

# HEATING AND COOLING IN LOW ENERGY HOUSES - RESULTS OF THE INTERNATIONAL RESEARCH PROJECT IEA HPP ANNEX 32

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**Abstract:** Annex 32 in the Heat Pump Programme (HPP) of the International Energy Agency (IEA) on the application of multifunctional heat pumps for heating and cooling in low energy houses with ten participating countries has been concluded in the end of 2010. Main working areas of Annex 32 have been the development of prototypes with extended functionality of cooling and partly dehumidification and the application of natural refrigerants. Furthermore, extensive field testing of marketable heat pumps in low energy houses has been a major research topic.

The prototypes show promising lab-test and simulation results of integrated multifunctional heat pumps with substantial energy savings up to 50% compared to state-of-the-art technologies. Field test results confirm generally reliable heat pump operation with good seasonal performance of about 4 for brine-to-water and 3 for air-to-water heat pumps, but also optimisation potentials were found. Final results have been documented in four reports, containing an umbrella report, a market overview with categorisation of multifunctional heat pumps, a report on the prototypes including lab-test and system simulation and a report on the field results in Annex 32.

**Key Words:** low energy houses, multifunctional heat pumps, integrated heating and cooling operation, field monitoring, heat pump prototypes

## 1 INTRODUCTION

The anthropogenic climate change is presently the biggest challenge for mankind. In many countries buildings are responsible for 40-50% of the CO<sub>2</sub>-emissions. Thus, low energy houses with considerably reduced space heating (SH) energy needs are considered as key strategy to achieve climate protection targets. Characteristics of low energy houses offer favourable conditions for the application of heat pumps which additionally contribute to emission reduction and primary energy savings.

### 1.1 Low Energy Buildings

Since the mid of the 1990ties, the energy consumption of new buildings has been successively lowered by introducing more stringent legal requirements for the SH energy needs in building codes. By thermal insulation of the building envelope, a compact air-tight building design, high-quality glazing with optimised gain-loss ratio and heat protection in summer by external shading, space heating needs can be significantly reduced. Nowadays, low energy houses are becoming the current building practices in many countries. Two main directions can currently be distinguished with regard to high performance buildings:

- The passive house approach (<http://www.passiv.de>) is widely recognised. The basic idea is to use passive gains to the largest extent possible by making the building envelope as good as possible. Thereby, typical (SH) needs of passive or ultra-low energy houses as low as 15 kWh/(m<sup>2</sup>a) are reached. Efficient system technology can further improve the primary energy performance and reduce CO<sub>2</sub>-emissions, but due to the investment in the building envelope system costs are more important.
- On the other hand, a Nearly or Net Zero Energy House approach is pursued. According

to current definitions, a Net Zero Energy Building (NZEB) is a grid-connected house, which produces (exports) as much energy as it consumes (imports) on an annual basis by renewable energies. This target can be reached by a high-performance envelope on ultra-low energy house level leaving only little remaining energy to be covered by renewable energy or, on the other hand, by a good low energy house and a highly-efficient system technology with higher quantity of installed renewable energy, which may be favourable in retrofitting where constraints for envelope measures may prevail.

The passive house concept clearly focuses on the building envelope by prescribing the space heating energy needs, the NZEB concept, on the other hand, leaves it open, how investments are weighted between either the building envelope or a highly-efficient and renewable system technology by just prescribing the net zero energy balance. Moreover, the balancing of the NZEB concepts comprises aspects of the energy grid and seasonal storage. While NZEBs are more in the pilot and demonstration phase, low- and ultra-low energy houses have reached considerable market growth which is illustrated in Figure 1 by the market developments in Germany and Austria.

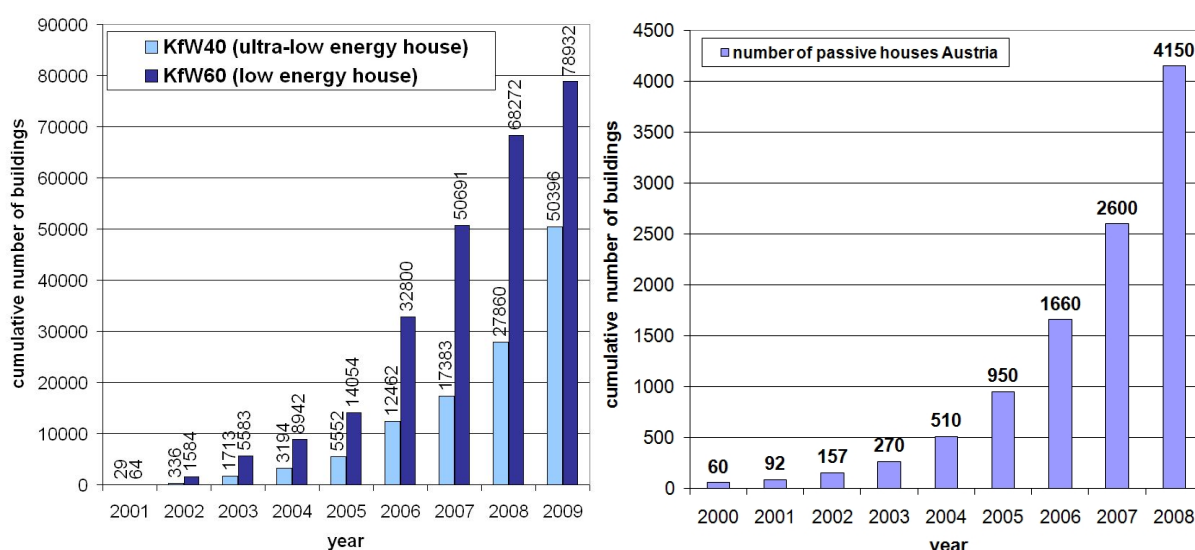


Figure 1: Market developments of low and ultra-low energy houses in Germany and Austria

## 1.2 Integrated heat pump systems on the market

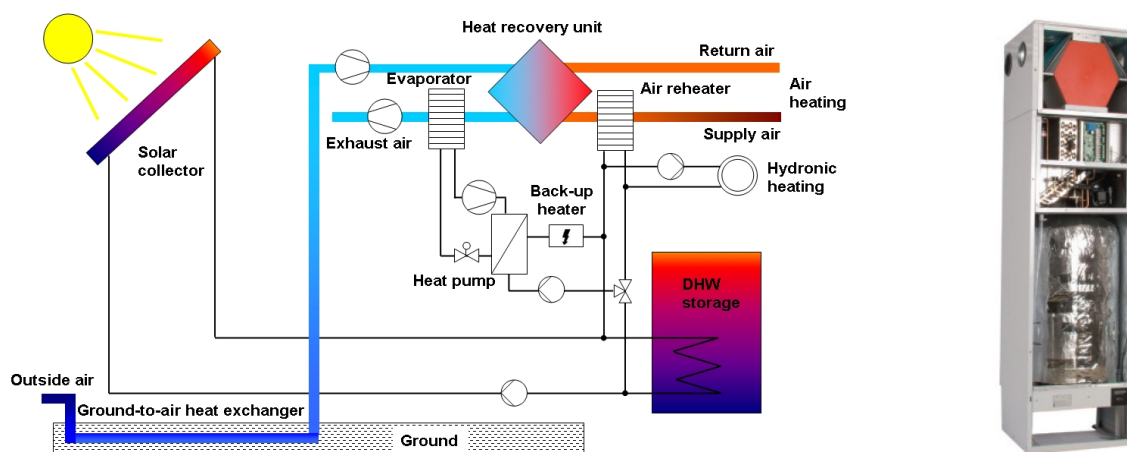
Low energy houses have other characteristics as conventional dwellings, which are:

- reduced SH needs, so domestic hot water (DHW) production constitutes a higher fraction of required heating energy
- air-tight building envelope, so mechanical ventilation is often required and installed
- risk of overheating in summertime, so comfort cooling may increasingly become an issue

With these building services, multifunctional integrated heat pumps are attractive, since

- waste heat, e.g. from space cooling operation, can be internally recovered for other building needs, e.g. DHW production
- different building needs can be covered simultaneously with efficiency gains, e.g. in case of a combined space heating and DHW operation by desuperheating

Besides combined SH&DHW integrated heat pumps have been developed mainly integrating the ventilation function by so-called ventilation compact unit with exhaust ventilation air heat pump for the use in ultra-low energy houses as depicted in Figure 2.



**Figure 2: Ventilation-based integrated heat pump concepts for low energy houses**

Within the time frame of Annex 32 from 2006-2010, a passive ground-coupled cooling has been integrated by some manufacturers, also in collaboration within the IEA HPP Annex 32. Details on the evaluation of a ground-coupled passive cooling function are given in paragraph 4.2.

## 2 RESEARCH FOCUS OF IEA HPP ANNEX 32

On this background, Annex 32 in the Heat Pump Programme (HPP) of the International Energy Agency (IEA) entitled "Economical heating and cooling systems for low energy houses" has been started with the participating countries Austria, Canada, France, Germany, Japan, the Netherlands, Norway, Sweden, Switzerland (operating agent) and the USA in order to assess the systems on the market and support the further development of heat pump systems for the use in low- and ultra-low energy houses and to prove the feasibility of marketable units and new developments. Table 1 gives an overview of national contributions.

**Table 1: Overview of national contributions to IEA HPP Annex 32**

Country	Focus of work
AT	Prototyping, lab-test and simulation of a 3-5 kW CO <sub>2</sub> 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 cooling
DE	Field test of ≈100 heat pumps in low energy houses and ≈80 heat pumps in existing buildings in co-operation with 7 manufacturers and 2 utilities
FR	Development and field test 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 evaluation 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 cooling incl. de-/humidification for NZEB

Thus, the research focus was set to the two items:

- prototypes of integrated multifunctional heat pumps with extended functionality
- Field monitoring of market available integrated heat pumps regarding performance and optimisation potentials

Based on the market state the prototypes in Annex 32 mainly address three aspects which were not covered by many of the marketable integrated heat pumps for the application in low energy houses in the beginning of Annex 32:

- Additional passive cooling function or simultaneous cooling and DHW function
- Additional dehumidification function
- Use of natural refrigerants with reduced global warming potential

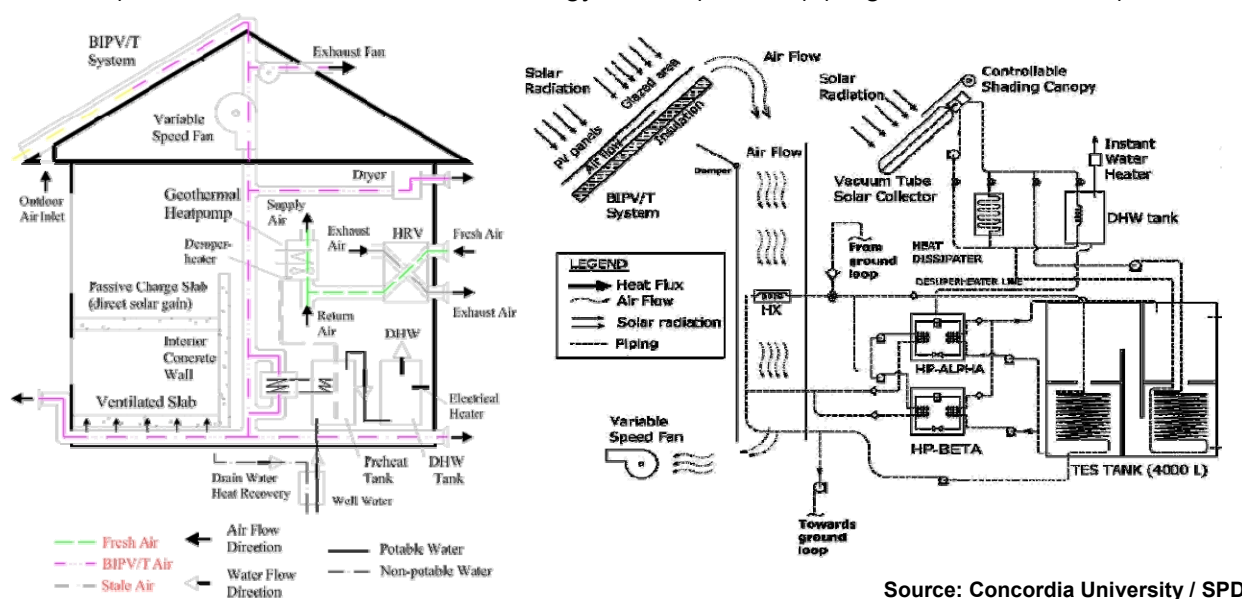
Most of the developed prototypes in IEA HPP Annex 32 are multifunctional integrated heat pumps in the typical capacity range of residential low and ultra-low energy houses of 3-5 kW.

### 3 RESULTS OF THE PROTOTYPE DEVELOPMENTS

#### 3.1 Integrated Heat Pumps Concepts For NZEB

##### 3.1.1 Building integrated PV/T system with heat pump

The Canadian contribution is the design, simulation and field monitoring of two so-called EQUilibrium™ Net Zero Energy Buildings (NZEB) within the P& D Initiative of the governmental Canadian Mortgage and Housing Corporation, the EcoTerra™ house (Candanedo et al., 2008) and the Alstonvale Net Zero energy house (ANZEH) (Pogharian et al., 2008).



Source: Concordia University / SPD

Figure 3: System concepts of the EcoTerra™ (left) and ANZEH (right) EQUilibrium™ houses

Besides a high-quality building envelope applying a thorough thermal insulation, large south-oriented triple-glazed windows with low-e coating and sufficient thermal mass by inside concrete wall and floor constructions, both houses incorporate a roof integrated PV/Thermal (PV/T) system as core component of design of the building technology. The EcoTerra™ house directly uses the heat of the PV/T for clothes drying, DHW preheating and storing the heat in a hollow concrete floor slab, while the ANZEH uses the heat, depending on the temperature, as heat source of two heat pumps. A ground loop, the main heat source for the EcoTerra™ house, only serves as back-up in the ANZEH.

##### 3.1.2 Integrated heat pump (IHP) prototype

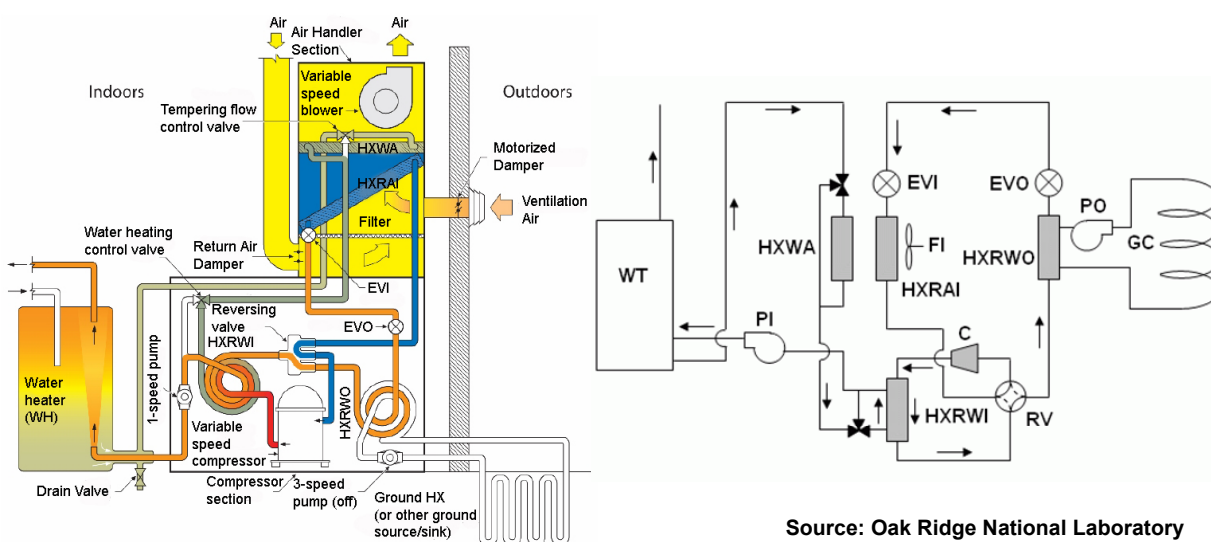
The contribution of the USA is dedicated to the development of an integrated heat pump (IHP) prototype for the application in Net Zero Energy Buildings (NZEB). Both an air-source

(AS-IHP) and a ground-source (GS-IHP) prototype have been developed. Both layouts are similar, but for the AS-IHP the ground coil loop including the pump and the heat exchanger are replaced by an outdoor refrigerant-to-air heat exchanger and a variable speed fan. In the following the GS-IHP concept is described. It is designed to cover the functionalities SH, DHW, ventilation (V) and space cooling (SC) including dehumidification (DH).

Figure 4 shows the principle of the GS-IHP. Three loops are interacting, a refrigerant, a DHW and a ground heat exchanger loop. Electrical energy consuming components are one variable speed compressor (C), one variable speed indoor blower (FI) and two pumps – one single speed pump (PI) for the DHW loop and a multiple-speed pump (PO) for the ground heat exchanger loop (GC). Four internal heat exchangers (HX) are included to meet the space conditioning and water heating loads: One refrigerant-to-air (fan coil, HXRAI), one water-to-air (tempering, HXWA), and two refrigerant-to-water (domestic hot water interface, HXRWI, and ground coil interface, HXRWO).

Further components shown are the reversing valve (RV) a refrigerant expansion valve (EV) depicted as separate indoor (EVI) and outdoor (EVO) expansion valves, which could also be replaced by a single, bi-directional EV. Outdoor ventilation air is drawn through a duct with flow control damper, mixed with recirculating indoor air and distributed to the space via the blower, FI. The heat exchanger HXWA uses hot water that is generated by heat recovery in the space cooling and dehumidification modes and stored in the hot water tank (WT), to temper the circulating air stream, as needed.

Modulation of compressor speed and indoor fan speed can be used to control both supply air humidity and temperature as required. With this arrangement, water heating and air tempering is accomplished simultaneously.



Source: Oak Ridge National Laboratory

**Figure 4: Ground-source IHP prototype in dedicated dehumidification and DHW mode**

Lab-tests have been carried out for calibrating the Mark VI Heat Pump Design model. Lab-test results are given in Murphy et al. (2007b). The model was integrated into TRNSYS to calculate the annual performance and compare it to a baseline HVAC system for a 167 m<sup>2</sup> NZEB. The baseline HVAC system is a modular system with DOE minimum required efficiencies: A split-system A/A heat pump providing space heating, cooling and dehumidification and a separate stand-alone dehumidifier for dehumidification during times without space cooling. A standard electric storage water heater provides DHW and ventilation is accomplished by a central exhaust air fan.

Simulations for both the AS-IHP and the GS-IHP were carried out for the five cities Chicago (cold), Phoenix (hot-dry), Atlanta (mixed-humid), San Francisco (marine) and Houston (hot-humid) representing the main climate zones of the US. For the GS-IHP a vertical borehole heat exchanger was assumed. For the GS-IHP results shows over 50% savings in all

locations reaching the highest energy savings of 65% in the marine climate of San Francisco and the lowest savings of 52% in colder climate of Chicago. For the AS-IHP simulated energy savings range between 46-67%, with minimum and maximum reached in the same climates. First economic evaluations have been accomplished, as well. Evaluated simple payback times vs. the baseline are in the range of 6.5-14 years for the GS-IHPs and 5-10 years for the AS-IHP dependent on the location based on 2006 prices and costs. Details on the estimations on energy savings and payback times are given in Murphy et al. (2007a). Currently, field tests of the prototype systems are ongoing.

### 3.2 Integrated Heat Pumps With Natural Refrigerants

#### 3.2.1 Feasibility studies of CO<sub>2</sub>-heat pumps in low energy houses

CO<sub>2</sub> is a favourable refrigerant due to a Global Warming Potential (GWP) of 1. Due to the low critical point of CO<sub>2</sub>, processes are usually operated transcritically and thus, the refrigerant is not condensed, but the superheated refrigerant vapour is cooled down in a gas cooler to reject the heat. Performance strongly depends on the inlet temperature of the sink to the gas cooler. The colder the inlet temperature to the gas cooler is, the better the performance gets. Due to high reachable temperatures and good temperature match in the gas cooler, CO<sub>2</sub> heat pumps show a good performance for DHW operation (e.g. Japanese CO<sub>2</sub> heat pump water heater (Eco-Cute)). Combined use for SH and DHW is not so common, yet.

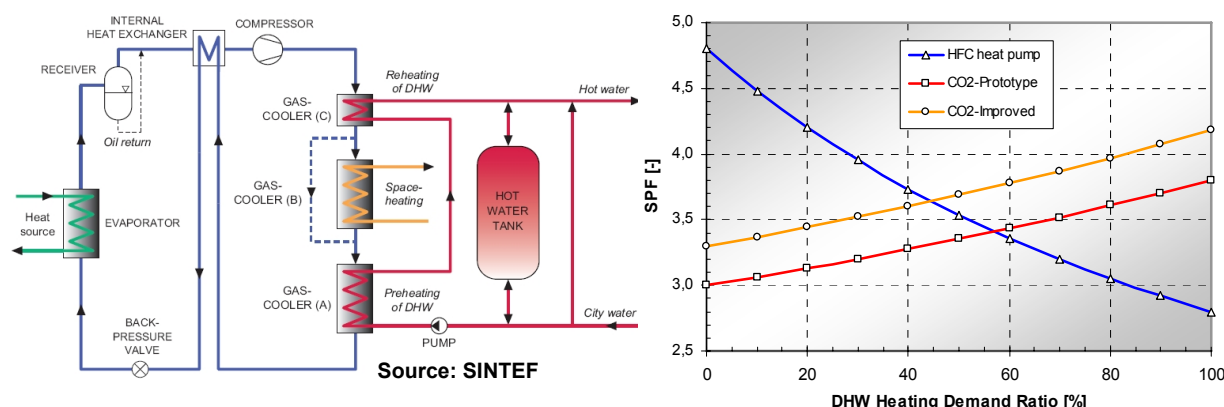


Figure 5: Layout of the prototype B/W CO<sub>2</sub> heat pumps and comparison to the state-of-the-art

In Norway, feasibility studies of CO<sub>2</sub>-heat pumps have been carried out as described in Justo Alonso and Stene (2010). Simulation results of a central 26 kW CO<sub>2</sub> heat pump water heater applied in low energy apartment houses yielded a seasonal performance factor of 3.7 with a water heat source of 7 °C and a DHW temperature of 65 °C. Considerable primary energy saving compared to common Norwegian designs of DHW systems are reached, making the system also economically beneficial.

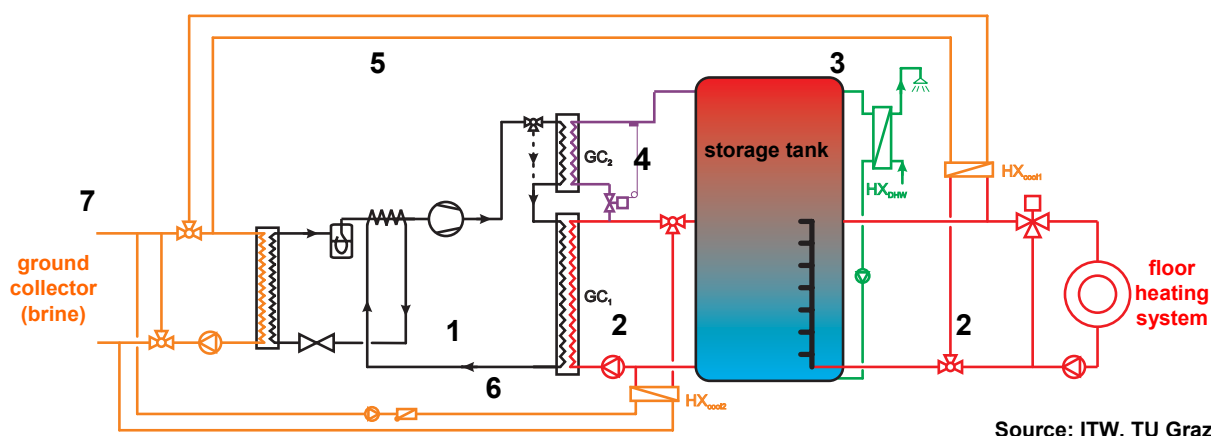
- about 75% primary energy saving compared to direct electrical immersion water heating
- about 25% primary energy saving compared to a solar water heater with a solar fraction of 50% and direct electrical back-up heating

For combined space and water heating lab-testing and simulations of a residential 6.5 kW heat pump showed that a CO<sub>2</sub> heat pump outperforms the best conventional HFC heat pumps at a DHW share of 55%. For improved CO<sub>2</sub> technology (improved compressor, ejector) with a 10% increased COP the break-even point is shifted to 45% DHW share.

#### 3.2.2 CO<sub>2</sub>-brine-to-water heat pump prototype

In the Austrian project a prototype of a CO<sub>2</sub>-B/W-heat pump has been developed covering the functions space heating, DHW production and space cooling (Heinz and Rieberer, 2010).

A schematic view of the system layout of the prototype is shown in Figure 6. A central buffer storage, which is charged by the heat pump, serves as hydraulic decoupling between the heating system (red lines, 2) and the heat pump (black lines, 1). The DHW (green lines, 3) is produced by the external heat exchanger  $HX_{DHW}$ . The control of the operation should as far as possible guarantee low return temperatures of the heating water to reach low inlet temperatures to the gas cooler ( $GC_1$ ) of the heat pump. In order to obtain cold temperatures at the bottom of the storage the return of the heating system is charged to the storage by a stratification device. The gas cooler (GC) is divided into two parts: In  $GC_1$  the water is drawn from the bottom of the storage and heated to the required temperature level of the floor heating system of 30-35°C and is charged to the middle of the storage (red lines, 2). In the upper  $GC_2$  (violet lines, 4) the preheated water is reheated to the DHW temperature of 50-55°C and charged to the upper part of the storage.



Source: ITW, TU Graz

Figure 6: Sketch of the CO<sub>2</sub>-B/W heat pump prototype developed in the Austrian project

With this configuration the operation modes space heating-only (only  $GC_1$  in operation), DHW-only and simultaneous space heating and DHW operation ( $GC_1$  and  $GC_2$  in operation) can be realized. In simultaneous operation the amount of DHW for the reheating in  $GC_2$  is controlled by a thermostatic valve. The cooling operation can be realized by an external hydraulic (orange lines, 5 and 6). For a passive cooling option a short cut between the source and the sink can be made by the heat exchanger  $HX_{cool1}$  (orange lines, 5). As emission system in the room the floor heating is used in the cooling operation, as well. For the active cooling operation the condenser heat of  $GC_1$  can be rejected by  $HX_{cool2}$  into the ground, in simultaneous cooling- and DHW operation the condenser heat is used for the DHW.

The prototype has been lab-tested to provide parameters for a TRNSYS model. The modelling is done by a HP performance map derived by the lab-testing and cycle simulation. Year-round simulations with the parameterised model in TRNSYS for a usual Austrian layout of horizontal ground collector in low energy house with large south-oriented glazing, external shading and floor heating confirm that the functions space heating, cooling and DHW can entirely be covered for Graz standard weather data. The simulations without space cooling show seasonal performance factors SPF generator /SPF system of 3.08/2.84. Differences between SPF generator and SPF system are due to storage losses and passive cooling. A cooling demand of 8 / (17) kWh/(m<sup>2</sup>a) in a normal (extreme) summer leads to higher SPF values of 3.16 (3.44)/3.21 (3.85), i.e. the high efficiency in passive cooling mode outweighs the storage losses. Excess hours of the indoor operative temperature can be reduced by 150 (1600) h, so that the operative temperature can be kept at about 26 °C.

Further optimisation potentials of the prototype are seen in the improvement concerning both the refrigerant cycle (compressor efficiency, better adapted compressors for the required capacity range, ejector) and the system configuration (integration of storage tank, control).

## 4 RESULTS OF THE FIELD MONITORING

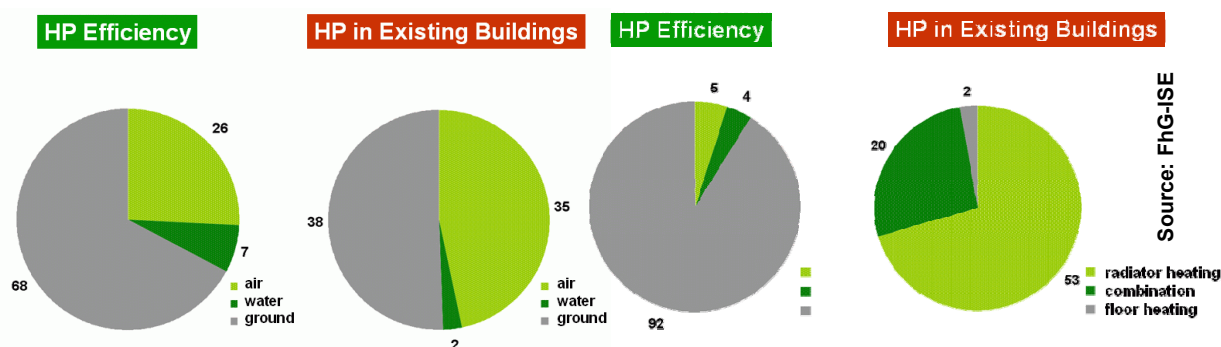
### 4.1 Heat Pumps For Combined Space Heating And DHW

In Germany two large field tests on the one hand in low energy houses ("HP Efficiency" project) and on the other hand as replacement for boiler in existing buildings have been contributed (Miara and Guenther, 2010). Table 2 presents the characteristics of the buildings in the two field tests.  $A_e$  refers to the average heated floor area of the houses.

**Table 2: Characteristics of the houses and installed systems in the German field tests**

Project	$\varnothing A_e$ [m <sup>2</sup> ]	SH energy need [kWh/(m <sup>2</sup> a)]	HP-capacity [kW]	Temperatures [°C]
HP-Efficiency (≈ 100 plants)	$\varnothing$ 192	20-50 (calculated need)	5-10	30-35 (floor heating) 45-65 (Radiator) ≈50 (DHW)
HP existing buildings (≈ 80 plants)	$\varnothing$ 190	$\varnothing$ 182 (fuel consumption)	$\varnothing$ 13.8 (B/W) $\varnothing$ 14.5 (A/W)	40-45 (floor heating) 45-65 (Radiator) 45-60 (DHW)

Figure 7 shows the heat sources and the emission systems applied in the field monitoring plants of the two projects.



**Figure 7: Heat sources and heat emission systems in the two German field test**

Table 3 presents the fractional energy use depended on the heat pump type in the two field tests. As can be expected, the DHW fraction is higher in low energy houses due to the lower space heating demand. Average auxiliary energy fractions for the heat source are with up to 7% in a good range except for W/W heat pumps, where source electricity makes up 15% of the total consumption. Back-up fractions are with an average of around 2% negligible, i.e. a monovalent design is feasible also for air-to-water heat pumps in German climate conditions.

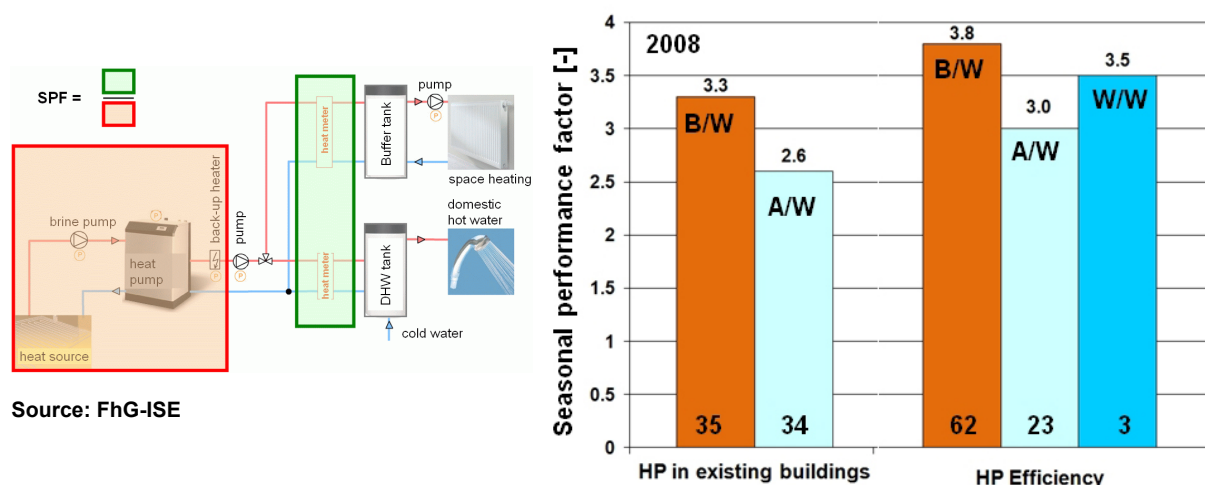
**Table 3: Energy fractions in the two German field tests**

Fractional Energy	HP in existing buildings		HP Efficiency		
	B/W	A/W	B/W	A/W	W/W
Back-up fraction	2%	1%	2%	2%	2%
Auxiliary fraction source	5%	3%	6%	7%	15%
DHW fraction	14%	12%	22%	28%	18%

Figure 8 left depicts the system boundary used for the evaluation of the SPF, which corresponds to a generator performance, i.e. produced heat divided by the electricity for the compressor, source pump and electrical back-up heater.

Figure 8 right shows the comparison of the systems in existing buildings and the heat pumps in the low energy buildings in 2008. Concerning the seasonal performance factors the B/W heat pumps reach the highest performance factors, in this field test even higher than the W/W systems due to the high auxiliary consumption. B/W systems reach an average

seasonal performance factor of 3.8 in the low energy houses and are 0.5 higher than in existing buildings which reflect the lower supply temperature in the low energy houses. A/W systems reach a lower average SPF of 3.0 and 2.6, respectively. The number of the evaluated systems is displayed at the bottom of the columns.



Source: FhG-ISE

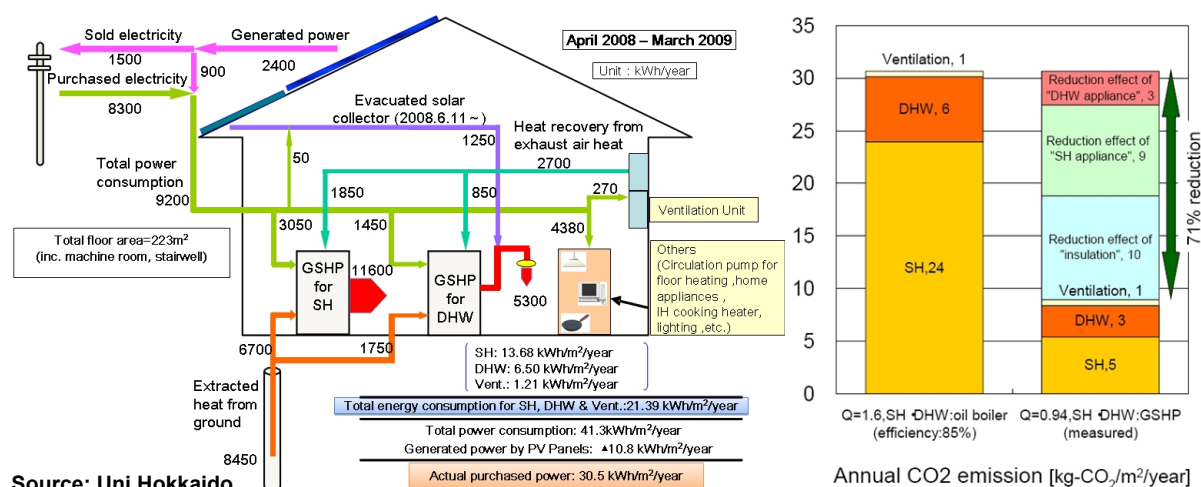
Figure 8: Heat sources and heat emission systems in the two German field tests

The field monitored SPF values of 9 heat pumps (3 A/W, 4 B/W, 1 DX/W, 1 W/W) for SH, DHW or combined operation from 2005-2008 at different locations in upper and lower Austria and Styria (Zottl, Huber and Koefinger, 2010) are in the same range as shown in Table 4.

Table 4: Range of SPF-values of year-round measurements of 9 heat pumps in Austria

HP-Type	A/W	B/W	W/W	DX/W
SPF SH	3.2-3.6	4.3-4.8	4.5	4.1
SPF DHW	2.5-3.6	2.4	3.1	-
SPF SH&DHW	3.0-3.5	4.0	4.2	4.1

The design heat load of these houses is in the range of 20-60 W/m<sup>2</sup> and installed capacity of the heat pumps is in the range of 8–33 kW. The emission systems are mainly floor heating systems, and average flow temperatures are with a range of 29 - 36 °C.



Source: Uni Hokkaido

Figure 9: Energy balance (left) and CO<sub>2</sub>-emission savings (right) in the Japanese field test

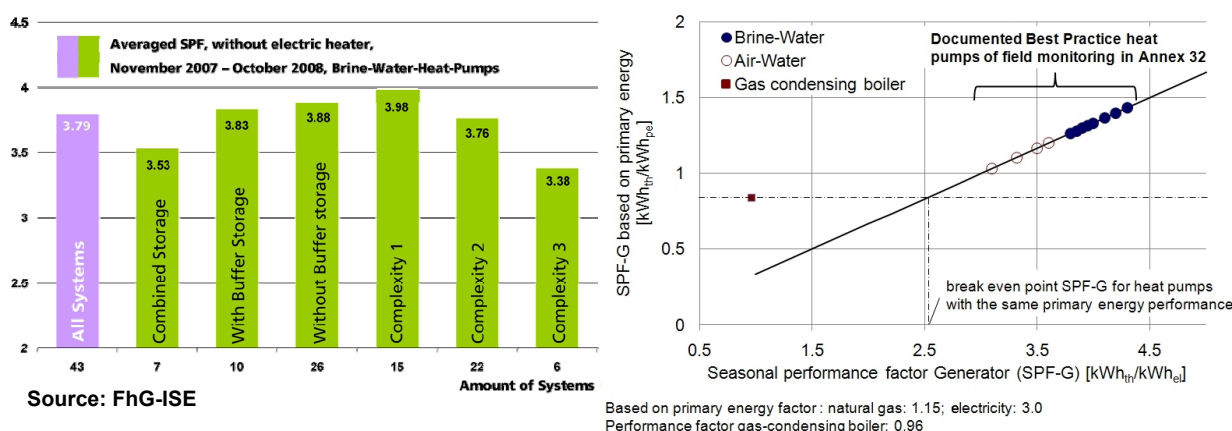
In Japan two inverter-controlled ground-source heat pumps installed in low energy houses have been field-monitored in the cold climate of the Hokkaido Island (Nagano, 2009). Space

heating COPs above >5 were reached in combination with a low temperature floor heating system of 35 °C/ 30 °C design temperatures, and overall seasonal performance is in the range of 3.8.

Compared to conventional buildings of the regions equipped with oil boilers, CO<sub>2</sub>-emission savings are in the range of 50-70%, which stem from both the building envelope improvement to low energy level (≈40-50%) and from the building technology (≈50-60%).

Figure 9 presents the system configuration and energy balance of the second field test (left) and the CO<sub>2</sub>-emission savings based on the emission factors of 410 gCO<sub>2</sub>/kWh for electricity and 203 gCO<sub>2</sub>/kWh for fuel-oil.

Figure 10 left gives an evaluation of the system performance based on the system configuration in terms of storage integration and the complexity (complexity 1 is the lowest) of the ground source systems in the German field test HP Efficiency, which is evaluated by the number of pumps, valves and heat exchangers. The figure confirms that the simpler system configurations tend to reach better system performance factors in many field tests, i.e. complex system configurations including combi-storages often do not meet the expected performance in field tests, as stated in former field tests, too.



**Figure 10: SPF of different hydronic configurations (left) and primary energy performance of the Annex 32 Best Practice Systems (right)**

Figure 10 right shows the SPF based on primary energy, which has been calculated as quotient of the SPF and the primary energy factor, of the A/W (red hollow dots) and B/W (blue bold dots) heat pumps documented in Best Practice Sheets in Annex 32. These SPF-values are compared to a gas condensing boiler of an efficiency of 0.96.

As can be seen, the seasonal performance factors of the generator system based on primary energy of all documented Best Practice systems are significantly higher than the primary energy efficiency of the condensing gas boiler and thus contribute to primary energy savings. At the used primary energy factors of 1.15 for natural gas and 2.97 for electricity, the break-even point for equal primary energy performance is an SPF of the heat pump of about 2.5 also marked in Figure 10 right.

#### 4.2 Results of an Integrated Ground-coupled Passive Cooling Function

Interest in a space cooling function also for residential buildings can be noticed in market developments. In order to provided an energy-efficient space cooling options, a passive operation of the ground source in summer can be considered, i.e. a use of the cooler ground temperatures by simply running the source pump without heat pump operation (also known as free, direct or natural cooling).

Within Annex 32 both simulation studies (Dott, Wemhoener and Afjei, 2010) and field monitoring of passive ground cooling in 4 low and ultra-low energy houses have been performed in Switzerland (Genkinger et al., 2010) and Austria (Zottl et al., 2010). Simulation results show that a ground-coupled passive cooling is capable to cover most of the

residential cooling needs even in extreme summers with a borehole heat exchanger designed for the space heating operation. In particular the heat exchanger to couple the ground and a floor emission system should be designed to a minimum temperature difference to extend the availability.

Simulation results yield SPF of the space cooling of 10-25 depending on the rejected cooling energy. The performance factor is mainly affected by the energy efficiency of the pumps. Results in the field monitoring projects are a bit lower than the simulated values and reach values from 7 - 15, which is due to partly low cooling loads (e.g. in a north-oriented and naturally shaded building) as well as standard instead of highly efficient pumps. Vertical borehole heat exchangers tend to reach higher SPF as horizontal ground collectors due to lower ground temperatures in summer. Measured indoor room temperatures could be lowered by 2-4 K by the passive cooling and temperatures below 26°C could be kept.

The passive cooling mode can easily be integrated in existing systems by adding a heat exchanger, an enhanced control and suited thermostatic valves, if required. Costs for the passive cooling option are with an investment of about 2000 € and operation costs for the pump electricity of about 12 €/a moderate. More details on cooling in residential buildings with heat pumps can be found in the Swiss contribution of Dott et al. (2011)

## 5 DELIVERABLES OF IEA HPP ANNEX 32

The results of IEA HPP Annex 32 has been summarised in 4 final reports. The umbrella report gives an introduction to low energy houses and an overview of the Annex 32 project, participants and national contributions as well as a summary of main results. Multifunctional heat pumps are categorised in the market overview report based on integrated functionalities to facilitate a system choice. The prototype system report documents the concepts, lab-test and simulation results of developed integrated heat pump prototypes. Finally, the field-monitoring report summarises the extensive field monitoring results, evaluated optimisation potentials and derived design recommendations.

Moreover, well performing systems in real operation have been documented as 4-page Best Practice Sheets and prototype systems/concepts have been summarised in 4-page System Concept Sheets. All deliverables are available for download on the Annex 32 website at <http://www.annex32.net>.

## 6 CONCLUSIONS

In the frame of IEA HPP Annex 32 multifunctional heat pumps adapted to the application in low energy houses have been developed and field-monitored, addressing the particular needs of these houses for multiple building services like additional ventilation, space cooling and dehumidification. Typical system integration opportunities like multiple use of the same source/sink and internal heat recovery by simultaneous production of different building needs have been explored, resulting in substantial energy savings of more than 50% compared to common state-of-the-art technologies.

While Annex 32 had a focus on the system integration and design, current market trends show an integration of solar components and heat pumps. In particular for Net Zero energy houses, where the integration of renewable energies is a central part of the concept, integration of solar components is essential, offering further opportunities of a building integration regarding energy and cost savings.

Future buildings will be built-up of multifunctional components, which contribute to cover the energy needs efficiently and cost-effective. Due to the above mentioned unique features, heat pumps are a core component for integrated and environmentally-sound building designs enabling the transformation to a sustainable society.

## 7 ACKNOWLEDGEMENTS

It has to be emphasized that the IEA HPP Annex 32 is a co-operative research project and contributions of all participating institutions are highly acknowledged.

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