Heat pumps for nZEB in IEA HPP Annexes 32 and 40

Heat pumps for the application in low energy buildings and nearly Zero Energy Buildings (nZEB) are investigated and developed in two Annex projects in the Heat Pump Programme (HPP) of the International Energy Agency (IEA) due to the unique features of heat pumps regarding high system performance, multifunctional use for different building services and load management capabilities. The projects deliver prototypes of new components, field monitoring results and design recommendations.

Keywords: nZEB, low energy building, multifunctional heat pump, system design, field monitoring, simulation.

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Buildings are responsible for about 40% of the CO_2-emissions in the EU. Both heat pumps and low energy buildings (LEB) have growing market shares in different parts of the world. With the implementation of the EU Energy Performance of Buildings Directive EPBD (2002) LEB have become the standard new building in many European countries with space heating (SH) needs around 50 kWh/(m²a) prescribed by building codes. Passive building envelope design can further decrease the space heating needs to 15 kWh/(m²a).

Energy needs in LEB differ significantly from energy needs in the existing building stock. Due to significantly reduced needs, space heating (SH) energy can be supplied by low temperature emission systems. Domestic hot water (DHW) heating needs, though, constitute a bigger share of the total heating requirement, so DHW performance gets more important. Further functionalities of the building technology have been added such as mechanical ventilation systems, which are increasingly installed or are even a requirement in residential LEB. Moreover, a space cooling (SC) function may be added in residential buildings due to increasing internal loads by electric equipment and increasing request for indoor comfort in high performance buildings. In countries like Japan and the southern federal states of the USA, also a dehumidification (DH) function is a requirement for the building technology.

Therefore, system configurations shall be adapted to the changed loads and functionalities in LEB. Interesting concepts are integrated system configurations with the ability of multifunctional operation, since

- waste heat, e.g. from exhaust air or recooling, can be recovered for other building needs, e.g. recooling energy from the heat rejection of the condenser heat in dehumidification mode can be used to heat the DHW storage as depicted in **Figure 1**;
- different building needs can be covered simultaneously with efficiency gains, e.g. in case of a combined SH and DHW operation by a desuperheater or multiple gas cooler as shown in **Figure 2** and **Figure 3**;
- systems are more cost-effective as separate components for different needs are avoided.

In this sense heat pumps have some unique features for the use in LEB, since they are

- highly-efficient with adequate temperature design of the systems;
- available on the market down to very low capacity ranges;
- using renewable energy at a minimum seasonal performance factor (SPF);
- environmentally-sound and can be operated entirely CO_2-free with renewable electricity;
- the only generator for SH and SC, even as simultaneous supply of different building needs (e.g. SC and DHW).

The IEA HPP Annex 32 work started with a market overview on integrated heat pump systems, and the target was the assessment, development and evaluation of different multi-functional heat pump solutions in LEB by simulation, prototyping and field monitoring. From the results design and control recommendations are derived. **Table 1** gives an overview of the contributions of the participating countries to Annex 32. Developments in the USA and Canada are aiming at adequate systems for Net Zero Energy buildings (NZEB).

Results of prototype developments

Developed prototypes mainly address three aspects which were not covered by many of the marketable integrated heat pumps in the typical capacity range of residential LEB of 3–5 kW:

- Additional passive space cooling or simultaneous active SC and DHW function;
- Additional dehumidification function;
- Use of natural refrigerants with reduced global warming impact.

Integrated air-source and ground-source heat pump (IHP) prototype development in the USA

At the Oak Ridge National Laboratory (ORNL), USA, an air-source (AS) and ground-source (GS) IHP prototype covering all building services including DH has been developed, lab-tested and simulated. System configurations are depicted in **Figure 1**.

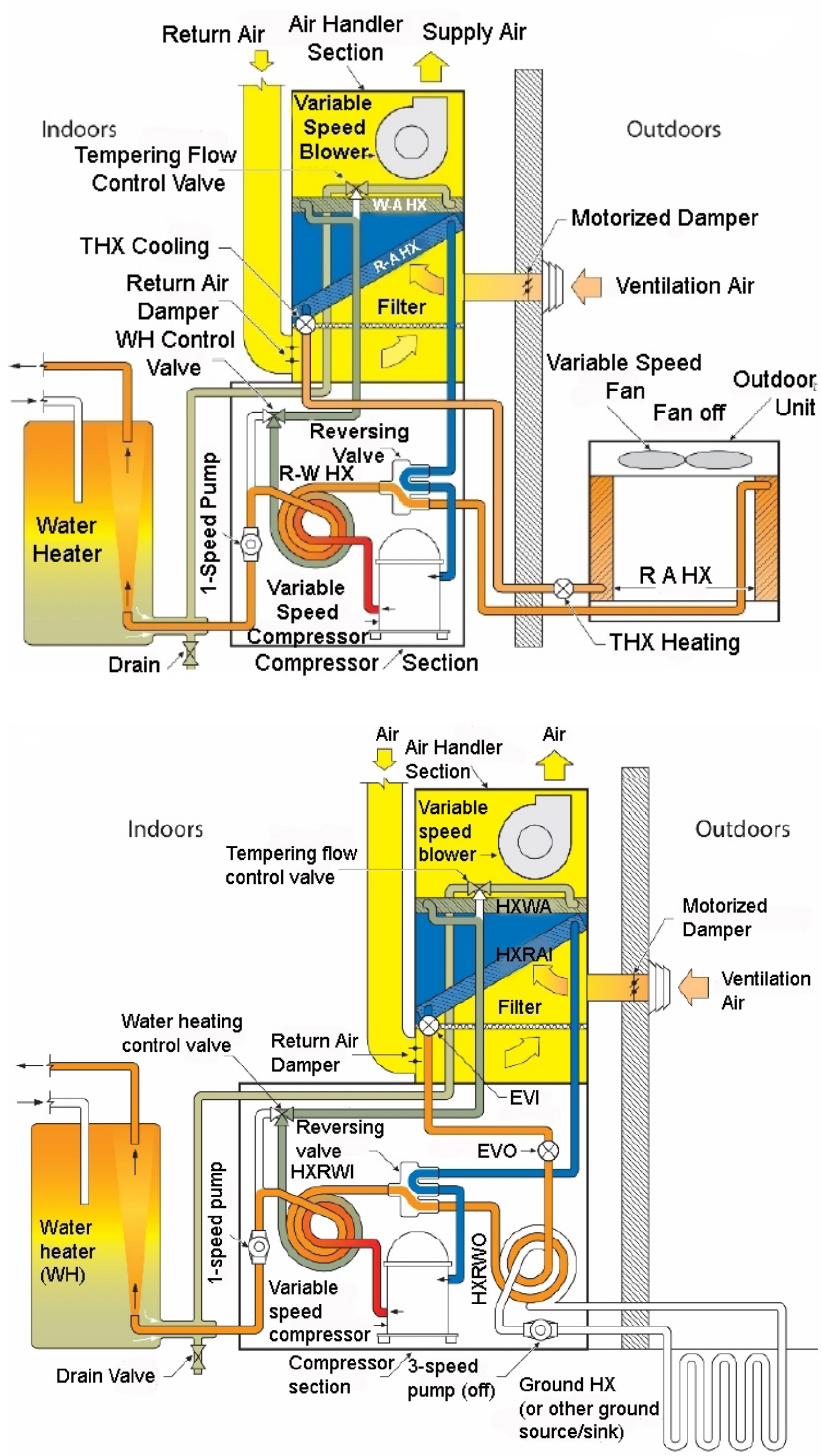


Figure 1. AS-IHP (top) and GS-IHP (bottom) in DH and DHW mode. (Baxter et al., 2008)

Annual simulations for a 167 m² residential LEB for 5 climate zones of the USA show energy saving potentials of 47–67% (52–65%) for the AS (GS) IHP compared to common technology according to minimum efficiency requirements of the US Department of Energy DOE. Estimates of the simple payback time are 5–10 years (6–15 years incl. borehole) for the AS (GS) prototype. After a field test and redesign, the GS-IHP is now available on the market, while AS prototypes are in field monitoring.

Prototypes with natural refrigerants

At SINTEF Energy Research in Norway, feasibility studies of HP with natural refrigerants have been carried out. A 6.5 kW B/W-HP prototype with CO_2 refrigerant shown in **Figure 2 top** uses a tripartite gas-cooler for combined SH and DHW operation for pre- and reheating or the DHW and space heating. Lab-testing and simulations results showed that the CO_2-HP prototype outperforms the best conventional HP with HFC refrigerants at a DHW share of 55%. For improved CO_2-technology (improved compressor, ejector) with a 10% increased Coefficient of Performance (COP) the break-even point is shifted to 45% DHW share, see **Figure 2 bottom**. Since DHW shares are rising in LEB, CO_2 could be an interesting refrigerant.

Prototype B/W-CO_2 heat pump in Austria

Based on a system layout and refrigerant cycle comparisons, a 5 kW CO_2-B/W HP prototype depicted in **Figure 3** has been built and lab-tested in Austria. In this system, a bi-partite gas-cooler is used. System simulations for SH, DHW, passive and active SC operation in a typical LEB yielded an overall SPF of 3.2 at high DHW share of 30% based on the delivered energy to the floor SH and DHW heat exchanger without the distribution pumps. In case of higher cooling loads, the performance increases due to the high performance of the passive SC. System improvements are seen in improved components (compressor efficiency for low capacities, ejector) as well as in the system integration of the buffer storage and control.

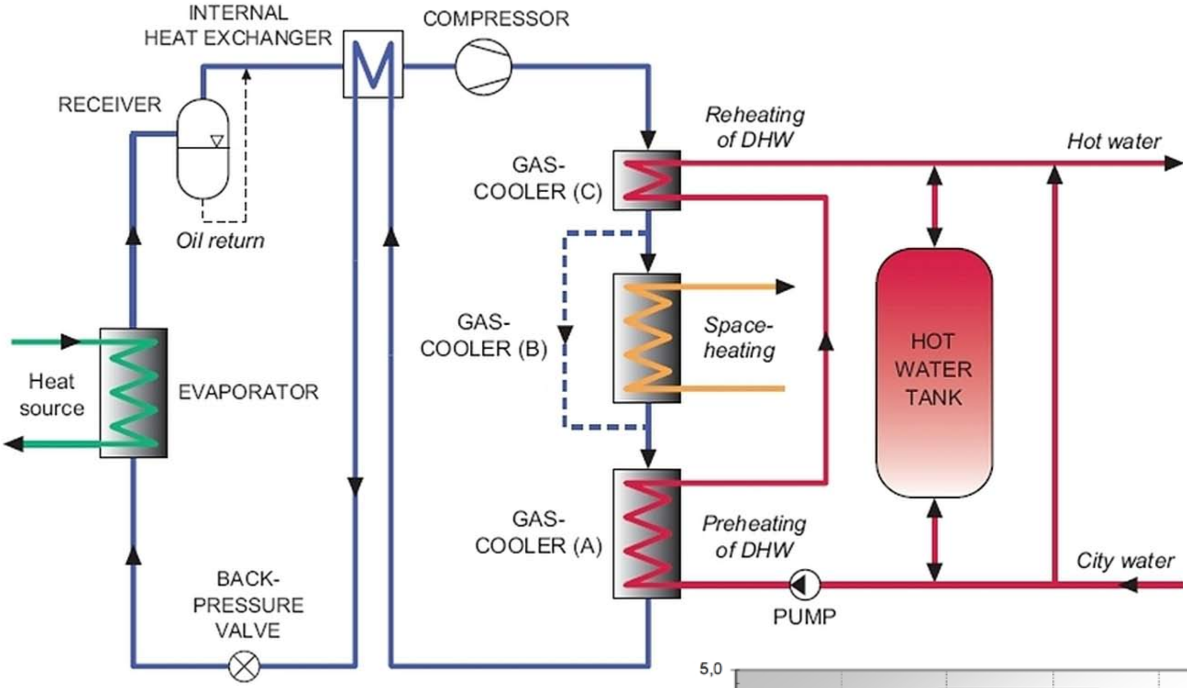
Results of field monitoring

A large number of results of about 200 field-monitored systems have been contributed to the IEA HPP Annex 32. In Germany two large field tests of 100 HP installed in LEB (HP Efficiency project) and 75 HP installed in existing buildings as replacement for boilers took place. Due to higher heating loads in the existing buildings, they are equipped with radiator emission systems of typical design temperatures of 70°C/50°C, while the LEB in the HP Efficiency project are mainly equipped with low-temperature floor heating of typical design temperatures of 35°C/30°C. **Figure 4 top** shows the overall seasonal performance factors (SPF) for SH and DHW operation and different heat pump types. The system boundary of the SPF includes produced heat of the heat pump and direct electrical back-up for the space heating and DHW operation and electricity supplied to the heat pump, the source pump and the electrical back-up. Auxiliary energies range between 3–7%, direct electrical back-up use is with 1–2% negligible. Measured DHW fractions are 10–15% in the existing buildings and 20–30% in the LEB. The number of the investigated systems is displayed in the bottom of the bars.

Figure 4 bottom shows the impact of the system design on the SPF. The complexity of the system has been determined depending on the number of installed pumps, valves etc.. From the field test results it can be concluded that more complex modular system designs tend to decrease the SPF due to possible installation errors and malfunctions. Also combined storages showed a lower

Table 1. Overview of contributions to IEA HPP Annex 32.

Country	Contribution to IEA HPP Annex 32
AT	• Prototyping, lab-test and simulation of a 5 kW CO_2 brine-to-water (B/W) heat pump; • Field test of 9 heat pumps for SH & DHW and 2 compact units with passive cooling.
CA	• Design and monitoring of two Equilibrium™ houses (NZEB) in Eastern Canada.
CH	• Integration of energy-efficient cooling in common heat pump systems for SH & DHW; • 2 field tests of heat pump systems for space heating and (passive) space cooling.
DE	• Field test of ≈ 100 heat pumps in low energy buildings and ≈ 70 heat pumps in existing buildings in co-operation with 7 manufacturers and 2 utilities.
FR	• Development of air-to-air (A/A) HP solutions for low energy houses.
JP	• Design optimisation of systems for moderate climate regarding capacity and operation; • Feasibility studies and field test of ground-source heat pumps for the cold climate zone.
NL	• Development of HP concepts for the market introduction of low energy houses.
NO	• Feasibility of heat pumps with natural refrigerants in Norwegian low energy houses; • Field test of propane water-to-water (W/W) HP prototype for passive houses.
SE	• Calculation and field test of Swedish heat pumps for low energy houses.
US	• Prototyping, lab-testing and simulation of highly-integrated multifunctional heat pump prototypes for SH, DHW, ventilation and SC incl. dehumidification for NZEB.



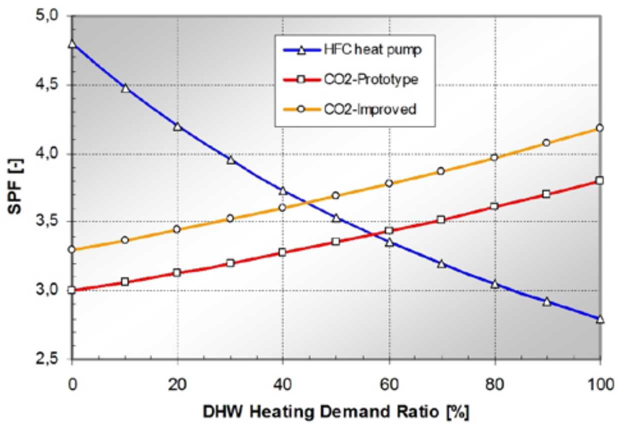


Figure 2. Layout of the prototype B/W-CO_2 heat pump (top) and comparison of a prototype and improved CO_2 heat pump to the state-of-the-art (right).
(Justo Alonso and Stene, 2010)

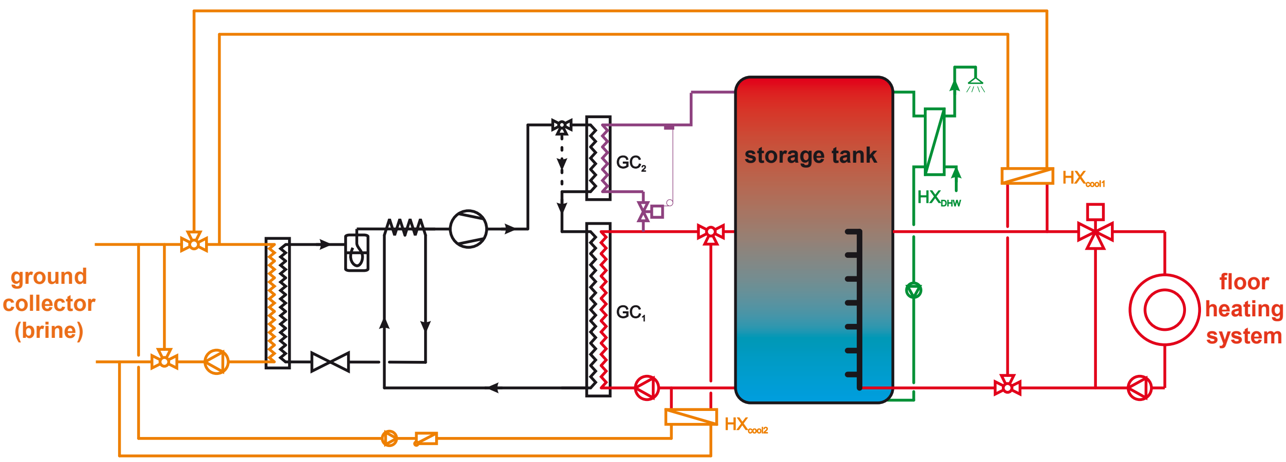


Figure 3. System layout of the Austrian prototype system (Heinz and Rieberer, 2010)

performance than other system configurations due to a possible increase of the supply temperature for the heat pump. Thus, modular system configurations with many components have to be installed carefully in order to avoid the decrease of the performance.

Moreover, 4 systems with ground-coupled passive SC have been monitored in residential passive houses. The performance of the passive SC mode is in the range of 8–15. The main impact on the performance is the rejected cooling load, since the pump power stays more or less the same independent of the cooling load. Several recommendations on the system integration, design and operation of passive ground-coupled cooling in LEB have been documented based on the monitoring and accompanying simulations.

All results of the Annex 32 have been summarised in four final reports (Wemhoener, 2011), which can be downloaded on the Annex 32 website.

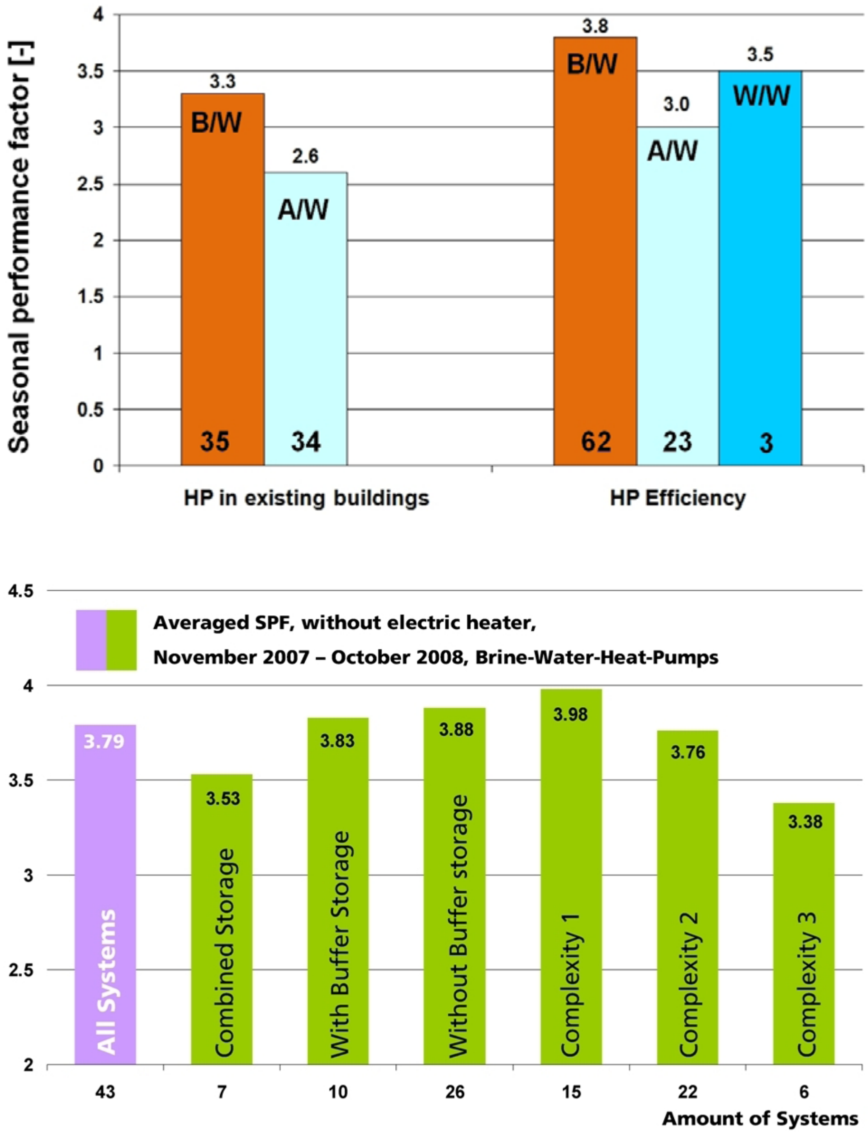


Figure 4. SPF of monitored heat pumps in LEB and existing buildings (top) and impact of system design on the SPF (bottom) based on Günther and Miara (2010).

Continuation of work in Annex 40

According the EPBD recast (2010) all new buildings in the EU shall be built as nearly Zero Energy Buildings (nZEB) by the beginning of 2021, while other countries like the USA, Canada or Japan are targeting the introduction of Net Zero Energy Buildings (NZEB) in the time horizon of 2020-2030. Concerning the nZEB requirements further integration and design options for heat pumps in these buildings occur:

- Integration of the heat pump operation with solar components installed in the building envelope on the source or sink side as well as heat and cold storage technologies
- Integration of the heat pump and the technical building system into energy grids, e.g. electricity grid (in the frame of smart grid activities) or district heating/cooling grids.
- Assessment of local load management and demand response capabilities of installed heat pumps in nZEB in order to maximise self-consumption of on-site renewable energy and improve grid interaction.

The IEA HPP Annex 40 started work in 2013 and is ongoing. Interim results are periodically published. The focus of the national projects is on the system comparison and improvement regarding integration of different heat generators, design and control of the systems as well as technology developments for the application in nZEB. **Table 2** gives an overview on the national contributions to Annex 40.

Table 2. Overview of national contributions to IEA HPP Annex 40.

Country	Contribution to IEA HPP Annex 40
CA	• Integration of HP and other generators (e.g. solar, CHP); • Analysis for different building types and uses; field test of nZEB with HP.
CH	• Integration of HP and solar for SH, DHW and SC for nZEB by simulations and testing; • Field monitoring of plus energy building with HP and electro-mobility.
DE	• Analysis and field monitoring of office buildings to optimise operation.
FI	• Development of energy-/cost-efficient HP solutions for nZEB in Finland.
JP	• Evaluation of HP and solar for nZEB buildings by simulations; • Derivation of technology and design recommendations.
NL	• Field test "Energy leap" and simulation of concepts for nZEB.
NO	• Prototypes/design tools of integrated HP with natural refrigerants in nZEB;
SE	• Prototype developments and field test of HP for nZEB in Swedish climate conditions.
US	• Field monitoring of IHP prototypes and variant developments. • Net Zero Energy Residential Testing Facility (NZERTF) for HP technologies; • Software development for comfort evaluation of radiant emission systems.

Conclusions

IEA HPP Annex 32 and the follow-up IEA HPP Annex 40 are dedicated to the development of heat pumps for the application in low energy buildings and nZEB. Due to the different building needs compared to existing building stock, heat pumps offer good performance values with adequate system design. Integrated heat pump concepts have particular advantages for these buildings and different concepts are developed, simulated, lab-tested and field-monitored in the Annex projects.

Heat pumps as an energy-efficient technology and flexible electricity consumer also enable the integration with storage and renewables energies (PV and solar thermal) in nZEB and provide flexibility for load management in smart grids. Multifunctional heat pumps can therefore become a key technology as a cost-effective way of creating high-sustainability carbon-neutral societies.

Acknowledgement

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