# HEAT PUMP CONCEPTS FOR NEARLY ZERO ENERGY BUILDINGS – INTERIM RESULTS OF IEA HPP ANNEX 40

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**Abstract:** Political targets for future building standards focus on the introduction of nearly or Net Zero Energy Buildings (nZEB/NZEB) with a horizon of 2020 (Europe, USA) to 2030 (Japan, Canada), even though there is no common definition for these types of buildings, yet. However, different initiatives try to derive a harmonized definition. The Annex 40 in the Heat Pump Programme (HPP) of the International Energy Agency (IEA) has started work in the beginning of 2013 in order to investigate heat pump concepts adapted to the requirements in nearly Zero Energy Buildings. The eight countries Canada, Finland, Japan, the Netherlands, Norway, Sweden, Switzerland (operating agent) and the USA are participating in the project. Heat pumps are already well-established in realized nZEB, generally combined with PV as dominating technologies to balance the energy consumption. Current work in the Annex 40 is dedicated to the investigation of system concepts by simulation and the experience from field monitoring of built nZEB in the participating countries. The paper gives an overview on the contributions of participants to Annex 40 and results of the state-of-the-art analysis.

**Key Words: nearly zero energy buildings, multifunctional heat pumps, field monitoring, system integration**

## 1 INTRODUCTION

The recast of the Energy Performance of Buildings Directive (EU, 2010) in Europe sets the objective that all new buildings shall be built as nearly Zero Energy Buildings (nZEB) 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 by 2020 and 2030, respectively, and also 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 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 weighted produced energy compared to the weighted 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 if 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 consumed energy can be produced by renewables on-site on an annual basis. However, this definition is incomplete regarding the system boundary, the energies taken into account and the weighting systems.

Moreover, with a broad introduction of the concepts as intended by the political objectives, aspect like load match between locally produced and consumed energy as well as interaction with energy grids, in particular the electricity grid should be considered, as well, 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, as referred to in chapter 3 in the frame of the results of the state-of-the-art analysis.

## 2 OUTLINE OF THE IEA HPP ANNEX 40 PROJECT

Annex 40 in the Heat Pump Programme (HPP) of the International Energy Agency (IEA) entitled "Heat pump concepts for nearly zero energy buildings" has started work in the beginning of 2013 with the six participating countries 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). In the end of 2013, the two further countries Canada and Finland joined the Annex 40, and there is further interest of Germany to join the Annex 40 soon. The project time is scheduled from 2013 – 2015.

The work in IEA HPP Annex 40 has been structured into four Tasks.

Task 1: State-of-the-art analysis
The objective is to gather experiences with realized concepts of nZEB pilot and demonstration buildings in the different participating countries. Results of the Task 1 will be detailed in the chapter 3.

Task 2: Analysis of system concepts
Based on the found concepts in the state-of-the-art analysis Task 2 is dedicated to a comparison of different concepts and improvements regarding energy performance and cost. Development potentials are seen in system and building integration as well as in design and control of the heat pump and renewable components.

Task 3: Technology development and field monitoring
Task 3 covers the adaption and further development of the heat pump to specific needs in nZEB, e.g. regarding capacity range, capacity control, multi-functional operation of the heat pump, temperature lifts and refrigerants. Moreover, testing in the laboratory and in the field are performed and evaluated.

Task 4: Integration of nZEB into the energy system
With the broad introduction of the nZEB concept as intended by political strategies in the building sector, also the local and regional interaction of the building with the grid has to be considered.

The Task 1 has been finished by the six participating countries and will be amended by the results of the countries that joined the Annex 40 recently. The participating countries are currently working on the Task 2 and Task 3, which is scheduled until the end of 2014. In parallel, work on Task 4 will begin in 2014.

### 2.1 National contributions in IEA HPP 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 HPP Annex 40 |
|---|---|
| **Canada** Hydro-Quebec, CANMET Energy | Integration of heat pump and other heat generators (e.g. solar technologies, CHP); Techno-economic analysis for different building types and uses; field monitoring and design of Canadian nZEB with optimized heat pumps. |
| **Finland** Green Net, VTT, Aalto Uni, SULPU | Development of energy-efficient and cost-effective heat pump solutions for nZEB in Finland by simulation for three different building types and different heat sources; outline of field evaluation and design recommendations. |
| **Germany** FhG-ISE, FH Nürnberg, TEB | System integration and field monitoring of residential and office buildings, derivation of a methodology for load match and grid interaction assessment and optimized operation. |
| **Japan** Uni Nagoya, Manufacturers | Evaluation of the combination of heat pumps and solar components for Japanese and European load conditions for nZEB buildings by simulations; derivation of technology and design recommendations. |
| **Netherlands** platform_31, TNO | Large field monitoring programme "Energy leap" in residential and non-residential buildings, simulation and comparison of different field-monitored concepts |
| **Norway** (SINTEF, NTNU, COWI) | Prototype developments of heat pump integration, design tools for heat pumps with natural refrigerants in nZEB; Field monitoring of new built and retrofit nZEB in Norwegian climate. |
| **Sweden** (SP, manufacturers) | Prototype developments of adapted heat pumps for single and multi-family buildings in Swedish climate conditions; Field monitoring of prototypes in nZEB buildings. |
| **Switzerland** (IET HSR, IEBau FHNW, Energie solaire SA) | Investigation of the integration of solar components and heat pump for multi-functional operation of space heating, DHW and space cooling for offices and residential buildings by simulations and hardware-in-the-loop testing; Field monitoring of a plus energy building with electro-mobility. |
| **USA** (ORNL, NIST, Uni Maryland) | Field monitoring and prototype development of an integrated heat pump (IHP); Residential NZE Testing Facility for heat pump technologies incl. simulation; Development of software for comfort evaluation of radiant emission systems. |

### 2.1.1 Canada

Canada is represented by the Research Institute of the utility Hydro-Québec. CANMET Energy of Natural Resources Canada is also interested to join the IEA HPP Annex 40. A techno-economic analysis of heat pumps for different building types (new building/retrofit) and uses (single and multi-family residential buildings, office buildings) shall be accomplished. Another focus is the system integration of the heat pump with other heat generators like CHP and solar technologies. Moreover, components will be lab-tested and field results will be contributed. As result recommendations on system layouts for nZEB with heat pumps and best practice systems for Canada are contributed to Annex 40.

### 2.1.2 Finland

Finland is represented by Green Net Finland, the research institute VTT and Aalto University as well as the Finnish heat pump association SULPU. Finland will investigate energy-efficient and cost-effective solutions for different heat pump types in three building envelope categories (new building standards and retrofit) by simulation analysis. Results will prepare a field test and recommendations on system solutions for Finnish nZEB.

### 2.1.3 Germany

The Fraunhofer Institute of Solar Energy systems (FhG-ISE) and the Ohm-University of Nürnberg are interested to join Annex 40. Both project contribution deal with load match and grid-interaction of nZEB. The FhG-ISE has a long-term monitoring of office buildings equipped with heat pumps and will evaluate the performance according to different system boundaries in order to identify optimization potentials. Moreover, a residential building is in monitoring. Both monitoring results will be used to deduce a methodology for the assessment of load match and grid interaction and recommendations to optimize the operation. In the project of the Ohm-University, office buildings shall be analyzed.

### 2.1.4 Japan

The participants from Japan are the University of Nagoya in collaboration with different Japanese manufacturers. The focus of the national contributions are simulation studies of different heat pump system layouts incorporating solar technologies for nZEB. Both the Japanese load conditions as well as the European load conditions shall be considered to derive optimized system configurations, designs and controls.

### 2.1.5 Netherlands

In the Netherlands the institution platform_31 is collaborating with the Dutch national research institute TNO in Annex 40. The Netherlands has a running monitoring project called "Energy leap", where different building concepts are field-monitored and compared. Based on the monitoring it is intended to perform simulations and compare results to the field monitoring in order to derive optimization of the performance. TNO has started the analysis of different housing concepts. Moreover, retrofit solutions with PV and prefabricated building components have been applied. Due to a favorable feed-in tariff of PV-electricity in the Netherlands, retrofit concepts using PV can be economically feasible and it is intended to build business cases upon the experiences from the field tests.

### 2.1.6 Norway

Norway is represented by the research institute SINTEF Energy research in collaboration with the Norwegian Technical University NTNU and the engineering company COWI. The project contribution of Norway is supported by Enova SF and the Zero Emission Building Research Institute (ZEB). Norway will develop HVAC solutions for heat pumps for the application in nZEB with a focus on Nordic climate conditions and the use of natural refrigerants. Also field evaluations are included in the project. Different monitoring projects in nZEB will start in the beginning of 2014. Norway has also started the development of a design tool for nZEB equipped with heat pumps.

### 2.1.7 Sweden

SP, the Technical Research Institute of Sweden is collaborating with Swedish heat pump manufacturers in Annex 40. A prototype development of adapted heat pumps for the application in nZEB for both single and multi-family buildings has been started. The prototypes for single- and multi-family buildings shall be tested by field monitoring in 2014. Moreover, field monitoring projects of nZEB shall start also in the beginning of 2014.

### 2.1.8 Switzerland

Besides the project management of the Annex 40 at HSR, the two Universities of Applied Sciences HSR in Rapperswil and Northwestern Switzerland (FHNW) in Muttenz work together with the company Energie solaire SA, a manufacturer of selectively coated unglazed solar absorbers. The objective is the system integration of heat pump and solar components for multi-functional use for space heating, DHW and space cooling. Simulation work of integrated concepts has started and is accompanied by lab-testing of prototype components in a hardware-in-the-loop environment, where models can be used to emulate the system behaviour for the tested component. Different types of selective coatings have been tested in the lab, and results serve to validate simulation results. Testing will be continued in summer 2014. The objective is to derive favorable system integration with improved components, design recommendations for the application in nZEB and adapted controls. Moreover, a field monitoring of a plus energy building with electro-mobility as local storage is ongoing.

### 2.1.9 USA

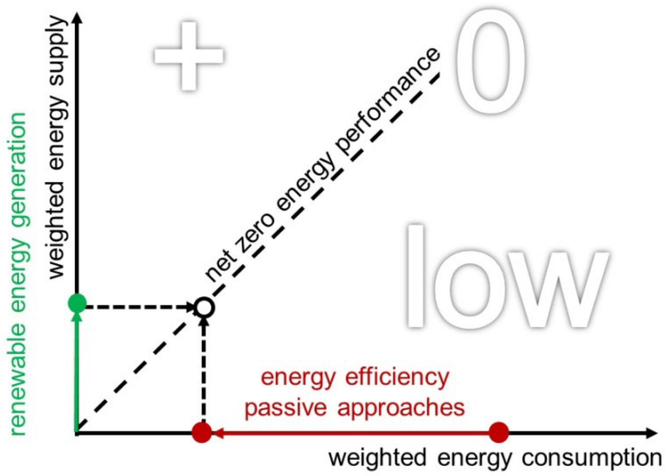
In the USA the Oak Ridge National Laboratory (ORNL), the National Institute of Standards and Technologies (NIST) and the Center for Environmental Energy Engineering (CEEE) of the University of Maryland collaborate in Annex 40. The ORNL has developed prototypes of highly Integrated Heat Pumps (IHP) for the operation in Net Zero Energy Buildings (NZEB) covering all building functions including dehumidification.

Two designs, a ground-to-air and an air-to-air heat pump have been developed, lab-tested and simulated. While the ground-coupled system is already market available, field monitoring and optimization of the air-source type is ongoing. Results of the field test are contributed to the Annex 40. Moreover, a "Net Zero Energy Residential Test Facility (NZERTF)" has been installed at NIST. The test house is equipped with tunable loads, so that equipment can be tested under different user conditions. Currently, an air-to-air heat pump is tested. Furthermore, at the CEEE of University of Maryland, a software to calculate indoor thermal comfort for the use of radiant heating and cooling panels is developed and currently validated with different test cases in order to optimize heat pump operation by reducing temperature lift, since radiant emission systems can work close to the room temperature.

## 3 RESULTS OF THE STATE-OF-THE-ART ANALYSIS

### 3.1 Definition of nearly Zero Energy Buildings

As stated before there is no precise and common definition of nZEB, yet. Therefore, in a joined IEA ECBCS Annex 52/SHC Task 40 a framework for items to be included for a consistent definition has been elaborated (Sartori et al. 2012). Figure 1 shows the basic concept of an NZEB and the items to be included for a complete definition. 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 basic principle and framework and the definition of the different criteria for the work in Annex 40 is depicted Figure 1.




- Building system boundary
  Physical boundary ***(building site)***
  Balance Boundary ***(incl. appliances)***
- Weighting system
  Metric ***(primary energy)***
  Symmetric weighting ***(yes)***
  Time dependent weighting ***(no)***
- nZEB Balance
  Balancing period ***(year)***
  Balance type ***(load-generation)***
  Energy efficiency requirements ***(legal)***
  Energy supply requirements ***(no)***
- Temporal characteristic
  load match ***(not yet)***
  grid interaction ***(not yet)***
- Measurement and verification

**Figure 1: Basic principle of nZEB and criteria of the common definition of nZEB (based on Sartori et al., 2012) and definition for the work in IEA HPP Annex 40**

The first aspect for the definition is the system boundary. The physical boundary refers to which energy is account as on-site production. In the EPBD recast (2010), also nearby production can be accounted in the physical balance. In order to clarify the terms of the directive the Federation of European Heating, Ventilation and Air-conditioning Association (REHVA) has publish a definition of nZEB in collaboration with the European standardization organization CEN depicted in Figure 2. According to this definition, energy production units in the country with a long-term contractually link can be considered as nearby and can be accounted to the on-site energy production.

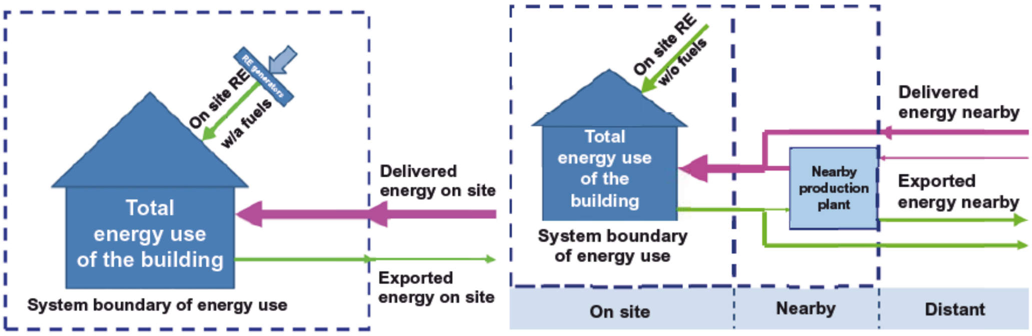



**Figure 2: REHVA/CEN definition of the physical boundary (Kurnitski, 2013)**

The second boundary denoted as balance boundary defines the energies taken into account, which is also denoted as ambition level. Different ambition levels are depicted in Figure 3. The least ambition would be to just balance the space heating energy demand, i.e. a zero heating energy house. Common definition comprise the balance of the total consumption of the building technology denoted as zero operational energy building or including also the electric appliances (plug loads) denoted as Zero Energy Building in Figure 3. Moreover, the type of building and boundary conditions concerning the site of the building in terms of climate zones and comfort levels has to be given. The largest balance boundary includes also the embodied energy for the erection of the building and the mobility due to the building location which could be considered as life-cycle analysis (LCA) approach.

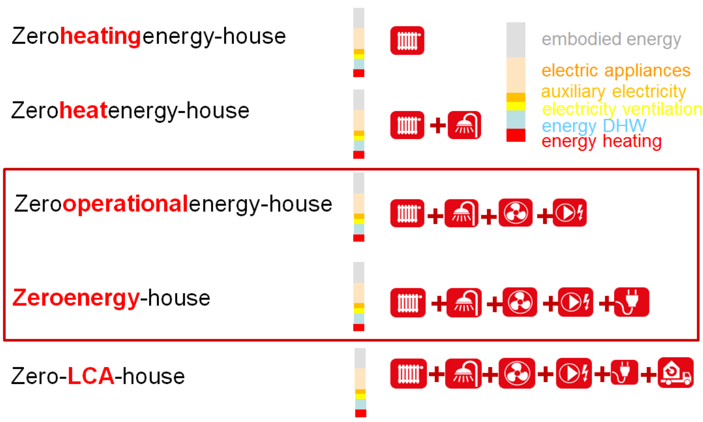



**Figure 3: Different ambition levels for nZEB (source: MINERGIE®)**

Figure 3 also shows the relation between the different energy amounts. In high performance buildings, building technology, the electric appliances and the embodied energy contribute each one third to the energy consumption of the building. It becomes clear that the design of the renewable production units on-site is significantly affected by the definition of the balance boundary.

The second basic criterion is the metric for the balance. The most common energy metric is primary energy, but also an unweighted metric of delivered energy has been discussed. In order to focus on climate change considerations $CO_2$-emissions would be another metric. An economic focused assessment would be stressed by a cost criterion. Furthermore, it has to be defined, if the weighting of imported and exported energy shall be symmetric to take into account the substitution effect in the grid, or asymmetric, by which certain technologies could be promoted. A time-dependent weighting could be motivated by dynamic energy prices in the future.

For the evaluation of the zero energy balance time periods have to be defined. Presently, mainly an annual balancing is applied. Also the type of balance has to be fixed, which could be a balance of the imported and exported energy (requiring data of the building operation) or load and generation balance (requiring only design data). Moreover, additional criteria concerning minimum energy efficiency requirements or minimum required renewable shares may be defined, e.g. by building codes.

For a broader introduction of nZEB load match and interaction with grids have to be considered, as well. The objective would be to design the building and system technology to minimize the impact on the grid, in particular the electricity grid. nZEB that could work in line with grid requirements have higher potentials for load management which is an additional benefit. Last but not least, definitions how to verify and measure the balance should be included in the definition.

Besides the definitions different labels have been introduced. In Switzerland, for instance, the MINERGIE® association certifies different types of high performance buildings. In 2011, a new label MINERGIE-A® has been defined and is a current implementation of the nZEB in Switzerland. Originating from Denmark the Active house alliance has launched a label combining the aspects of energy efficiency, comfort and environment for the labeling.

### 3.2 Market introduction of nZEB in different countries

The introduction of nZEB in different regions of the world is quite different. In central European countries as Austria, Germany and Switzerland, already a significant number of together several hundreds of nZEB have been built. First buildings date back to the 1990 like the energy autarkic or the heliotrope building both situated in Freiburg (Brsg.), Germany. Experience has been gained by monitoring projects of many buildings. In the last years, the number of realized nZEB significantly increased. In Switzerland, for instance, the MINERGIE-A® label to certify an nZEB is becoming quite popular. Introduced in March 2011, already more than 300 residential buildings have been certified (state Jan. 2014).

In Scandinavian countries, nZEB are rather in the introduction and the monitoring results of the first nZEB buildings will partly be contributed to IEA HPP Annex 40. Several buildings in Norway and Sweden are in the planning and construction phase and monitoring will begin in 2014

Canada has launched a field testing of so-called EQuilibrium houses, where 13 pilot and demonstration buildings with multiplication potential all over Canada have been subject of a detail monitoring. Most of the concepts incorporated a heat pump and solar technologies in the building envelope. The results of the monitoring and the integrated system configurations will be contributed by Canada to the IEA HPP Annex 40.

In the USA the Department of Energy (DOE) has a long term goal to maximize the energy efficiency of the US building stock by year 2020 requiring a deep energy reduction of the building technology used. According to current statistic about 100 realized NZEB have been built in the USA. Concerning systems for NZEB a scoping analysis of different building technology options for the application in NZEB revealed that heat pumps are the most promising solutions. Therefore, already in 2005 the development of dedicated heat pump equipment for NZEB has been initiated. Besides the integrated solution, non-integrated heat pumps are applied in NZEB, e.g. air-to-air heat pumps or heat pump water heater.

In Japan different pilot and demonstration buildings are in the planning or realization phase. One building is erected on the campus of the University of Tokyo and will be monitored.

### 3.3 HVAC technologies applied in nZEB

Experiences of monitored nZEB confirm that the zero energy balance for the building can be reached by a sufficiently large PV area in single family houses. In MINERGIE-A® certified buildings (zero-operational building) the average PV system is about 5.5 $kW_p$ corresponding to about 50 $m^2$ of PV area (Hall et al., 2014). The highly energy-efficient operation of the heat pump is favorable to reach the balance. In multi-family houses (Gütermann, 2012) and office buildings (Naef, 2010) with extended balance boundary to include also the electricity for appliances, it may depend on installed appliances and user behavior whether a Net Zero balance is reached.

In fact heat pumps have different unique features for the use in nZEB

- With adequate design heat pumps are highly efficient allowing for more freedom on the building envelope and the design of the renewable energy systems for the balance.
- Heat pumps have the capability to cover different building services like space heating, DHW and space cooling, even in simultaneous operation.
- The source energy is considered renewable in the EU, if a minimum seasonal performance requirement of a Seasonal Performance Factor (SPF) of 2.63 is kept.
- Heat pumps can connect different energy sources and sinks effectively.

Therefore, heat pumps are already a well-established technology as system technology of built nZEB. Figure 4 shows an evaluation of the installed system technology in the first 216 MINERGIE-A® certified buildings in Switzerland. Besides the solar PV system which is practically installed on every building to meet the net zero energy balance, the heat pump is the dominating system technology with about 90% for the space heating and DHW operation. In about 20% of the houses, a solar collector mainly to support the DHW production is included, as well. Some installations also include pellet or wood boilers. Fossil energies like gas or oil have no share in MINERGIE-A® buildings.

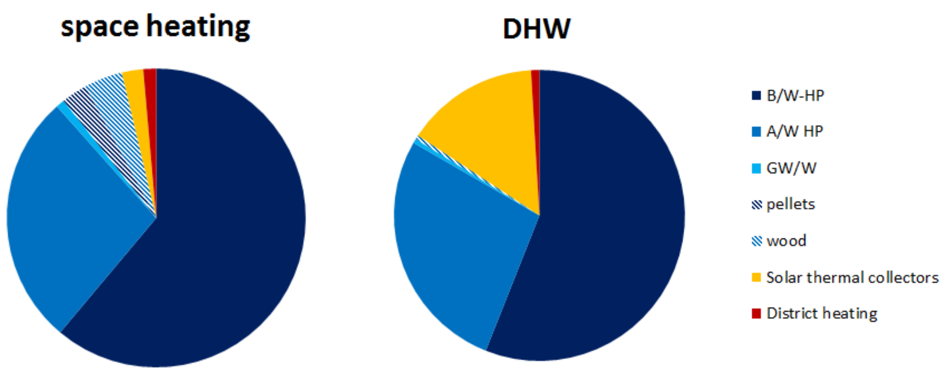



**Figure 4: Space heating and DHW installations in MINERGIE-A® certified buildings (based on Hall et al., 2014)**

Currently, the MINERGIE-A® certification only comprises residential single and multi-family buildings. Figure 5 gives an overview of the system technology installed in nZEB buildings based on documented buildings in Voss and Musall (2011) which also comprise non-residential buildings. Figure 5 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, as well. In small buildings heat pumps are the dominating heat generator which is often combine with solar thermal collectors mainly for DHW operation.

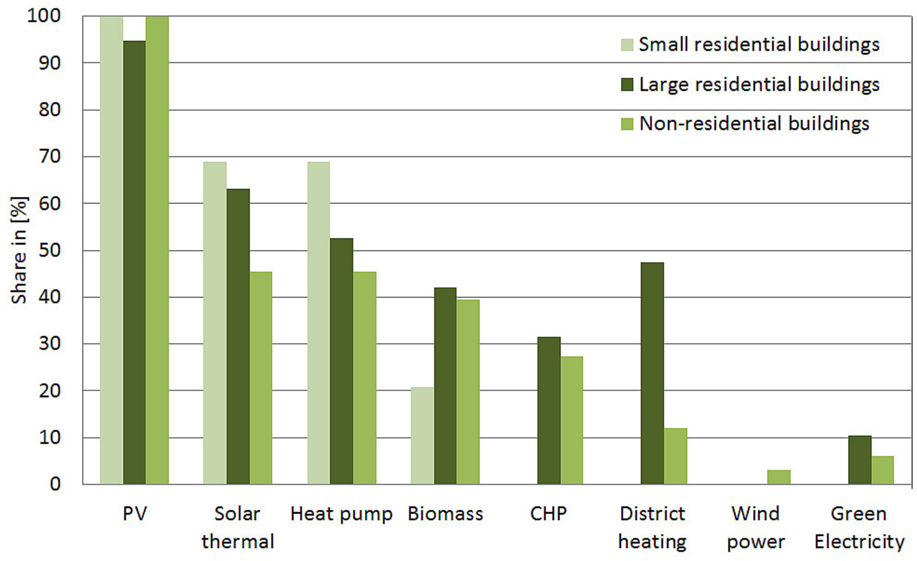



**Figure 5: System technology in international projects of residential and non-residential nZEB (based on Voss and Musall, 2011)**

### 3.4 Integrated heat pump developments dedicated to high performance buildings

Despite the dominating position of the heat pump concerning the system technology, most of the heat pumps are not integrated heat pumps concerning the other installed system technology. For passive houses already integrated solutions using the ventilation air as heat source/sink have been introduced. The advantages of the integrated, often packaged, solutions are that

- internal heat recovery and simultaneous operation can improve the performance
- investment in better, e.g. capacity-controlled components is rewarding, since they are used for various functions.
- control of the systems can be optimized, since components are known
- the entire system technology is very compact and space-efficient

Conventional passive house units normally integrate the functions space heating, DHW and ventilation. Some units are also extended to an active cooling mode by a reverse cycle operation or to simultaneous cooling and DHW production mode. Some ground-coupled units can also be used for passive cooling. In the USA a highly integrated heat pump prototype integrating the building functions space heating and cooling, DHW production and dehumidification has been developed at ORNL. The development was explicitly dedicated to the application in NZEB. The air-source prototype is currently in field monitoring and results will be contributed to IEA HPP Annex 40. A sketch of the air-source IHP is shown in Figure 6.

The installation of solar technologies on-site offers further integration options which are currently investigated in pilot and demonstration projects. Different combinations of heat pump and solar thermal collector have been investigated in the joined Annex IEA SHC Task 44/HPP Annex 38. There are different integration options. On the source side the solar technologies can be integrated in serial configuration, i.e. they serve as heat source for the heat pump. This could also be realized by a storage of the heat source, e.g. as ice storage or as regeneration of the ground. In larger systems with borehole fields, the ground can also be used as seasonal storage. Figure 6 right shows the integration of the heat pump and an air-cooled photovoltaic-thermal (PV/T) collector which is used for preheating the air of an air-source heat pump. The system concept was planned in the frame of the Canadian EQuilibrium field test.

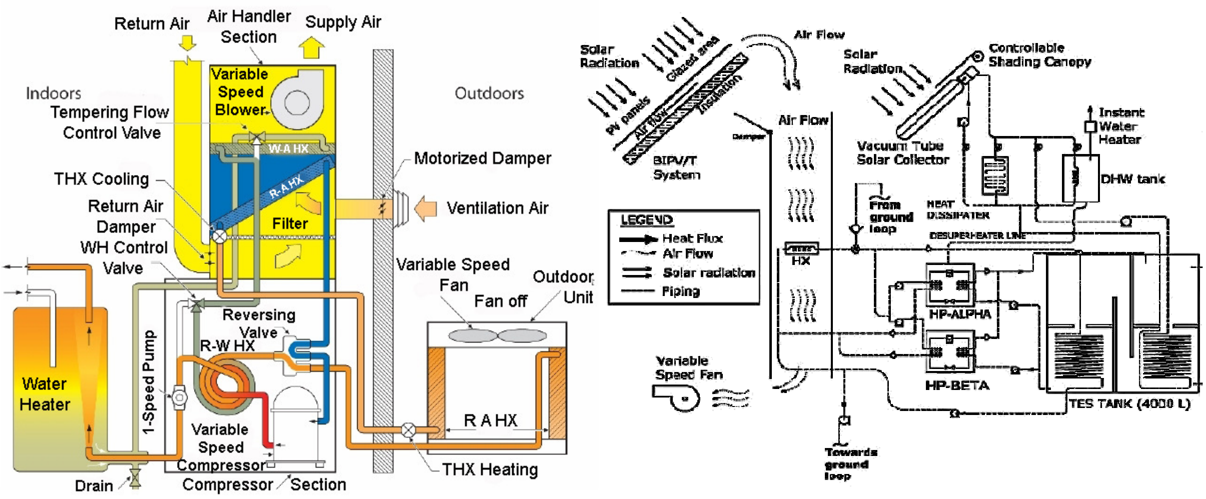



**Figure 6: Sketch of the IHP prototype developed at ORNL (left, Murphy et al., 2007) and concept with air-cooled solar PV heat source (right, Pogharian et. al., 2008)**

## 3.5 Further developments of heat pumps

In new buildings and nZEB with high quality building envelope the heat is normally emitted to the room by radiant emission system enabling low supply temperatures close to the room temperature. In case of good source conditions, temperature lifts for heat pumps may become small allowing for increased COP values. Heat pumps optimized for low temperature lifts are currently under development. In the US project contribution to Annex 40 a software to assess the thermal comfort in the room for arbitrary configuration of the radiant emission systems is developed. Moreover, current market developments show increasingly capacity-controlled heat pumps units, e.g. by inverter control. In particular for air-to-water heat pumps better SPF values can be reached, approaching values of ground-coupled heat pumps. Both developments of capacity-control and low temperature lift can further increase heat pump performance in the favorable conditions of nZEB.

Besides the already mentioned advantages of heat pumps in nZEB, the heat pump has also storage and load management capabilities. With increasingly realized nZEB, the integration of the building into the energy grid is becoming important, since the unsteady renewable supply becomes a challenge in particular for the electricity grids. Therefore, a high degree of self-consumption and the capability of the building technology to work in line with the grid requirements is an important feature. nZEB are acting as so-called "prosumers" as energy producing and energy consuming units which also offer storage capacity to the grid.

In this sense, the heat pump as one of the main electricity consumers in nZEB which is connected to local storages (e.g. DHW water storages, building thermal mass by floor heating) offers the possibility of a demand shift in times where local energy (e.g. by the PV systems) is available. Thus, buildings may act as variable load and producers in future intelligent energy grids (smart grids). A prerequisite for this operation is a metering of the current energy production and demand and a display to inform the user actively or information directly transferred to grid management. Heat pump manufacturers are starting to enhance their heat pump controls to "smart-grid-ready" technology and different utilities in Europe are performing field test of local or regional smart grid applications. In Germany, PV-systems equipped with local battery storage already get higher subsidies to improve load match and self-consumption of the locally generated electricity.

A further option for local storage and load management is the link to electro-mobility, which can serve as consumer and storage. However, the period of use have to be adapted to the local needs in order to shift consumption and storage. Different concepts of electric vehicles acting as demand side management or bi-directional electrical storage, which can be discharged by the electric appliances of the building, are investigated.

## 4 CONCLUSION AND PERSPECTIVE

Political target and strategies for the building sector strongly focus on the nZEB concepts for the time period after 2020. Even though there is no uniform definition up to now, most realized pilot and demonstration plants of nZEB focus on the physical boundary of the building itself in order to balance the energy consumption. Regarding the balance boundary most nZEB buildings take into account either the building technology or the total energy consumption including the plug loads by appliances as balance boundary. While passive houses with high performance building envelopes have already reached large market shares in European countries, nZEB are rather in pilot and demonstration phase. However, in the central European countries Austria, Germany and Switzerland, several hundreds of nZEB and plus energy buildings have been built and partly monitored. Also in the USA about hundred NZEB have been realized. In Scandinavian countries, several buildings are in planning and construction and monitoring results will be contributed to the IEA HPP Annex 40.

Heat pumps are already well-established in the existing pilot and demonstration nZEB buildings due to their unique features to realize energy-efficient and cost-effective nZEB. In fact the political nZEB objective could be a large market opportunity for heat pump markets in the residential and non-residential building sector. IEA HPP Annex 40 has the objective to contribute to the analysis and comparison of different system concepts and field monitoring results under the different boundary conditions in the participating countries. Expected results are recommendations of system configurations as well as further development of heat pumps for the application in nZEB. Potentials are seen in system and building integration of different heat generators, efficient DHW production, capacity range and temperature lift. Also the design and control of systems shall be considered. By the field monitoring projects, real-world experience with installed systems shall be documented, as well.

By the nZEB strategy, buildings also become prosumers, which has implications for the integration of buildings in energy grids. Also in this respect heat pumps can contribute to the local load management and can open up storage options for surplus electricity production as heating or cooling energy. Building system technology is thus becoming an active part not only of the buildings, but also of the energy grids leading to the perspective of an extension of the nZEB concept to clusters of buildings or city quarters. This could increase the load match if buildings with different load profiles are combined by energy grids. The heat pump as highly-efficient transformation technology of electricity to heating and cooling energy can be a central component to link different loads and storage capacities and is thus becoming a basic component in future energy systems.

## 5 ACKNOWLEDGEMENTS

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Continuously updated information on the IEA HPP Annex 40 is found on the Annex 40 project website at http://www.annex40.net

## 6 REFERENCES

EU 2010. Directive 2010/31/EU of the European Parliament and Council of May 19, 2010 on the energy performance of buildings (recast), Journal of the European Union L 153/13, 18.6.2010

Gütermann A. 2012. Monitoring of performance plus-energy-multi-family house Bennau (SZ), Final report of SFOE research project, research programme Energy in buildings, Winterthur

Hall, M., Geissler, A., Burger, B. 2014. Two years of experience with a net zero energy balance – Analysis of the Swiss MINERGIE-A®-Standard, Energy Procedia SHC 2013, Elsevier.

Kurnitski, J. (Editor) 2013. REHVA nZEB technical definition and system boundaries for nearly zero energy buildings, 2013 revision for uniformed national implementation of EPBD recast prepared in cooperation with European standardization organization CENREHVA Report 4

Murphy, R. W., Rice, C. K., Baxter, V. D., Craddick, W. G. 2007. Air-Source Integrated Heat Pump for Near Zero Energy Houses: Technology Status Report, ORNL/TM-2007/112, July, US

Naef, R. 2010. Marché International Support Office, Kemptthal, Kanton Zürich, Final report of SFOE research project, research programme energy in buildings, Zurich

Pogharian, S., Ayoub, J., Candanedo, J.A., Athienitis, A.K. 2008. Getting to a net zero energy lifestyle in Canada, The Alstonvale net zero energy house, 23rd European PV Solar Energy Conference 2008, Valencia

Sartori, I., Napolitano, A., Voss, K. 2012. Net zero energy buildings: a consistent definition framework, Energy and Buildings, pp. doi:10.1016/j.enbuild.2012.01.032

Voss, K., Musall, E. 2011. Net zero energy buildings: international projects of carbon neutrality in buildings, detail green book, Munich