IEA HEAT PUMP PROGRAMME

Heat Pump Concepts for Nearly Zero Energy Buildings

Heat pumps are core technologies in nearly Zero Energy Building (nZEB) strategies for thermal energy management in combination with renewable energy technologies (PV or thermal) and storage.

Short background of nearly Zero Energy Buildings

The introduction of nearly or Net Zero Energy Buildings is closely linked to political target dates of 2020 (EU, USA) to 2030 (Japan). However, there is as yet no precise definition of a nearly/Net Zero Energy Building (nZEB/NZEB).

Different pilot and demonstration (P&D) projects have been realized, mainly as residential nZEBs. Heat pumps are already well-established in these buildings, but there are still options for further developments regarding such aspects as system and building integration as well as design and control of modified systems for these types of buildings. In addition, buildings with heat pumps are becoming active players in the energy system by acting as an enabler of low temperature renewable heat that couldn't be used otherwise, and the heat pump offers the option to store electricity surplus as thermal energy, which opens up opportunities for smart controls and load management, requiring local storage and intelligent meters.

Policies required to speed up market uptake

- **Harmonization of nZEB definition and support of technology evaluations** — Due to current understanding a nearly Zero Energy Building is "a grid-connected building which produces (exports) as much energy as it consumes (imports) by renewable sources on an annual basis"
- **Support of promising technologies and concepts demonstrated by field monitoring**
- **Support for favourable market conditions for renewable energy and support of grid infrastructure**

Potential Energy and CO_2 savings with the technology

The building sector is one of the biggest consumers of energy with associated CO_2 emissions, responsible for about 40 % of total CO_2 emissions in the EU. Heat pumps can supply space heating and cooling, domestic hot water, and are a cost-effective way of cutting CO_2 emissions. Several field monitoring projects have shown that nZEBs with heat pumps are CO_2 neutral, or even generate a surplus of energy. The heat pump, as an energy-efficient technology and a flexible electricity consumer, also allows integration with storage and renewable technologies (PV or thermal) in conjunction with nZEB buildings, and provides flexibility for power management in smart grids. Heat pumps in nZEBs can therefore become a key technology as a cost-effective way of creating high-sustainability carbon-neutral societies.

Ongoing activities in the area

- **Definition of nZEB** — Harmonization of the different definitions of nZEB could facilitate implementation of the concept in different countries. The limits of the nZEB concept for single buildings, and extension of the concept to clusters of buildings in a small heating network or with a common generation of renewable electricity with windpower or bio energy are also interesting aspects where acceptance of the nZEB standard extends to a wider system boundary.
- **Integrated Heat pumps/Renewable/Storage systems** — Design and optimisation to get maximum energy performance at an acceptable cost.
- **Technology developments and field monitoring** — In order to facilitate evaluation of system concepts and technologies, the performance of different solutions should be compared, and the results used to produce recommendations for configuration, design and controls. There is potential for further improvement and development in system and building integration of heat pumps and components. This should be supplemented with field monitoring to gather real-world experience of technology performance and interaction, and to reveal development potentials.
- **Integration of buildings into energy grids** — In order to use the local load management and storage capabilities of buildings with heat pumps, products should be further developed to suit them for the use in smart grids in order to overcome potential load mismatches and to operate buildings in synergy with energy grids.
  The above aspects are addressed in IEA HPP Annex 40. The eight participating countries Canada, Finland, Japan, The Netherlands, Norway, Sweden, Switzerland (Operating Agent) and the USA - collaborate in this corporate research project within the framework of the IEA HPP. Started in 2013, the project runs until 2015.
  Current information regarding the annex can be found at **http://www.heatpumpcentre.org**.

EXAMPLE IN EUROPE: Plus energy multi-family house with electro-mobility in Rupperswil, Switzerland

Fig. 2: Multi-family house Rupperswill [Source: IEBau]

The multi-family house (MFH) shown in Figure 2 with electro-mobility near Rupperswil (Canton Aargau, Switzerland), was built in 2011 by Setz Architects, and has been monitored since October 1st, 2011 by the Institute of Energy in Building (IEBau) of the University of Applied Sciences and Arts Northwestern Switzerland.

The all-electric building on passive house level with calculated space heating demands of 23.7 kWh/(m²a) and domestic hot water demands of 10 kWh/(m²a) based on an energy reference area of 396 m² consists of two 4.5-room apartments in the ground floor and first floor (each 110 m²) and one 1.5-room apartment in the basement (40 m²).

The brine-to-water heat pump[1] with a 180 m vertical borehole heat exchanger and a low-temperature floor heating system[2] is supplemented by a 20 kilowatt peak[3] solar PV system on the roof. A shared electric car for the occupants is also included in the building concept.

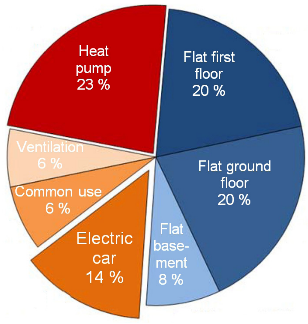

Fig. 3: Annual electric consumption [Source: IEBau]

Fig. 3 shows the breakdown of electricity consumption. In addition to the demand for appliances (plug loads), with about 50 % consumption (blue), the highly-efficient heat pump (red), with 23 % of the annual consumption, covers the entire space heating and DHW demand. At 14 % of annual energy demand, the electric car (orange) is the other main consumer. Both heat pump and electric car permit flexible operation, which contributes to optimised self-consumption.

Fig. 4 shows the electricity balance for summer operation. The building consumes 4939 kWh, of which 60 % were covered by the 12521 kWh of PV-generated electricity. About 75 % of the PV generation was exported to the grid, which met a residual load of 1975 kWh or 40 % of the building consumption, leading to a net export to the grid of 7581 kWh. It was calculated that an optimised load shift of electricity consumers into PV production times from 10.00 to 16.00 could enhance self-consumption by a further 15 %.

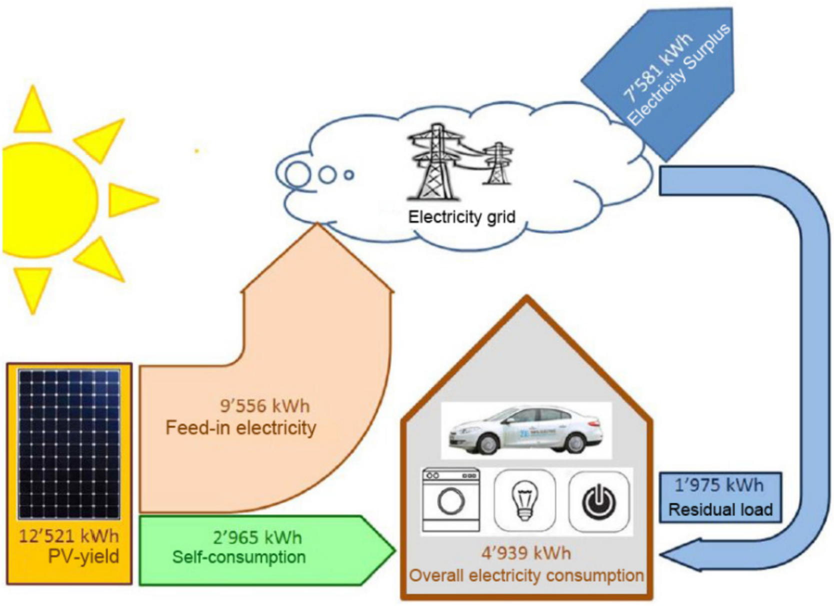

Fig. 4: Summer balance [Source: IEBau]

***Summarising**, an all-electric building, with considerable electricity surplus production, can be realised with state-of-the-art technologies in Switzerland. The highly energy-efficient heat pump operation enables on the one hand increased electricity surplus of the building for local mobility or export to the grid, and on the other hand optimises the self-consumption of PV electricity and opens up storage options for local load management in connection with the building and storage systems.*

1) 8.9 kW/COP 4.5 at B0/W35
2) design 30°C/25°C
3) kilowatt peak (kWp). Solar electricity systems are given a rating in kilowatts peak. This is essentially the rate at which it generates energy at peak performance for example at noon on a sunny day.

EXAMPLE IN USA: DOE/ORNL development of a multifunctional Integrated Heat Pump (IHP) for NZEB

The Department of Energy's (DOE) Building Technologies Program (DOE-BT) has a long-term goal to maximize the energy efficiency of the US building stock by 2020. To achieve this target will require a substantial reduction of the energy used by energy service equipment (equipment providing space heating and cooling, water heating, etc.) to about 50 % of that of today's best practice.

One approach to achieving this is to develop a single piece of equipment that provides multiple services. Oak Ridge National Laboratory (ORNL) has developed a general concept for such an appliance, known as the integrated heat pump (IHP), and is working with manufacturers to develop both air-source and ground-source versions (AS-IHP and GS-IHP). The GS-IHP system concept (see Fig. 5) uses a variable-speed (VS) compressor, a VS indoor blower, a VS pump for a ground heat exchanger (GHX) fluid circulation, and a VS pump for hot water circulation.

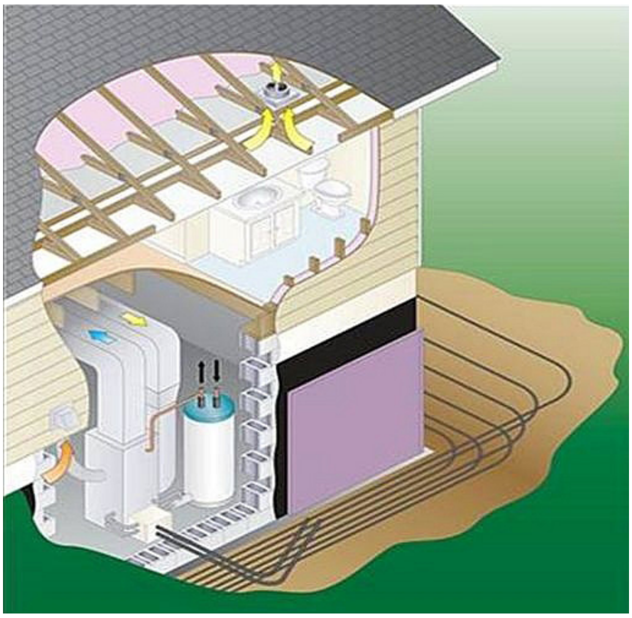

Fig. 5: Conceptual installation of the residential ground-source IHP [Source: ORNL]

Field testing of prototypes of the GS-IHP system were conducted from 2011 to early 2013 at a research house in Oak Ridge, Tennessee. Based on the measured steady-state performance of the prototypes, it was estimated that the system would achieve ~58 % annual energy savings relative to a minimum-efficiency system (air-source heat pump + electric resistance water heating) at the Oak Ridge location. Annual performance simulations of the prototype with vertical well ground heat exchangers (GHX) in five US locations predict annual energy savings of 57 % to 61 %, averaging 59 % relative to the minimum-efficiency suite, and 38 % to 56 %, averaging 46 % relative to a state-of-the-art two-speed ground-source heat pump with a desuperheater water heater.

A new heat pump product based on the GS-IHP prototype has been introduced to the US market. Field testing of an AS-IHP prototype is planned to start in 2014 at a research house near Oak Ridge, Tennessee.

Fig. 6: Net Zero Energy Residential Test Facility [Source: NIST]

The US has also installed a Net Zero Energy Residential Test Facility (NZERTF) (see Fig. 6) on the campus of the National Institute of Standards and Technologies (NIST).

The Center of Environmental Energy Engineering (CEEE) at the University of Maryland is developing software for the comfort evaluation of radiant panels (see Fig. 7), since heat pumps work most efficiently when the temperature rise is minimized. Thus, in an nZEB, the heat sink fluid should be as close to the desired room temperature as possible, which in many cases requires radiant heating/cooling panels. Despite considerable experience of such devices, correct and most energy-efficient utilization of them remains a challenge, especially in retro-fit situations. The developed software aims at maximizing comfort for building occupants while still maintaining maximum energy efficiency.

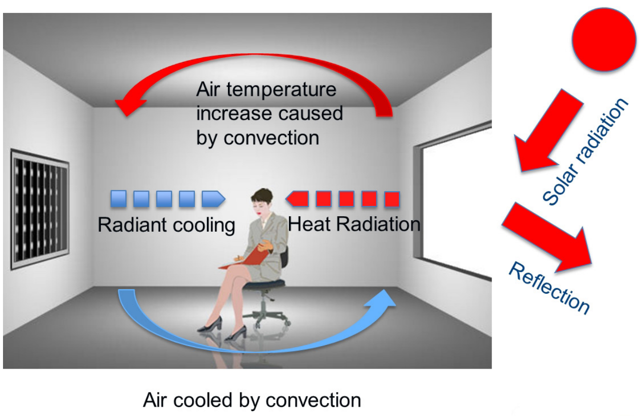

Fig. 7: Software development for thermal comfort evaluation of radiant panels [Source: CEEE]

EXAMPLE IN EUROPE: No energy account for residential nZEBs in RijswijkBuiten, the Netherlands

Fig. 8: Dwellings in RijswijkBuiten

In the new residential area RijswijkBuiten in the Netherlands approximately 3.500 dwellings are developed as nZEB. To reduce the demand of space heating, the nZEBs are built with optimal thermal insulation, triple-glass and a low air permeability.

As the Netherland has a mild climate zone this doesn't need to be extreme to the level of passive houses. Thus the peak capacity for heating does not exceed 3 kW in extreme winter conditions. The energy demand is further reduced by applying efficient technologies with a balanced ventilation system with high efficiency heat recovery and a shower water heat recovery system. Space heating and cooling is supplied by a 3,5 kW brine-to-water heat pump with a vertical borehole heat exchanger and dc pumps accompanied with a low-temperature floor heating/cooling system. The heat pump also covers the domestic hot water demand by heating a storage water heater of 150 litres. The electricity demand for space heating, space cooling, domestic hot water and ventilation is covered by a 3 kilowatt peak solar PV system on the roof. This solar PV also covers the other electricity demand of domestic energy use which has an average of 3000 kWh/year.

Energy costs zero approach

To keep the residential nZEBs affordable for consumers, a local **Energy Service Company (EsCo)** has been established. The EsCo finances the complete energy system, i.e. heat pump and solar PV system. They rent the complete system to the end user, i.e. the owner/occupant of the dwelling. In return, the inhabitant pays an monthly rent which is equal to the energy cost savings of the residential nZEB compared with a new reference dwelling equipped with a gas-fired boiler (see figure 9). To guarantee the performance of the system, a contract is made between the EsCo and the inhabitant in which it is assured that the annually PV-generated electricity covered the total annual energy demand for space heating, space cooling, domestic hot water and ventilation for a period of 25 years.

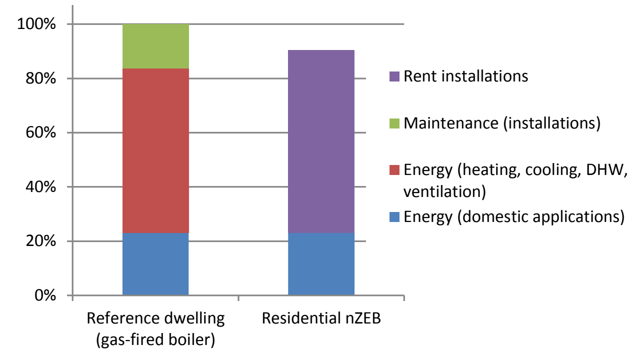

Fig. 9: Energy costs, Dwellings in RijswijkBuiten

In case of insufficient PV-generated electricity, the EsCo counterbalances the amount of electricity from the grid. In order to be able to guarantee this performance, the energy system is integrated in close harmony with the architectural aspects of the building. Moreover the guaranteed performance is the result of a long experience in monitoring and a deep understanding of the heat pump by members of the EsCo.

What is the IEA Heat Pump Programme?

The Programme is a non-profit organisation funded by its member countries. It is the foremost worldwide source of independent information and expertise on environmental and energy conservation benefits of heat pumping technologies.

What is the aim of the Heat Pump Programme?

The aim is to achieve widespread deployment of appropriate practical and reliable heat pumping technology systems that can save energy resources while helping to protect the environment.

Why is that important?

The world's energy and climate problems are well known. The buildings sector is responsible for a very considerable proportion of greenhouse gas emissions. Heat pumps are a key technology in the solution to break this trend.

What needs to be done?

By disseminating knowledge of heat pumps worldwide, we contribute to the battle against global warming. In order to increase the pace of development and deployment of heat pumps for buildings and industries, we need to increase R&D efforts for heat pumps, and we need to implement long-term policies for further deployment of heat pumps.

Contact us

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