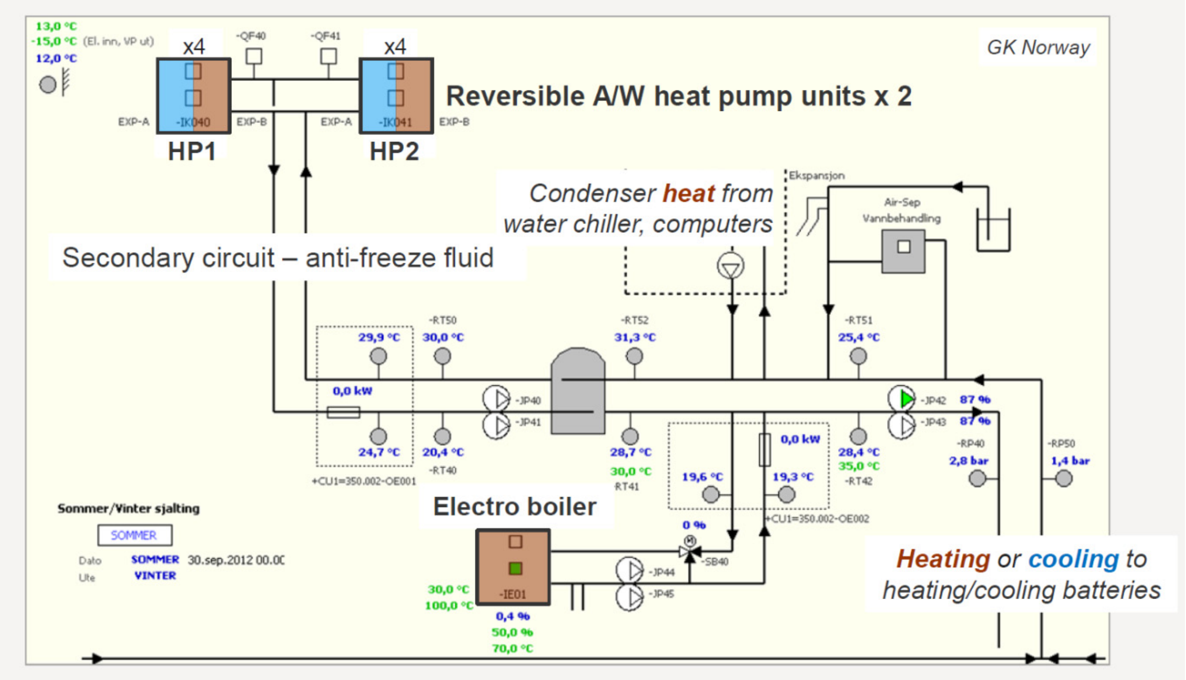


Figure 29 System design of the heating and cooling system at Miljøbygget GK, Oslo (GK Norway, 2013).

Space heating and space cooling are solely provided be heating and cooling of ventilation air, i.e. there is no separate radiator system for space heating. *Figure 30* shows a principle sketch of the ventilation system with the heating/cooling battery (heat exchanger).

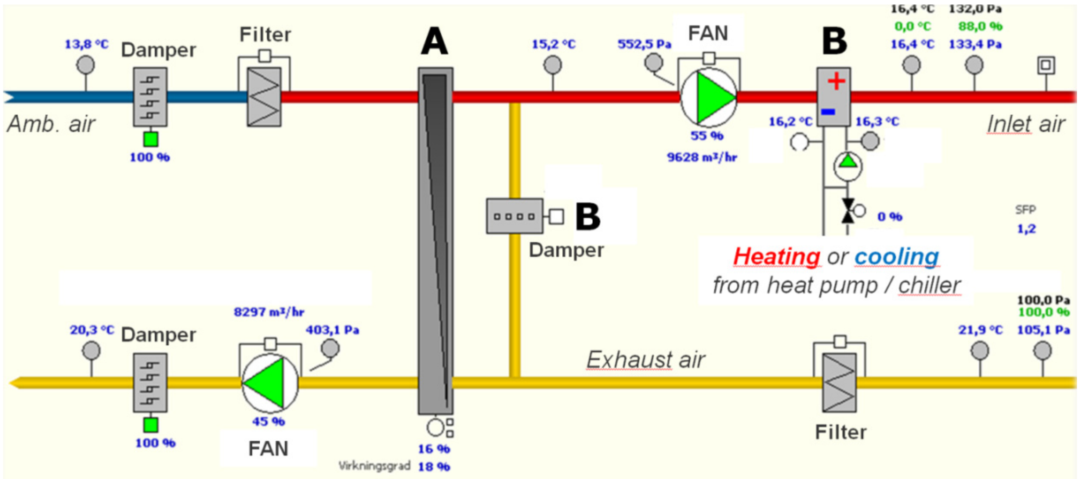


Figure 30 System design for the ventilation units. A = heat recovery heat exchanger, B = brine-to-air heat exchanger for combined heating and cooling of ventilation air (GK Norway, 2013).

In order to reduce installation costs and pressure drop combined heating and cooling batteries have been used. The design temperature for space heating and space cooling are 35/30 °C and 10/15 °C, respectively. The relatively low temperature level in heating mode and high temperature level in cooling mode is favourable with regard to the Seasonal Performance Factor (SPF) and operating conditions for the units. The ventilation system is based on VAV (Variable Air Volume), and Lindivent active inlet air valves are used to control the air flow and maintain the ventilation efficiency (constant inlet air velocity in the rooms).

Figure 31 The reversible air-to-water heat pump and chiller units (GK Norway, 2013).

Table 16 Project summary – passive house office building with reversible heat pump / chiller.

Project	2012 – Miljøhuset GK, Oslo/Norway
Building – type, area	Office building, 14,300 m²
Building – standard, certification	Passive house, BREEAM NOR certified
Heating demand	Space heating, preheating of hot water – 200 kW
Cooling demand	Space cooling, computer cooling – 500 kW
Heat source/sink for the heat pump	Ambient air
Heat pump specification	Reversible air-to water heat pump. T_{stop} = -12 °C
Working fluid (refrigerant)	R410A
Average COP – heat pump	To be monitored

4.1.4 Tveitta Borettslag (Block of Flats) – Heat Pump Water Heater

The three block of flats in Tveitta Borettslag (housing cooperative) in Oslo was built in 1969 and have 819 apartments. The buildings have recently been refurbished for €40 million, and the specific annual energy use has dropped from 280 to 140 kWh/(m^2a). In order to be classified a passive house according to the Norwegian standard NS 3701 (2012), the specific energy use should be approx. 70 to 80 kWh/(m^2a). However, this project has been included in this report since the hot water heating technology applied represents the most energy efficient and environmentally benign technology for hot water heating. In NZEB buildings such as single-family houses, semi-detached houses, block of flats, apartment buildings, hotels, nursery homes, hotels, sport centres etc. the annual heating demand for hot water heating typically constitutes 60 to 80 % of the total annual heating demand, and it's crucial to apply an energy efficient hot water heating system.

Each block of flats has a centralized hot water heating system, and the electric immersion heaters have been replaced by heat pump water heaters using carbon dioxide (CO_2, R744) as the working fluid. Each CO_2 heat pump unit has a nominal heating capacity of approx. 100 kW, and the units have been manufactured by Green&Cool in Sweden. The installation is the first large-capacity CO_2 heat pump system in Norway (Kuldeteknisk, 2013).

Figure 32 Tveitta Borettslag, Oslo, Norway.

The block of flats have an exhaust air ventilation system without heat recovery, and the heat pumps utilize 22 °C exhaust air as heat source. Each brine-to-water heat pump unit is connected to two brine-to-air heat exchangers by means of a secondary circuit. The heat exchangers are located at the rooftop while the heat pumps are located in machinery rooms in the basement. Each heat pump unit are connected to several 1000 litres hot water tanks.

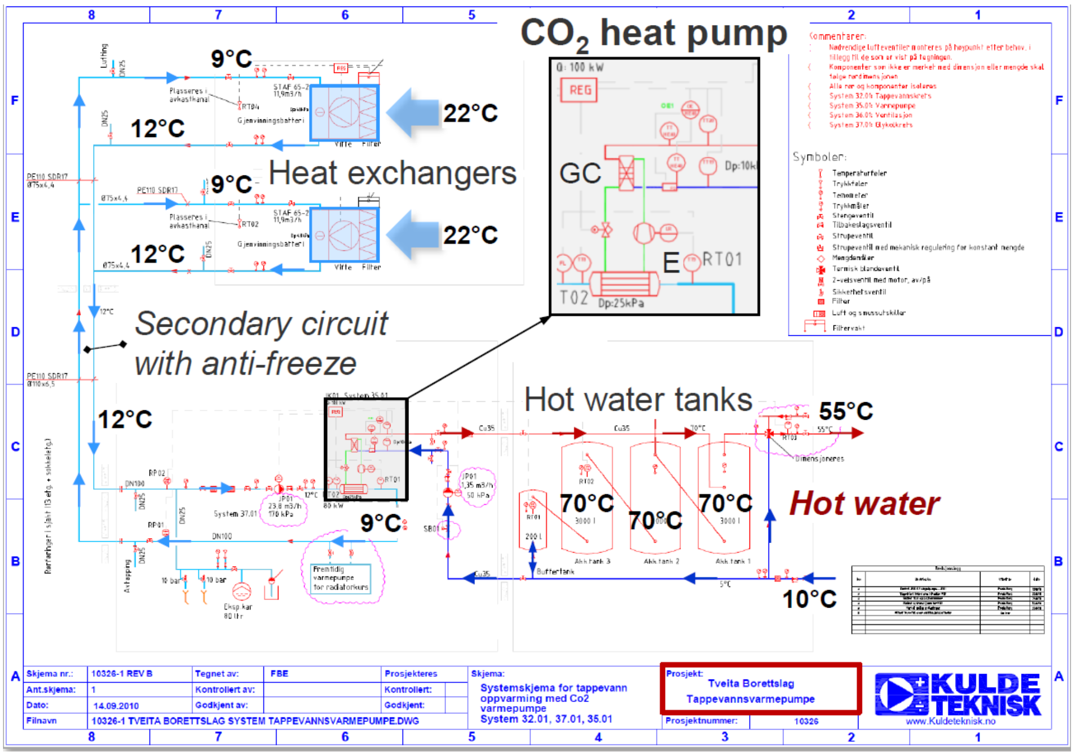


Figure 33 System design for the CO_2 heat pump water heater at Tveitta Borettslag (Kuldeteknisk, 2013).

The set-point for the hot water temperature is about 70 °C. However, due to the unique properties of the CO_2 heat pump cycle, the heat pumps can supply water up to approx. 95 °C, i.e. no reheating with electric immersion heaters is required. This increases the system COP. The measured COP for the heat pumps ranges between 3.8 and 5.0 (Kuldeteknisk, 2013), which represents about 75 to 80 % energy saving compared to the former electric immersion heaters.

Table 17 Project summary – block of flats with novel CO_2 heat pump water heaters

Project	2011 – Tveitta Borettslag, Oslo/Norway
Building – type, area	Block of flats, 819 apartments
Building – standard, certification	From 1969, refurbished
Heating demand	Domestic hot water (DHW) heating
Cooling demand	None
Heat source/sink	Exhaust ventilation air
Heat pump specification	3 x 100 kW, brine-to-water heat pump water heater
Working fluid (refrigerant)	Carbon dioxide (CO_2, R744)
Average COP – heat pump	Above 4 – measured value

4.1.5 Marienlyst School – Small-Scale District Heating System with Heat Pump

Marienlyst skole (school) was the first school in Norway to be designed according to the Norwegian passive house standard NS 3700/01 (2010/2012). The net energy demand and annual supplied energy to the 6,450 m² building was according to NS 3031 (2007) estimated at 70 kWh/(m²a) and 75 kWh/(m²a), respectively. The estimated total heating demand is approx. 200.000 kWh/a (Enova, 2013).

The school is connected to both a small-scale district heating system where the base load is a heat pump system utilizing a football field as heat source, and a large-scale district heating system where a seawater heat pump is the base load together with biomass-fired boilers. The specific supplied energy is larger than the specific net energy demand since the Norwegian standard NS 3031 (2007) presupposes that the default system efficiency/COP of district heating systems is lower than 1, despite the fact that high-efficiency heat pumps are used as the base load.

Figure 34 Marienlyst scool in Drammen. Right – heat pump system supplying heat to the small-scale district heating network (Enova, 2013).

Table 18 Project summary – school with heat supply from district heating system

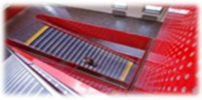
Project	2010 – Marinelyst skole (school), Drammen
Building – type, area	School, 6450 m²
Building – standard, certification	Passive house
Heating demand	Space heating, heating of ventilation air, DHW heating
Cooling demand	Not available
Heat source/sink	Football field sea water
Heating plant, heat pump specification	Small-scale and large-scale district heating systems based on high-efficiency heat pumps

4.1.6 Miscellaneous Norwegian ZEB Buildings with Heat Pumps

a) NSB Kompetansesenter (Office Bldg.) – Air-to-Water Heat Pump

Table 19 Project summary – passive house office building with air-to-water heat pump.

Project	2010 – NSB Kompetansesenter, Drammen/Norway
Building – type, area	Office building, 7,100 m²
Building – standard, certification	Passive house (82 / 69 kWh/m²y)
Heating demand	Space heating and heating of ventilation air
Cooling demand	Space cooling
Heat source/sink	Ambient air
Heat pump specification	400 kW, air-to-water heat pump
Working fluid (refrigerant)	R407C
Average COP – heat pump	Not available



NSB
Kompetansesenter
DRAMMEN

b) The Bellona Building (Office Bldg.) – Ground-Source Heat Pump

Table 20 Project summary – passive house office building with ground-source heat pump.

Project	2010 – Bellonahuset, Oslo/Norway
Building – type, area	Office building, café, showrooms etc. – 3,100 m²
Building – standard, certification	Passive house (84 / 68 kWh/m^{2}y)
Heating demand	Space heating, heating of ventilation air, DHW heating
Cooling demand	Space cooling
Heat source/sink	Bedrock – 14 boreholes, 300 m deep
Heat pump specification	Ground-source heat pump for heat supply to several buildings combined with solar collectors (280 m²), thermal energy storages (heating and cooling)
Working fluid (refrigerant)	Not available
Average COP – heat pump	Not available

HISTORIEN OM
BELLONAHUSET

c) Scandic Vulkan Hotel – Ground-Source Heat Pump

Table 21 Project summary – passive house office building with ground-source heat pump.

Project	2011 – Scandic Vulkan Hotel, Oslo/Norway
Building – type, area	Hotel – 140 rooms
Building – standard, certification	Passive house (135 kWh/m^{2}y)
Heating demand	Space heating, heating of ventilation air, DHW heating
Cooling demand	Space cooling
Heat source/sink	Bedrock – 14 boreholes, 300 m deep
Heat pump specification	Ground-source heat pump, heat supply to several buildings, thermal energy storages (heating, cooling)
Working fluid (refrigerant)	Not available
Average COP – heat pump	Not available


#1 2011
VULKAN
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4.2 Upcoming ZEB Projects with Heat Pumps

Heat pumps represent an important technology for heating and cooling of passive house buildings and NZEB in Norway due to the considerable system flexibility (heating/cooling, capacity range), high energy efficiency and the possibility of utilizing the heat source (seawater, groundwater, bedrock) for free cooling[3].

4.2.1 PowerHouse One (Office Bldg.)

Norway's first energy-positive office building will be built in Trondheim.

Powerhouse One will be an innovative office building with new environmental technology and technical solutions. The building will have a unique architectural design and will measure approximately 16,000 m² in total. It will be located by the waterfront at Brattørkaia.

The building, designed by the world famous company Snøhetta, will have a highly compact design, with low heating requirements and superior ventilation systems. The entire oblique roof of the building will be covered with solar cell modules. A heat pump and cooling system utilizing sea water as heat source and heat sink will cover the entire heating and cooling demand of the building. Due to the relatively low seawater temperature, most of the cooling demand will be covered by free cooling/heat exchange (Thyholt, 2012).

During the year, heating, lighting and low temperature environmental thermal energy (seawater) will enable Powerhouse One to produce more thermal and electrical energy than it consumes. The net surplus energy is estimated at *6 kWh/(m²a).*

The project is currently in the planning phase and construction work is planned to start in 2013-14, subject to all necessary approvals. The building should be completed in 2015-16.

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[3] *The heat source is used as a heat sink and provides cooling with minimal energy use.*

Figure 35 The planned plus energy building, "Powerhouse One", Trondheim (ZEB, 2013).

Figure 36 The planned plus energy building, "Powerhouse One", Trondheim (ZEB, 2013).

Table 22 Project summary – plus energy office building (ZEB, 2013).

Project	Powerhouse One, Trondheim
Building – type, area	Office building, 16,000 m^2
Building – standard, certification	Passive house + solar cell modules for electricity generation and heat pump for thermal energy production (heating, cooling) – plus energy building, 6 kWh/(m^2y)
Heating demand	Space heating, heating of ventilation air, DHW heating
Cooling demand	Space cooling
Heat source/sink	Seawater – temperature range approx. 5 to 12 °C
Heat pump specification	High-efficiency water-to-water heat pump for heating and cooling. Free cooling from the seawater. The heat pump unit should preferably have inverter controlled compressors, DX evaporator with electronic expansion valve or flooded evaporator system, as well as enhanced heat exchanger surfaces etc. in order to maximize the COP
Working fluid (refrigerant)	Preferably a zero-GWP natural working fluid – ammonia (R717), propane (R290) or carbon dioxide (CO_2)

4.2.2 The Skarpnes Project (Res. Bldgs.)

The Skarpnes residential development project in Arendal in the southern part of Norway comprises 40 dwelling units – single-family houses and block apartments. Skanska Norway is the owner of the project, and the development of the zero-energy dwellings is being done in close cooperation with the Zero Emission Building (ZEB) research centre (ZEB, 2013).

The energy goal of the buildings is net zero-energy on an annual basis. In addition, the greenhouse gas emissions related to the operational energy of the buildings should also be zero on an annual basis. There is also an aim achieving low embodied energy and greenhouse gas emissions related to the buildings materials and products.

The thermal energy demand of the buildings will be covered by an optimized *ground-source heat pump* and thermal solar collector system on the roof connected to a centralized hydronic heating system in the buildings. The heat distribution system comprises a floor heating system in the bathroom and porch as well as one or two radiators per residence or flat. The washing machines and dishwashers will be using "hot fill", which means that water from the hot water tank (renewable heat) replaces integrated electric water heating.

Figure 37 Examples of a washing machine and a dishwasher designed for "hot fill".

Excess heat from the solar collectors during summer will provide *thermal charging* of the boreholes in order to maintain the annual energy balance of the boreholes. The supply air in the single-family homes will be pre-heated or pre-cooled by the cold brine from the boreholes in counter-flow heat exchangers. This was regarded a more robust and energy efficient solution than using shallow ground heat exchangers located in the ground around the buildings.

While the apartment buildings will have solar collectors mounted on the roof, the single-family homes will have integrated vertical facade collectors for each building. An important reason for mounting the collectors on facades, and not more optimally placed on roof, is the desire of using the solar collectors as an architectural feature.

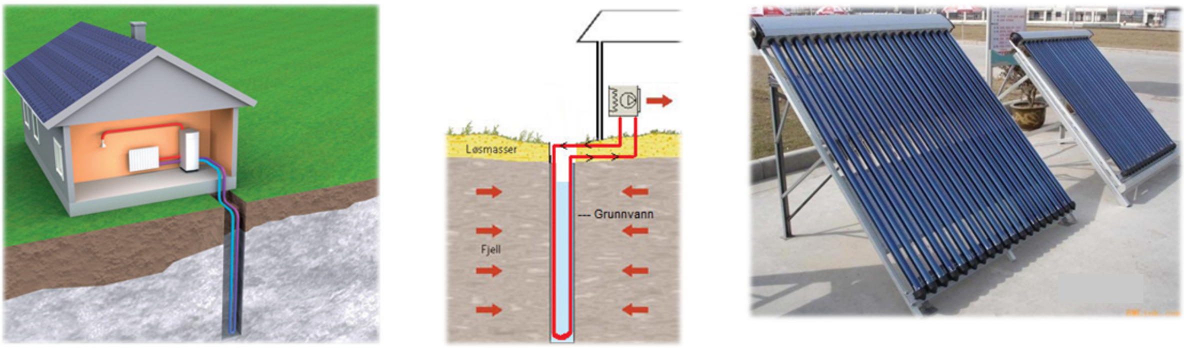

Figure 38 Utilization of ground-source heat pumps and solar collectors for heating of the buildings.

In the design phase *heat recovery from grey water* was considered. However, due to the relative high investment costs and the requirement for regular cleaning of the grey water heat exchangers this energy conservation concept was not implemented.

To reach the zero emission goal, the south-east and south-west facing roofs with a tilt of 30° are partly covered by solar cell modules (PV). The production of solar electricity in summer will exceed the demand of the buildings, and export of energy to the grid will be necessary. During the year there will be a net annual electricity balance.

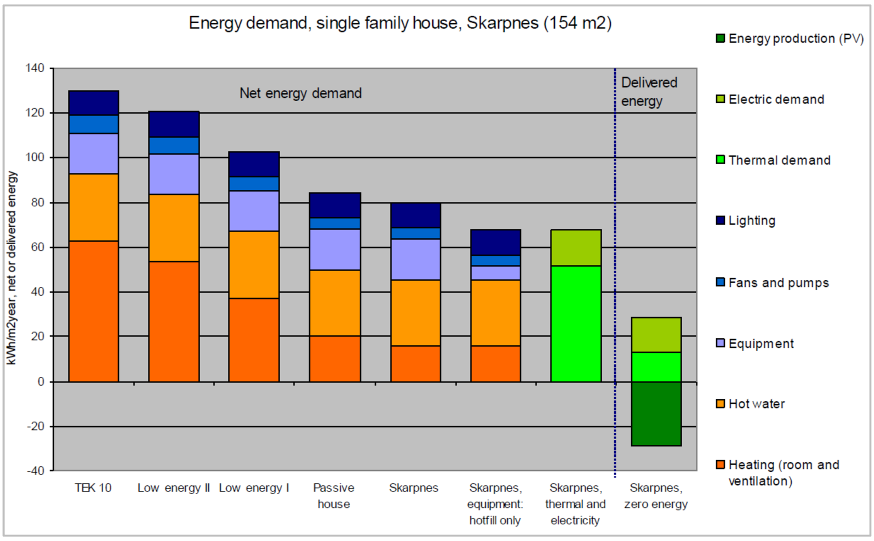

Figure 39 Net energy demand for different kinds of energy standards including the Skarpnes project.

4.2.3 The Ådland Project (Res. Bldgs.)

The Ådland residential development project in Arendal in Bergen at the western coast, will comprise 500 to 800 ZEB residences with an average heated area of 90 m². Bybro AS is the owner of the project, and the development of the zero-energy dwellings is being done in close cooperation with the Zero Emission Building (ZEB) research centre (ZEB, 2013).

The annual heating demand has been estimated at 2,2 GWh/a, while the annual electricity demand is approx. 850 MWh/a. *Figure 40* shows the estimated monthly heating demand (MWh) for space heating, hot fill machines and domestic hot water. The annual space heating demand represents a relatively small share of the total annual heating demand.

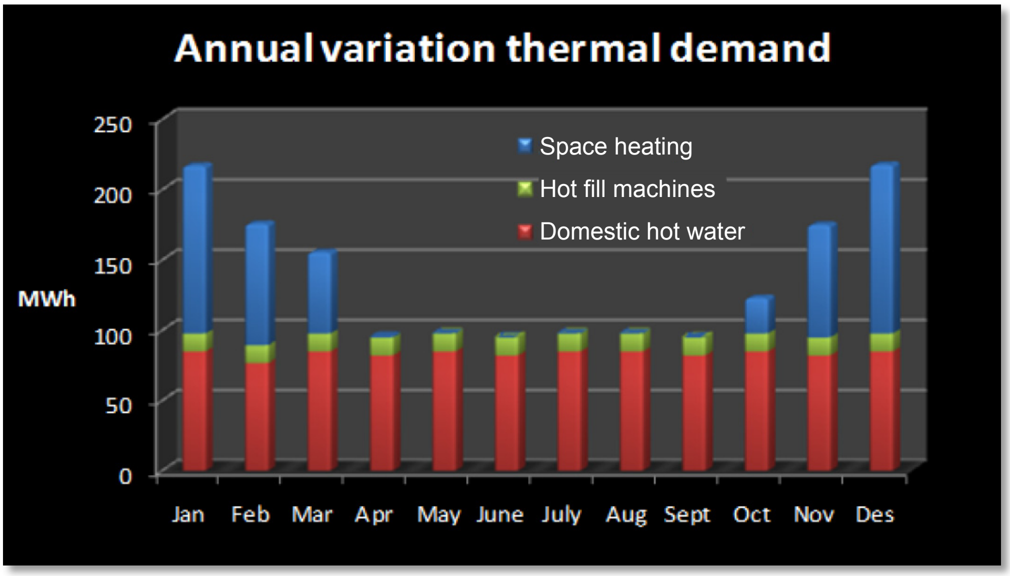

Figure 40 Monthly heating demand (MWh) for space heating, hot fill washing machines and dishwashers as well as domestic hot water (ZEB, 2013).

Two options for thermal and electric energy supply have been evaluated. The first option is a combination of solar collectors for domestic hot water production and a biogas-/biofuel-fired combined heat and power (CHP) plant for generation of heat and electricity as well as solar cell modules (PV) for electricity generation. The second option is a combination of solar collectors, *heat pumps* and solar cell modules. The final system design is not yet defined.

Figure 41 shows the estimated annual heat supply from a thermal energy system comprising solar collectors and heat pumps.

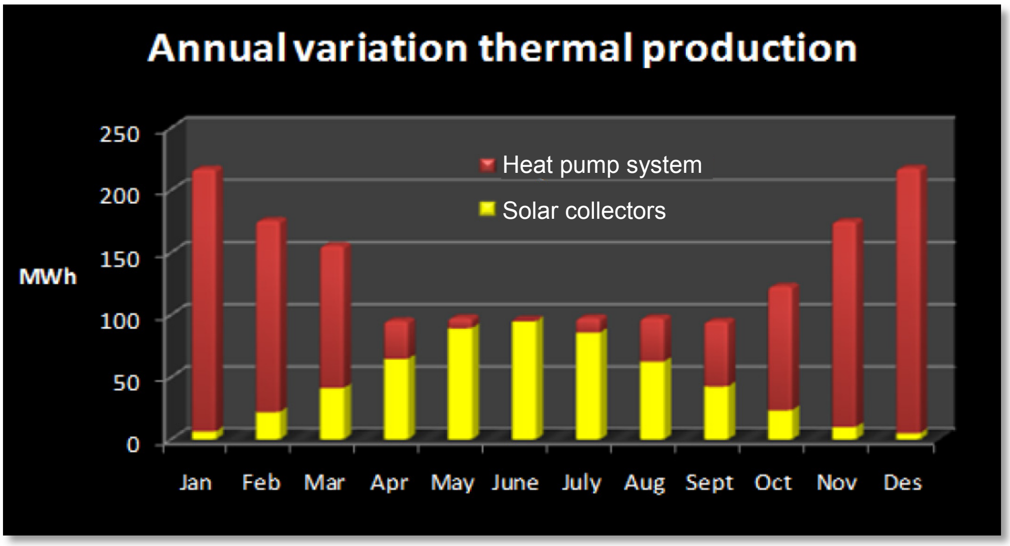

Figure 41 Monthly heat supply from heat pumps and solar collectors (ZEB, 2013).

4.2.4 The Østre Hageby Project (Res. Bldgs.) – Low Temp. District Heating

A new passive house project with block of flats is being planned for Østre Hageby in Stavanger on the western coast. The project comprises 60 to 70 flats, and they will be designed according to the Norwegian passive house standard, NS3700. The thermal system design is provided by AC Enko Klima & Energi AS.

A ground-source heat pump system with 200 m vertical boreholes in bedrock will cover most of the annual heating demand for space heating and domestic hot water heating (DHW). In order to achieve a high Seasonal Performance Factor (SPF) for the heat pump and minimize heat losses, a small-scale district heating network will distribute low-temperature water at max. 55 °C to a single high-efficiency heat exchanger in each flat. Since the domestic hot water volume on the secondary side of the heat exchanger is less than 3 litres (no hot water accumulator, direct system), 50 °C supply water temperature is sufficient to avoid legionella problems. All washing machines and dishwashers will be connected to the hot water system ("hot fill system"). *Figure 42* shows the main principle of the ground-source heat pump system connected to the low-temperature small-scale district heating system.

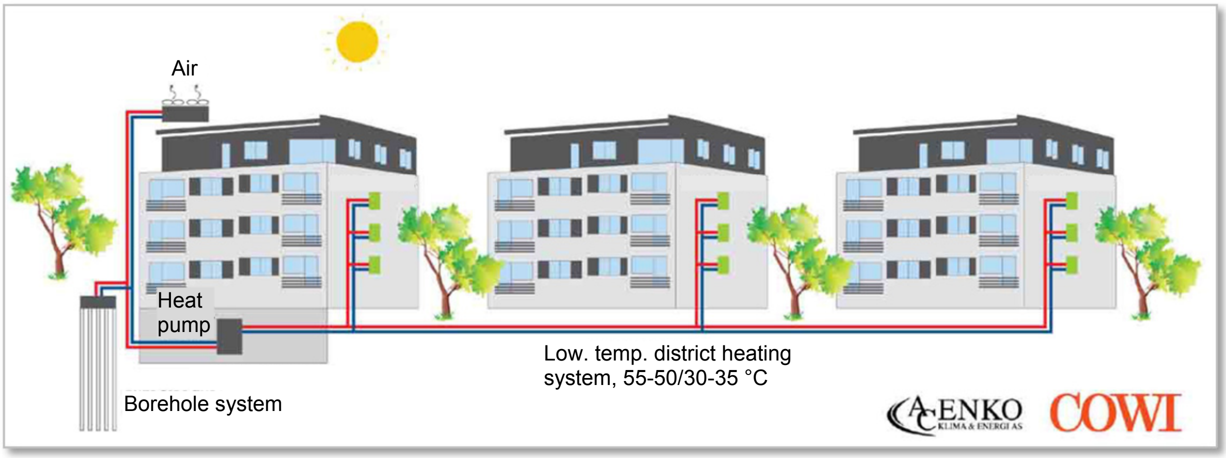

Figure 42 Principle sketch of the ground-source heat pump and low-temperature district heating system for heat supply to the planned block of flats at Østre Hageby (Energirapporten, 2012).

In order to maximize the Seasonal Performance Factor (SPF) of the heat pump system, the borehole heat exchangers (BHE) are connected to a dry cooler (brine-to-air heat exchanger) located at the rooftop. The heat exchanger transfers heat from the ambient air during the spring, summer and autumn, and increases the average annual temperature of the anti-freeze fluid in the borehole system.

4.2.5 Powerhouse Kjørbo (Office Bldg.) – Retrofit Heat Pump Systems

Powerhouse One will refurbish two office buildings from 1980 situated in Sandvika not far from Oslo. The organization comprises the world famous architect's office Snøhetta, the contractor Skanska, the environmental organization Zero, the aluminium manufacturer Norsk Hydro AS and the governmental property company Entra Eiendom AS.

Figure 43 Powerhouse Kjørbo, Sandvika (Energirapporten 9/36, 2013).

Each building have a heated area of about 2,600 m^2, and the current total annual energy use is roughly 260 kWh/(m^2a). When the buildings have been upgraded the annual energy use for space heating, space cooling, heating of ventilation air, lighting systems etc. for each building is estimated at 50,000 kWh/a, which corresponds to about 20 kWh/(m^2a).

The building envelope, the ventilation system and the heating/cooling system will be renovated by utilizing well-known technologies. Walls, roof and windows will have low U-values and superior air-tightness. Efficient solar shading systems and exposed concrete surfaces will minimize the cooling demand of the buildings. The VAV ventilation system will utilize high-efficiency heat recovery units, and the Specific Fan Power (SPF) will be minimized.

A ground-source heat pump system with 250 m deep boreholes will cover the space heating, hot water heating and space cooling demands for each building. Due to the relatively low ground temperature most of the cooling demand will be covered by the cold energy wells (free cooling). There is no available information about the design of the heat pump system.

Solar cell modules (PV) will be used to generate electricity, and the estimated annual production is estimated at 40 kWh/(m^2a) or approx. 50,000 kWh/a for each building.

4.3 Conclusions of Field Experience of Realised NZEB

In Norway, heat pump systems represent one of the main options for heating and cooling of residential and non-residential passive house buildings and ZEBs. However, in most cases traditional system designs and technology have been implemented, resulting in higher investment costs, lower energy saving and more maintenance than that of system optimized for this kind of buildings. Since there are no requirements for minimum instrumentation, performance testing and field monitoring of heat pump system in the Norwegian building code and other relevant standards and regulations, there are hardly any on-site performance data available.

In order to improve the performance of the heating and cooling systems in future passive house and ZEBs, it's of crucial importance that HVAC and thermal energy consultants, technology suppliers, installers, contractors (construction firms), development companies and building owners start to implement optimized system designs and technologies.

5 National Contributions to IEA HPP Annex 40

This chapter is to prepare the discussion on the next Annex 40 working meeting, which, according to the current state, will take place end of May 2013.

5.1 Outline of the National Project Contributions

Outline of the national project contribution to co-ordinate the work with the project of the other participating countries.

5.2 Feedback on Tools to be Applied

- Applied design and calculation methods
- Applied simulation tools/models, software

5.3 Expected Results from the IEA HPP Annex 40

Form of deliverables, e.g.

- Technical handbook
- Design recommendations
- Calculations methods, tools
- Computer tools
- Simulations models
- Prototype systems
- Best practice systems
- etc.

6 Acknowledgments

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