# Heat Pump Integration and Design for nZEB

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**Abstract**

Nearly Zero Energy Buildings (nZEB) will be the future standard for new buildings. They are to be widely introduced in the time frame of 2020-2030, thus building technologies for nZEB are of high interest. IEA HPT Annex 40 has investigated and compared different building technology options for nZEB in case studies, using loads and economical boundary conditions of the respective countries. Evaluations were performed regarding performance and cost. Furthermore, new integrated heat pumps have been developed according to national requirements for HVAC systems and real performance has been evaluated by field monitoring.
Results of the case studies confirm that heat pumps are both energy-efficient and cost-effective for the application in nZEB. Due to the different climate and economic boundary conditions, the results show a certain robustness regarding changing boundary conditions. For larger buildings district heating and CHP are economically feasible, too. Field monitoring of integrated systems confirm that performance improvements can be achieved by higher integration of the heat pump and multifunctional use.
The work is continued regarding integration options for larger buildings and group of buildings as well as cost-effective design. Besides performance and cost the energy flexibility of future building technology may become an additional requirement for the building technology. Heat pumps as one of the main electricity consumers can play an important role also in this respect.

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Keywords: nearly Zero Energy Buildings; multi-functional heat pumps, field monitoring, system integration

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## 1. Introduction

The recast of the Energy Performance of Buildings Directive [1] in Europe sets the objective that all new public buildings shall be built as nearly Zero Energy Buildings (nZEB) from 2019 on and all new buildings from 2021 on. Also in the USA and Canada Net Zero Energy Buildings (NZEB) are in focus of the political strategy, in order to be widely introduced between 2020 and 2030 and in Japan, NZEB are planned to be the building standard by 2030.

Even though political strategies strongly refer to the nearly or Net Zero Energy objectives, there is little available knowledge about standard cost- and performance optimized building technologies to reach nearly or Net Zero Energy consumption. While low- and ultra-low energy houses, e.g. according to the passive house standard, already show considerable market penetration and growth in several European countries, nZEB are rather in the pilot and demonstration phase in order to prove a nearly zero, net zero or even plus energy balance. In plus energy buildings a surplus of produced energy compared to the consumed energy is achieved by installed renewables on-site on an annual basis.

However, it is not clear how an nZEB will be defined or whether there will be a common definition. Due to the common understanding, an NZEB is a grid-connected building with highly reduced energy needs where the weighted consumed energy can be produced by weighted renewable production on-site on an annual basis. However, this definition is incomplete, e.g. regarding the system boundary (what does on-site mean, since the EPBD also considers nearby production), the energies taken into account (including plug loads or just building technology, including mobility, life-cycle consideration) and the weighting system.

Moreover, with a broad introduction of the concepts as intended in the political objectives, aspects like load match between locally produced and consumed energy as well as interaction with energy grids, in particular the electricity grid should also be considered and buildings should be designed to work in line with the needs of the energy grids. Last but not least, the definition of the building has an impact on design and system configuration.

## 2. Approach

Annex 40 in the Heat Pumping Technologies (HPT) Technology Collaboration Programme (TCP) of the International Energy Agency (IEA) entitled "Heat pump concepts for nearly zero energy buildings" has been accomplished with the nine participating countries Canada, Finland, Germany, Japan, the Netherlands, Norway, Sweden, Switzerland and the US. The operating agent is the Institute of Energy Technologies (IET) of the University of Applied Sciences Rapperswil HSR in charge of the Swiss Federal Office of Energy (SFOE). The project has been concluded in the end of 2015. Final reports have been published in summer 2016 and are available on the website of the HPT Heat pump centre (www.heatpumpingtechnologies.org) and the Annex 40 project website (www.annex40.net).

The objectives of the Annex 40 were to

- Characterise the state-of-the-art of nZEB in the participating countries
- Compare different building technologies regarding performance and cost
- Further-develop heat pumping technologies for the application in nZEB
- Gather real world operation of heat pumps in nZEB from monitoring results
- Consider aspects like load match and grid interaction

### *2.1 National contributions to IEA HPT Annex 40*

Table 1 gives a more specific overview of the contributions of the participating countries in Annex 40 comprising the activities and contributions in Task 2, Task 3 and Task 4.

Table 1. Overview of contributions of participating and interested countries to Annex 40

| Country/Institution | Contribution to IEA HPT Annex 40 |
|---|---|
| **Canada** (CANMET Energy, Hydro-Quebec) | • Case studies for different building types and –uses<br>• Technology development of solar assisted heat pump system with ice-slurry storage |
| **Finland** (Green Net Finland, Aalto Univ., VTT) | • Development of energy-efficient and cost-effective heat pump systems for nZEB in Finland by simulation of case studies for single- and multi-family houses |
| **Germany** FhG-ISE | • Long-term field monitoring of low energy office buildings, evaluation of load management options and grid-supportive operation |
| **Japan** (University of Nagoya Japanese manufacturers) | • Case studies for nZEB office buildings with heat pumps for Japanese and European load conditions<br>• Technology developments for nZEB, documentation of monitoring results |
| **Netherlands** (Platform 31, TNO) | • Field monitoring „Energy leap" for market implementation of nZEB, evaluation of user comfort and cost-effectiveness as well as retrofit concepts for nZEB |
| **Norway** (SINTEF, NTNU, Cowi AS) | • Design software for heat pumps with natural refrigerants in nZE office buildings, documentation of field monitoring results of nZEB in Norway |
| **Sweden** (SP, Swedish manufacturers) | • System comparison of nZE single- and multi-family houses with Swedish weather conditions, prototype developments of adapted heat pumps for nZEB |

| | |
|---|---|
| **Switzerland** (IET HSR, IEBau FHNW Energie Solaire SA) | • Integration of solar absorber and heat pump for multifunctional operation in offices, system comparison of heating systems for MINERGIE-A®,<br>• Field monitoring MINERGIE-A® with electro-mobility, evaluation of load management options |
| **USA** (ORNL, NIST CEEE Uni Maryland) | • Field monitoring of integrated and multifunctional heat pumps (IHP)<br>• Commissioning/operation NZEB test facility (Net Zero Energy Residential Test Facility – NZERTF)<br>• Software development ThermCom for comfort evaluation of low-ex heating and cooling systems |

## 3. State of the Art of nZEB

### *3.1. Definition of nearly Zero Energy Buildings*

The most ambitious driver for the introduction of nZEB is currently the recast of the EU-Directive on the Energy Performance of Buildings EPBD [1] in the EU which prescribes the introduction of nZEB for new public buildings by the beginning of 2019 and for all new buildings by the beginning of 2021. The main steps of the time schedule towards the introduction of nZEB are depicted in Fig. 1. In the EU, the definition of nZEB is a task of the member states (MS). In 2015 at the interim report on intermediate targets of MS for nZEB, see Fig. 1, a definition of nZEB has been available in 15 countries.

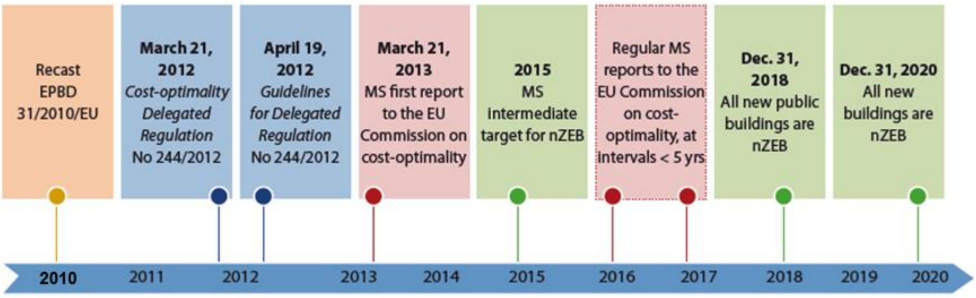


Fig. 1. Time schedule for the implementation of nZEB [2]

In further 3 countries, the nZEB requirements have been defined and are expected to be implemented in the national legislation. In the remaining 9 member states (including Norway and Brussels region), the definition is still under discussion and has not been finalised, yet [3].

However, existing definitions vary both regarding criteria and required limits for the criteria, thus, a comparability of the current definition in the countries is difficult. Therefore, in the joined IEA ECBCS Annex 52/SHC Task 40 a framework for items to be included for a consistent definition has been elaborated [4]. Fig. 2 left shows the basic concept of an NZEB and the items to be included for a complete definition as stated in Fig. 2 right. The intention of the framework is to derive buildings, which are comparable, even though the definition may not be entirely identical and allows e.g. the EU member states to set some details in the definition according to country-specific requirements. The criteria printed in bold letters are the most chosen options in current definitions.

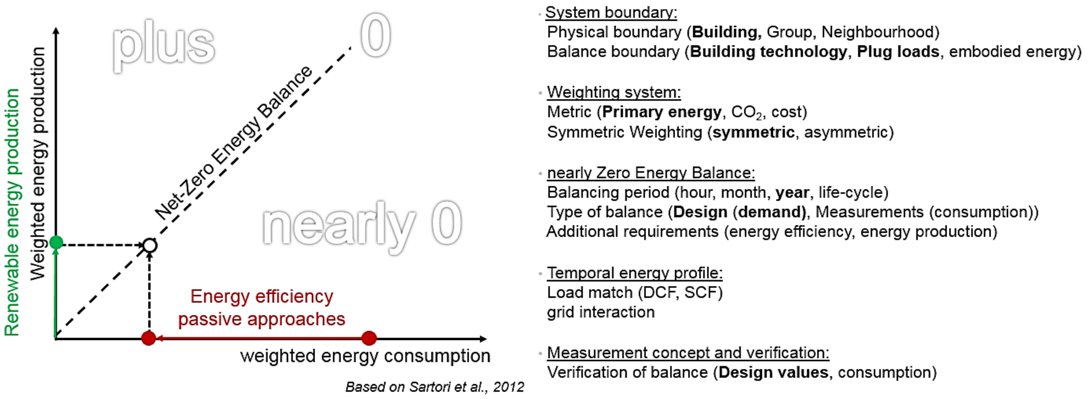


Fig. 2. Basic principle of NZEB and criteria for a uniform definition of NZEB (based on [4])

As collaboration of the Federation of European Heating, Ventilation and Air Conditioning Associations REHVA and the European standardisation organization CEN a common definition and a certification procedure for nZEB have been elaborated.

The certification scheme a four-step procedure also denoted as hurdle race and has been introduced as informative Annex in [5], which is depicted in Figure 3 The first certification criterion ("hurdle") refers to the space heating needs and is thus a criterion for the quality of the building envelope.

The second criterion limits the overall primary energy and is hence a criterion on the overall energy performance. The third criterion refers to the non-renewable energy defining thus a requirement of renewables share. The fourth criterion is the energy balance, which to reach the nearly zero energy criterion.

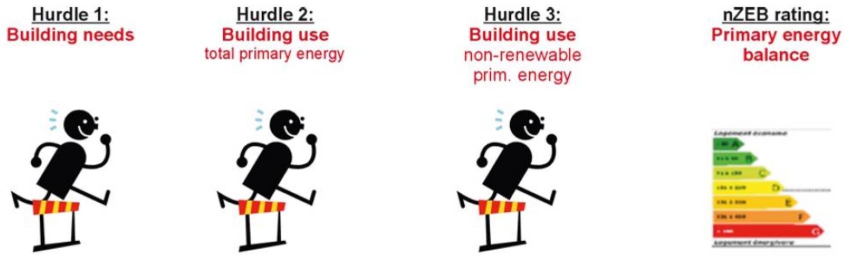


Fig. 3. "Hurdle race" of the single criteria for nZEB certification acc. to prEN 15603 (2013) [5] ([6])

If the member states implemented this certification scheme, there would still be options to adopt the limits to national particularities, but the definitions would still be the same regarding the criteria, which would enable a good comparability of the definitions among the different member states.

The system boundaries for the standardization is given in Fig 4 left. In Sept. 2015 the Building Technology Office (BTO) of the US Department of Energy DOE published a definition for NZEB, which generally corresponds to the REHVA definition. It is depicted in Fig. 4 right. Thus, the two definitions are a step to a uniform implementation of NZEB.

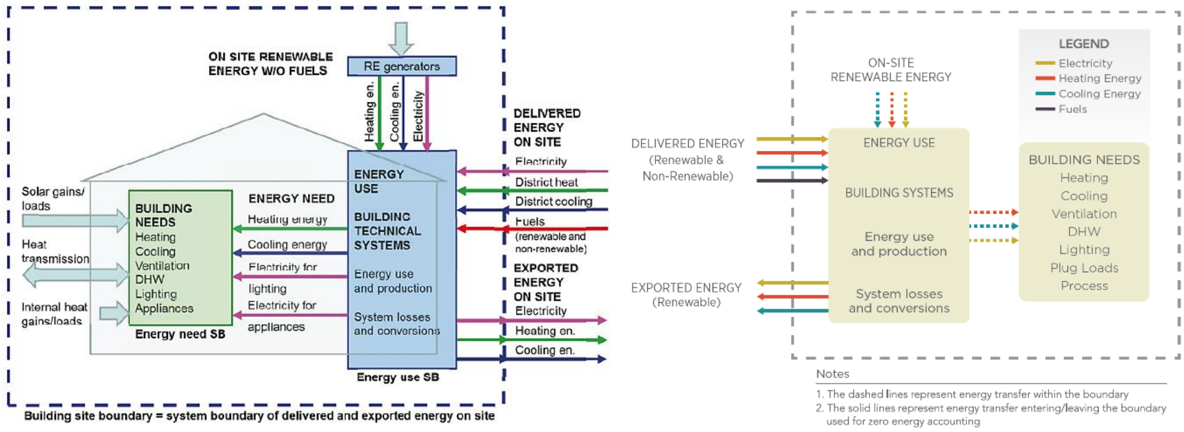


Fig. 4. System boundary of nZEB according REHVA/CEN definition [7] and DOE definition [8]

## *3.2. Building technologies in nZEB*

Fig. 5 shows an evaluation of installed building technology in nZEB. Fig. 5 left comprises 29 small residential buildings, 19 large residential buildings and 33 non-residential buildings. In all building categories the dominating role of solar PV systems as technology to balance the energy consumption by renewable energy production on-site is obvious. If the solar PV is combined with a heat pump, which is the case in about 70% of the buildings, and no fuel is used for back-up a so-called all electric building results, which only uses electricity as end energy. These type of buildings established as archetype for nZEB.

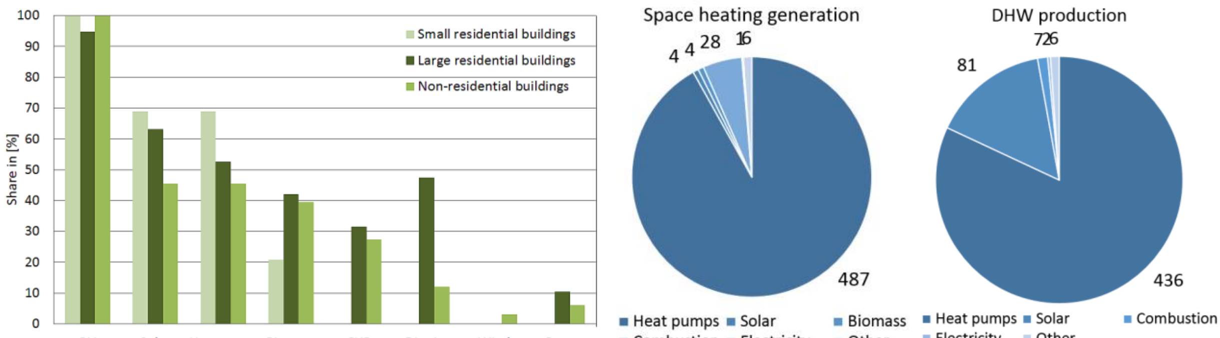

Fig. 5. System technology in international nZEB projects [9] and systems installed in certified MINERGIE-A® buildings (based on database at www.minergie.ch)

Fig. 5 right shows installed systems in about 530 Swiss nZEB projects according the MINERGIE-A® label for space heating and DHW. Heat pumps have obviously become the standard system for these buildings. For space heating generation about 90% and for DHW production, about 80% of the systems are heat pumps. DHW systems are more often combined with solar thermal systems, while in space heating, most systems are monovalent.

## 4. Results of the IEA HPT Annex 40

The work in the Annex 40 has been divided in three tasks. Task 2 of the IEA HPT Annex 40 was dedicated to the system assessment regarding performance and cost, Task 3 to the technology development as well as lab- and field testing of prototypes and Task 4 to field monitoring. In single field monitoring, also demand response capability were evaluated. In the following selected project results of the different tasks are presented in more detail. All results of the single tasks are found in the final reports of the Annex 40.

### *4.1. Task 2: System assessment*

As example for the system assessment in Task 2 the results of a Swiss case study for residential and office buildings according to the MINERGIE-A® label, a common Swiss implementation of a nearly zero energy buildings, are detailed for the central European climate. As single-family building for the Swiss energy and cost comparison of different building systems, the reference framework of IEA HPP Annex 38/SHC Task 44 [10] was adapted. As multi-family building a five-storey building was taken. As example for an office building the headquarter of the Marché restaurants in Kemptthal was chosen, which is a three-storey building. The results confirm that for Swiss boundary conditions of the MINERGIE-A®-label, i.e. the balance boundary of the building technology without plug loads, heat pumps in combination with PV are the most cost-effective systems for single-family buildings regarding energy efficiency and annual cost based on a 25-year life-cycle analysis, as depicted in Fig. 6 left. For low heat load at ultra-low energy house level, air-to-water (A/W)-heat pumps reach the lowest annual cost due to the lower investments. For higher loads and larger buildings, ground-source heat pumps are more favourable regarding life-cycle cost. Systems with biomass, especially biogas, have the highest life-cycle cost. In multi-family-buildings combined heat and power (CHP) and district heating reach similar life-cycle cost as the heat pumps under the set boundary conditions of system and energy cost, which is depicted in Fig. 6 right. Biomass systems, in particular biogas, are the most expensive system solutions like in single-family houses.

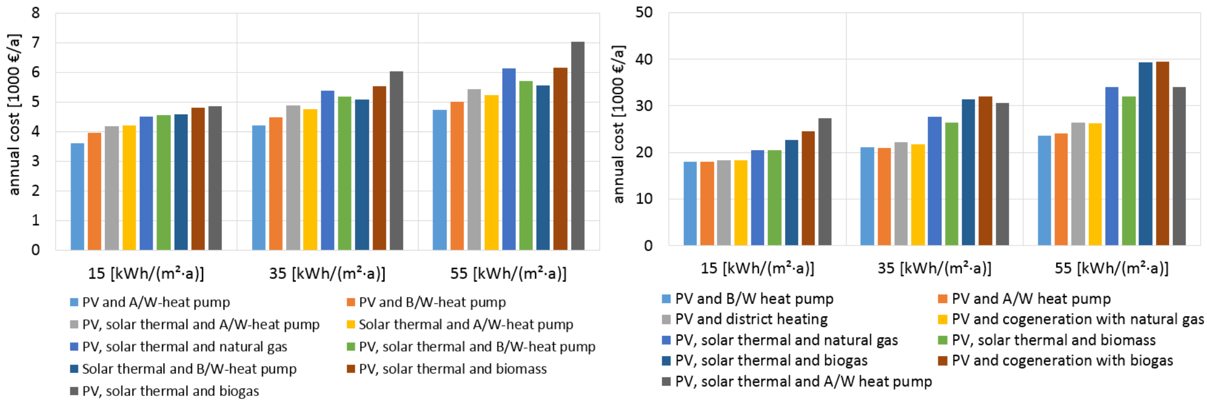

Fig. 6. System comparison for single-family (left) and multi-family houses (right) in Switzerland [11]

For office buildings, nearly the same order of systems cost results as for the multi-family buildings. In office buildings the plug loads of the ICT equipment and lighting as well as cooling load have been included into the balance boundary. Under the chosen boundary conditions smaller office buildings with three storeys can still reach a nearly zero energy balance according to MINERGIE-A® with PV installed on the roof, while larger buildings also need PV installation in the facade or further electricity producing technologies like CHP.

Several similar case studies have been performed in the other participating countries of the Annex 40. In particular in Sweden and Finland under the boundary conditions of Nordic climate and different cost structure, also the heat pump systems reach the lowest life-cycle cost. Thus, this shows a certain robustness of the results regarding changing boundary conditions.

In Japan several case studies for office buildings have been performed. In case of pronounced cooling and dehumidification loads, it may get hard to reach the nZEB despite architectural optimisations for daylight use and high performance values of the equipment.

In Canada, case studies for office buildings showed a clear separation of favourable systems depending on market conditions. While in the Eastern provinces with the cities like Halifax and Montreal, especially adapted cold climate air source heat pumps are cost-effective systems, the gas prices in the Western provinces of cities like Toronto, Edmonton and Vancouver are too low for the heat pumps and CHP systems to compete with the gas boiler.

Besides the case studies, also two design tools have been developed in the Annex 40. In Norway, the development a tool for cost-optimal design of zero emission buildings using optimization algorithms in ongoing. In the next steps, the basic system configuration of heat pump and back-up heater shall be extended to a larger variety of system configurations also including free-cooling and cooling by reverse operation of the heat pump. In the USA a design tool for emission systems for space heating and cooling has been developed, which enables a detailed thermal comfort evaluation based on a model reduction of CFD input data. The tool is intended to evaluate radiative surface heating and cooling emission systems, but also convective systems like induction units as well as ducted and ductless air-conditioners can be investigated.

### *4.2. Task 3: Technology development and testing*

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

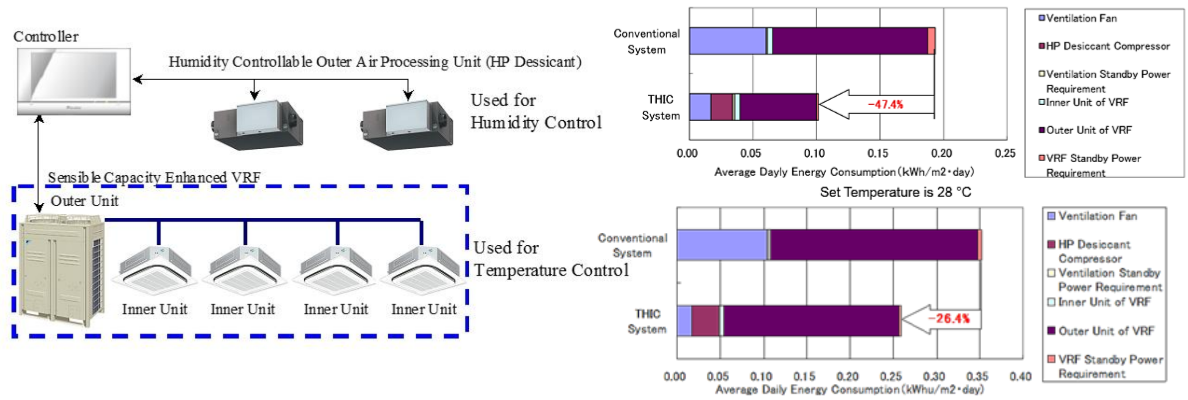


Fig. 7: Configuration of the HVAC system (left) and energy reduction in summer (right, top) and winter operation (right, bottom) [12]

The system denoted as **<u>T</u>**emperature and **<u>H</u>**umidity **<u>I</u>**ndividual **<u>C</u>**ontrol (THIC) performs a separation of the sensible cooling load and the latent dehumidification load. The latent load is covered by a HP Desiccant system which

has been further developed to decreased regeneration temperatures of the desiccant of 40-50 °C, so the regeneration can be accomplished efficiently with the heat pump.
Adsorption and desorption are accomplished in parallel while the heat pump transfers the heat from the adsorption to the desorption process, which significantly increases the performance.
Due to separation of the latent load, pressure difference for the VRF heat pump can be decreased. The VRF heat pump has been optimised for low pressure differences. A new scroll compressor was developed which is far more tolerant for the operation with the small pressure difference operation, which makes it possible to notably reduce the pressure difference and increase the performance.
The test of the unit was accomplished in two office rooms in summer and in winter operation. Fig. 7 left shows the system configuration of the THIC and Fig. 7 right show the achieved energy savings during the summer and winter test. Despite the energy saving of about 50% the control of the indoor condition has been better by the THIC system than by the conventional system. In winter test, energy saving of about 25% have been achieved. Based on the measurements a model of the system was developed. The overall energy savings were determined by year-round simulations. Results of the overall energy saving are depicted in Fig. 8 left yielding an energy saving potential of about 75%. Concluding, the impressive energy saving without any reduction of the indoor thermal environment conditions has been achieved by the reduction of air-conditioning loads by individual control of temperature and humidity, the development of the HP desiccant for efficient humidity control and the development of the sensible capacity enhanced VRF for efficient temperature control, especially in spring or autumn. By the energy reduction, it is much easier and more cost-effective to achieve an nZEB consumption due to reduced generation needs on-site to meet the balance.

Further technology developments refer to a highly integrated heat pump at Oak Ridge National Laboratory (ORNL), which can provide the different functions space heating and cooling, DHW and dehumidification in different simultaneous operation modes. A sketch of the air-source prototype is depicted in Fig. 8 right. While the ground-source system is already on the market, variants of the air-source system have been developed and field monitoring in Annex 40. Field monitoring results show average performance factors of 5.1 in space cooling mode and 4.4 in DHW mode by the combined operation, e.g. simultaneous space cooling and DHW production,. The dedicated DHW mode reaches performance factors of about 2.6. Thus, a significant increase of performance is achieved by the system integration of different operation modes. Also developments of the integration of solar technologies and heat pumps have been accomplished in the Task 3 of Annex 40.

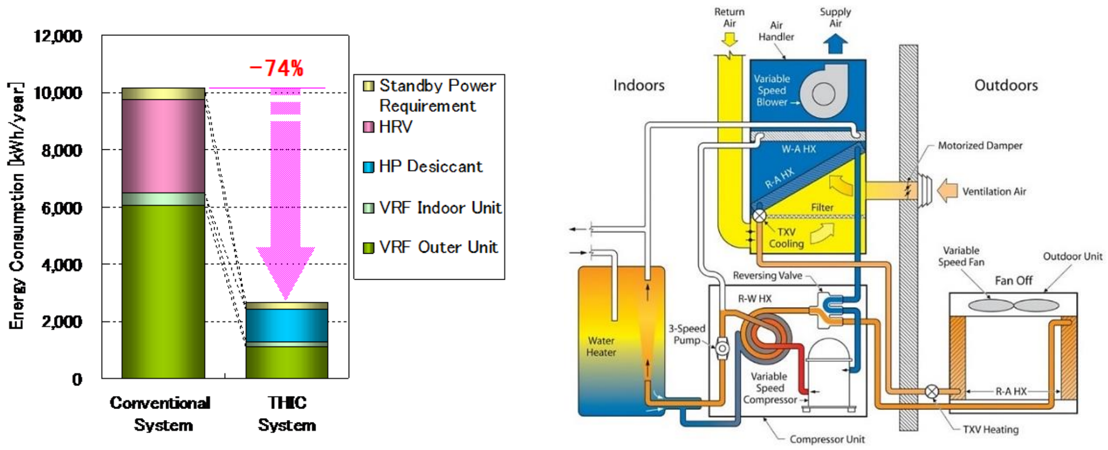


Fig. 8: Comparison of energy reduction by the THIC system with conventional air-conditioning systems (left) [12] and layout of the air-source integrated heat pump of ORNL [13]

### *4.3. Task 4 – Field monitoring and integration into energy systems*

Within the projects of the Research Centre on Zero Emission Buildings (ZEB) in Norway the first nZEB in Norway are being currently monitored as pilot projects. "Powerhouse Kjørbo" is one of the pilot and demonstration projects which has been monitored by the NTNU. The project refers to the retrofitting of an office building to a plus-energy building in Sandvika near Oslo. Fig. 9Fig. right shows the retrofitted building and a hydraulic scheme.

The building with an energy reference area of 5200 m² has a calculated specific heating energy need of 19.1 kWh/(m²a), a design heat load of 52 kW and a DHW need of 4.8 kWh/(m²a) after the retrofitting. The cooling load is 65 kW and the specific cooling energy needs 1.8 kWh/(m²a).

The heating and cooling needs are provided by a 64 kW brine-to-water (B/W) heat pump with 10 single U-tube borehole heat exchangers of 225 m depth each. The heat pump is also used as chiller for back-up cooling. For back-up heating the building has a connection to a district heating grid. Furthermore, an 8.5 kW B/W heat pump for DHW production is installed. For balancing the energy demand a solar PV-generator of 1,556 m² is installed, which yields a calculated electric energy of 225,000 kWh/a.

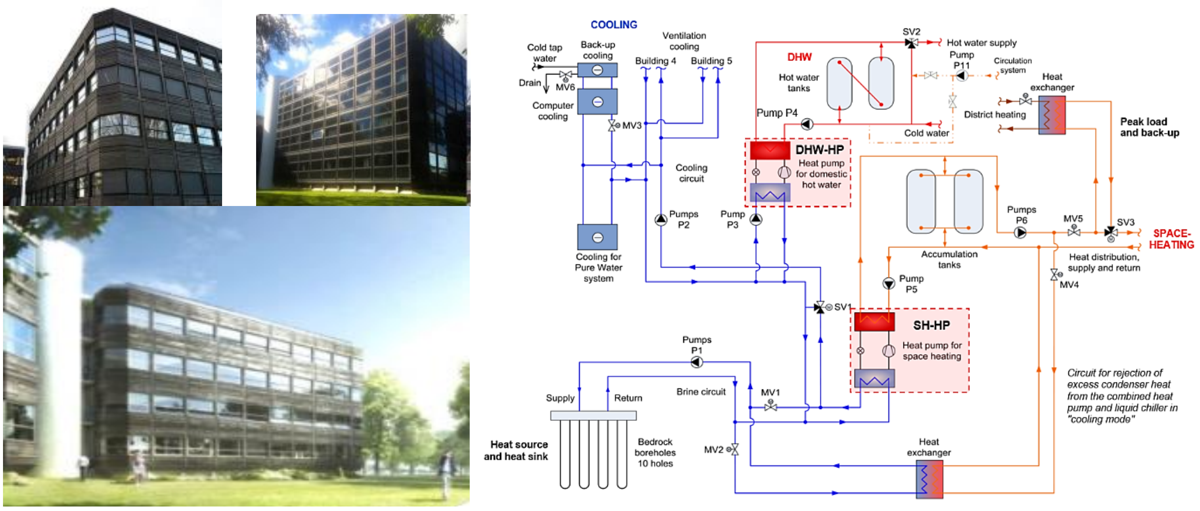


Fig.9: View of Powerhouse Kjørbo (left, source ZEB) and hydraulic scheme of the building (right) [14]

The measured heating energy demand is 29% higher than the calculated value, the measured DHW needs are about 60% lower as planned. The cooling energy is 11% higher. The measured peak load for heating is about 37% and the peak cooling load around 29% higher than the design values.

Despite the high design temperatures of 50 °C for space heating due to retrofitted building, the monitoring shows a good $SPF_{SH}$ of 3.9 including the auxiliary energy for the source pumps of the boreholes. In DHW mode an $SPF_{DHW}$ of 2.9 is reached.

Optimisation potentials are seen in the dimensioning of the borehole field (only 5 boreholes to cover 90 % of the heating energy needs), frequency control instead of intermittent control of the compressors as well as in the use of buffer storages, application of natural refrigerants, and a better use of the waste heat from the active computer cooling.

Besides the Powerhouse Kjørbo, also monitoring projects of a $CO_2$ heat pump water heater (HPWH) installed in 3 blocks of flats of totally about 800 flats and an air-source heat pump installed in a new nZE office building in passive house standard were accomplished. The results of the $CO_2$-HPWH for the blocks of flats reached a $SPF_{DHW}$ of 4.4 with 70 °C DHW supply temperature and an exhaust air heat source around 20 °C. These results are very good despite some identified optimisation potentials.

## 5. Continuation of research in IEA HPT Annex 49

Due to approaching deadlines for the definition and introduction of nZEB according the EPBD recast, see chap. 3, the interest in cost-effective system solutions for nZEB is continuously high. Therefore, research of IEA HPT Annex 40 will be continued in IEA HPT Annex 49 entitled "Design and integration of heat pumps for nZEB". On the one hand, developments and investigations which have begun in Annex 40 shall be further developed. On the other hand, a new focus is set.

The IEA HPT Annex 49 started in October 2016. At the point of time of writing, the five countries Belgium, Germany, Norway, Switzerland and the USA have joined the Annex 49. Furthermore, Austria, Canada, Finland/Estonia, Japan, Sweden and the UK declared interest to join the Annex 49. Table 2 gives and overview on contributions to the Annex 49.

Table 2. Overview of possible contributions of participating and interested countries to Annex 49

| Country/Institution | Contribution to IEA HPT Annex 40 |
|---|---|
| **Austria**<br>Univ. of Innsbruck | • Monitoring and simulation of two nZEB buildings for performance optimisation |
| **Belgium** | • Cost-effective integration and design of nZEB system |

| | |
|---|---|
| Free Univ. Brussels | |
| **Canada**<br>CANMET Energy | • Design and optimization of solar assisted heat pump system with ice-slurry storage |
| **Finland/Estonia**<br>Aalto Univ., Tallinn Univ. | • Modelling and simulation of ground-coupled heat pumps (energy piles, horizontal collectors)<br>• Design of heat pumps and heat emission systems for nZEB application |
| **Germany**<br>TH Nürnberg, Uni Braun-schweig, TEB | • System integration, design and field monitoring of 8 terrace houses and passive house<br>• Development of control strategies for smart grid integration |
| **Japan**<br>University of Nagoya | • Case studies for nZEB office buildings with heat pumps for Japanese and European load conditions<br>• Documentation of monitoring |
| **Norway**<br>SINTEF, NTNU, Cowi AS | • Design tool for cost-effective heat pumps and developments of heat pumps with natural refrigerants<br>• Investigation/monitoring of nZE demonstration buildings and neighbourhoods in Norway |
| **Sweden**<br>SP | • Monitoring and comparison of heat pump system in two equal test houses<br>• Evaluation of 20 field monitored heat pump systems |
| **Switzerland**<br>IET HSR | • Integration and design options of solar absorber and heat pump system<br>• Field monitoring of NZEB with façade integrated PV |
| **UK**<br>Glen Dimplex | • Evaluation of design and control of nZEB model houses |
| **USA**<br>ORNL,NIST<br>CEEE Uni Maryland | • Concluding field monitoring of integrated heat pump variants (IHP)<br>• Technology testing and comfort evaluation in NZEB test facility (NZERTF)<br>• Evaluation of personal cooling methods to reduce loads in NZEB |

The investigations in Annex 40 were related to the system assessment. Based on that Annex 49 is dealing with a more in-depth evaluation of integration options as well as the design and control of components. Moreover, the building technology may get new tasks, e.g. the provision of flexibility to the connected energy grids, in particular the electricity grid. This may have an impact on future system design and on storage integration. But not only a short-term flexibility, but also the seasonal mismatch has to be taken into account for a holistic assessment of the system solutions. In this regard, the ground may be an interesting option to transfer source energy from the summer to the winter months by ground regeneration of borehole fields during summertime.

Furthermore, also the economic boundary conditions are rapidly changing. For instance, PV prices and subsidy scheme are changing, which affects the design and layout of systems and reduction of feed-in tariffs give a higher importance to a high self-consumption rates to guarantee an economic operation of the PV system.

Furthermore, decreasing prices of electrical batteries due to e-mobility may have an impact on self-consumption rates and demand response.

As further aspect, the investigations performed in Annex 40 were limited to single buildings, but an extension to groups of buildings or entire nearly zero energy neighbourhoods may open the consideration for collective systems connected by micro-grids and load balancing between buildings.

## 6. Conclusion

IEA HPT Annex 40 has investigated heat pump applications in nZEB. Even though political target focus on nZEB as standard for the next generation of high performance buildings, and an ambitious time schedule for the broad introduction of nZEB is set in the EU, no uniform definition of nZEB exists, yet. However, some steps are taken by CEN, REHVA and DOE to harmonise the different definitions and criteria of nZEB.

In built nZEB, heat pumps have already a large diffusion due to the high performance, but many of the built nZEB are single family houses where the balance can be reached easier due to a sufficient surface area for PV installation in the building envelope. Moreover, many of these buildings have been built as pilot and demonstration projects for the approval of the nearly zero energy balance, and are not cost-optimally designed.

In Annex 40 system comparison of different building technologies for nZEB has been performed in case studies for the different boundary conditions in the participating countries. Heat pumps are both energy-efficient and cost-effective systems for the application in nZEB in central European and Nordic climate conditions according to the results of these case studies. In larger buildings like multi-family and office buildings, also district heating and CHP may reach comparable life-cycle cost depending on market prices. Furthermore, two design tools for heat pump system design and comfort evaluation of heat emission systems in nZEB have been developed.

Moreover, different technology developments of heat pumps for nZEB regarding highly integrated heat pumps for multifunctional use of different building services and integration options of solar components have been performed. A prototype development of an integrated air-source heat pump for space heating, DHW, space cooling and dehumidification at ORNL in the USA yielded a PF above 5 in space cooling and dehumidification and 4.4 for DHW in the summer period field monitoring. Field monitoring results of an improved HVAC system with separation of sensible and latent load in Japan achieved a whole year energy saving of 75% at the same comfort conditions compared to a conventional system.

With the politically intended broad introduction of nZEB by 2021 also aspects of the integration of nZEB into connected energy grids regarding grid interaction will gain importance. The implementation and the grid interaction will also be determined by the definition of nZEB in the different member states of the EU and outside Europe. NZEB or even plus energy buildings by PV tend to produce a higher surplus of electricity and may cause higher grid interaction than nZEB, and may therefore require larger demand response capabilities. Therefore, by simulations and field evaluations first evaluations of demand response capabilities of heat pumps have been accomplished. Heat pumps are often the main electricity consumer besides the plug loads, and thus offer a load shift potential to grid supportive operation.

Based on the Annex 40 results, it can be conclude that heat pumps are both an energy efficient and cost-effective building system technology in nZEB application and will play an important role in future high performance buildings fulfilling nZEB requirement, not only due to the energy and cost aspects, but also due to demand response capabilities to support operation of connected energy grids. However, further research issues are the optimal design of systems under consideration of performance, cost and demand response. Moreover, storage integration options both on thermal and on electrical side and the extension of the concept to the neighborhoods or even communities are further research topics. These topics are addressed in a follow-on project of Annex 49 which is currently in the starting phase.

IEA HPT Annex 40 has been concluded. Final reports and further information on the Annex 40 is found on the Annex 40 project website at http://www.annex40.net.

**Acknowledgements**

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