Annex 32

Economical heating and cooling systems for low energy houses

Final Report

Operating Agent: Switzerland

IEA Heat Pump Programme

2011

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Box 857, SE-501 15 Borås
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Phone: +46 10 16 55 12

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Preface

This project was carried out within the Heat Pump Programme, HPP which is an Implementing agreement within the International Energy Agency, IEA.

The IEA

The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of over 40 Implementing Agreements.

The IEA Heat Pump Programme

The Implementing Agreement for a Programme of Research, Development, Demonstration and Promotion of Heat Pumping Technologies (IA) forms the legal basis for the IEA Heat Pump Programme. Signatories of the IA are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the IA collaborative tasks or “Annexes” in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operates for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex. The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

The IEA Heat Pump Centre

A central role within the IEA Heat Pump Programme is played by the IEA Heat Pump Centre (HPC). Consistent with the overall objective of the IA the HPC seeks to advance and disseminate knowledge about heat pumps, and promote their use wherever appropriate. Activities of the HPC include the production of a quarterly newsletter and the webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the IEA Heat Pump Programme and for inquiries on heat pump issues in general contact the IEA Heat Pump Centre at the following address:

IEA Heat Pump Centre
Box 857
SE-501 15 BORÅS
Sweden
Phone: +46 10 16 55 12
E-mail: hpc@heatpumpcentre.org

Final report IEA HPP Annex 32

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Economical heating and cooling systems for low energy houses

Schweizerische Eidgenossenschaft
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Final report IEA HPP Annex 32

Project outline and summary of main results

Worked out by

Carsten Wemhoener (Editor)
Operating Agent IEA HPP Annex 32
Institute of Energy in Building
University of Applied Sciences North-Western Switzerland
E-Mail: carsten.wemhoener@fhnw.ch

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Operating Agent (Switzerland):
Institute of Energy in Building, Univ. of Applied Sciences Northwestern Switzerland, Muttenz
Carsten Wemhöner, carsten.wemhoener@fhnw.ch

National team leaders in IEA HPP Annex 32

Austria:
Institute of thermal engineering (IWT), Graz Technical University
Ao. Univ. Prof. Dr. René Rieberer, rene.rieberer@tugraz.at

Canada:
Laboratoire des technologies de l`énergie (LTE), Hydro Quebec, Shawinigan
Vasile Minea, PhD, minea.vasile@lte.ireq.ca

France:
Electricité de France, R & D, Loing-sur-Moret
Catherine Martinlagardette, catherine.martinlagardette@edf.fr

Germany:
Fraunhofer Institute of Solar energy systems (FhG-ISE), Freiburg (Brsg.)
Marek Miara, marek.miara@ise.fraunhofer.de

Japan:
Graduate School of Engineering, Hokkaido University, Sapporo
Prof. Dr. Eng. Katsunori Nagano, nagano@eng.hokudai.ac.jp

The Netherlands:
Agentschap NL
Onno Kleefkens, onno.kleefkens@agentschapnl.nl

Norway:
SINTEF Energy Research, Trondheim
Maria Justo Alonso maria.justo.alonso@sintef.no, Dr. Ing. Jørn Stene (2006-08) jost@cowi.no

Sweden:
SP Technical Research Institute of Sweden, Borås
Svein Ruud, svein.ruud@sp.se

Switzerland:
Institute of Energy in Building, Univ. of Applied Sciences Northwestern Switzerland, Muttenz
Prof. Dr. Thomas Afjei, thomas.afjei@fhnw.ch

USA:
Oak Ridge National Laboratory, Oak Ridge, Tennessee
Van D. Baxter, baxtervd@ornl.gov

Contents

PREFACE

Introduction to IEA HPP Annex 32

Since the mid of the nineties low energy buildings with a significantly reduced energy consumption down to ultra-low energy standard (typical space heating energy need of 15 kWh/(m^2a)) or even net zero energy consumption (on an annual basis by an integration of on-site renewable energy systems) have been realised.
These building concepts recently show strong market growth in different European countries. Many governments address the spread of low energy buildings as a major strategy to reach climate protection targets according to the Kyoto protocol. Heat pump markets are growing in many countries as well.
Low energy buildings have significantly different load characteristics compared to conventional existing buildings. This requires adapted system solutions to entirely use energy-efficiency potentials for the remaining energy needs.
Integrated heat pump solutions have favourable features for the use in low energy houses. The main advantages are the potential for internal heat recovery and simultaneous operation to cover different building needs at the same time as well as installation space and cost benefits. This leads to a significantly improved system performance in an adequate capacity range to reduce primary energy consumption and cut CO_2-emissions and costs.
However, in many countries, no adequate system solutions are available on the market or energy performance of available and newly-introduced low energy house technology is not yet approved by field experience. Therefore, system development and field approval of functionality and real-world operational performance of the systems are needed. These are the main working areas of IEA HPP Annex 32.

Main objectives of IEA HPP Annex 32

The main objectives of the IEA HPP Annex 32 are the further development and field monitoring of integrated heat pump systems for the use in low energy buildings, leading to the following objectives:

- To characterise the state-of-the-art in the different participating countries
- To assess and compare the energy performance of different system solutions for the residential low energy house sector
- To develop and lab-test new system solutions of integrated heat pumps in the low-energy-house capacity range including the use of natural refrigerants
- To accomplished field tests of new developments and marketable systems and to document best-practice examples
- To disseminate the results

Results of the IEA HPP Annex 32

The results of IEA HPP Annex 32 comprise:

- Overview of market system solutions of integrated heat pumps for low energy houses
- Design recommendations of the standard system solutions
- New system developments as prototypes including lab-test and simulation results
- Documentation of field monitoring results of new and marketable systems
- Dissemination of results by a website, workshop presentation and reports

1 INTRODUCTION TO LOW ENERGY HOUSES

This chapter gives an introduction to low energy houses in terms of means to reach low energy consumption, the definitions and the policy targets linked to low energy houses.

1.1 Characteristics of low energy buildings

Advantages of low energy buildings can be categorised in terms of indoor comfort, environmental impact and economy.

Low energy houses provide better indoor comfort by

- higher indoor wall temperatures (reduced temperature asymmetries)
- reduced draught due to air-tightness of the building
- better indoor air quality in case of mechanical ventilation system by
  - Automatic extraction of indoor pollutants, moisture, odours
  - Protection against building damage by moisture
  - Filtering of the inlet air (pollutants, pollen, moisture) (only for balanced ventilation)

Low energy houses are environmentally-sound due to

- Significant reduction of space heating energy requirements
- Lower supply temperature requirements for the heating system promotes the use of environmental and renewable energy sources

Low energy houses have economical benefits by

- Savings in operation costs
- Value-conservation by high-quality building with extended durability
- Lower dependency of energy prices
- Limited additional investment costs

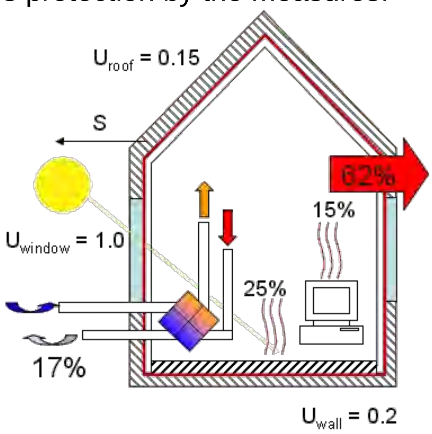
1.1.1 Strategies to achieve low energy buildings

The strategies to reach low energy consumption going hand in hand with above mentioned comfort and economical benefits can be different for the winter and summer operation of the building. Some of the strategies have benefits in summer and winter operation, e.g. thermal insulation and air-tightness, while others like large south-oriented windows need additional attention in summer operation in order to reduce the risk of overheating.

1.1.1.1 Winter operation

The winter operation of the building has a focus on heat loss protection by the measures:

- High thermal insulation, avoidance of thermal bridges
- Compact building style (surface-to-volume (A/V) ratio)
- Air-tight building
- Minimum hygienically necessary air exchange rate
- Ventilation heat recovery
- Optimisation of passive solar gains
- Orientation of the building
- High-quality glazing
- Use of thermal mass to store gains



1.1.1.2 Summer operation

The summer operation of the building has a focus on heat gain protection by the measures:

High thermal insulation

- Minimum hygienically necessary air exchange,
  Bypass of the ventilation heat recovery
- Reduction of external gains (shading, functional glazing)
- Reduction of internal gains by energy-efficient devices
- Use of building thermal mass
  - o for buffering peaks of gains
  - o discharge of thermal mass by passive measures (e.g. night-time ventilation)
- Additional energy efficient comfort cooling

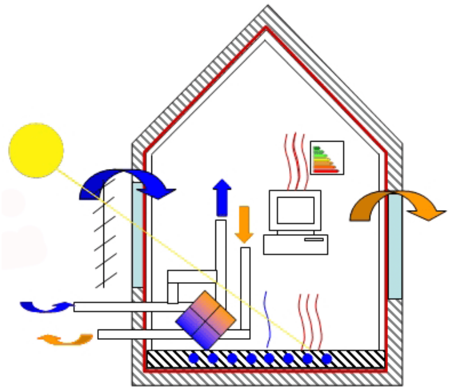


Fig. 1 shows a comparison of typical measures for a low- and ultra-low energy house including typical values.

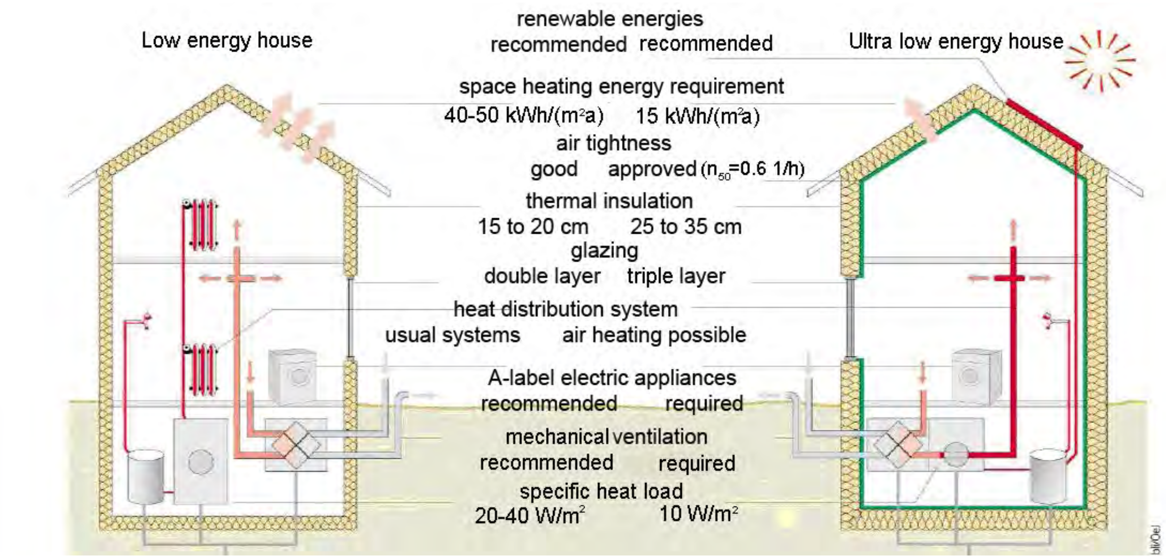


Fig. 1: Comparison of typical values for low- (left) and ultra-low energy houses (right) for the (modified of MINERGIE®)

1.2 Building standards and legal requirements

1.2.1 Overview

Fig. 2 gives a picture of the development of heat energy requirements of different building categories for a German single family house (3-4 persons, 150 m^2 heated area, surface-to-volume ratio 0.84) distinguished between the space heating needs due to transmission and ventilation losses. Starting from existing buildings with a heat demand in the range of 200 kWh/(m^2·a) the development ends with ultra-low energy houses, e.g. passive house with space heating needs of only 15 kWh/(m^2·a). On the other hand, an ultra-low energy consumption can be reached by Net Zero Energy Buildings (NZEB), which have a good building envelope, which, however, does not necessarily correspond to a passive house. A working definition of a Net Zero Energy Building is a "grid-connected house with highly reduced needs which generates (exports) as much energy as it consumes (imports) by renewable energies on an annual basis". However, a clear definition of several aspects like system boundary, calculation period, static or dynamic calculation at what time step, comfort and loads, site or source energy metric, only operational energy or lifecycle analysis, assessment of mismatch between generated and used energy in the grid and a necessity to define minimum efficiency requirements is missing. Thus, a thorough definition of a Net Zero Energy Building is currently elaborated in the joined IEA ECBCS Annex 52/SHC Task 40 (http://www.iea-shc.org/task40).

If even more energy is produced than consumed on an annual basis, the building is entitled plus energy house, since a surplus of produced energy is exported to the grid. A house whose energy bill becomes net zero under the same conditions can be considered net zero-energy-cost house. The production of net zero-carbon housing, whose value is from time to time considered as equivalent to the net zero-energy counterpart, may perhaps require further steps to be achieved. Farhar (2008) suggests that to achieve a zero-carbon housing target, the amount of exported electricity should be 20% higher than the energy used for the operation of a house for at least 25 years.

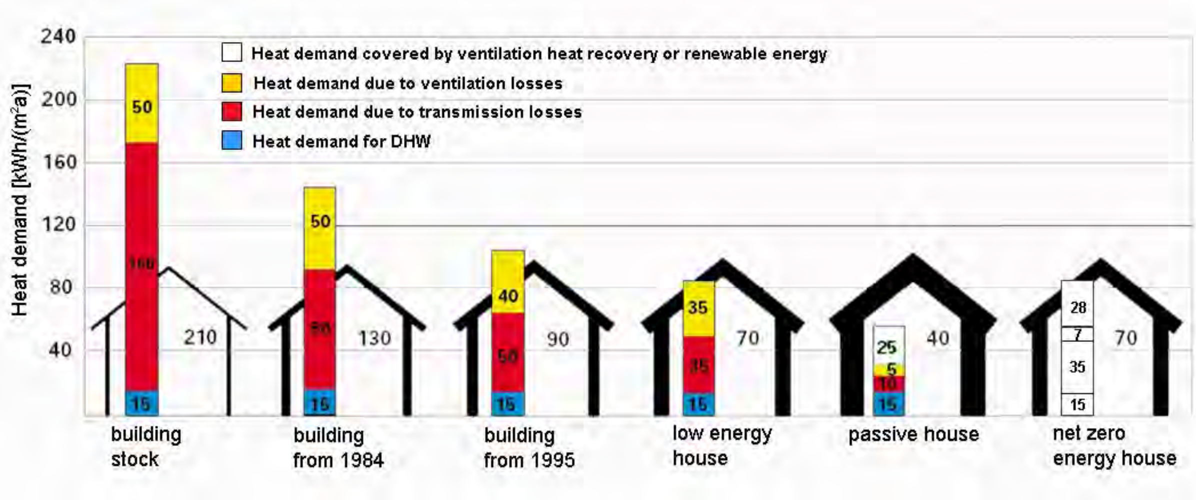


Fig. 2: Energy losses of different building categories for a single family house in Germany with 150 m² heated area and a surface-to-volume ratio of 0.84 (modified of Viessmann)

1.2.2 Legal requirements

Most European countries set requirements

- on the heat loss through single building components (expressed as U-value) or on the overall heat loss factor of the building (expressed as UA-value incl. ventilation) and
- on the overall space heating energy need or on the delivered or primary energy to cover the space heating need.

Tab. 1 gives an overview on legal requirements for U-values in different participating countries and a typical range of low and ultra-low energy houses taken from RWE (2010).

Tab. 1: Sample of requirements for the U-values of different construction components

Requirements on U-values [W/(m²K)]					
	AT	CH (SIA 380/1:2009)	NO (TEK 2007)	LEH	ULEH
Wall-to-outside	0.35	0.2	0.18	0.2..0.3	0.08..0.15
Floor-to-ground	0.40	0.28	0.15	< 0.3	< 0.15
Roof-to-outside	0.20	0.2	0.13	< 0.15	0.06..0.15
Windows	1.4	1.3	1.2	0.8	< 0.8

Until 2007 the legal requirement for the space heating energy need of the building was in the range of 100 kWh/(m^2a). However, with the implementation of the EU-Directive 2002/91/EC (2003) on the Energy Performance of Buildings (EPBD) many countries revised the building standards and lowered the limit for the space heating energy needs to about 80 kWh/(m^2a) in 2007. In some countries, also a verification of a summer comfort is included in the requirements, i.e. a proof that no overheating occurs in summer. In 2009, some coutries revised the requirement once again, e.g. Germany with the EnEV (2009) and Switzerland with the implementation of the Muken (2008), leading to a space heating requirement of about 50 kWh/(m^2a).
In the Netherlands, no limit on the space heating energy need is set, but an overall performance characteristic called Energy Performance Coefficient (EPC) including the building envelope and the building technology is calculated according to the Dutch standard NEN 5128 (2004) in order to limit CO_2-emissions. The current building regulation requires an EPC value of 0.8, which has been lowered from EPC = 1.0 in the beginning of 2006. In 2011 it will be lowered to 0.6.
Japan has quite different climate zones reaching from cold winters in the northern Hokkaido area to the hot climate on the island of Okinawa. Fig. 3 depicts the climate zones and related cities, heating degree days and temperatures. 80% of the Japanese population lives in the moderate climate region IV where the Japanese cities Tokyo, Yokohama, Osaka, Kyoto and Nagoya are located.

Region	HDD18-18	City	Average Temp
I Region	>3500	Sapporo (Hokkaido)	8.3℃
II Region	>3000 <3500	Aomori,Akita	10-11℃
III Region	>2500 <3000	Sendai, Fukushima	13-14℃
IV Region	>1500 <2500	Tokyo, Osaka Fukuoka	15-17℃
V Region	>500 <1500	Kagoshima Miyazaki	18-19℃
VI Region	< 500	Okinawa	23℃

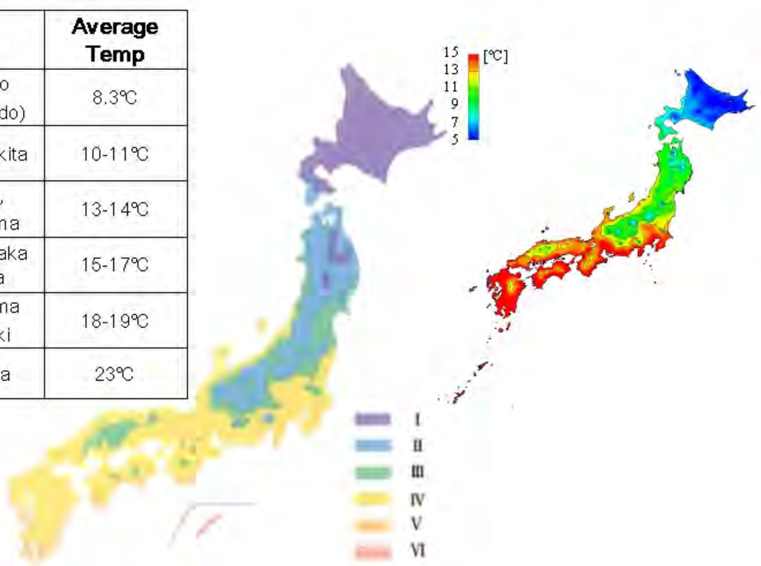


Fig. 3: Climate zones of Japan with cities, average temperature and heating degree days

Therefore, the requirement on the space heating need depends on the climate region and is given in Tab. 2. The Q-value is defined as overall heat loss of the building for transmission and ventilation and the μ-value as the ratio of the total solar heat gain of a building to the amount of solar radiation incidented to the building in summer.

Tab. 2: Criteria of yearly heating and cooling energy requirement in Japan

Climate region	I	II	III	IV	V	VI
Reference value of yearly heating and cooling energy [kWh/(m^2a)]	110	110	130	130	100	80
Reference values of thermal loss coefficient (Q-value) (overall U-value) [W/(m^2K)]	1.6	1.9	2.4	2.7	2.7	3.7
Reference values for solar heat gains (μ-value) [-]	0.08		0.07			0.06

1.2.3 National definitions of low energy buildings

There is no clear definition of a low energy house. In most European countries, typical values for characterising a low energy house are the area-specific heat load [W/m^2] and the area specific annual space heating energy need [kWh/(m^{2}a]], which are related to the country specific building regulation. Even though principle calculation methods in the single European countries are similar and based on European standards, single values, e.g. the reference area may differ.

In the following some characterisations of low energy houses in the participating countries related to the respective building regulations are given:

- In Austria, low energy houses are defined as houses with a specific heat load lower than 40 W/m^2 and a space heating energy need in the range of 50 kWh/(m^2·a).
- In Switzerland, a low energy house is a house corresponding to the MINERGIE® label with a typical heat load of 20 W/m^2 and weighted delivered energy of 38 kWh/(m^{2}a).
- In Norway, definition of typical needs of the low energy house are a heat load of 30-40 W/m^2 and a space heating energy need less than 58 kWh/(m^2·a) for Oslo climate.
- In the Netherlands a low energy house is an intermediate between houses with an Energy Performance Coefficient (EPC) < 0.7 and passive houses with an energy need of 15 kWh/(m^2·a) having an EPC of typically 0.4. Such low energy houses are offered in several concepts by smaller building project developers.
- In Japan, a low energy house is a house with a better performance than according to the standard for next generation.

For the definition of an ultra-low energy house, many countries refer to the German passive house standard. The passive house standard and further building labels are given in chap. 2.2.

1.2.4 Strategic objectives in different countries

In the following strategic objectives are summarised which document the policy trends for low energy houses in the single participating countries of IEA HPP Annex 32 and the EU.

In the EU the 20-20-20 by 2020 target has been set, referring to 20% less CO_2-emissions, 20% enhanced energy efficiency and 20% renewable energy share to be reached by the year 2020. In order to translate these objectives, three EU Directives have been enacted:

- **EU Directive on the Energy Performance of Buildings (EPBD-recast, 2010)**
  Besides an outline of energy efficiency measures and requirements for building energy labelling (building energy certificate) the recast of the directive sets the target that all new buildings in the EU shall reach near zero energy consumption by the year 2020.

- **EU Directive on Energy related Products (ErP, 2009)**
  The directive sets guidelines for product labelling, among others also heat generators and air-conditioner. The motivation is to make the EU products top runners in energy efficiency. If current drafts are realised, much higher minimum requirements for heat generators will be introduced between 2011-2015, setting the efficiency of an average condensing boiler as minimum requirement for heat generators by 2015. Products not fullfilling the requirement will be banned from the market. Heat pumps are ranked among most efficient generators.

- **EU Directive on the Promotion of Renewable Energy Use (RES, 2009)**
  The directive defines criteria and calculation methods which energies are considered renewable. For heat pumps the directive defines the source energy to be considered renewable, if the Seasonal Performance Factor (SPF) reaches a value higher than 2.63. This value has been lowered in 2010 from 2.88 in 2005 due to an increase of the average electricity generation efficiency, which was changed from 0.4 to 0.43.

National objectives in different European countries are implementations of the EU targets:

- In Austria, the development towards net zero energy buildings is part of the objective of the "Energy Strategy Austria" of the Austrian government. Newly built buildings shall be nearly zero energy buildings according to the EPBD in the future by a very low energy demand of the building and the use of renewable energy. Concerning the retrofitting of buildings the renovation rate shall be increased to 3%/year until the year 2020.
- In France, low energy houses according to the French BBC label (see chap. 2.2.3) shall become the standard by 2012. By 2020 plus energy houses according to the Bepos label shall be mandatory.
- In Germany the building directive (Energie EinsparVerordnung – EnEV) has been tighten in 2009 by ≈30% to a value of 50 kWh/(m^2a). This means, all new buildings in Germany approach low energy house demand. Two further steps of about 30% reduction in energy needs are planned for 2012 and 2015, which would make the passive house the standard building by 2015.
- In Norway, building directives have been tightened in 2010. Passive houses are seen as important standard to promote climate protection. Also, a zero emission building research institute (ZEB) has been founded. Heat pumps are seen as important technology for the low energy house market segment.
- In the Netherlands new buildings shall be built climate neutral by 2015, i.e. shall reach a net zero carbon emission building, which means that the building's carbon emissions are offset by the generation of energy through non-carbon-emitting means.
- In Switzerland, EU directives are not binding, but the tightened cantonal building directive (MuKEn, 2008) has been implemented in 2009. It prescribes a space heating energy need of 50 kWh/(m^2·a) and supply temperatures of floor heating systems lower than 35 °C. The strategic goals of the MINERGIE®-Association is to extend the fraction of MINERGIE-P® buildings (see chap. 2.2.5 for building labels). Moreover, overall retrofitting to MINERGIE® or MINERGIE-P® standard is to be promoted. Furthermore, new MINERGIE® products in the direction of Net Zero Energy Building concepts are in preparation.

Also in North America, the NZEB target is a major item of the strategic goal for the building sector:

- In Canada, the broad introduction for Net Zero Energy Buildings is strived by 2030. Currently, there is no broad application of the concept, but just the EQuilibrium Pilot and Demonstration Initiative of the Canadian Mortgage and Housing Corporation with 12 test houses, which are extensively monitored.
- In the USA the strategic goal of the governmental Department of Energy (DOE) is a broad introduction for new residential Net Zero Energy Buildings by 2020. New commercial buildings shall reach net zero energy consumption by 2030, and all buildings shall be NZEBs by 2050. Different initiatives are nationwide in progress, focussing on different aspects.

In Japan, high performance buildings are seen as important means for climate protection as well. Besides thermal insulation, in particular heat pump technology is in focus as energy efficiency technology (HPTCJ, 2007).

2 Building Markets

2.1 Overview market state

State of building markets differ between the European countries. While in the central European countries Germany, Austria and Switzerland as well as in Norway low and ultra-low energy houses already show significant growth rates, other countries like Sweden and the Netherlands are rather in the market introduction phase.
In the Netherlands some pilot and demonstration projects have been realised in the low energy house market, but the Dutch building market is characterised as a sellers-market as the demand for certain types of houses (single family, low cost) is bigger than the production. This means that there is a strong impediment for market development towards energy efficient high-quality dwellings. Low energy houses are therefore mainly built by small project developers, who try to establish in this niche market with significant growth potential together with other stakeholders like the Dutch passive house association and local governments.
In Japan, some zero energy houses have been realised, but low energy buildings are rather in the market introduction. However, the government has set the target to improve housing insulation as a strategy to reduce CO_2-emissions.
The US Department of Energy (DOE) has set the target to reach market diffusion of net zero energy by 2020. Therefore, energy consumption of homes shall be successively lowered, while use of on-site renewable energy shall increase.

2.2 National certification schemes and markets

2.2.1 Austria

Certification scheme:

Certification in Austria is mainly adopting the criteria of the German passive house standard (see chap. 2.2.4).

Markets:

The number of built houses per year shows a significant growth, which is depicted in Fig. 4. Scenarios of the IG-Passivhaus AT estimate 10000 built passive houses in Austria by the end of 2010.

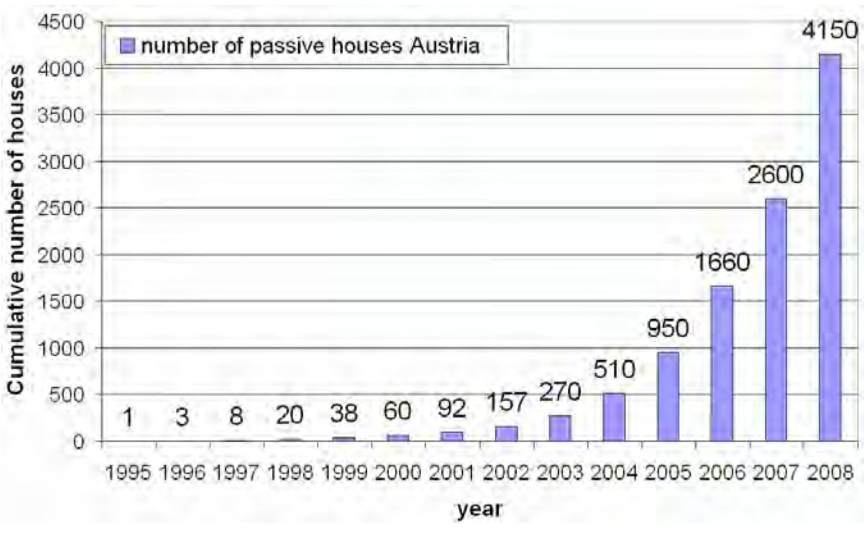


Fig. 4: Development of passive houses in Austria (source: IG Passivhaus, 2010)

2.2.2 Canada

Certification schemes:

In Canada the R-2000 standard was introduced a long time ago and is well-known. R-2000 is a voluntary Canadian standard for energy efficient homes based on the National Building Code, which results in at least 30% less energy consumption than a conventional home. R-2000 considers besides the energy consumption, air-tightness and ventilation also the building materials used.

Based on R-2000 other labels are derived, e.g. the Novoclimat label of the Canadian Province Québec. Novoclimat is an initiative of the Energy Efficiency Agency of Québec based on defining a home which account for at least 25% energy savings by better thermal insulation, an improved air-tightness, highly-efficient heating system and with an enhanced indoor comfort, e.g. in terms of air-tightness.

Markets:

In Canada more than 15000 homes have been built and certified to the Canadian standard R-2000.

2.2.3 France

Certification schemes:

There are labels of five levels of certification of low energy houses: HPE, HPE ENR, THPE, THPE ENR, and BBC of labelling low energy houses.

HPE (High Performance Environmental) house certification and derived labels

- HPE 2005: maximum energy consumption of 10% lower than RT2005.
- HPE ENR 2005: Additionally, space heating should either be generated by biomass at 50% minimum or by more than 60% of renewable energy.
- THPE 2005: maximum energy consumption is 20% lower than RT2005.
- THPE ENR 2005: maximum energy consumption lower than 30% of RT2005 and additional requirement on biomass or renewable heat generators (six options), e.g. 50% of the DHW is generated by solar panels and 50% of the space heating is generated by biomass.

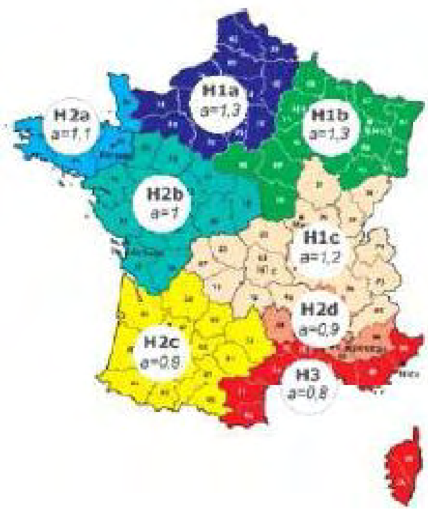
BBC (Batiment à basse consommation)-2005 and BBC Effinergie label

The energy requirements of the BBC-2005 label keep the primary energy consumption of the dwellings under a maximum C_{max} calculated as follow:

$$C_{max} = 50 \cdot (a+b)[kWh_p/(m^2a)]$$

eq. 1

where a [0.8..1.3] and b [0.1..0.2] are the factors set according to climate region and altitude, respectively. For example, it should not exceed 65 $kWh_p/(m^2a)$ in the H1 climate zone and 40 $kWh/(m^2a)$ in the H3 climate zone (altitude < 400 m). By only setting a limit on primary energy consumption the BBC-2005 label leaves it open to optimise building energy needs by improvement of the envelope or by use of efficient generators on the other hand. Energy performance defined in the BBC label are set as target values for the next thermal regulation for new dwellings, which is expected to be published in 2012. A CO_2 emission indicator is under discussion.



The BBC-Effinergie® label (http://www.effinergie.org) is very similar with the BBC-2005 label which is extended by requirements on air-infiltration, building envelope performance and compactness of dwellings. Existing dwellings can obtain the BBC-Effinergie® label if they comply with a primary energy consumption which does not exceed the limit value of 80 kWh/(m^2a). Regarding the service sector, buildings have to keep their consumption 50% lower than the reference values set in the last enforced thermal regulation, the RT2005.

Markets

The market share of low energy houses is small, yet. By October 2008 only about a hundred of dwellings have obtained the BBC label. Thus, the low energy houses construction is still far from reaching the threshold of wide market. It can be noticed that those buildings are only dedicated to environmentally friendly people, so far.

The concept concerns especially individual houses and has been initiated first by small constructors. However, invitations to tender are rapidly growing, even for collective dwellings and service buildings. Larger companies start to launch projects in the market of low energy buildings. Moreover, real performances of such low energy dwellings are not well-known. Currently, constructors and other actors deliver easily information about targets before and while the construction or renovation, but real performance of the performed service is much more difficult to obtain.

2.2.4 Germany

Certification schemes:

Germany has several labels for low and ultra-low energy houses. The most common label is the passive house to certify an ultra-low energy house.

The passive house concept originates from the Passive House Institute (PHI) in Darmstadt, Germany (http://www.passiv.de). According to the definition of the PHI "A passive house is a building, where indoor thermal comfort (in terms of ISO 7730:2005) can be kept by only reheating of the hygienic necessary air volume flow".

If this definition shall be fulfilled, the area-specific heat load must not exceed the limit of ≈10 W/m^2. However, to get the certification of a house as passive house, the following requirements have to be met:

- Annual space heating need below 15 kWh/(m^2·a)
- Primary energy consumption for all building services incl. household appliances 120 kWh/(m^2a) (redistribution normally 60 kWh/(m^2a) for space heating/DHW, and 60 for household appliances)
- Approved air-tightness of 0.6 h^{-1} by blower door testing

Due to the low values for the space heating energy need, a focus of the standard is on the building envelope. The certification is usually approved by an Excel-based calculation tool called "Passivhaus Projektierung Paket" (Passive House Planning Package (PHPP)), current version PHPP (2007), which is based on the European standard EN 832 (2002), but further developed to a sophisticated design tool incorporating the calculation of the technical building system, as well. The passive house standard and concept is meanwhile wide-spread over Europe and outside Europe.

Governmental subsidies by low-interest credits are paid for passive houses as well as for so-called KfW energy saving houses.

The KfW 60 (40) house is the name of a German programme for energy-efficient houses of the German governmental bank "Kreditanstalt für Wiederaufbau" (http://www.kfw.de). The requirements for the building are based on the German building regulation EnEV (2009) and are as follows:

- Primary energy requirement less than 60 (40) kWh/(m^2a) for SH and DHW production
- Specific heat loss coefficient H_T [W/m^2_{AN}] is 30% lower than required acc. to the EnEV.

Thereby, KfW 60 is in the range of good LEH and KfW 40 in the range of ULEH.

Markets

In Germany about 10000 passive houses are built. The large part of them is financially supported by the KfW since the year 2000. Besides passive houses, the above mentioned energy saving houses 40 and 60 are subsidised. Fig. 5 gives the development of these subsidy programmes as cumulative number of buildings.

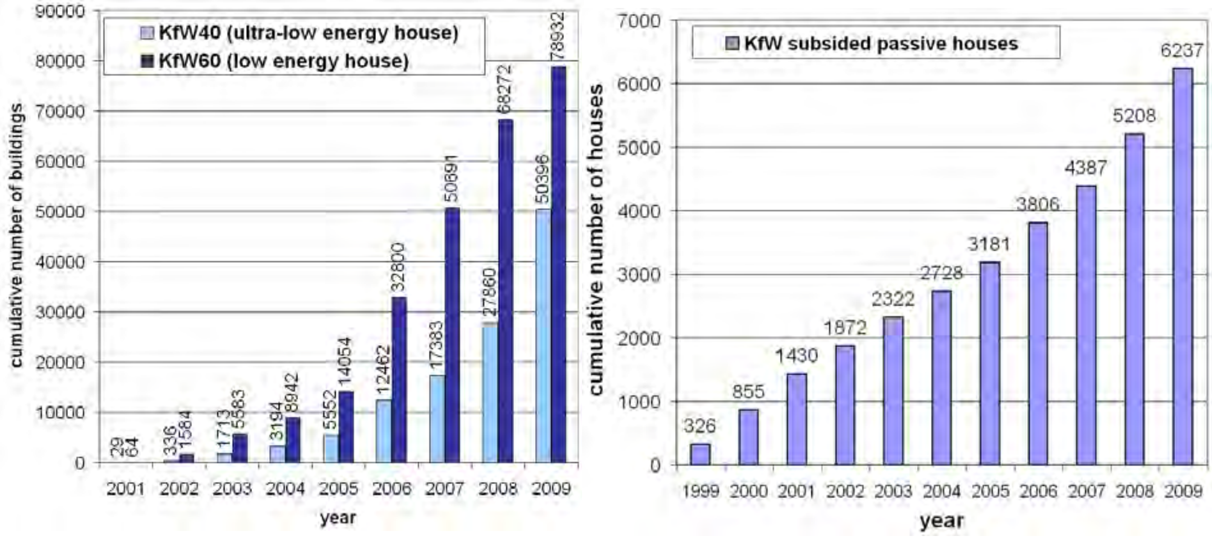


Fig. 5: Development of KfW subsidised energy saving houses (left) and passive houses (right) in Germany since the start of the programmes (source: KfW, 2010)

2.2.5 Switzerland

Certification schemes

MINERGIE® (http://www.minergie.ch) is a registered trademark voluntary quality building label for low energy houses (since 1998). MINERGIE-P® is the respective label for an ultra-low energy house (since 2002). Values are based on the SIA 380/1 (2009). Other building types (offices, schools etc.) can be certified as well, but have different limits and some have additional requirements. The following requirements for a certification acc. to MINERGIE® (MINERGIE-P®) have to be fulfilled for a residential building.

- Space heating energy need lower than 90% (60%) of the legal requirement SIA 380/1.
- Weighted delivered energy limit lower than 38 (30) kWh/(m^2a) (see definition below, alternately space heating energy lower than 15 kWh/(m^2a) for MINERGIE-P®)
- Controlled ventilation system (MINERGIE®: controlled automatic window airing possible, MINERGIE-P®: mechanical ventilation required)
- Highly-efficient electric appliances (energy label A) recommended (required)
- Approved air-tightness of <0.6 h^{-1} (MINERGIE-P® only, blower-door testing)
- Additional cost shall be limited to max. 10% (15%) higher than a similar standard building (not controlled for the label)

The weighted energy limit is calculated according to eq. 2

$$\frac{Q_{H,nd} - Q_{V,rvd}}{3.6} \cdot f_{MIN} / \eta_{gen} + \frac{Q_{W,nd}}{3.6} \cdot f_{MIN} / \eta_{gen} + \frac{E_{CV,in}}{3.6} \cdot f_{MIN} \le \text{MINERGIE - limit} \qquad [kWh/m^2]$$

eq. 2

where

$Q_{H,nd}$	energy need for space heating	[MJ/m²]
$Q_{V,rvd}$	recovered ventilation losses by ventilation heat recovery	[MJ/m²]
$Q_{W,nd}$	energy need for domestic hot water	[MJ/m²]
$E_{CV,in}$	energy input for ventilation and air conditioning	[MJ/m²]
f_{MIN}	MINERGIE® weighting factor for the respective energy carrier	[-]
η_{gen}	efficiency of the generation	[-]

Moreover, retrofitted buildings can be MINERGIE®-certified, if the limit of < 80 kWh/(m²·a) is reached. For MINERGIE-P®, no differentiation is made between new and retrofitted buildings. Since the weighted delivered energy limit depends on the energy need as well as on the energy carrier, it is between delivered energy and primary energy, since MINERGIE® weighting factors are not identical to primary energy factors. Energy produced on-site, e.g. by PV, can be subtracted from the electricity consumption.

Markets

In contrast to the spread of MINERGIE® in the new building sector, which has a strong acceptance and a steady growth, ultra-low energy houses according to MINERGIE-P® are still a niche market, as well as retrofitting of buildings to MINERGIE®-level.

Present market figures (state Oct. 2010):

- 25% of new building market are MINERGIE®certified (≈17793)
- further 15% of new buildings comply, but are not certified
- ≈ 1200 certified retrofitted buildings
- ≈ 789 MINERGIE-P® buildings
- ≈ 86 MINERGIE-ECO®-buildings (see chap. 2.2.10.3)

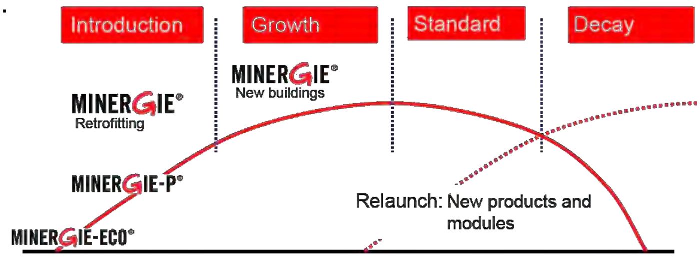


Fig. 6: Market state of MINERGIE®-Products (translated from MINERGIE®)

2.2.6 Norway

Certification schemes:

Certification in Norway is mainly oriented at the German passive house standard. However, due to the significantly colder climate in parts of the country compared to the central European countries Germany and Austria, presently an adoption of the passive house standard for Nordic climate conditions is in progress. (Andresen, Dokka and Lexow, 2008).

Markets:

Husbanken

In Norway, the Husbanken (state housing bank) promotes the spread of low energy houses. In the recent years, significant market increase is observed. Information around the situation of low energy houses in Norway can be found on the website of the state housing bank www.husbanken.no and on a website particularly dedicated to low energy houses at www.lavenergiboliger.no and http://www.passiv.no/. Roughly 1% of the Norwegian single-family houses, 10 % of the apartment buildings (blocks of flats) and 8% of the office buildings are currently of low-energy standard. An overview based on total heated areas is given in Tab. 4 (Andresen, 2010).The low-energy buildings include about 2800 single-family houses, 1900 apartments and 10 non-residential buildings whereas the passive houses include 15 single-family houses, 30 apartments and 3 non-residential buildings. No zero energy or plus energy buildings have been built yet, but several projects will probably be initiated during 2010. The main focus has been on new buildings, but renovation to low-energy and passive house standard are starting to gain interest and a few projects are under planning.

Tab. 3: Constructed total heated areas (THA, m^2) between 2005 and 2010 for Norwegian residences and non-residential buildings with different performance levels (Andresen, 2010).

Type of building	Standard	Low Energy	Passive	Zero Energy	Plus Energy	Total
Single family houses	9'346'419	103'802	2'800	0	0	10'388'021
Apartment blocks	5'381'544	598'208	2'324	0	0	5'982'076
Office buildings	1'533'144	128'212	0	0	0	1'661'356
Education buildings	1'947'797	6'600	6'230	0	0	1'960'627
Other types of build.	17'875'393	23'451	15'129	0	0	17'913'973

Together with the Norwegian State Housing Bank and the National Office of Building Technology and Administration (be.no), the different market players will play an important role in developing the future Norwegian market for low-energy and passive houses/buildings, including housing construction companies (e.g. Mesterhus, Skanska Bolig, Norgeshus, Nordbohus, Block Watne), co-operative building societies and development companies for housing construction.

2.2.7 USA

Certification Schemes:
The USA has several certification schemes for energy-efficient housing. The most widespread certification is the ENERGY STAR® label (http://www.energystar.gov).

ENERGY STAR® is the government-backed symbol for energy efficiency. The mark identifies new homes, buildings, and more than 50 types of products that are energy efficient and offer the features, quality and performance that today's consumers expect.

To earn an ENERGY STAR® certificate, homes must meet the guidelines for energy efficiency set by the U.S. Environmental Protection Agency (EPA). ENERGY STAR® qualified homes are at least 15% more energy efficient than homes built to the 2006 International Energy Conservation Code (IECC). ENERGY STAR® homes include a variety of energy-efficient features including: energy efficient insulation, high-performance windows, tight construction and ducts, energy efficient heating and cooling equipment and ENERGY STAR® qualified lighting and appliances.

Markets:
Among the numerous government-sponsored energy-efficient home programs the ENERGY STAR® qualified homes have reached a number of 1.000.000 built single-family houses in November 2009. This accounts for about 17% of the market index (increased from 10% in 2005), which compares the number of ENERGY STAR® qualified homes built to the number of privately owned housing units permitted in each state (Vohra 2006, McElhaney and Baxter 2009). Fourteen states have exceeded a 20% market penetration.

2.2.8 Other countries

In the other European countries participating in Annex 32, i.e. the Netherlands and Sweden, are still in the market introduction.
In the Netherlands, smaller project developers offer different concepts for low energy houses. Moreover, different pilot and demonstration projects have been launched (Koster, 2010). P&D projects focus both on building and system technology.
In Sweden, several low energy house P&D projects have been carried out, which were intensively measured and evaluated, e.g. the Lindås passive housing estate near Gothenburg.

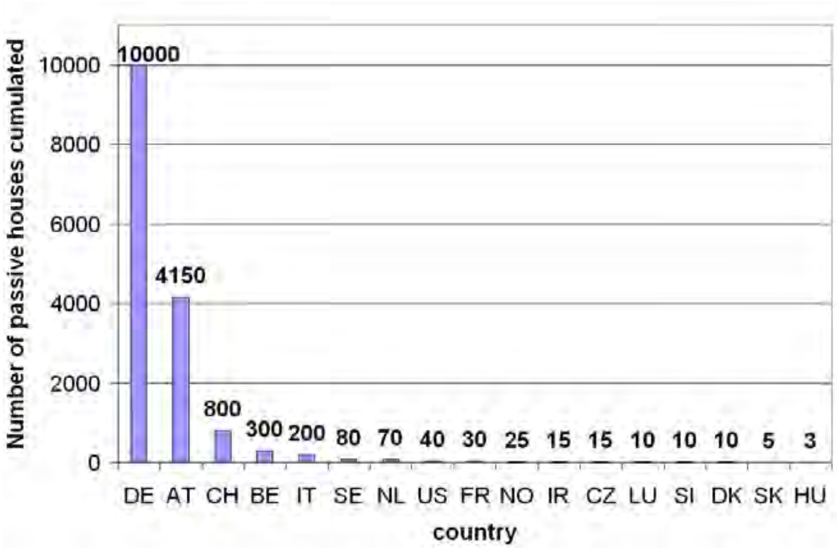


Fig. 7: Passive houses in different countries (source: IG-Passivhaus AT, 2009)

Summarising, the built passive houses in different countries are given in Fig. 7. For Switzerland, only passive houses are counted, but MINERGIE® (see chap. 2.2.5) is not included.

2.2.9 Retrofitting potentials

The highest energy saving potential in the building sector is not in the field of new buildings, which make-up only a small share of the market, but in the building stock. Thus, retrofitting of buildings to low energy standard is one major strategy to reduce CO_2-emissions in order to keep climate protection targets of the Kyoto protocol.

2.2.9.1 Potentials

An example of the potentials is given in Fig. 8 showing the energy consumption of the building stock in canton Zurich vs. Mio m^2 energy reference area parameterized with the year of construction. Buildings erected between 1920 and 1970 have the highest specific annual energy consumption.

Afterwards, due to the introduction of limits in building regulations the annual energy consumption decreased significantly up to today's legal requirements or low and ultra-low energy houses. This situation is very typical for central European countries. Moreover, the red line in Fig. 8 gives the reduction potential of the annual energy consumption when applying current MINERGIE® technology and reaching the MINERGIE® standard for retrofitting, which defines a value of weighted delivered energy of 120 W/(m^2·a) (former values according to SIA (2001) for the building stock). Fig. 8 visualises the huge potential in the building stock by retrofitting to low energy houses. It can also be seen that in today's building activities, there is a reduction potential of ~50%, i.e. not every new buildings are built according to the available low energy technology.

In Switzerland, the most common retrofit measures according to a query of investors, architects and installers are an additional thermal insulation and an exchange of the windows. Regarding the system technology, common measures are a change to heat pumps, wood or solar thermal systems as well the installation of a mechanical ventilation system.

In Austria the main retrofit measures in the period of 1991-2001 was the renewal of windows (~300.000 buildings), and an additional thermal insulation (~150'000 buildings). Furthermore, a fuel change of the heating system can have an impact on the CO_2-emissions. In Austria, the renovation rate of the building stock to reach the Kyoto targets has been determined to 5%/year, which would mean a significant increase of the 1% reached in 2007 and stresses the importance of the retrofitting of the building stock.

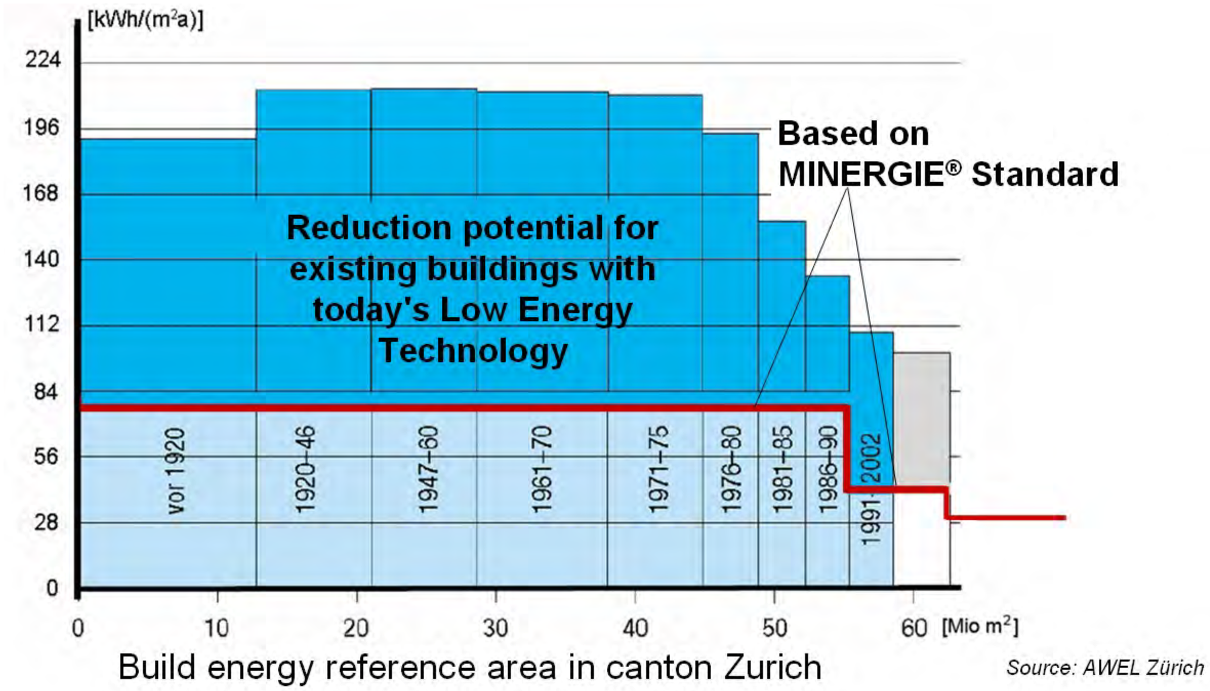


Fig. 8: Development of the space heating energy consumption in the residential sector in the 20th century (example for canton Zurich) and energy saving potential by retrofitting to state-of-the-art MINERGIE® technology

In Germany, a subsidy program for the reduction of CO_2 emission in the building sector has been launched. According to the Bundesregierung (2008) 400.000 flat have been substantially retrofitted since the introduction of the subsidy program in 2006.
In Switzerland, renovation activities of home owners are subsidised as well. Information is found on http://www.dasgebaeudeprogramm.ch.

2.2.9.2 Retrofitting with prefabricated building components

Prefabrication may have in strong influence in future retrofitting due to several advantages like better quality control for the manufacturing, easier and faster installation, cost reduction and less impact for the home owner or tenants.

Within IEA ECBCS Annex 50 (www.empa-ren.ch/a50.htm) concepts for retrofitting with prefabricated building components are investigated. The target is to reach low energy house level by the retrofitting.

2.2.10 Sustainability labels

Sustainabilty labels are often found as well under the term “Green Buildings”. Besides requirements regarding energy, comfort or cost, other criteria for the certification are added, e.g. considerations to occupants’ health and building materials.

2.2.10.1 Leadership in Energy and Environmental Design (LEED)

According to the website http://www.usgbc.org/ "LEED is a green building certification system, providing third-party verification that a building or community was designed and built using strategies aimed at improving performance across all the metrics that matter most: energy savings, water efficiency, CO_2-emissions reduction, improved indoor environmental quality, and stewardship of resources and sensitivity to their impacts.

Developed by the U.S. Green Building Council (USGBC), LEED provides building owners and operators a concise framework for identifying and implementing practical and measurable green building design, construction, operations and maintenance solutions.
LEED is flexible enough to apply to all building types – commercial as well as residential. It works throughout the building lifecycle – design and construction, operation and maintenance, tenant fitout, and significant retrofit.
LEED for Neighborhood Development extends the benefits of LEED beyond the building footprint into the neighborhood it serves."

LEED is also used in Canada as LEED Canada.

2.2.10.2 German sustainable building council

The German certificate of sustainable building (Gütesiegel Nachhaltiges Bauen) has been introduced in 2009, is available in the categories gold, silver and bronze and applies the following superordinate criteria:
Ecological quality, economical quality, socio-cultural and functional quality, technical quality, process quality and quality of the location. The single categories have several sub-criteria, which are evaluated.

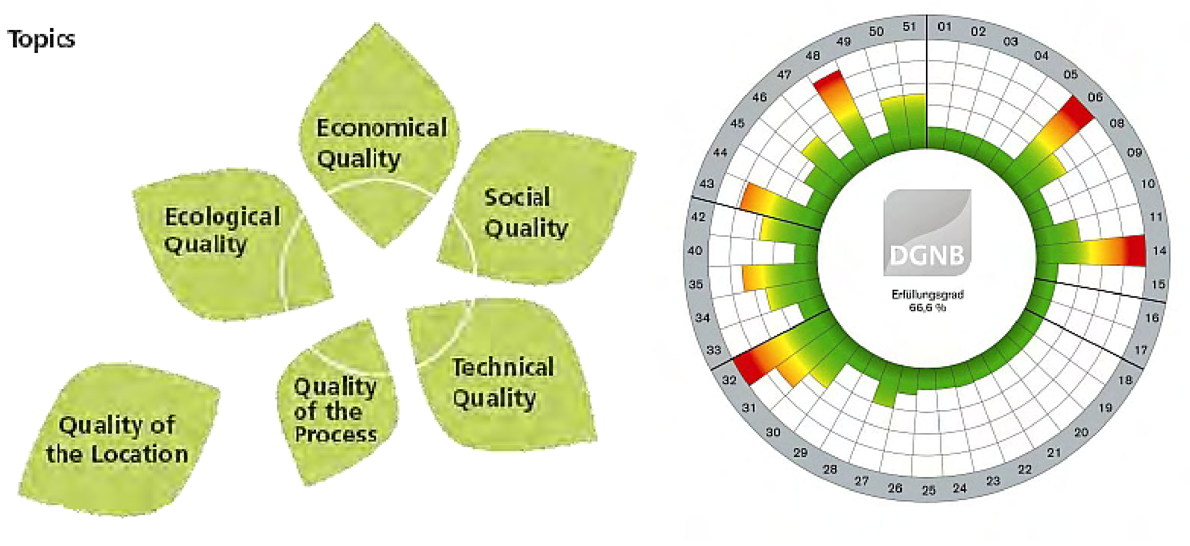


Fig. 9: Depiction of criteria and the assessment of the German sustainable building certificate (taken from DGNB, 2009)

Further information on the single criteria is found on the website: http://www.dgnb.de

2.2.10.3 MINERGIE-ECO®

In June 2006 a third MINERGIE® product, the label MINERGIE-ECO®, has been introduced in co-operation of the MINERGIE® and the eco-bau association (http://www.eco-bau.ch). The MINERGIE-ECO® label amends the energy aspects of the MINERGIE®/MINERGIE-P® label by further criteria concerning the aspects health (e.g. light, noise, indoor air quality) and building ecology (e.g. materials, manufacturing, dismantling/recycling).

An overview is given in Fig. 10. Compliance with the standard is approved by an electronic questionnaire ((y/n) answers). Some basic criteria with regard to avoidance of toxic materials have to be fulfilled in any case. For all other categories, at least 50% positive answers are required and in total 67% have to be attained.

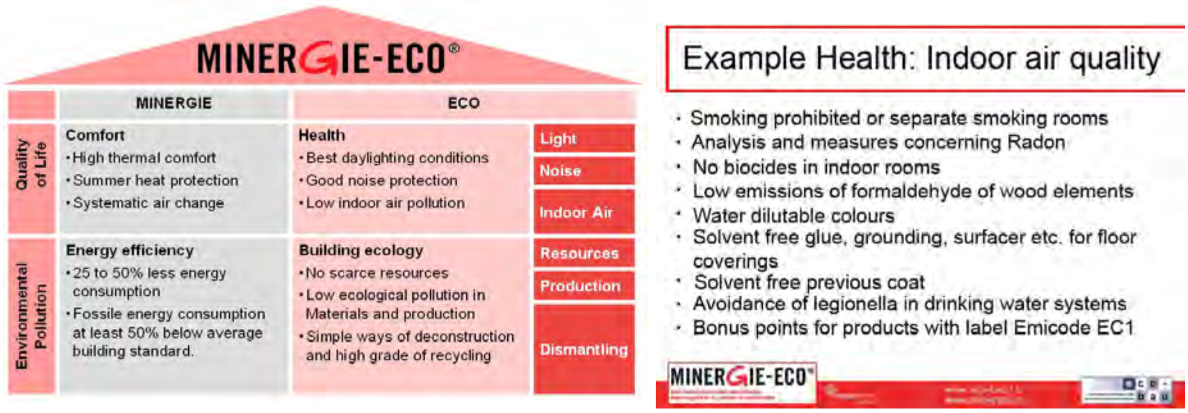


Fig. 10: Criteria of the MINERGIE-ECO® and sample of criteria for indoor air quality

2.2.10.4 Other certification of sustainable buildings

Moreover, further labels and certification schemes in other countries for certifying sustainable buildings are in operation, for instance

- CASBEE (Japan)
- BREEAM (UK)
- BREEAM Netherlands (The Netherlands)
- HQE (France)

2.3 Costs of low energy buildings

2.3.1 Cost evaluation of MINERGIE® houses

The MINERGIE®-standards formally limit the additional costs of MINERGIE® to 10% and of MINERGIE-P® houses to 15% higher costs than a standard new building. Evaluations of built MINERGIE® houses revealed, that average cost of MINERGIE® houses are about 9% higher than new houses built according to the legal requirement. That means additional costs to achieve a good quality low energy house are limited.
For MINERGIE-P®, cost evaluations have shown that the values of 15% can be met, as well. Evaluations show a value 5% of 14% based on 2 investigated houses. Main reasons for the higher costs are the thorough thermal insulation, the high-quality windows and the mechnical ventilation system. Only about 1/3 of higher investment cost can be compensated by lower operation cost at current energy prices (Stokar & Partner, 2009). However, the building quality and value conservation is another reason to go for MINERGIE-P®.

2.3.2 Cost characteristic of passive houses

Concerning German passive houses, the Passivhouse Institute published the cost evolution according to Fig. 20. Starting with the cost of a low energy house with a space heating need of ~40 kWh/(m^2a) investment costs for the reduction of the space heating needs are rising stronger than the cost saving of the energy cost, i.e. total costs are increasing.
However, if the passive houses are realised with an air heating system, cost of the space heating distribution and emission system can be saved, which leads to same total cost as for a low energy building.

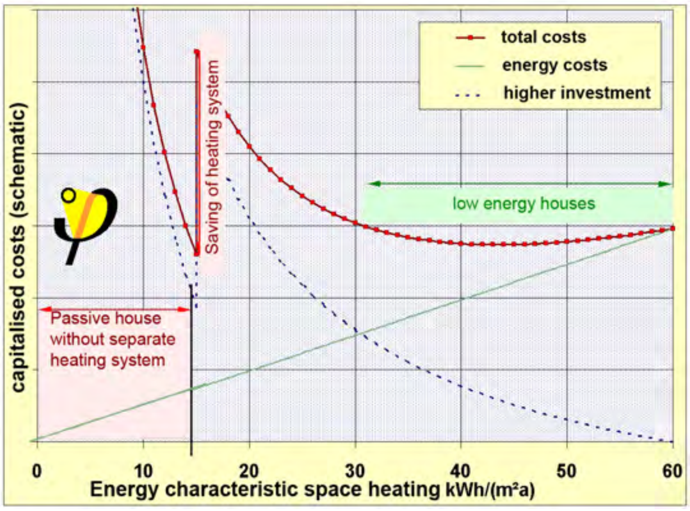


Fig. 11 Costs of low and ultra-low energy houses (translated from www.passiv.de)

In case of a heat load for space heating of 10 W/m^2, the necessary space heating energy can be supplied by reheating the supply air of the ventilation system. Since the upper temperature is limited to about 50°C due to dust burning, the capacity of only the hygienically necessary inlet air volume flow is not sufficient to cover the space heating need in case of higher heat loads. The hygienically necessary air volume flow rate shall not be exceeded, since the heat load of the house increases, more fan electricity is consumed and noise problems may occur.

Mainly due to the possible cost reduction, an air heating system is the favoured concept of German passive houses as depicted in Fig. 20.
In Austria and Switzerland, however, there is some scepticism regarding air heating emission systems, mainly due to capacity limitation, limited cost saving and user preferences. Therefore, the MINERGIE® association recommends a surface emission system as well for MINERGIE-P® houses (Humm, 2006).
Nevertheless, in Austrian passive houses, ventilation compact units with air heating are a standard system as in German passive houses (see chap. 3.3.2), and in some of the realised Swiss MINERGIE®-P houses, ventilation compact units are used, as well.

3 SYSTEM SOLUTIONS

This chapter gives an overview on building technology applied in low energy houses. As in the building market, most developed markets of adapted system technology for the specific needs of low energy houses are found in the central European countries Germany, Austria and Switzerland.
However, due to targets and strategies of the national governments and the EU, manufacturers are developing more and more system concepts as well in countries with emerging low energy house markets.

3.1 Short overview of system solutions with heat pump

Tab. 4 gives an overview of heat pump solutions for low energy houses. More details are given in chap. 5.1 and part 1 of the final report of Annex 32 where a detailed overview of system solutions including a heat pump based on the functionalities of the system is given.

Tab. 4: Categorisation of heat pump solutions (Justo Alonso and Stene, 2010)

Air-source / ground-source heat pumps	**Heat source(s)**	**SH**	**SC**	**VH**	**DHW**
• Air-to-air heat pump	Ambient air	■	■		
• Air-to-water heat pump (integrated)	Ambient air	■	■		■
• Air-to-water heat pump	Ambient air				■
• Brine-to-water heat pump (integrated)	Ground-source	■	■		■
• Brine-to-water heat pump	Ground-source				■
Ventilation air heat pumps – type EV 1)	**Heat source(s)**	**SH**	**SC**	**VH**	**DHW**
• Ventilation air heat pump	Exhaust air				■
• Ventilation air + air-to-air heat pumps	Exhaust air + ambient air	■	■		■
• Ventilation air HP (integrated)	Exhaust air	■			■
• Ventilation air HP (integrated)	Exhaust air + ground-source	■			■
Ventilation air heat pumps – type BV 2)	**Heat source(s)**	**SH**	**SC**	**VH**	**DHW**
• Ventilation air heat pump	Exhaust air	■	■	■	
• Ventilation air heat pump	Exhaust air + ambient air	■		■	■
• Ventilation air heat pump (integrated)	Discharge air (+ ambient air)	■	■	■	■

SH	Space heating – hydronic heat distribution system, heating of ventilation air recirculated air
SC	Space cooling – distribution of chilled ventilation air
VH	Heating of ventilation air – heating system as integrated part of the ventilation unit
DHW	Heating of domestic hot water (DHW)
Combined	Combined space heating and hot water heating (integrated heat pump system)
CVHD	Compact Ventilation and Heating Device (compact unit). Combined SH/SC and DHW heating.
Exhaust air	Warm outlet air from an exhaust air ventilation system
Discharge air	Cold outlet air after the heat recovery unit in a balanced ventilation system
Ground-source	Bedrock, groundwater or soil (ground) as heat source
Brine system	Indirect ground-source system. Application of a ground heat exchanger, GHE (ID 32-40 mm PE tubes) connected to a closed secondary circuit where a circulating anti-freeze. Vertical BHE (80-250 m) in bedrock systems, horizontal BHE in ground systems.

1) *EV = exhaust air ventilation system – not recommended in low-energy and passive houses*
2) *BV = balanced ventilation system*

3.2 Overview of system solution without heat pump

3.2.1 Fossil fuel boilers

Fossil fuel boilers are the classical heating system in the building stock with the following advantages

- There is a lot of technical experience of installers.
- Gas and oil are still quite cheap fuels, even though strong oil price oscillations took place recently
- Low return temperatures, as they can be realised in low energy houses, are favourable for condensing boilers, which further extract the condensation heat of the stack gas.

However, gas boilers for low energy houses have some disadvantages, as well.

- Boilers usually have a higher capacity than needed in the field of low and particularly of ultra-low energy buildings, but there are also modulating boilers, which can modulate down to about 10% of the capacity.
- Natural gas is the fossil fuel with the least CO_2-emissions and modern burners have been optimised concerning emission of pollutants. However, natural gas is still a fossil fuel and contributes to CO_2-emissions.
- Moreover, additional costs due to the connection to the gas networks or local gas tank and installations for the flue gas exhaust occur. Pipe work cost can be reduced by a location of the boiler in the roof-top, which may have advantages in connection with a solar system.

3.2.2 Wood stoves, wood boilers (Pellet, wood chips, fire wood)

In the frame of the discussion on CO_2-emission, heating systems based on wood became popular again, since wood has a neutral CO_2 balance.

There are different kinds of system configurations for the use of wood.

- Wood boilers, which are placed in a technical room, with automatic conveying of the wood into the boiler, are mainly used as other fuel boilers. The system integration of this kind of boiler is similar to that of conventional oil or gas boilers, i.e. in low energy houses, a buffer storage is often installed due to higher capacity of the units.

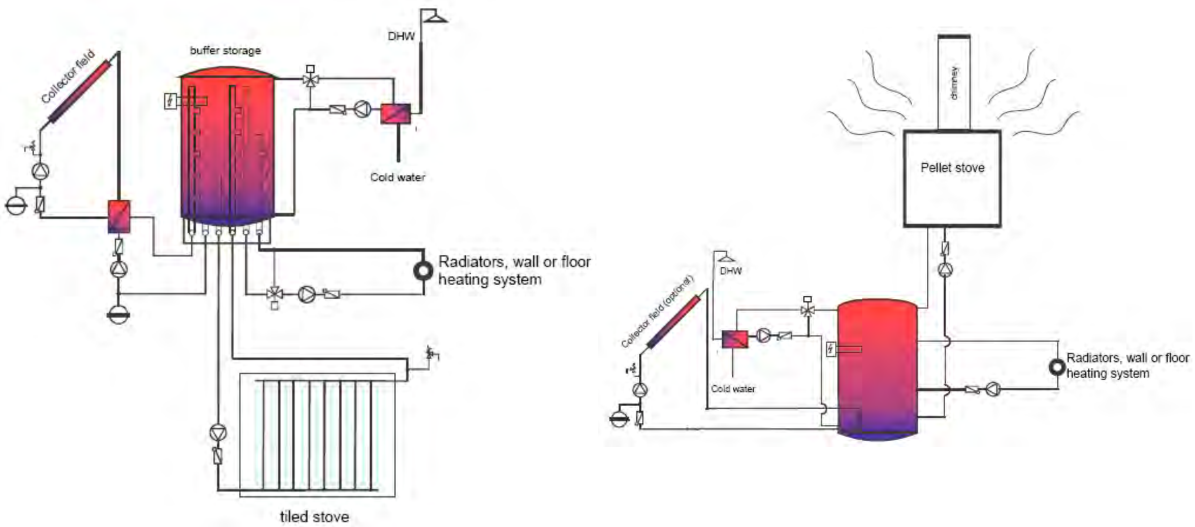


Fig. 12: Sample system integrations of wood tiled store and pellet stove for low energy houses, also combined with a solar thermal system (source: Streicher et al. (2004))

- Tiled wood stoves, which are placed inside the room, is shown in Fig. 12 left. These systems release about 50% of the heat into the room. A heat exchanger is integrated into the stove, which enables the extraction of heat and charges the water into a buffer storage. The temperature and the heating capacity of the stove are not constant during its operation. At the beginning of the combustion the stove's temperature rises quite quickly and drops slowly (6 to 12 hours) after achieving its maximum temperature. In order to use the temperature of the stove in an optimum way, it can be connected to the buffer storage by a stratified inlet. As only about 50% of the capacity of the stove can be extracted by the heat exchanger, it has to be possible to heat a large part of the building directly with the stove (open architecture). The combustion air should not be drawn from the living space, but supplied externally (e.g. via a pipe-in-pipe flue gas system). The buffer storage is used to supply the hydraulic heating system (floor, wall or low temperature radiator heating system) and the preparation of DHW (e.g. instantaneous DHW preparation via an external plate heat exchanger as shown in Fig. 12). Outside the heating season the tiled stove cannot be used to heat the buffer storage, as it would also heat the living space. Therefore, an additional heat source for the DHW preparation is needed, e.g. solar collectors in combination with an electric auxiliary heater. In spring and autumn, when the buffer storage gets charged by the solar collectors, the tiled stove can also be used as a space heating system, by pumping hot water from the tank through the heat exchanger of the stove.
- Pellet stoves, which are placed inside the room, is shown in Fig. 12 right. A fraction in the range of 20-30 % is directly released into the room, the rest is decoupled by the hydronic heating system. Due to this heat release in the room, the pellet boiler cannot be used for DHW operation in summertime. Therefore, a second heat generator has to be installed, for instance a solar thermal system with electrical back-up heater. Moreover, the combustion air should be provided from the outside, e.g. as tube-in-tube system, where the inner tube is used for the flue gas and the outer tube for the combustion air.
- Wood boilers or stoves can also be combined with an air heating system, when the reheating exchanger in the supply air duct is connected to the hydraulic heating system.

3.2.3 Solar systems

- Solar systems are quite common in new buildings to support the DHW production. Usual design of the solar collector in single family houses is to cover about 50% of the DHW energy need, which corresponds to a collector surface of about 5m^2 for a 4-person single family house.
- The remaining DHW need is covered by the back-up system, e.g. the heat generator for the space heating need or an electrical back-up heater. However, solar energy can also contribute to cover the space heating energy. If the solar energy is used for both space heating and DHW, the collector surface is usually increased to at least 10 m^2. Common system configurations for solar assisted space heating and DHW are shown in Fig. 13. Highly integrated systems have a back-up boiler integrated in the solar storage tank, which is used for space heating and DHW, see Fig. 13 upper right. The installation of solar systems has the advantage that renewable energy is used to avoid primary energy use and CO_2-emissions. On the other hand, a solar system leads to additional costs due to the bivalent system configuration.

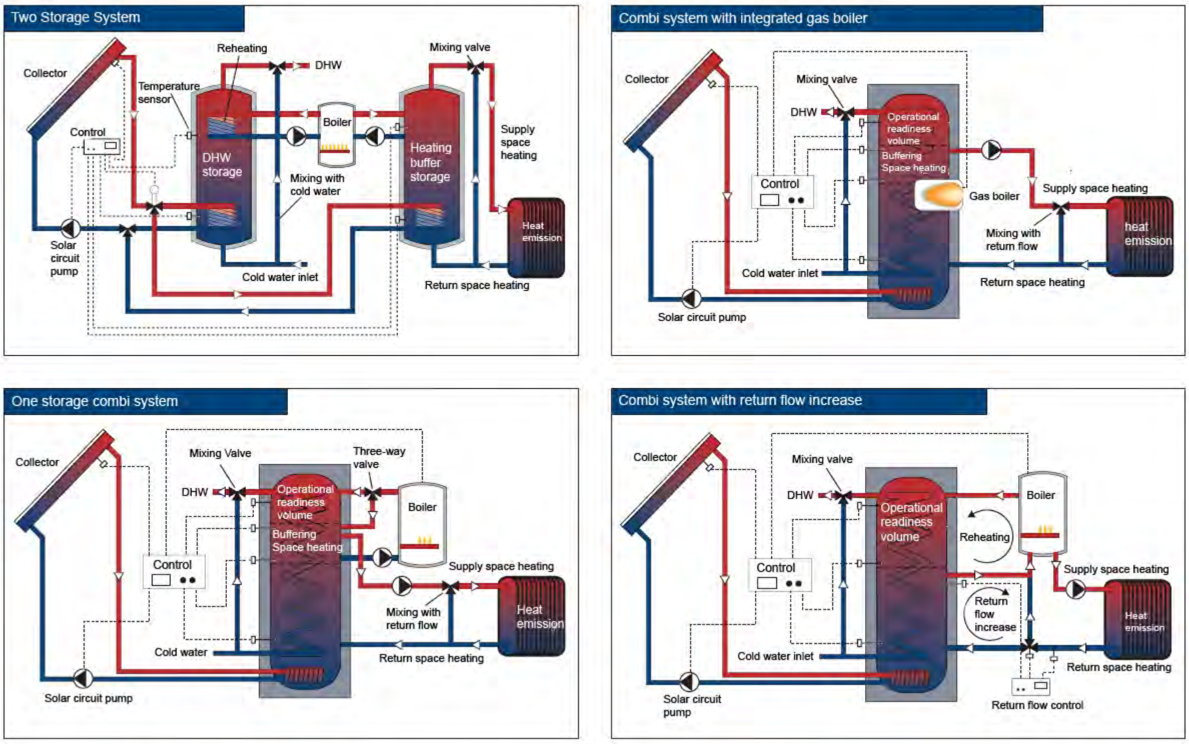


Fig. 13: Common configurations for solar combi systems for SH and DHW (from BINE 2001)

3.2.4 System solutions under development

Other system solutions like Micro-CHP are not economically for low energy single family houses, since the space heating need is decreasing and an economical operation requires a heat-driven operation. A solution could be to supply several houses by district heating.
Fuel cells are still under development, and first field tests may start by 2012.
Thermally-driven heat pumps for the residential sector are also under development supported by the developments of thermally-driven chillers for solar cooling applications. First systems were introduced into the market recently, e.g. an adsorption heat pump by the German manufacturer Vaillant.

3.3 Comparison of system solutions in different countries

3.3.1 Comparison of system solutions in France

Within the national contribution of France to Annex 32 a system comparison of different market available system solutions on the French market have been compared under the conditions, that the house reaches the BBC–2005 label. The total results are presented below, details on the results are found in Evin and Martinlagardette (2009). Boundary conditions and assumptions are given in Annex B1. Tab. 5 shows the system variants considered for the comparison.

Tab. 5: System solutions considered in the comparison (EDF R&D 2008)

Technologies	Building insultation	Space Heating system	DHW production	Ventilation system
1. W/W HP BSWH	Ushell ref -26%	Floor heating & geothermal HP	Best Solar + elelctric DHW **(BAT)**	B-hygro
2. A/W BHP SWH	Ushell ref -26%	Best air-to-air HP (multi-split) **(BAT)**	Solar + electric	B-hygro
3. A/W HP BSWH	Ushell ref -26%	Floor heating & air-to-water HP	Best solar + electric **(BAT)**	B-hygro
4. A/W HP thermo HW	Ushell ref -26%	Floor heating & air-to-water HP	Thermod. HW **(BAT)**	B-hygro
5 Bshell A/W HP SWH	Ushell ref -44% **(BAT)**	Floor heating & air-to-water HP	Solar + electric	B-hygro
6. Joule PV BSWH	Ushell ref -44% **(BAT)**	Joule effect convectors	Best Solar + electric + 14m2 PV	B-hygro
7. BGas_Boiler SWH_gas	Ushell ref -26%	Floor heating & gas condensing boiler **(BAT)**	Solar + Gas	B-hygro
8. BWood_Boiler SWH	Ushell ref -26%	Floor heating & Best wood pellet boiler **(BAT)**	Solar+ electric	B-hygro

Legend: A/A – air-to-air, A/W – Air-to-water, B – Best, BAT – Best available technology, B-hydro – room-wise ventilation rate set acc. to relative humidity, HP – heat pump, SWH – Solar water heater, Thermd. HW – Heat pump water heater, Ushell ref – U-value of the building envelope below reference value, W/W – water-to-water

For choosing these system combinations it was found that only one of the Best Available Technologies (BAT) of the three categories U-values of the building envelope, space heating system and DHW system was necessary to reach the BBC label. Fig. 14 shows a comparison regarding delivered ($kWh_{fe}/(m^2a)$) and primary energy ($kWh_{pe}/(m^2a)$ and CO_2-emissions.

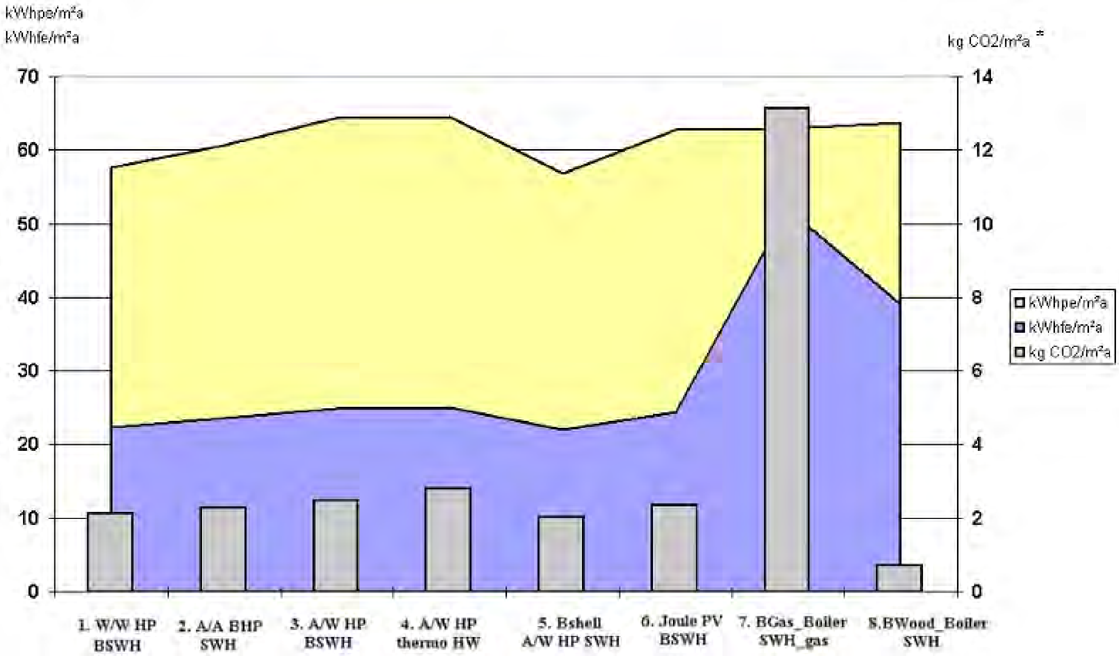


Fig. 14: Comparison of total cost for system variants in France (EDF R&D 2008)

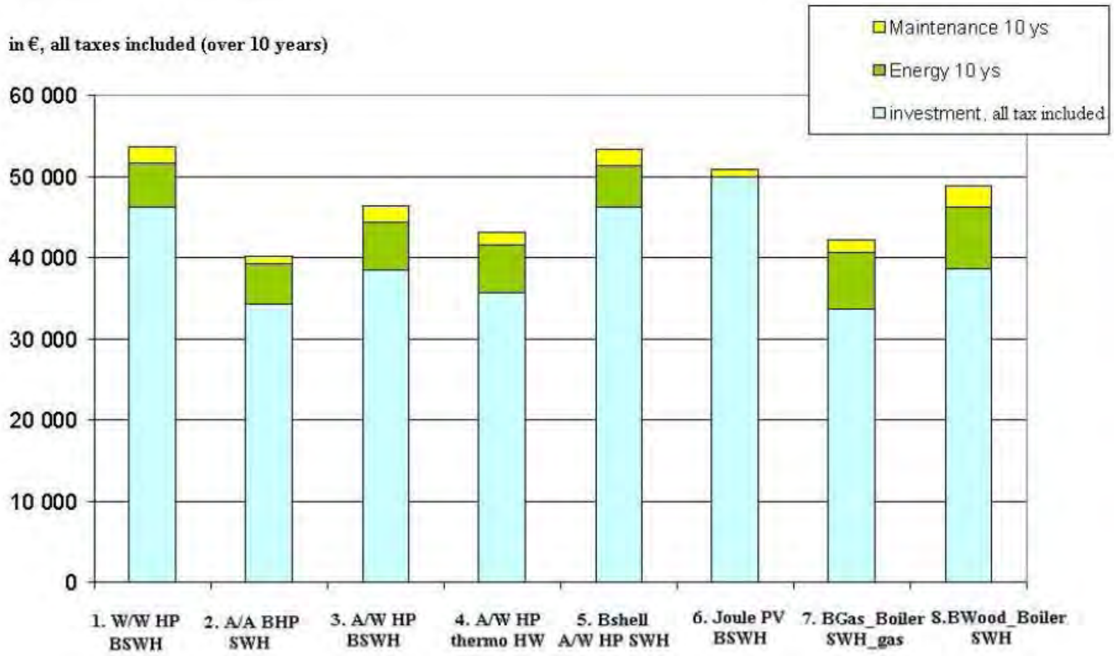


Fig. 15: Comparison of cost for system variants in France (Evin and Martinlagardette, 2009)

The best solutions regarding the environmental impact are thus the combinations W/W heat pump with best available solar water heater, the A/A best available heat pump with solar water heater and the best U-value with an air-to-water heat pump and solar water heater.
Fig. 15 shows the total cost evaluation of the system combinations. Here, the A/A best available heat pump with solar water heater, the A/W heat pump with heat pump water heater and the best available gas boiler with solar water heater supported by the gas boiler.

Tab. 6: Categorisation of heat pumps solutions (Evin and Martinlagardette, 2009)

	Energy consumption [kWh_{pe}/m^2]	**Final energy [kWh_{fe}/a]**	**CO_2 emission [kg/m^2a]**	**Energy cost [€/a] all taxes included**	**Energy Maintenance [€/a], all taxes included**	**Investment [€] related to energy efficiency without tax credits**	**Overall annualised cost oer 10 years [€] with tax credits**
1. W/W HP BSWH	64.3	3990	2.46	537	737	46285	5366
2. A/A BHP SWH	60.7	3534	2.46	490	590	34325	4023
3. A/W HP BSWH	64.4	4472	3.06	581	781	38510	4632
4. A/W HP thermo HW	64.6	4247	2.93	581	731	35760	4307
5. Bshell A/W HP SWH	56.8	3605	2.38	503	703	46270	5330
6. Joule PV BSWH	62.8	7024 w/o PV	4.89	-138 with PV	-38 with PV	49890	4951 with PV
7. BGas_ Boiler SWHgas	63	10987	11.38	695	845	33730	4218
8. BWood Boiler SWH	63.8	12797	1.48	756	1026	38630	4889

Summarising, the best solution concerning primary energy and investment cost is a best available air-to-air heat pump with solar water heater and U-value of the envelope 25% below the legal requirement.

The best solutions regarding CO_2 emission are wood pellets and solutions integrating a heat pump. Regarding delivered energy all solutions are more or less equal except for the gas boiler. Thus, since investment costs are very important for the choice of technologies, combinations with heat pumps are favourable, in particular A/A heat pumps.

3.3.2 Comparison of system solutions in Switzerland

The World Wildlife Fund (WWF) has made a study on heating systems in a standard single-family and multi-family building for Swiss boundary conditions in 2009. Assumptions used for energy calculation, the system efficiencies, the cost and the environmental impact are documented in Appendix B 2. The heating systems are evaluated for a 200 m^2 low energy house with a space heating energy need of 56 kWh/(m^2a).
In Fig. 16 a cost comparison is shown for the different heating systems including the fossil fuels oil and gas, also in combination with solar water heating system. Moreover, the depiction contains a CO_2 tax and external cost, as well. It can be seen, that the heat pump solutions achieve the lowest annual cost under the Swiss market and energy prices, even though investment costs are higher than for fossil fuel systems.

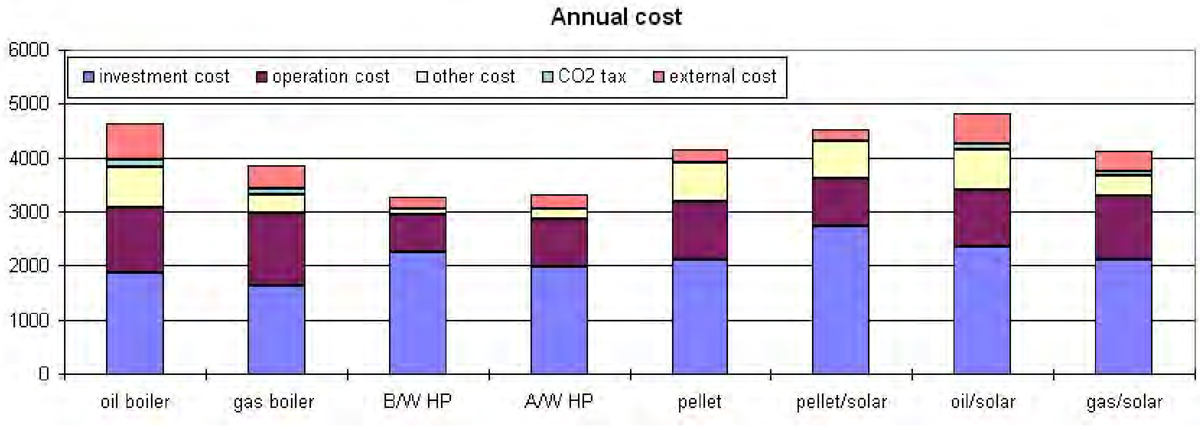


Fig. 16: Cost comparison of common heating systems for Switzerland (source: WWF, 2009)

In Fig. 17 a comparison of the environmental impact based on direct CO_2 emissons and CO_2 equivalents is shown for the different heating systems. Due to the CO_2 neutral combustion, the pellet systems have the least CO_2 equivalents. CO_2 equivalents of heat pumps are in the same range as the combination of a gas condensing boiler and a solar system.

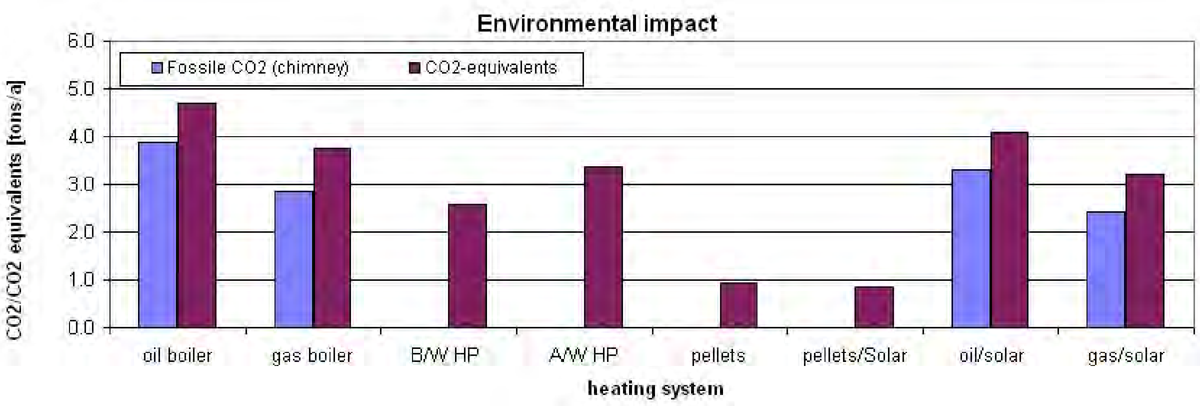


Fig. 17: Comparison of CO_2 emissions for common heating systems for Switzerland (source: WWF, 2009)

Oil systems have the most CO_2-equivalents. Concerning the operation a carbon free operation of the heat pump is possible, if the heat pump is operated with purely renewably generated electricity.

3.4 Installed systems in low energy houses

In the following some statistical evaluations on applied systems in low energy building of the largest low energy house markets in Germany, Switzerland and Austria are presented.

3.3.1 Applied systems in MINERGIE® Buildings

Fig. 18 shows the installed heating systems in residential MINERGIE® houses of the period until 2009 (MINERGIE, 2010). The evaluation is made based on m^2 energy reference area. Heat pumps are the clearly dominating system with about 60% for space heating.

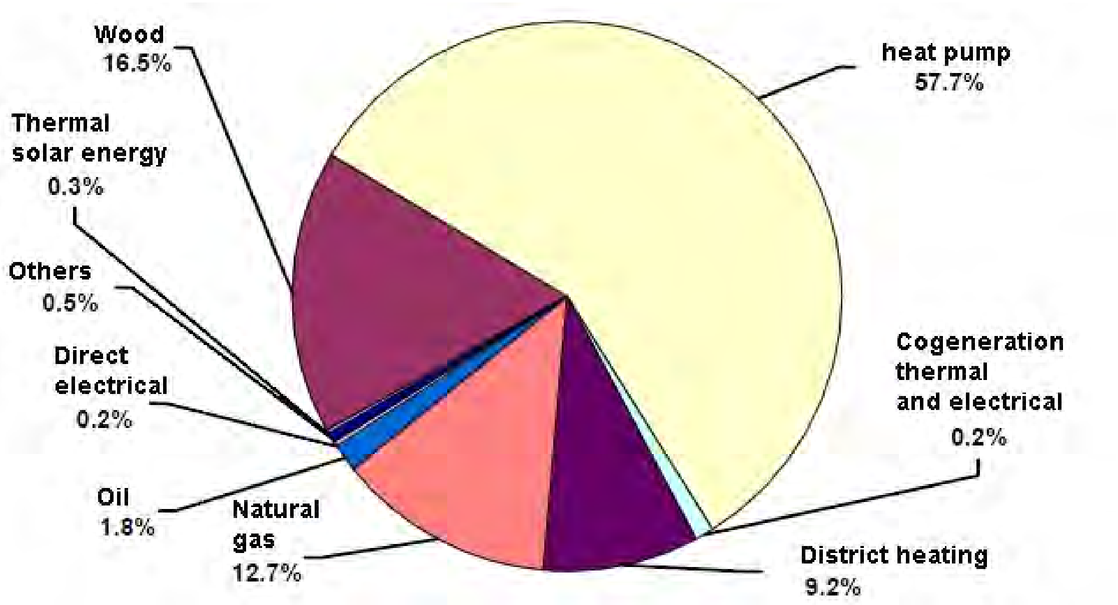


Fig. 18: Space heating (left) systems installed in residential buildings acc. to MINERGIE®, evaluated on 24. February 2010

The use of natural gas and oil for space heating is only about 15%, i.e. about 75% of space heating operation is accomplished by the heat pump and wood. District heating is used in about 10% of the buildings, while direct electrical and solar thermal fractions are negligible with a fraction below 1%.
Systems used in DHW operation are depicted in Fig. 18. In DHW operation, heat pumps are also the dominating system technology with about 50%. Together a fraction of about 15% wood and about 10% solar thermal a fraction of 75% is reached. The direct electrical fraction of 3.7% can be explained by installed back-up heatings together with heat pump for DHW operation. Fuel oil and natural gas make up a fraction of 10 %, while district heating also contributes 10% of the DHW generation. Other technologies including co-generation are negligible with a fraction below 1%.

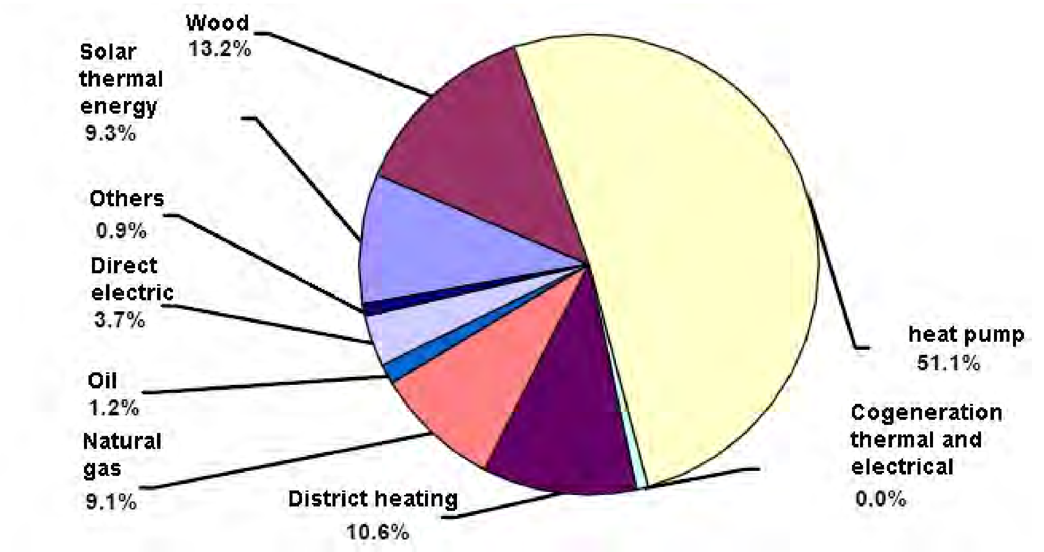


Fig. 19: DHW systems installed in residential buildings acc. to MINERGIE®, evaluated on 24. February 2010

3.3.2 Applied systems in passive houses

As outlined highly integrated ventilation compact units with exhaust air heat pump (see detailed description of the technology in part 1 of the final report of IEA HPP Annex 32) are the standard system for houses according to the German passive house standard.

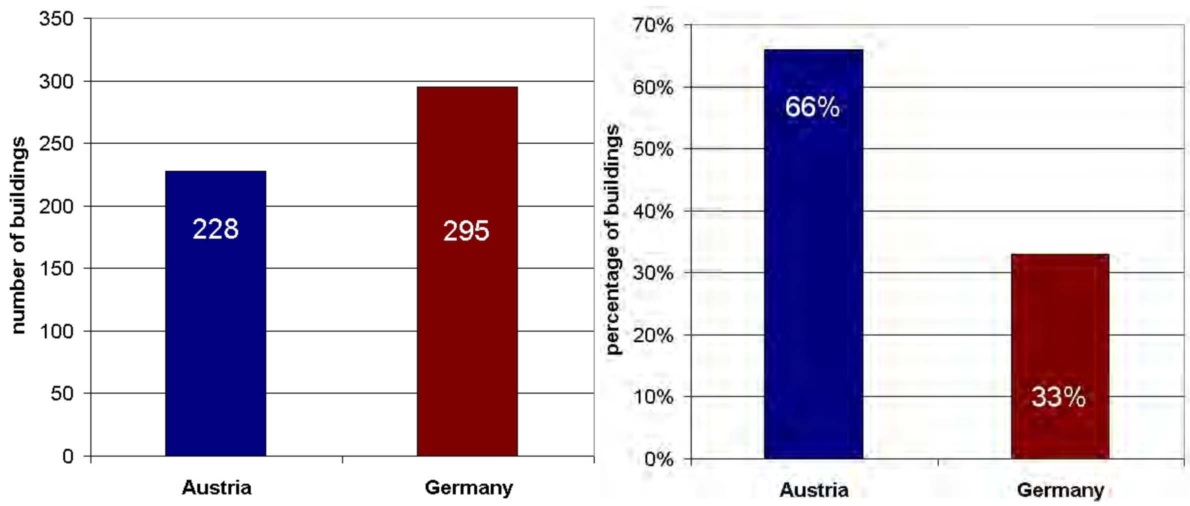


Fig. 20: Space heating and DHW systems installed in retrofitted building to MINERGIE® (category single family and multi-family houses) (Pfluger, 2008)

The Passivhaus Institut (PHI) has made an evaluation of the number of installed units and the market share, which is given in Fig. 20, based on a database operated by the IG Passivhaus. The basis for the evaluation are 345 of ~1700 passive houses in Austria and 894 of ~5000 passive houses in Germany. (Pfluger, 2008)

4 IEA HPP ANNEX 32 PROJECT & NATIONAL CONTRIBUTIONS

The IEA HPP Annex 32 entitled “Economical heating and cooling systems for low energy houses” in the Heat Pump Programme (HPP) of the International Energy Agency (IEA) is carried out cost- and task-shared with the ten participating countries AT, CA, CH, DE, FR, JP, NL, NO, SE, US. The project management (Operation Agent) is accomplished by the Institute of Energy in Building (IEB) of the University of Applied Sciences Northwestern Switzerland (FHNW) in charge of the Swiss Federal Office of Energy (SFOE).
The main objectives of IEA HPP Annex 32 are

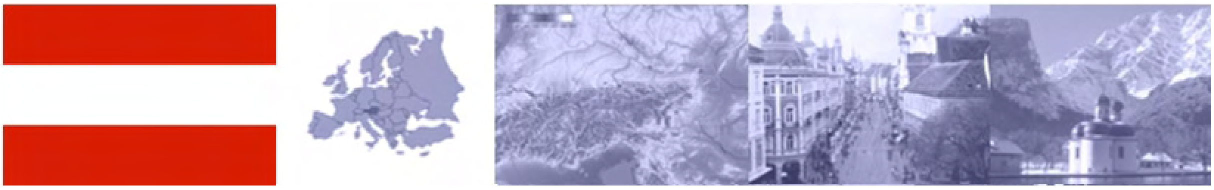
- **System development**
  - New concept for heat pumps in low energy houses in the capacity range of 3-5 kW
  - Application of natural refrigerants (CO_2 (R744) and Propane (R290))
  - Prototype developments and laboratory testing
  - System integration of additional functions (ventilation, cooling, de-/humidification)
  - Standardised system solutions
- **Assessment of practical operation by field testing**
  - Field test of new developments and marketable systems
  - Evaluation of functionality
  - Identification of optimisation potentials, hints for further system developments
  - Design recommendations and Best Practice Systems

Tab. 7 gives an overview on the focus of the national contributions of the participating countries in IEA HPP Annex 32.

Tab. 7 Overview of national contributions to IEA HPP Annex 32

Country	Focus of work
AT	• Development, prototyping, lab-test and simulation of a 3-5 kW CO_2 B/W heat pump. • Field testing of 9 combined heat pumps for SH and DHW and 2 compact units
CA	• Design and monitoring of two EQuilibrium houses (NZEB) in Eastern Canada
CH	• Design guidelines of energy efficient heat pump systems for space heating and cooling. • Field test of 2 heat pump systems for space heating, DHW and space cooling
DE	• Field testing of 100 state-of-the-art residential heat pumps in co-operation with seven manufacturers and two utilities. • Field test of 70 retrofit heat pumps for replacement of boilers with German Utility E.ON
FR	• Development and field test of A/A heat pump solutions for low energy houses
JP	• Design optimisation of systems for moderate climate regarding capacity and control • Feasibility studies and field tests of ground-source heat pumps for the cold climate zone
NL	• Promotion of market introduction of low energy houses, documentation of system solutions and upcoming concepts
NO	• Feasibility of heat pumps with natural refrigerants in Norwegian low energy houses (cold climate conditions) • Field test of novel W/W heat pump with the refrigerant propane for passive houses
SE	• Assessment and redesign of Swedish heat pump systems (capacity range, auxiliary consumption) • Further development of Swedish heat pumps for the application in low energy houses (e.g. exhaust air heat pump with hybrid source, combined space cooling/DHW)
US	• Development of a multifunctional heat pump system for SH, cooling, DHW, ventilation incl. de-/humidification for Net Zero Energy Houses • Prototyping, lab-testing, simulations and field test of the system

4.1 Austria



National Team leader	
	Ao. Univ. Prof.-Dr. René Rieberer, Institute of Thermal Engineering (IWT), TU Graz Inffeldgasse 25/B, 8010 Graz, Austria Phone: +43-(0)316-873-7302, rene.rieberer@tugraz.at, http://www.iwt.tugraz.at
National institutions involved	
	Dr. Andreas Heinz, IWT, TU Graz, http://www.iwt.tu-graz.at
	Andreas Zottl, Heinrich Huber, Christian Köfinger, Austrian Institute of Technology, Vienna, http://www.ait.ac.at
National contribution supported by	
	Leistungsgemeinschaft Wärmepumpe Austria, http://www.lgwa.at Bundesverband WärmePumpe Austria, http://www.bwp.at
National contribution financially supported by	
	Austrian Ministry of Transport, Innovation and Technology, http://www.bmvit.gv.at Österreichische Forschungsförderungsgesellschaft mbH, http://www.ffg.at

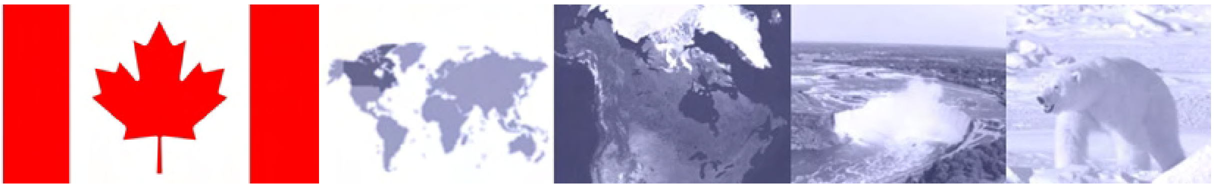
Project overview

The national project at IWT is dedicated to the development of an integrated heat pump in the capacity range of 3-5 kW, preferentially using a natural refrigerant, e.g. CO_2 (R744) or propane (R290). The project comprises

- the system assessment of 3 possible system layouts
- the cycle analysis to identify the best of 3 refrigerants for the chosen system layout
- the construction of a prototype and lab-testing
- detailed simulations of the chosen system and its dynamic interaction with the heating system and the building (dynamic simulations in TRNSYS).

The system and cycle analysis resulted in a prototype concept for a CO_2-B/W heat pump. The system incorporates a horizontal ground collector, the CO_2 heat pump and a buffer storage, which is connected to a low temperature space heating emission system and a plate heat exchanger for instantaneous DHW preparation. The heat pump concept has a bi-partite gas cooler, by which space heating energy can be produced in the lower part (temperature level about 35°C) and DHW energy can be reheated in the upper part to the temperature level of the DHW of about 55°C. This configuration also enables a simultaneous space heating and DHW operation. Moreover, a passive and active cooling function can be realised by an external hydraulic. Also a simultaneous active cooling and DHW operation is possible. Results of the project are described in detail in the prototype report (part 2 of the final report of Annex 32).
The Austrian Institute of Technolgy (AIT, formerly arsenal research) joined the Austrian team in 2008 for field monitoring of combined operating heat pump systems for space heating and DHW. 9 systems have been field monitored. Moreover, two ground-coupled compact units with horizontal collector for the functions space heating, DHW, ventilation and passive ground cooling have been in field monitoring for one year. Summarising results on the field tests are documented in the field test report (part 3 of the final report of Annex 32) and as Best Practice sheets.

4.2 Canada



National Team leader	
	Vasile Minea, Ph. D., Laboratoire des technologies de l'énergie (LTE), Hydro-Québec 600, avenue de la Montagne, Shawinigan (Québec) G9N 7N5, Canada Phone: 819-539-1400 (1507), minea.vasile@lte.ireq.ca, http://www.ireq.ca
National institutions involved	
	Prof. Andreas Athetinitis, PhD, José Candanedo, Cheng Bu Concordia University, Montréal, http://www.concordia.ca
	Bradley Bredeche, Aloutte Homes Ltd., http://www.alouettehomes.com
	Sevag Pogharian, Sevag Pogharian Design, Montréal, http://www.spd.ca
	Solar Building Research Network, http://www.solarbuildings.ca Canadian Mortgage and Housing Corporation, http://www.cmhc-schl.gc.ca/

Project overview

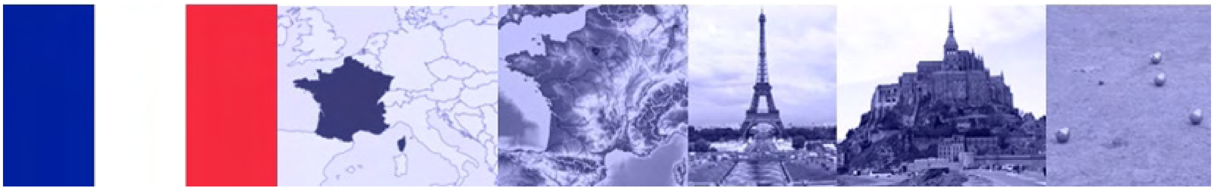
The national project of Canada presents EQuilibrium™ Housing Pilot and Demonstration Initiative by the Canadian Mortgage and Housing Corporation (CMHC). EQuilibrium™ housing follows a Net Zero Energy approach and integrates high-performance, energy-efficient passive solar design and commercially available on-site renewable energy systems such as solar heating, air- and ground-source heat pumps. EQuilibrium™ housing also incorporates the principles of occupant health and comfort, affordability, resource conservation and reduced environmental impacts. These significantly reduce greenhouse gas emissions and minimize the detrimental environmental impacts of housing on water, land and air. The goals of the EQuilibrium™ housing initiative is to build the capacity of Canada's housing and renewable energy industry sectors to create high-quality housing across the country over the long term and achieve acceptance of low-impact healthy houses and sustainable communities. Twelve demonstration projects have been selected by the Canadian Mortgage and Housing Corporation throughout Canada.

In the frame of Annex 32 two EQuilibrium™ Houses in Eastern Canada are designed, simulated and investigated in field monitoring. The EcoTerra™ House of the Home Building Company Aloutte Home is a house of prefabricated components, which has been erected in one day in Eastman, Quebec. The building technology incorporates as core components a building integrated PV/thermal (BI-PV/T) and a ground-source heat pump. Furthermore, other innovative technologies are field-tested, e.g. a waste water heat recovery and a hollow floor slab to store the preheated air of the PV thermal system.

The second house, the Alstonvale Net Zero Energy House, is based in Hudson, Quebec, and also incorporates a building integrated PV/Thermal. The concept of a Net Zero energy lifestyle incorporates besides the design of a Net Zero consumption of the house also mobility aspects by integrating the car battery charging into the energy concept and a local food production. Thereby, different aspects of sustainability are integrated in the concept of the house. Core components of the technical building system are two heat pumps for capacity control, a ground loop, a BI-PV/T as heat source and a heat storage.

System concepts are documented in two system concepts sheets and single pilot technology concepts are treated in the prototype system report (part 2 of the final report of Annex 32).

4.3 France



National team leader	
	Catherine Martinlagardette, Electricité de France (EdF), Research and Development, Departement ENERBAT, Avenue des Renardières, 77818 Moret sur Loing Cedex, France, Tel. +33-(0)1-60737191, catherine.martinlagardette@edf.fr, http://www.edf.fr
National institutions involved	
	Françoise Evin, Electricité de France (EdF), R&D,Dep. ENERBAT, http://www.edf.fr

Project overview

France joined the Annex 32 in September 2008. EDF R&D finished a study on the comparison of different energy systems for low energy houses. The study was carried for a typical newly built French house of 115 m² according to the requirements of the French low energy building label BBC (http://www.effinergie.org). The building type is traditional (breeze block + internal insulation with polystyrene or polyurethane).

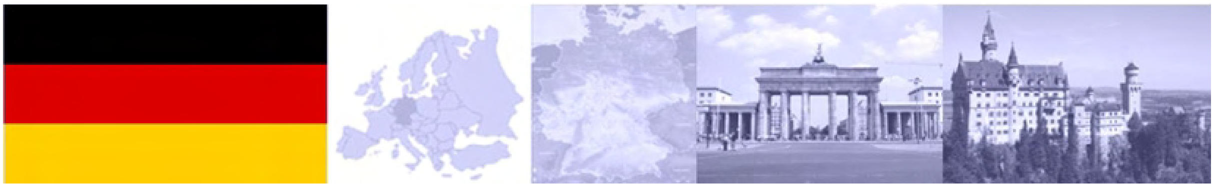
Space heating is provided by a heat pump (variants air-to-water, water-to-water or air-to-air), by Joule effect, by a condensing gas boiler or a wood pellet boiler. Domestic hot water production is done by solar water heaters or heat pump water heaters. The system variants have been compared according to different criteria: primary energy consumption, CO_2-emissions, delivered energy consumption as well as operation and investment costs.

Result of the study is that under the above boundary conditions heat pumps for heating and domestic hot water production offer the best compromise regarding energy and investment costs as well as CO_2 emissions, see chap. 3.3.1.

Based on this study EDF R&D has investigated the following items within Annex 32:

- French market overview for new houses and new collective buildings and evolution of applicable regulations
- Comparison of system solutions on the French market
- Laboratory tests of a heat pump compact unit
- Field monitoring of a BBC labelled building with air-to-air heat pump.

4.4 Germany



National Team leader	
Fraunhofer ISE	Marek Miara, Fraunhofer Institute of Solar Energy systems (Fhg-ISE) Heidenhofstrasse 2, D-79110 Freiburg, Germany, Phone: +49-(0)761-4588-5529 marek.miara@ise.fraunhofer.de, http://www.ise.fraunhofer.de
National institutions involved	
VIESSMANN	Dr. Andreas Bühring, Viessmann Wärmepumpen GmbH, http://www.viessmann.com
National contribution supported by	
e.on, EnBW, alpha innotec, HAUTEC, IVT, NIBE, STIEBEL ELTRON Technik zum Wohlfühlen, Vaillant	
Utilities: E.ON Energie AG, EnBW Vertriebs und Servicegesellschaft mbH	
Manufacturers: Alpha Innotec GmbH, Hautec GmbH, IVT, Nibe Systemtechnik GmbH, Stiebel Eltron GmbH & Co KG, Vaillant Deutschland GmbH & Co. KG, Viessmann Wärmepumpen GmbH	
National contribution financially supported by	
	Bundesministerium für Wirtschaft und Technologie, http://www.bmwi.de

Project overview

The national project of Germany is dedicated to the field monitoring of heat pumps. Two large projects are currently ongoing and will continue until the end of 2010. One field monitoring called "HP Efficiency" of about 100 heat pumps is conducted by the Fraunhofer Institute of Solar Energy Systems (FhG-ISE) in co-operation with 7 heat pump manufacturers and 2 utilities. The heat pump types in field testing are air-source, water-source as well as ground-coupled heat pumps. Instrumentation of the first part of the field test with 70 units has been started in 2006. In 2008, 35 further heat pumps are installed. Results shall serve to evaluate the actual seasonal performance

- of the latest generation of heat pump systems with space heating and DHW operation
- derive technical expertise for the further development of heat pumps for well-insulated houses

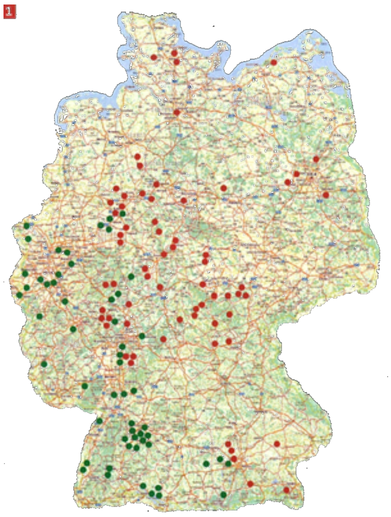


Fig. 21: German field test sites

The sites of the field monitoring systems are shown as green dots in the map in Fig. 30. The second field test is dedicated to the replacement of boilers with heat pumps in buildings with high supply temperature requirements in charge of the German utility E.ON in the years 2006-2009. Heat sources for the retrofit application are ground- and air-source heat pumps. The selected houses comprise annual energy needs for space heating in the range of 150-250 kWh/(m^2/a) and requirements for high supply temperatures. Results shall deliver the feasibility of this retrofit option in terms of energy savings, CO_2-emission reduction and the economy of the system. The sites of this field test are marked as red dot in Fig. 30. Results of the field test are documented in the field test report (part 3 of the final report of Annex 32) and performance of single systems are described in Best Practice sheets.

4.5 Japan

National Team leader	
	Prof. Dr. Eng. Katsunori Nagano, Urban & Environmental Engineering Graduate School of Engineering, Hokkaido University N13-W8, Kita-ku, Sapporo 060-8628, Japan, Phone: +81-(0)11-706-6285, nagano@eng.hokudai.ac.jp, http://www.hokudai.ac.jp/
National institutions involved	
	Hirofumi Ida, Tokyo Electric Power Company, http://www.tepco.co.jp
	Yasukazu Kawaraguchi, Archi-tec Consultant, http://www.architec.jp
	Prof. Dr. Sayaka Takeda Kindaichi, University Tokyo, http://www.u-tokyo.ac.jp
	Dr. Xiaomei Li, HPTCJ, http://www.hptcj.or.jp
	Dr. Takao Katsura, Fujiwara Environmental Science Institute Ltd.
National contribution supported by	
Manufacturers: Fujitsu, Panasonic, Daikin, Toshiba, Misawa, Asahi Kasei, Morinaga Engineering, Mitsubishi	
National contribution financially supported by	
	Nedo, http://www.nedo.go.jp

Project overview

The Japanese national project in Annex 32 deals with the design and further development of heat pump systems for low energy houses for the cold and moderate climate zones of Japan.

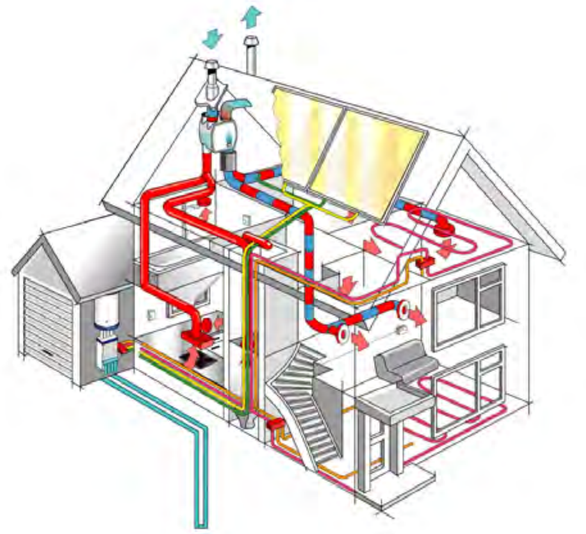
In the cold region of Hokkaido Island, most of today's heating systems are using fuel oil. For this area, adequate heat pump solutions shall be developed for the low energy house applications. Two ground-coupled systems have been field-monitored by Hokkaido University. The systems use inverter-controlled ground-coupled heat pumps with borehole heat exchangers, mechanical ventilations systems, heat pump water heaters as well as solar technologies. Moreover, other prototype technologies like a passive humidity control by packed beds of siliceous shale in the ventilation system are evaluated in the field monitoring. Results are documented in Best Practice Sheets and in the field test report (part 3 of the final report).

80% of the Japanese population lives in the moderate climate zone (Tokyo, Osaka), where space heating and space cooling requirements exist. Reverse operating heat pump air conditioners for space heating in winter and air-conditioning in summer are very popular. However, the design of the system is not adequate for highly-insulated dwellings. In the frame of the Japanese project, a design method has been derived, which matches the heat load of low energy buildings and yields a better seasonal performance due to higher part load efficiency. Moreover, the control of the systems has been evaluated. Last but not least, developed methods have been integrated in the new on Energy Efficiency Act enacted in 2009. Results are documented in the field test report (part 3 of the final report).

4.6 Netherlands

National team leader	
	Onno Kleefkens, Agentschap NL, Netherlands Croeselaan 15, 3521 BJ Utrecht, Tel:+31-(0)88-6022449, Fax: +31-(0)88-6029025 onno.kleefkens@agentschapnl.nl, http://www.agentschapnl.nl
National institutions involved	
	Sibe Jan Koster, Q+P Communicatie en Innovatie, http://www.qpcommunicatie.nl/
National contribution supported by	
	Vos Property development building company, http://www.isozero.nl

Project overview



In the Netherlands low energy houses are in the market introduction phase. A problem for the introduction of low energy houses is a generally rather low energetic building quality in the Netherlands in terms of thermal insulation and air-tightness, since the building market of the Netherlands is a seller's market and buildings of any quality (within the building standards) can be sold. Further specific market barriers like the national building traditions have been identified (Kleefkens, 2006). However, different market players are presently pushing high-quality buildings and dwellings with low energy consumption.
Nevertheless, currently a generally accepted system technology for these dwellings is missing. Some market players offer integrated concepts with heat pumps as system technology, but the building technology is not optimised for the application field of low energy houses. Thus, market conditions are favourable to link adequate heat pump developments to the emerging market of high-quality low energy houses in the Netherlands. Thus, starting from an evaluation of existing approaches, adequate system technology for the application in low energy buildings shall be developed as co-operation between Dutch heat pump manufacturers, building companies and research institutes.
Moreover, in the frame of Annex 32 existing calculation procedures and models for the energy consumption shall be validated for low energy houses. Furthermore, field testing of low energy houses is planned in co-operation with the building companies and is started in 2010. Further activities are means to support the market introduction of both low energy houses and heat pumps in the Netherlands.
Upcoming system concepts have been documented in System Concepts Sheets.

4.7 Norway

National team leader	
SINTEF	Maria Justo Alonso, SINTEF Energy Research, Dept. of Energy Processes 7465 Trondheim, Norway, Phone: +47-(0)735-93901 maria.justo.alonso@sintef.no, http://www.sintef.no
National institutions involved	
COWI	Jørn Stene, Dr. Ing., National team leader 2006-2008, COWI AS, http://www.cowi.no
NTNU	D. Zijdemans, T. Hjerkinn, Norwegian University of Science and Technology (NTNU) http://www.ntnu.no
National contribution financially supported by	
enova	Enova SF, http://www.enova.no

Project overview

Norway has a strong growth in low-energy buildings in the recent years, and about 100'000 low-energy houses are already built, or are in the construction or design phase (state 2007). Adequate technologies for heating, cooling and ventilation are needed for this rapidly emerging market. Heat pumps are seen as a promising solution for heating and cooling of low-energy buildings due to high energy efficiency, utilisation of renewable energy sources, great flexibility in system design and heating capacities, and the fact that relatively high energy prices und low interest rates are favourable when investing in relatively expensive heating technologies. The different focuses of the Norwegian national project are feasibility studies for the application of heat pump systems using natural refrigerants in low-energy houses, prototyping and field monitoring.

A feasibility study of a central CO_2 heat pump water heater for a low energy block of flats has been carried out. Four different system configurations have been simulated in order to identify the system layout with the highest SPF. Simulations results prove that the CO_2 HPWH has a 20% higher seasonal performance factor than conventional HPWH. Thus, the CO_2 HPWHs are seen as promising solution for central water heating of low energy apartment houses. Moreover, CO_2 heat pumps for space heating and DHW for the application in low energy and passive houses have been investigated. A tri-partite gas cooler has been identified as best solutions combined with a low temperature heating system, where the cold water is preheated in a first part of the gas cooler, the space heating system is heated in the middle part of the gas cooler and the DHW is reheat in the third part of the gas cooler where the hot CO_2 vapour enters after the compressor. SPF comparison shows that at a DHW demand of about 50%, which may be reached in passive houses, brine-to-water CO_2 heat pumps will outperform the state-of-the-art brine-to-water heat pumps available on the market. Results are documented in the prototype report (part 2 of the final report of Annex 32).

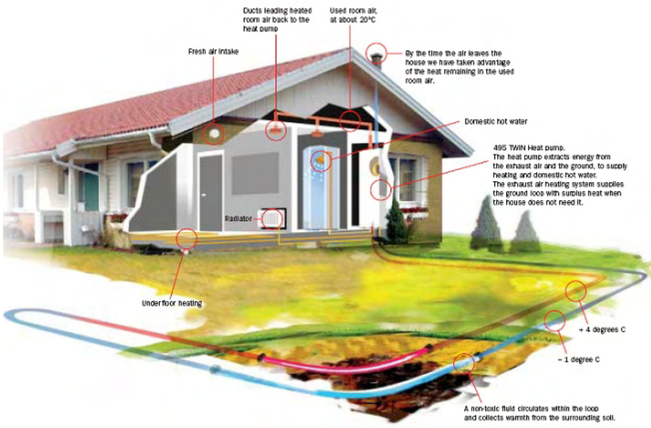
Furthermore, a 3 kW integrated propane water-to-water heat pump for space heating and DHW has been developed in co-operation with the NTNU. A prototype has been designed and lab-tested at the NTNU. Presently, the prototype is installed in a passive house of a design heat load of 2.9 kW in Flekkefjord in Southern Norway. The prototype is connected to a floor heating system and monitored for two heating periods 2007/08 and 2008/09. In the first heating period, optimisation potentials have been identified and the prototype has been optimised. Results are documented in a System concept sheet and in the prototype report (part 2 of the final report of Annex 32).

4.8 Sweden

National team leader	
SP	Svein Ruud, SP Technical Research Institute of Sweden, Industrigatan 4, P.O. Box 857, SE-501 15 BORÅS, Sweden, Phone: +46-(0)10-5165514 svein.ruud@sp.se, http://www.sp.se
National institutions involved	
IVT, NIBE, LB-HUS, VästkustStugan, NCC, AB Sätila Bygg	
Manufacturers: IVT AB, Nibe AB, Thermia, LB-Hus, VästkustStugan, NCC, Sätila Bygg AB	
National contribution financially supported by	
Energimyndigheten	Swedish Energy Agency, http://www.energimyndigheten.se

Project overview

Sweden has one of the largest heat pump markets in Europe (EHPA, 2009). However, the low energy house market is in the introduction phase and therefore, adequate system technologies for low energy houses are still missing on the Swedish national market.



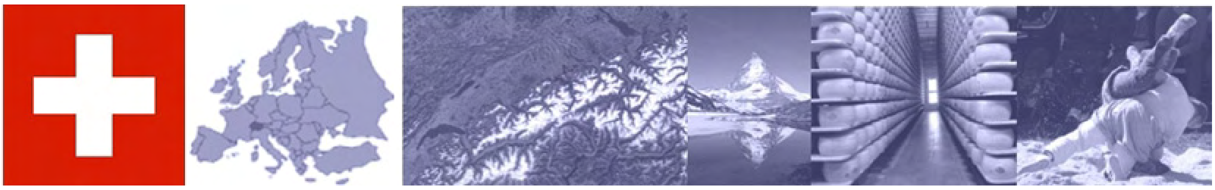
A preliminary study of SP has shown that heat pumps are a viable option for low energy houses at the boundary conditions of the Swedish climate and energy prices (Ruud, 2008).

However, marketable components and systems are not adequate for the application in low energy houses and further improvement of system concepts and components is intended in order to reach a high performance for the application. Therefore, product development is needed and consequently, the focus of the Swedish national contribution to Annex 32 is the examination and redesign of Swedish heat pumps for the application in low energy houses.

As first step, Sweden therefore made extensive comparison of different system solutions according to changing legal requirements. An evaluation of different heating systems for low energy houses shows that for the southern Swedish climate, exhaust-air heat pumps are a feasible option, while for the northern Swedish climate ground-coupled systems are the preferred system.

Moreover, Sweden has evaluated existing monitoring results of exhaust air and ground-coupled heat pumps which are very popular in Sweden. Field test of three low energy house pilot plants have started in the end of 2009, among other systems a combination of ground-coupled heat pump, but could not be included in the time frame of IEA HPP Annex 32.

4.9 Switzerland



Operating Agent (in charge of Swiss Federal Office of Energy SFOE)	
n|w Fachhochschule Nordwestschweiz	Carsten Wemhöner, Institute of Energy in Building (IEBau), University of Applied Sciences Northwestern Switzerland (FHNW), St. Jakobs-Str. 84, CH-4132 Muttenz, Phone: +41-(0)61-467-4573, carsten.wemhoener@fhnw.ch, http://www.fhnw.ch/iebau
National team leader	
n|w Fachhochschule Nordwestschweiz	Prof. Dr. Thomas Afjei, IEBau, FHNW, http://www.fhnw.ch/iebau
National institutions involved	
n|w Fachhochschule Nordwestschweiz	Ralf Dott, Andreas Genkinger, Norbert Lederle, IEBau, FHNW http://www.fhnw.ch/iebau
SATAG THERMOTECHNIK	Hans Hohl, Viessmann Switzerland, Operating Division SATAG Thermotechnik, http://www.satagthermotechnik.ch
National contribution financially supported by	
Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizra Swiss Federal Office of Energy SFOE	Swiss Federal Office of Energy SFOE, Research Programme cogeneration, refrigeration and heat pump technologies, Head: Prof. Dr. Thomas Kopp, http://www.bfe.admin.ch, http://www.energieforschung.ch

Project overview

The Swiss national project is dedicated to the integration of a cooling function in heat pump systems for low energy houses. As result, typical system configurations for space heating/-cooling and DHW production, eventually coupled to a mechanical ventilation system, are derived.

Background of the project is an increased interest of space cooling options in residential dwellings. However, there are still insecurities about the hydraulic configuration, the operation limits, reachable comfort as well as system performance and adequate control strategies. Favourable for the application are marketable system configurations already containing a heat pump and further components which can be used for a pre- and passive cooling in summertime. These passive cooling opportunities should be deployed first and active cooling with a reverse operation of the heat pump should only be used to cover peak loads, if necessary, in order to minimize additonal energy consumptions. On the other hand, active cooling can also have a high performance when applied in simultaneous operation with DHW.

Five basic typical system configurations and component variants have been derived and are investigated in simulations. Objective of the project is to derive a simple and robust hydraulic configuration of the system and design for the chosen system configurations. Results are documented in the field monitoring report (part 3 of the final report of Annex 32).

In parallel, two field tests of ground-coupled heat pump systems with included passive cooling functions have been accomplished. One system is installed in a multi-family house according to the Swiss ultra-low energy house standard MINERGIE-P® and the other in a single family house according to MINERGIE®. In focus was the functionality and performance of the the passive cooling operation. The results of the field test are presented in two Best Practice Sheets and the field testing report (part 3 of the final report of Annex 32).

4.10 United States of America

National team leader	
	Van D. Baxter, Residential Building and Equipment Research, Engineering Science and Technology Division, Oak Ridge National Laboratory P.O. Box 2008, Building 3147, Oak Ridge, TN 37831-6070, USA Phone: 865-574-2104, baxtervd@ornl.gov, http://www.ornl.gov
National institutions involved	
	Arun Vohra (retired, national team leader 2006/07), Antonio Bouza, US Department of Energy, Building Technology Program, http://www.doe.gov
	Dr. C. Keith Rice, Dr. Richard W. Murphy, William Craddick, Melissa Voss Lapsa Oak Ridge National Laboratory, http://www.ornl.gov
	Daniel Ellis, Climatemaster, http://www.climatemaster.com
	Oklahoma City Habitat for Humanity
National institutions involved - Zero Energy Building Research Alliance (ZEBRAlliance)	
Manufacturers: TVA, Schaad companies, Barber McMurry Architects	

Project overview

The project of the United States is dedicated to the development of a highly-integrated heat pump (IHP) for Net Zero Energy House (NZEH) application as a co-operation of the Building Technology Program of the US governmental Department of Energy (DOE) and the Oak Ridge National Laboratory (ORNL). A motivation for the technology development is the strategic goal of the DOE to have market available net zero energy technology by the year 2020. In this respect, the development is intended for future implementation and not for today's housing markets.

In a detailed scoping study by Baxter (2005) considering various system layout options, the IHP concept proved to be the most promising system for NZEH, covering the functionality for all building services of space heating (SH), water heating (DHW), ventilation (V), space cooling (SC), humidification (H) and dehumidification (DH). An integrated concept incorporating a heat pump has the advantage of simultaneous production of different building services, e.g. simultaneous SC and DHW in summer operation, while in stand-alone systems, the heat may be wasted. Thereby, higher investment costs of more energy-efficient components like variable speed controlled fans are justified, since they are used for multiple functions. An air-source (AS) and a ground-source (GS) IHP has been developed. An overview on the system concept, energy results and cost estimations by simulations are given in chap. 5.2.3, a detailed description is contained in the prototype report. Field monitoring of the GS-IHP starts in summer 2010, while the field test of the AS-IHP is schedule to begin in winter 2010/2011 as co-operation of the ZEBRAlliance. Details on the field test are documented in a System concept sheet.

Moreover, the US national team has contributed results of the Oklahoma Central Habitat for Humanity field test results of a housing estate with 16 low energy houses equipped with ground coupled heat pumps. Details on results are documented in a Best Practice sheet.

5 SUMMARY OF MAIN RESULTS

This chapter gives a summary of the main results of Annex 32. Details on the single topics are given in the other parts of the final report of IEA HPP Annex 32.

5.1 Market overview of integrated heat pump systems

In the following a summary of the market overview of existing multifunctional system solutions is presented. Since multifunctional heat pumps are in the focus of Annex 32, the classification is based on the system functionality. As introduction, source and emission systems are discussed. Details to the single chapters are found in part 1 of the final report of Annex 32.

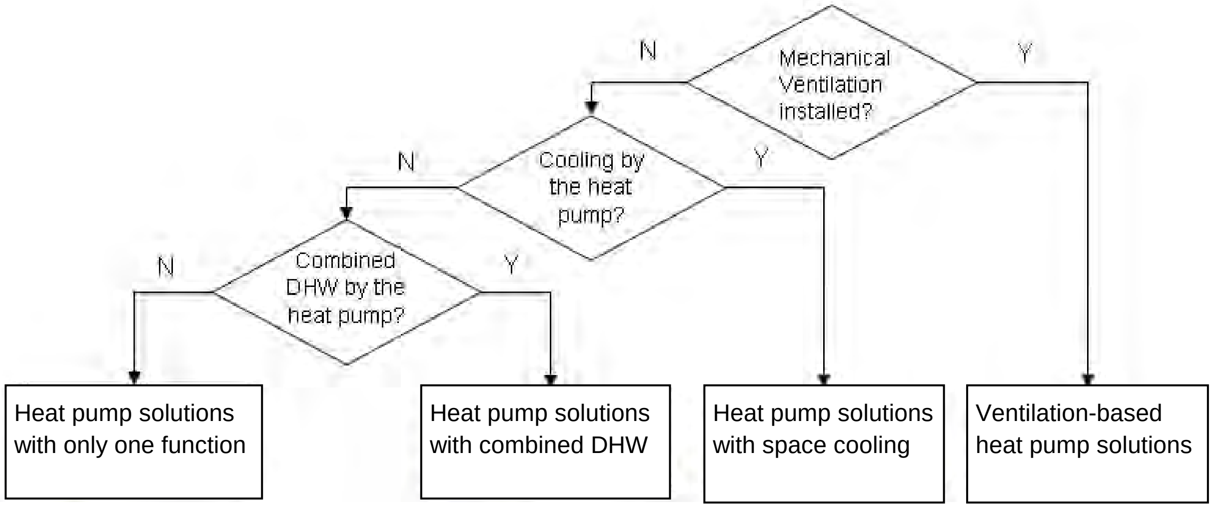


Fig. 22: Top-level system classification based on the integrated functionalities

5.1.1 Heat sources and heat emission

In Europe, outside air and the ground are the predominant heat sources used in the residential sector. However, in low energy buildings with mechanical ventilation system, exhaust air is increasingly used as heat source. New developments are shown in Fig. 23. Systems with multiple sources appeared on the market, e.g. an additional ground source for exhaust air heat pumps (Fig. 23 left). Moreover, a new ground source system is increasingly installed in Austria (Fig. 23 right). The system uses a heat pipe filled with CO_2 which is operated by using a natural cycle of the fluid, whereby the CO_2 is evaporated in the ground, the vapour rises to the top of the pipe, is condensed and the liquid returns to the bottom by gravity. Thus, the system does not require auxiliary energy for the source.
Heat emission is mainly accomplished by floor heating systems due to lower required flow temperatures in Europe. In Japan and the USA air-source and air emission systems are very common. In the USA, central ducted systems are used, while in Japan, heat pump air conditioners as single or multi-split systems for heating and cooling are mainly applied. Floor heating systems as emission system are not yet common, even though in Japan some manufacturers are starting a market introduction (Hasegawa, 2007).

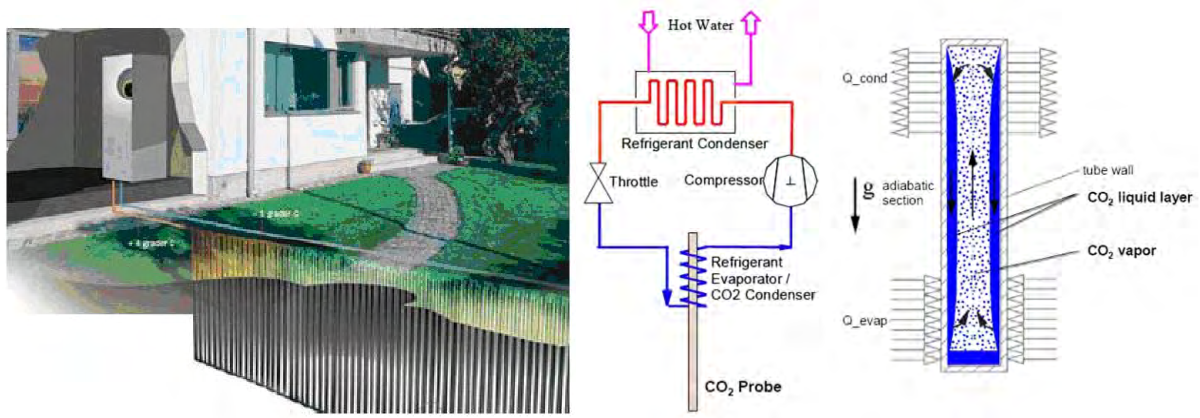


Fig. 23: Ditch collector as additional heat source for an exhaust air heat pump (left) and CO_2 heat pipe as ground source system (right)

5.1.2 Ventilation based-solutions

Ventilation based integrated system solutions can be distinguished in exhaust air systems and systems with balanced ventilation. Exhaust air systems are common for DHW production, but also integrated solutions with space heating function are on the market. Balanced ventilation systems are mostly designed for the space heating and eventually active space cooling function by reverse operation, where the exhaust air is used as source (heating) or sink (cooling) and the supply air is used for distribution and emission. If the exhaust air heat pump can be switched to a DHW storage, also a DHW function can be integrated. Fig. 24 shows the integration of a so-called ventilation compact unit with exhaust air heat pump (shortly "compact unit")

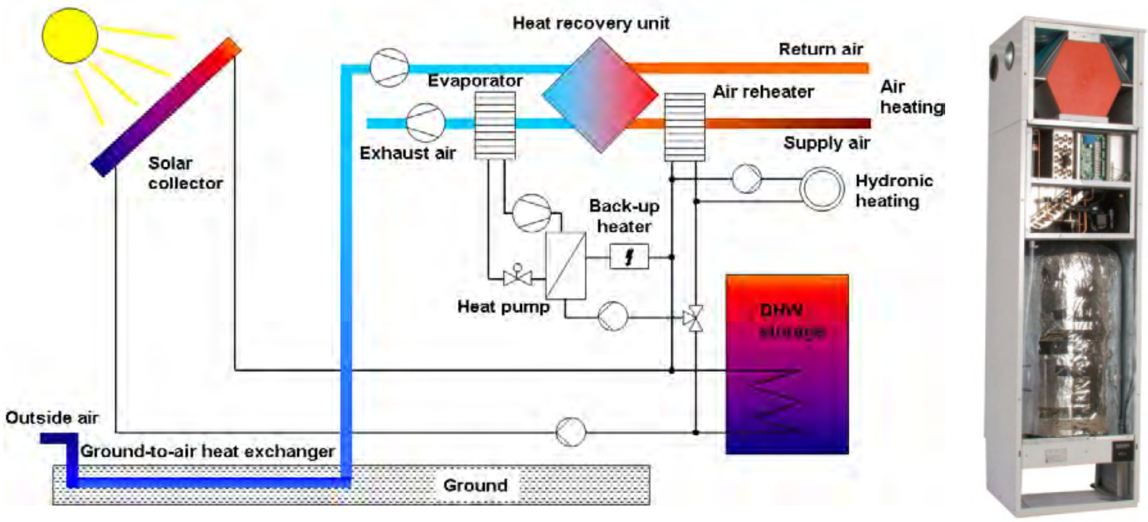


Fig. 24: Sample system configurations of heat pump compact units with additional components and cut-away of a compact unit (Type VP18-10P of manufacturer Nilan)

Ventilation compact units additionally include a passive ventilation heat recovery and cover the functions space heating, ventilation and DHW, some also include a cooling option by reverse operation.
However, the capacity of the exhaust air is limited by the ventilation rate to about 1.0-1.5 kW. Therefore, a ground-to-air heat exchanger to increase the inlet temperature and an additional outdoor air volume flow for the heat pump evaporator are used to increase the heating capacity.

5.1.3 Integrated cooling function

Systems with integrated cooling function not coupled to the ventilation can be differentiated in ground- or water-coupled passive cooling (see Fig. 25 left) and active cooling by reverse operation of the heat pump (see Fig. 25 right) and distinguished by the heat source.

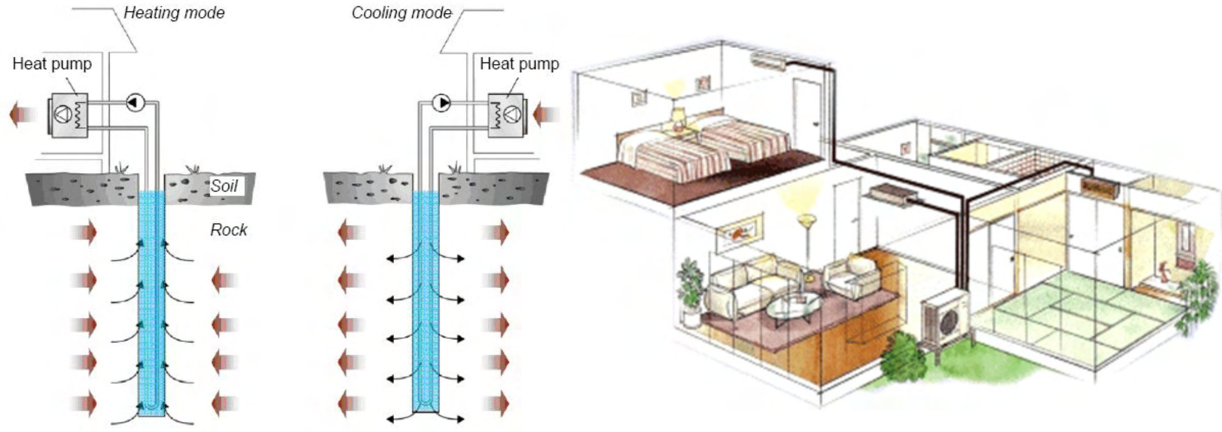


Fig. 25: Sample system of ground-source heat pump (Stene, 2007) with passive cooling and multi-split air-to-air heat pump air conditioner with active cooling (Ida, 2010)

Passive cooling is also called free cooling, natural cooling or direct cooling and refers to using the potentials of ambient sources colder than the indoor air temperature in summertime, e.g. the ground or ground water.

5.1.4 Combined space and DHW heating

For combined operating space and water heating heat pumps, alternate and simulatineous operation exists.
In Europe mainly alternate operation by switching the heat pump from space to DHW heating is found on the market. Fig. 26 left shows the common configuration of alternate operating heat pumps, where the DHW storage and the space heating emission system are connected in parallel and the heat pump is switched from one operation mode to the other.
Fig. 26 right shows a Norwegian system configuration where in winter operation, the space heating water is produced by the condenser and stored in the lower part of the storage, while the DHW is produced by the desuperheater and stored in the upper part. In summer operation, condenser heat is used to preheat the DHW and the desuperheater reheats the DHW to the design temperature.
While only few system with desuperheater are on the market in European countries, e.g Austria, France and Norway, simultaneous operation by desuperheater is more common in North America.
Systems with single functionality, mainly space heating, are meanwhile well-established in many European countries. Standardised system configurations have been derived and installation and operation of heat pumps has reached a robust and high-quality level with normally well performing installations. However, as the optimisation potentials derived by field monitoring results show (see chap. 5.4.5), there are still optimisation potential regarding design, control and operation. In Japan, CO_2 heat pump water heaters, which cover a DHW-only operation, have reached a considerable market share. For 2010 cumulative sold unit shall reach 5.2 millions.

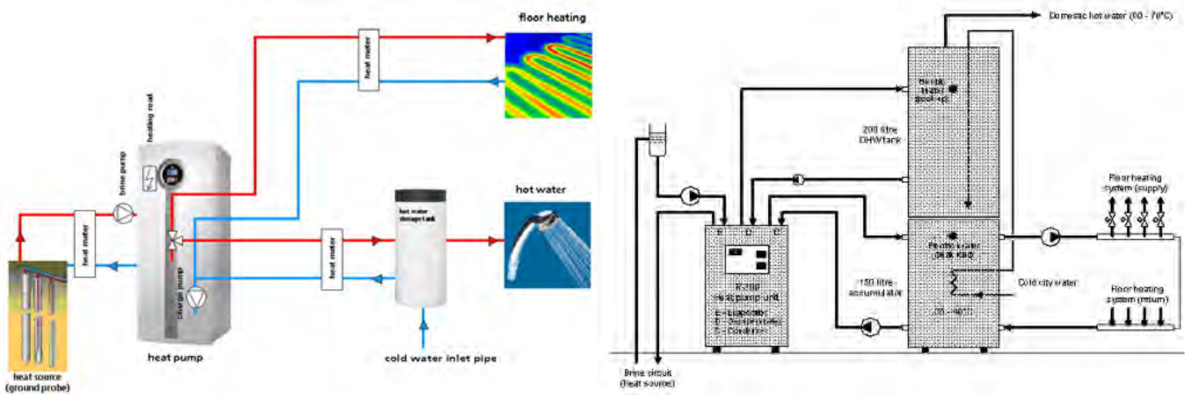


Fig. 26: System configuration with alternate DHW production (Miara, 2008) and simultaneous DHW production by desuperheater (Jakobsen, 2003).

5.2 Developed prototype systems

This chapter summarises the results of the prototype developments in the frame of IEA HPP Annex 32. Details to the single prototypes are given in part 2 of the final report.

5.2.1 Feasibility studies of CO_2-heat pumps in low energy houses

In Norway, feasibility studies of CO_2-heat pumps have been carried out (Justo Alonso and Stene, 2010). CO_2 is a favourable refrigerant due to a Global Warming Potential (GWP) of 1. Due to the low critical point of CO_2, processes are usually operated transcritically and thus, the refrigerant is not condensated, but the superheated refrigerant vapor is cooled down in a gas cooler to reject the heat. Performance strongly depends on the inlet temperature of the cold 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_2 heat pumps show a good performance for DHW operation (e.g. Japanese CO_2 heat pump water heater called Eco-Cute systems), while combined use for space heating and DHW is not yet so common.
For combined space and water heating lab-testing and simulations of a residential 6.5 kW heat pump showed that a CO_2 heat pump outperforms the best conventional HFC heat pumps at a DHW share of 55%.
For improved CO_2 technology (improved compressor, ejector) with a 10% increased COP the break-even point is shifted to 45% DHW share, as shown in Fig. 27.

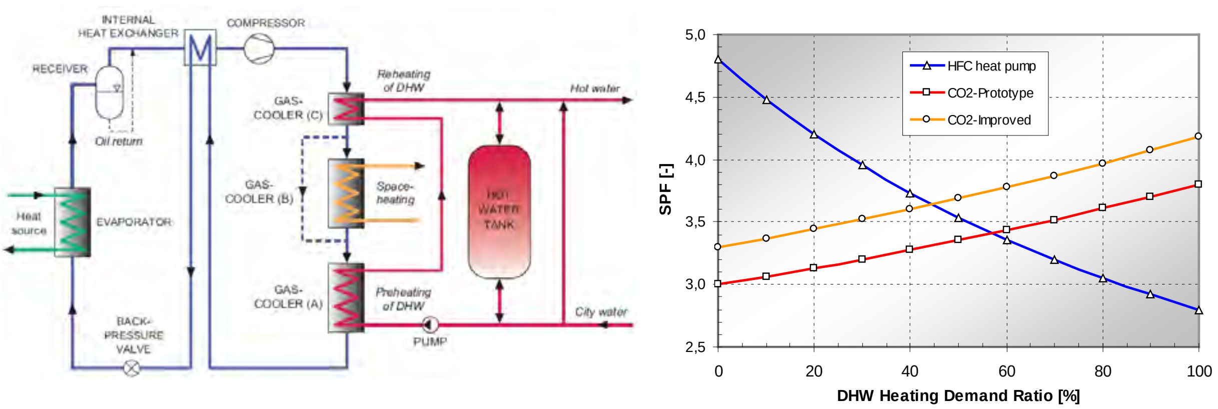


Fig. 27: Layout of the prototype B/W CO_2 heat pump and comparison of a prototype and improved CO_2 heat pump to state-of-the art (Justo Alonso and Stene, 2010)

Simulation results of a central 26 kW CO_2 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

5.2.2 CO_2-brine-to-water heat pump prototype

In the Austrian project a prototype of a CO_2-B/W-heat pump is 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 Fig. 28. 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 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.
With this configuration the operation modes space heating-only (only GC_1 in operation),

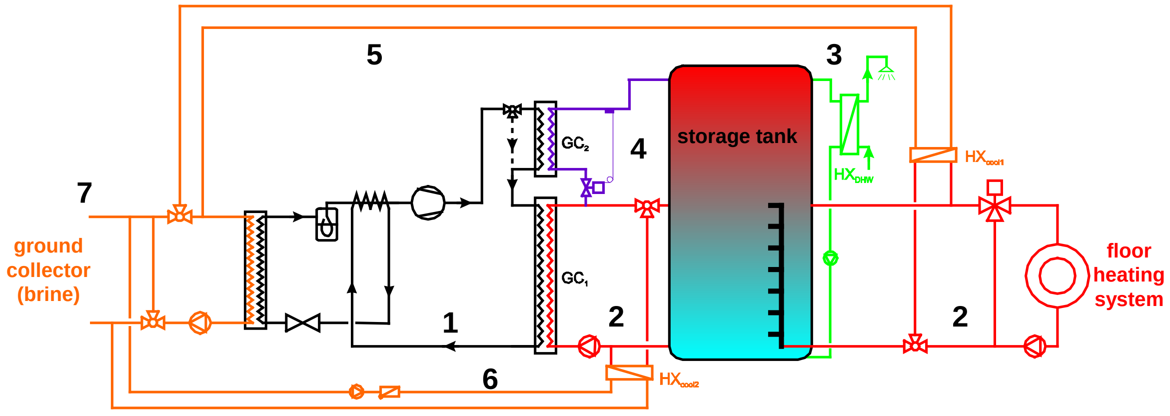


Fig. 28: Sketch of the CO_2-B/W heat pump prototype developed in the Austrian project (Heinz and Rieberer, 2010)

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 heat of GC_1 can be rejected by HX_{cool2} into the ground while the evaporator extracts heat from the room, in simultaneous cooling- and DHW operation the gas cooler 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.

With the parametrised model three variants of year-round simulations have been performed with TRNSYS (2005) for a low energy house with large south-oriented glazing and an external shading device as described in Heimrath and Haller (2007). The low energy building has a heat load of 6.1 kW at design conditions (T_{OD} = -12°C at T_{ID} = 20°C) and a space heating demand of 40 kWh/(m²a) for an average climate of the city Graz, Austria. It is equipped with a 100 m^2 floor heating system, which is designed to low design flow temperature of 32°C. As source system a 150 m^2 horizontal ground collector (ground properties: density 1800 kg/m³, thermal conductivity 2.5 W/(mK), heat capacity 1.26 kJ/(kgK)) is used, which has a nominal power consumption of the source pump of 75 W at 1000 kg/h massflow of the brine. System layouts with horizontal collector and floor heating are typical configurations of ground-source heat pump systems in Austria.

The results of the simulations show that with the used assumptions the functions space heating, space cooling and domestic hot water can be entirely covered. Three seasonal performance factors have been evaluated. SPF_1 is limited to the heat pump cycle and takes into account the heat rejected by the gas coolers and the evaporator in active cooling mode divided by the electricity consumption of the compressor. SPF_1 is thereby similar to the boundary of the COP. SPF_2 additionally takes into account the consumption of the brine pump. SPF_3 is related to delivered energy to the floor heating and DHW and additionally takes into account the passive cooling mode. Thus, heat losses of the buffer storage are not considered as delivered energy.

The simulation without space cooling show seasonal performance factors SPF1/SPF2/SPF3 of 3.20/3.08/2.84. Thus, without passive cooling, the delivered energy is significantly lower than the produced energy by the heat pump, and differences are due to storage losses.

In case with cooling, a cooling demand of 8 kWh/(m^2a) leads to higher SPF values of 3.29/ 3.16/3.21, i.e. mainly the high performance values in passive cooling outweigh the storage losses. Without cooling operation, summerly operative temperature exceed the boundaries of DIN 1946-2 (1994) for 150 h due to the high south-oriented glazing fraction despite the external shading, while with a high fraction of passive cooling as well as some active cooling with simultaneous DHW production, the operative temperature can be be kept below the boundary of the summerly operative temperature.

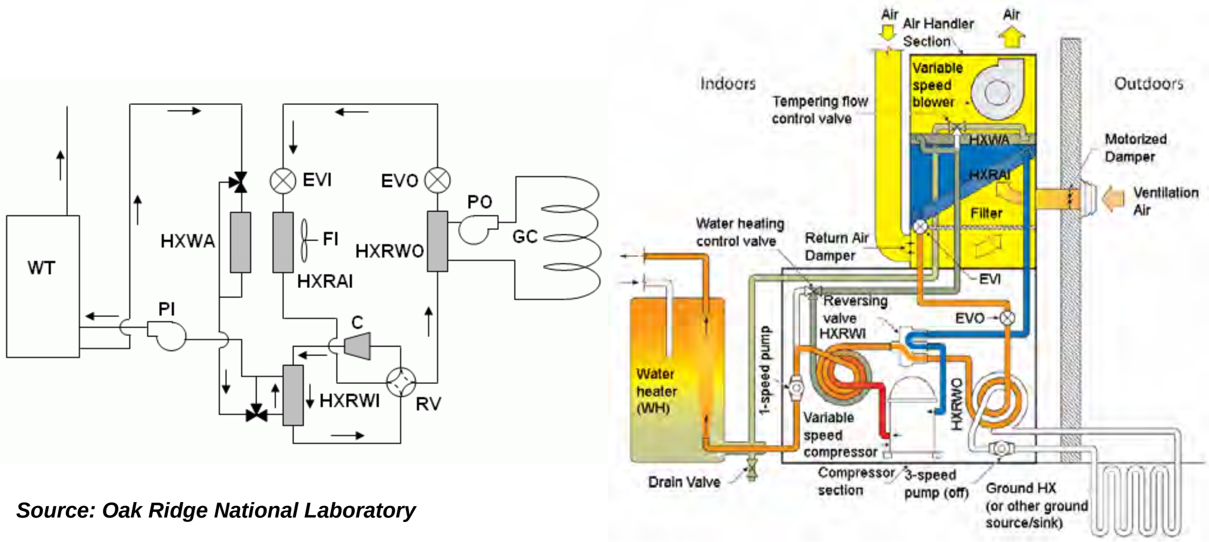
For weather data of the extremely hot summer 2003 in Graz differences with and without cooling increase due to a cooling demand of 17 kWh/(m^2a). Without cooling the boundary of the operative temperature is exceeded by 1600 h/a while with cooling, the boundaries can be kept.

Since the passive and simultaneous cooling operation is very efficient, overall SPF increases for the extreme summer to 3.64/3.44/3.85, i.e. the storage losses are more than outweighted by the increased passive cooling operation.

As conclusion, the performance of the unit reaches an SPF of 3.2 for space heating, DHW and space cooling. This seems relatively low in comparison to optimum marketable HFC heat pumps with low temperature design, but it has to be kept in mind that the capacity of the unit – adapted to the needs of a low energy building – is quite low (Poor efficiency of small compressors) and that the DHW share of the total heat demand in the simulations is relatively high (30%). However, there is potential for improvement concerning the efficiency of the system both in the refrigerant cycle (compressor efficiency, better adapted compressors for the required capacity range, ejector technology) and the system configuration (integration of storage tank, control). Summarising, the prototype contains an environmentally-sound refrigerant and the functionalities space heating, DHW and space cooling, and is therefore a promising solution regarding future low energy houses, which may have high DHW shares and higher cooling demands due to climate change.

5.2.3 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). According to a definition of the US Department of Energy (DOE) a residential NZEB is "a home with greatly reduced needs of energy through efficiency gains (60-70% less than conventional practice) with the balance of annual energy needs supplied by renewable technologies." (Baxter et al., 2007).



Source: Oak Ridge National Laboratory

Fig. 29: Ground-source IHP prototype in DH and DHW mode (Murphy et al., 2007a)

An air-source (AS-IHP) and a ground-source (GS-IHP) prototype are 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).
Fig. 29 left 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) and 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.
Lab-tests have been carried out for calibrating the Mark VI Heat Pump Design model (http://www.ornl.gov/~wlj/hpdm). More detailed lab-test results are given in Murphy et al. (2007b). The model was integrated into TRNSYS to calculate annual performance and compare it to a baseline HVAC system for a 167-m^2 NZEB.

The baseline heating, ventilation and air-conditioning (HVAC) system consists of a standard split-system A/A heat pump with DOE minimum required efficiency (Seasonal Energy Efficiency Ratio (SEER) 13 and Heating Seasonal Performance Factor (HSPF) 7.7) providing space heating, cooling and dehumidification. A separate stand-alone dehumidifier with an energy factor EF_d=0.0014 m^3/kWh is used for dehumidification during times without space cooling. A standard electric storage water heater with DOE minimum energy factor EF=0.90 provides DHW. Ventilation is provided using a central exhaust 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 USA. For the GS-IHP a vertical borehole heat exchanger was assumed. For GS-IHP results show over 50% savings in all locations reaching the highest 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 delivered energy savings range between 46-67%, with minimum delivered energy savings in the cold climate of Chicago, and maximum savings in the marine climate of San Francisco.
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 2 systems are ongoing. Field test of the GS-IHP has started in summer 2010, while the field test of the AS-IHP has started in the end of 2010, so field monitoring results cannot be included in the time frame of Annex 32. An outline of the field monitoring is given in a System Concept Sheet.

5.2.4 Prototype of a propane W/W heat pump installed in a passive house

An integrated 2.9 kW water-to-water heat pump has been developed using the natural refrigerant propane. The integrated system is designed for space heating and DHW production including a simultaneous space heating/DHW mode by desuperheating. The layout of the system is shown in Fig. 30 left.

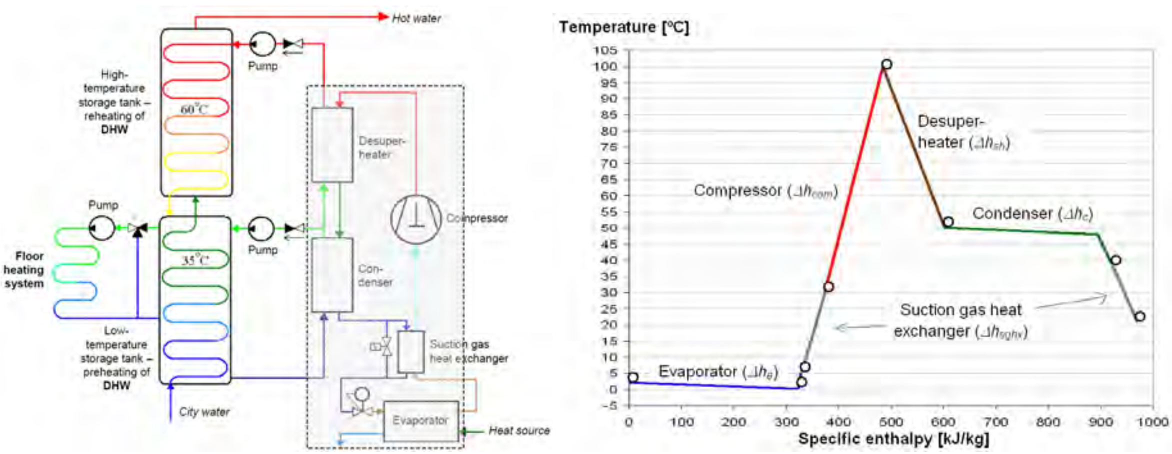


Fig. 30: Layout of prototype W/W heat pump with propane (Justo Alonso and Stene, 2008)

The system incorporates two storage tanks, a 300 l low temperature tank for the preheating of the DHW and the floor-heating system and a 300 l high temperature tank for the reheating of the DHW. The suction gas heat exchanger is mainly used to increase the discharge gas temperature at the compressor outlet to augment the potential of the desuperheating for the DHW production, as depicted in Fig. 30 right.

Due to the flammability of the refrigerant propane and a refrigerant charge of 250 g (i.e. >150 g), construction of the prototype has been accomplished according to the safety requirements of the EN 378:2008.
The system has been in field monitoring for 2.5 years in a low energy/passive house located in Flekkefjord in southern Norway, which has a design heat load of 3 kW. The heat source used is lake water. The average SPF of the entired monitoring period is 3.7 based on used energy after the storages and compressor energy and 3.1 including also the pumps.

5.2.5 Building integrated PV/T system with heat pump

The Canadian contribution is the design, simulation and field monitoring of two so-called EQuilibrium^{TM} Net Zero Energy Buildings (NZEB) within the Pilot and Demonstration Initiative of the governmental Canadian Mortgage and Housing Corporation, the EcoTerra^{TM} house and the Alstonvale Net Zero energy house (ANZEH).

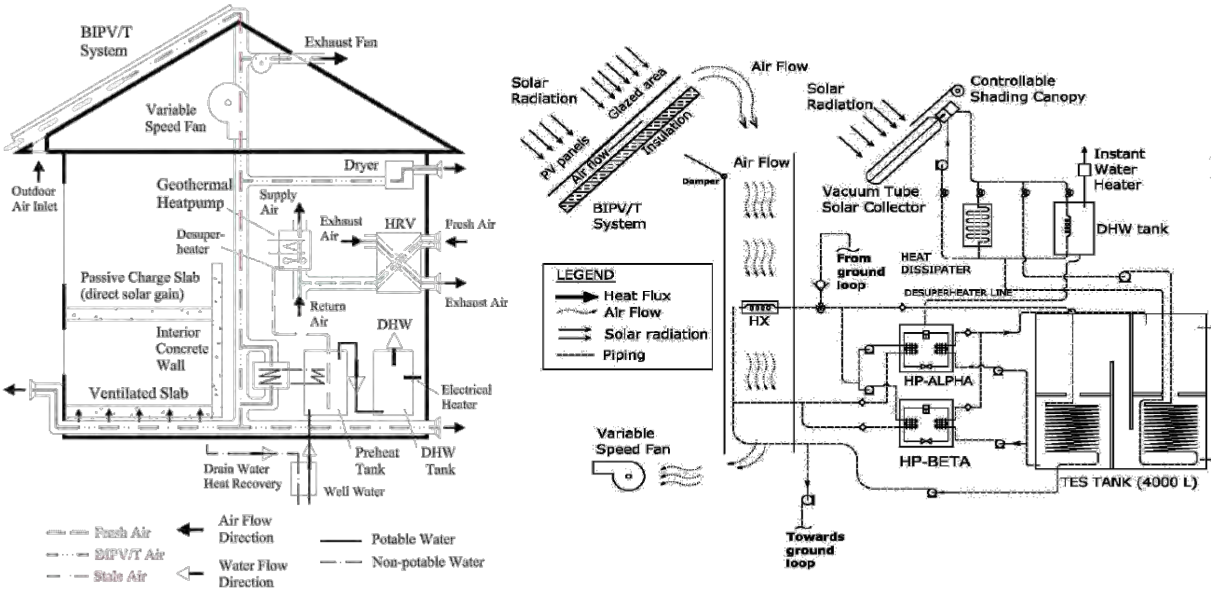


Fig. 31: System concepts of the EcoTerra (Candanedo et al., 2008) (left) and ANZEH (right)(Pogharian et al., 2008)

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/T systems as core component of design of the building technology.
The EcoTerra^{TM} house directly uses the heat of the PV/T for clothes drying, DHW preheating and storing the heat in a hollow 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 as depicted in Fig. 31.
Both houses are to be extensively field monitored. First results of the EcoTerra home are included in the prototype report (part 2 of the final report), further results could not be covered in the time frame of Annex 32.

5.3 System design

This chapter gives a summary on design recommendations derived in the frame of IEA HPP Annex 32. Details to the single prototypes are given in part 3 of the final report.

5.3.1 System integration of ground-coupled passive cooling function

In Switzerland, design recommendations for the integration of a passive cooling function into heat pump system for space heating and DHW were derived by simulations.

5.3.1.1 Recommended hydraulic system configuration

Fig. 32 shows the recommended hydraulic integration of the passive cooling operation in common system layouts for heat pumps of combined space heating and DHW with borehole heat exchanger.

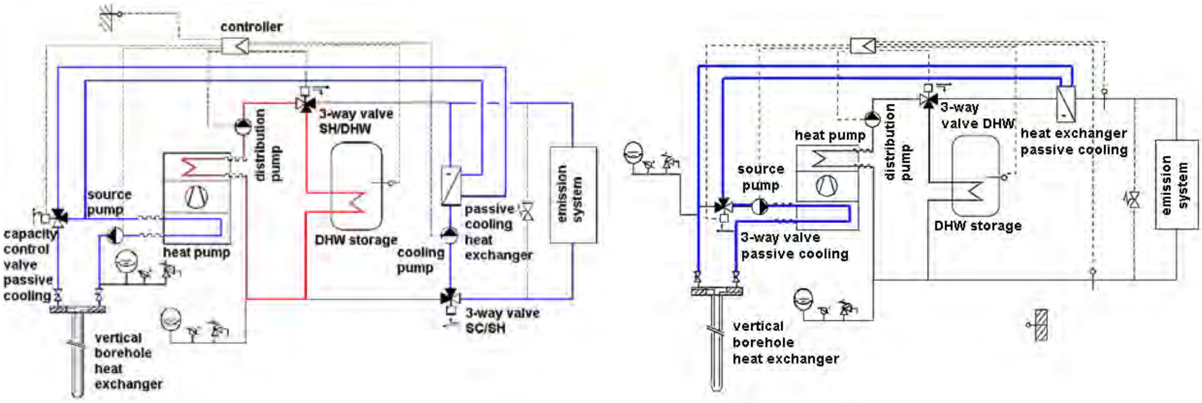


Fig. 32: Recommended hydraulic integration of passive cooling in B/W heat pump system with borehole heat exchanger with (left) and without (right) active cooling option (based on Dott, Afjei and Huber, 2007)

- The simultaneous SC&DHW is not recommended, since the improvement is with 1.7% negligible due to a short-term storage effect of the rejected heat in cooling mode in the ground.
    - Hydraulic simplification useful
- Operation with self regulation effect (design to max. flow temperature of 30°C) yields
    - further simplification of the hydraulic design (no thermostatic valves)
    - maximised COP by low space heating and higher space cooling flow temperatures

5.3.1.2 Recommended hydraulic integration of the borehole heat exchanger

The vertical borehole heat exchanger shall always be integrated in serial configuration in the order of the flow heat pump evaporator–vertical borehole heat exchanger–floor cooling heat exchanger, since the configuration maximises the COP and minimises the danger of frost in the cooling heat exchanger as depicted in Fig. 33.

5.3.1.3 Component design

Borehole heat exchanger

Usually no extra design of the borehole heat exchanger is needed for the space cooling operation, so the vertical borehole heat exchanger shall be designed according to the space heating requirements

- Design of the borehole heat exchanger (BHX) for the space heating operation is sufficient to cover about 90% of the cooling, i.e. at present ambient conditions no active cooling operation is required in Switzerland with adequate system and building design.
- The design of the heat exchanger to connect the BHX with the floor emission system is crucial for the degree of provided cooling energy
  - recommended design to a temperature difference of 1 K yields 94% cooling energy at a guaranteed capacity of the BHX of 26 W/m.
  - design to a temperature difference of 3 K decreases the cooling energy to 66% at a guaranteed capacity of the BHX of 13 W/m.

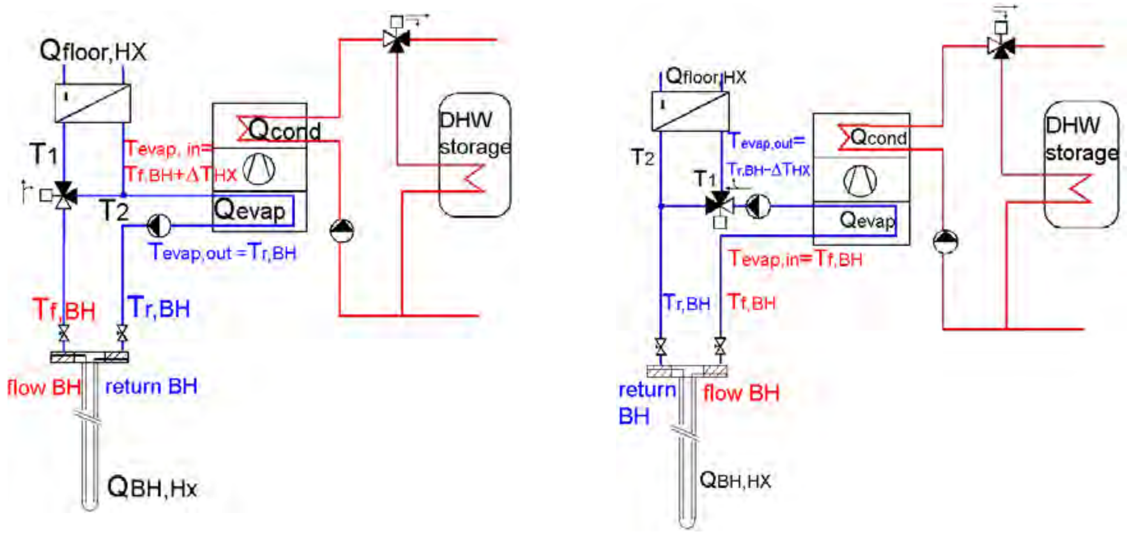


Fig. 33: Variants and recommended integration (left) of the BHX (Dott, Afjei and Huber, 2007)

<u>Cooling heat exchanger to connect borehole and floor emission system</u>

The cooling heat exchanger for the coupling of the ground and the floor shall be designed to the lowest temperature difference possible in order to minimise the loss of temperature level of the heat transfer and maximise the covered space cooling energy need by passive cooling operation as seen above. However, since the performance depends on the electrical power consumption of the circulation pump, as well, which depends on the pressure drop, an optimisation of the thermal characteristic and the pressure drop yields the optimum design of the heat exchanger.

5.3.1.4 Control

As stated above, a design with large surface of the emission system in order to achieve low flow temperature in heating and high flow temperatures in cooling mode is recommended. With this design a moderate cooling curve which increases supply temperature with increasing outdoor air temperatures can maximise the capacity of the borehole for passive cooling operation, minimises the risk of condensation on the floor and yields adequate indoor comfort. Under Swiss boundary conditions a dew point control is usually not required. However, rooms with higher moisture content (e.g. kitchen, bathroom) shall not be cooled by the floor.

5.3.1.5 Performance

Seasonal performance factors for the passive cooling function are in the range of 10-25 mainly dependent on the cooling load, since the auxililary energy stays more or less constant. Thus, the use of highly-efficient source pumps is recommended.

5.3.1.6 Comfort

A passive ground cooling with vertical borehole heat exchanger coupled to a low-temperature floor heating system can reduce the room temperature by 2 to 4 K depending on the applied shading. In combination with a passive air cooling with maximum air exchange rate of 1 ACH and consequent shading, operative temperatures can be kept below the boundary of 28°C. The design of the components for the space heating operation is sufficient for the space cooling operation, as well.
Concerning local comfort a floor temperature between 20°C and 29°C shall be kept. Rooms with higher comfort requirements, e.g. bathrooms due to barefoot walking, shall not be cooled by the floor.

5.3.1.7 Cost

Integration of a passive cooling function requires the further components cooling heat exchanger to directly connect the borehole to the floor, a regulation valve for the control with cooling curve, an extended control strategy which covers the cooling operation and depending on the emission system switchable thermostatic valve suited for space heating and cooling operation. In new single family buildings, these components add up to an additional investment of 1500-2000 €/a. The additional operational electricity cost at an electricity price of 0.1 €/kWh amounts to about 12 €/a for the passive cooling.

5.3.2 Design of heat pump air conditioners according to Japanese results

In Japan, design of heat pump air conditioners of single or multi-split, which are the standard heating and cooling system in the moderate climate zone in Japan, used to be a simple catalogue method, which led to overdimensioned systems with lower performance in low energy houses. In the frame of IEA HPP Annex 32 a new design method considering the operation control (continuous or intermittent operation) and the cumulative frequency of the heat load of house led to an improved design method, which has been implemented in the New Act on Rational Use of Energy in Japan, which was enacted in 2009.

5.4 Field monitoring results

This chapter outlines the results of manifold field test projects in the frame of IEA HPP Annex 32. Results of the field monitoring projects are detailed in part 4 of the final report of Annex 32. Individual systems solutions with good performace results in the field monitoring are documented as Best Practices sheets, which contain details on the the system concept, the field monitoring and performance. Field test of prototypes or other upcoming concepts, which could not be entirely covered in Annex 32 are outlined in System concept sheets.

5.4.1 Extensive field tests of heat pumps in new and existing buildings

An extensive field test to analyse the performance of heat pumps in low energy houses („HP-Efficiency“, http://wp-effizienz.ise.fraunhofer.de) is carried out in co-operation with 7 heat pump manufacturers and 2 utilities (see chap. 4.4).
Another field test is dedicated to the investigation of heat pumps as replacement for boilers in existing buildings, which is accomplished in co-operation with the German utility E.ON (http://wp-im-gebaeudebestand.de).
Fig. 34 left shows the plant locations in Germany (green dark dot for LEH, red light dots for existing buildings) and Fig. 34 right the system boundary used for the evaluation of seasonal performance factor (SPF), derived by a division of produced heat of the heat pump by the consumed electricity of the installed generators (incl. direct electrical back-up) and auxiliaries for the source systems.

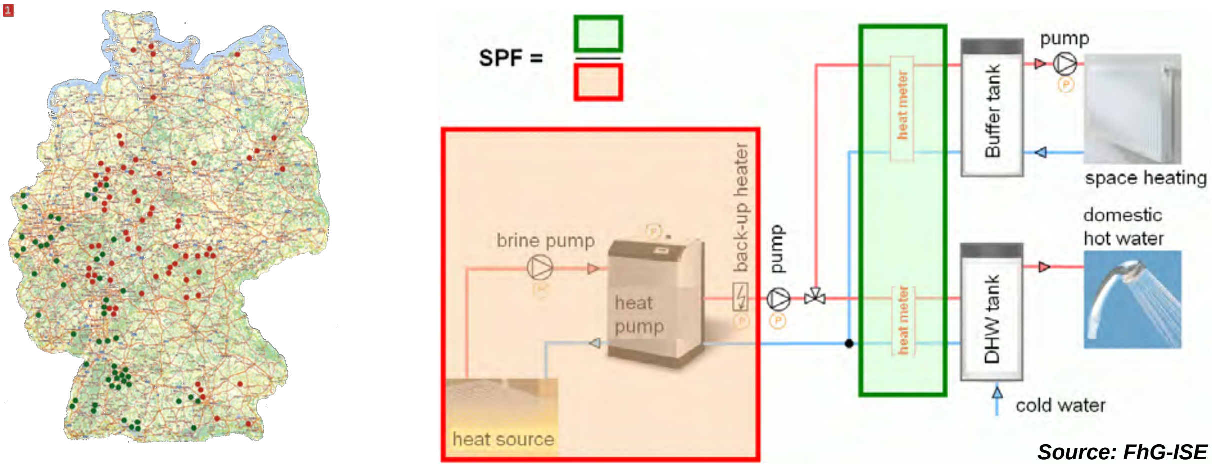


Fig. 34: Plant locations and system boundaries of the field tests (Miara et al., 2008)

Tab. 8 presents the average energy reference area (A_e), the space heating energy need (as range of calculated values of new LEH and average fuel consumption of existing buildings, respectively), installed heat pump capacity and temperatures for SH and DHW.

Tab. 8 Characteristics of the houses and installed systems in the German field tests

Project	ø A_e [m^2]	SH energy need [$kWh/(m^2a)$]	HP-capacity [kW]	Temperatures [°C]
HP-Efficiency (≈ 100 plants)	ø 192	20-50 (calculated need)	5-10	30-35 (floor heating) 45-65 (Radiator) ≈50 (DHW)
HP existing buildings (≈ 80 plants)	ø 190	ø 182 (fuel consumption)	ø13.8 (B/W) ø14.5 (A/W)	40-45 (floor heating) 45-65 (Radiator) 45-60 (DHW)

Fig. 35 shows the heat sources and the emission systems applied in the field monitoring plants in the two projects.

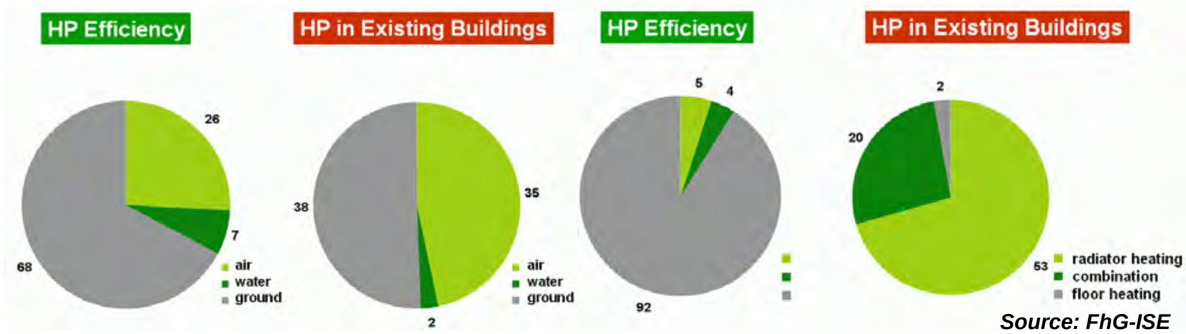


Fig. 35: Heat sources (a) and emission systems (b) in the HP-Efficiency and HP in existing buildings field test

Fig. 36 gives the seasonal performance factors of the year-round measurements in 2008. Since some of the systems have been installed in 2008, not all systems depicted in Fig. 36 have been considered, so that the number of evaluated systems for the SPF calculation is given, as well. Concerning the seasonal performance factors the brine-to-water heat pumps reach the highest performance factors, which are even higher than the water-to-water systems.

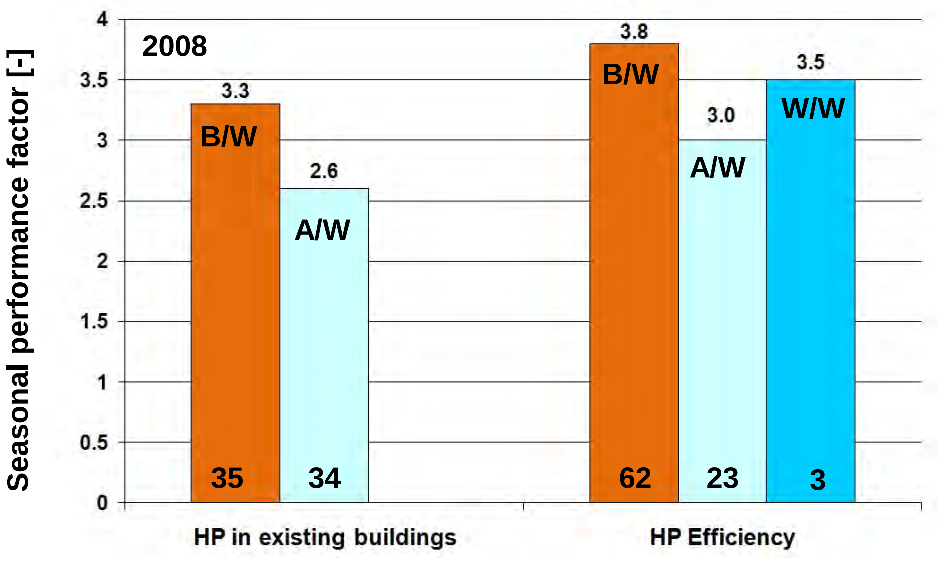


Fig. 36: SPF values of 2008 in the HP-Efficiency and HP in existing buildings field test

Brine-to-water systems have a seasonal performance factor of 3.8 in the low energy house and are 0.5 higher than in existing buildings which reflect the lower supply temperature in the low energy houses.
For the air-to-water systems the difference in 2008 is in the same range, but the three year average is only 2.8, so the difference decreases to 0.2. This is due to the relatively high average temperature of 36°C, i.e. also in the low energy houses, the potentials for a lower temperature lift are not entirely realised.

Tab. 9 Characteristics of the houses and installed systems in the 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%

Tab. 9 depicts respective back-up fractions, auxiliary energy fraction for the source pump and the DHW fraction in the two field tests.

5.4.2 Field tests of space heating and DHW heat pumps in Austria

In the Austrian project, 9 heat pumps (3 A/W, 4 B/W, 1 DX/W, 1 W/W) for space heating, DHW or combined operation at different locations in upper Austria, lower Austria and Styria have been field-monitored (Zottl, Huber und Köfinger, 2010).
The same system boundary as depicted in Fig. 34 right is used for the evaluation.
The year-round monitoring took place in different years from 2005-2008. The design heat load of the houses is in the range of 20 W/m^2- 60 W/m^2. Due to partly large living space of up to 300 m^2, the installed capacity of the heat pumps is in the range of 8–33 kW.
The emission systems are mainly floor heating systems, but also 2 radiator systems are applied. However, average flow temperatures of the emission systems are with a range of 29°C -36°C low.
Tab. 10 gives a summary of resulting seasonal performance factors.

Tab. 10 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

5.4.3 Field results of systems with ground-coupled passive cooling function

Within some field test projects an integrated passive cooling function by the source system of the ground-source heat pumps, which only uses auxiliary energy, have been evaluated, too. Various manufacturers are now offering system amendments for passive cooling on the market (also called “free cooling”, “natural cooling” or “direct cooling”).
A passive cooling function with a borehole heat exchanger has been evaluated by a field monitoring within the Swiss national project. Field monitorings took place a multi-family ultra-low energy house certified according to the Swiss MINERGIE-P® standard in Basel over a time period of two years (Genkinger et al., 2010). Weekly performance factors of the comfort cooling function is in the range of 8-15. The indoor thermal comfort could be enhanced by the passive cooling operation, lowering indoor summer temperatures by 2-3 K. Moreover, DHW performance may be enhanced by the passive cooling function due short-term higher ground temperatures than in the case without cooling operation. A seasonal effect of the passive cooling operation on the ground temperature could not be observed.
In the frame of the Austrian project two ventilation compact units with ground-coupled heat pump installed in passive houses have been measured, also including a passive cooling function by the horizontal ground collector used as source system. The passive cooling function in these two systems yielded weekly performance factors in the range of 7-12.5.

Tab. 11 SPF-values of ground-source heat pumps with passive cooling (2008-2009)

SPF	SH	DHW	passive SC	Overall
Hitzendorf	4.7	3.7	4.7	4.1
Judendorf-Straßengel	4.3	3.6	9.0	4.3
Basel	4.4	2.7	8.1	3.9
Muolen	3.8	3.1	7.3	3.8

5.4.4 Field results of capacity-controlled heat pumps

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. 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_2-eq.-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%). Fig. 37 presents the system configuration and energy balance of the second field test and the CO_2-eq.-emission savings based on the CO_2-eq.-emission factors of 0.41 kg_{CO2}/kWh for electricity and 0.0678 kg_{CO2}/MJ for fuel-oil.

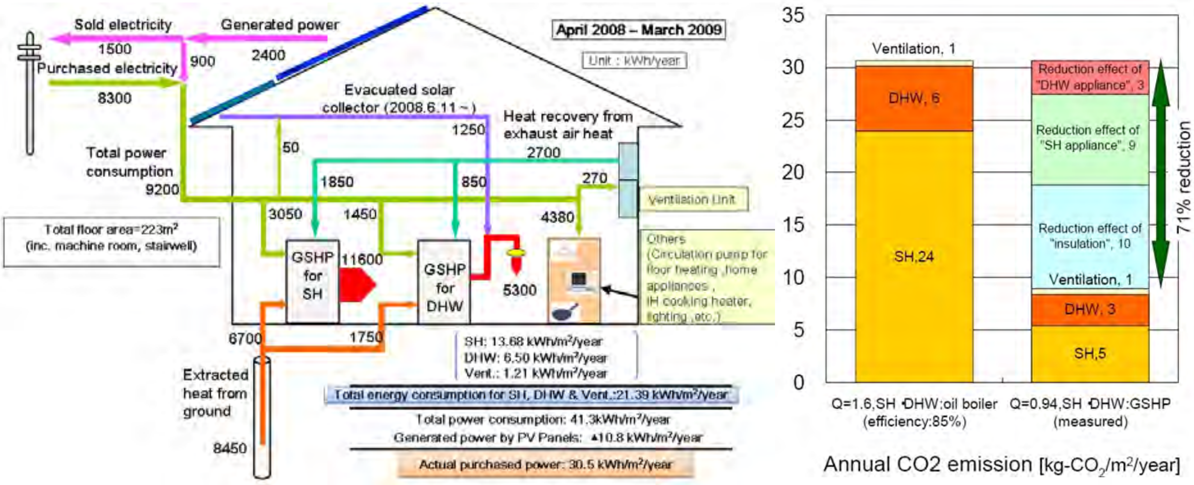


Fig. 37: Annual energy balance (left) and CO_2-emission savings (right) of the second Japanese field monitoring house (Nagano, 2009)

5.4.5 Optimisation potentials and recommendations

Typical operational problems of the heat pump systems can be classified regarding the system control, the system installation and the design.
One problem often encountered is the heat management in combi-storages for space heating and DHW which cause too high temperatures for the space heating mode and therefore decrease the SPF. In extreme cases, the DHW temperature of 55°C is reached instead of the necessary 35°C for the floor heating system. Furthermore, valves which do not entirely close or wrong installation of non-return valves can cause heat losses or discharging of the storage.
Moreover, control of the circulation pumps can be optimised. There are systems which show a longer pump operation time than necessary or pumps which run through the whole heating period. Furthermore, source pumps in ground coupled systems are often overdimensioned. Both problems cause augmented auxiliary energy consumption.
The following recommendations have been derived by the experience of the field monitoring:

- Thorough design of the system and the components (source, storage, emission system) to the requirements of the house. Lowest possible design temperatures of the emission system.
- Check of loading control strategies for the storage, control of supply temperature for heating system
- Hydronic balance, thorough and continuous thermal insulation of storage ports and pipes, in particular for combi-storages
- Deactivation of supporting direct electrical back-up heaters in case of B-W-heat pumps (except for the drying-out phase of the building due to danger of damaging the borehole heat exchanger in case of excess heat extraction)
- System design as simple and robust as possible, since in many field tests complex hydraulic systems with integrated storages do not meet the performance targets.

5.4.6 Environmental impact

Summarising, Fig. 38 shows the SPF based on primary energy, which has been calculated as quotient of the SPF and the primary energy factor, of the air-to-water (red hollow dots) and brine-to-water (blue bold dots) heat pumps documented in Best Practice Sheets.
These SPF-values are compared to a gas condensing boiler with an efficiency of 0.96 according to the average efficiency of a field test of 59 condensing boilers in Germany reported in Wolff et al. (2004).
As can be seen, of 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.

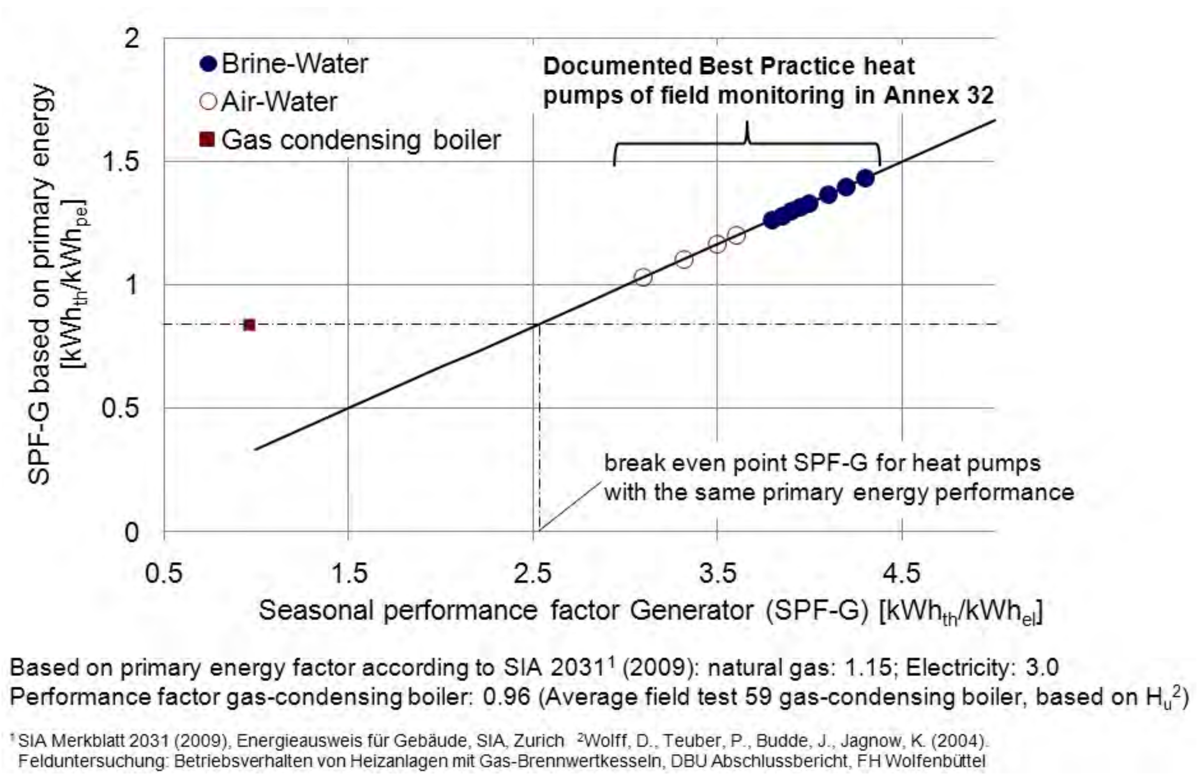


Fig. 38: Comparison of SPF based on primary energy of documented Best Practice systems to a condensing boiler for Swiss primary energy factors (gas 1.15, electricity 3.0)

6 CONCLUSIONS

In many countries, the energy consumption of buildings accounts for 40% of the total CO_2 emissions. Thus, low energy houses with considerably reduced energy consumption are a key strategy to achieve climate protection targets.
Since the mid of the nineties, the energy consumptions of new buildings were successively lowered by introducing more stringent legal requirements for the space heating energy needs in building codes and directives. This led to the development of buildings with significantly reduced space heating needs down to about 15 $kWh/(m^2 \cdot a)$ in houses according to the German passive house standard. In low energy houses, the heat load is significantly reduced and the domestic hot water (DHW) heat requirement can reach up to half of the total heat energy requirement. Moreover, ventilation is often required, and with increasing outdoor temperature, a comfort cooling may be asked by the users. Meanwhile, low energy houses show significant market growth in different European countries, while in North America, the strategic goal is the establishment of Net Zero Energy Buildings (NZEB) by 2020 (USA) to 2030 (Canada). Governments stimulate the market of low energy houses by financial support in order to fulfil climate protection targets.
Consequently, the building technology has to be adapted to the specific requirements of low-energy houses in order to guarantee an efficient operation and maximise the reduction of CO_2-emissions. In fact, system solutions for low energy houses have already been established in some national markets, but developments are not finished, yet.
Annex 32 in the Heat Pump Programme (HPP) of the International Energy Agency (IEA) entitled "Economical heating and cooling systems for low energy houses" started in 2006 with the participating countries Austria, Canada, France, Germany, Japan, the Netherlands, Norway, Sweden, Switzerland (operating agent) and the USA in order to support the further development of heat pump systems for the use in low- and ultra-low energy buildings and to prove the feasibility and performance benefit of new and marketable systems.
This report gives an overview on the background of low energy houses, building and system markets, the national contributions and the main result of IEA HPP Annex 32. Focus of the R&D in the frame of Annex 32 was on the one hand the development of new integrated heat pump concepts including lab-testing, simulation and assessment of respective prototypes. Thereby, mainly the integration of new functions, in particular a passive and active cooling function and a dehumidification and the application of natural refrigerant are addressed. Simulation results of the prototype developments confirm potentials of up to 50% compared to marketable systems.
On the other hand, extensive field monitoring of marketable integrated heat pumps for low energy houses proved the feasibility and good performance of the application in low energy houses. All field-monitored heat pumps in low energy houses achieve primary energy and CO_2 emission savings compared to best fossil system technology like gas condensing boilers. Single system with good performance and partly substantial savings compared to conventional practice were documented as Best Practice.
Last but not least, design recommendation both by simulation and field monitoring were documented for the application of integrated heat pump systems in low energy houses.
Details are given in other parts of the final report of IEA HPP Annex 32, which describe the single tasks in more detail.
While Annex 32 concentrated on system integration, current trends also include a building integration, using the building façade and roof as parts of the system technology. This approach opens the scope to even higher integration of the system and building envelope technologies, which may lead, by use of further synergies, to even more comprehensive and high-quality, high performance and low cost sustainable building concepts.

7 ACKNOWLEDGEMENT

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9 APPENDIX

The Appendix comprises the chapters

- **A: Publications under IEA HPP Annex 32**
- **B: Boundary conditions for system comparison**

A PUBLICATIONS UNDER IEA HPP ANNEX 32

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B BOUNDARY CONDITIONS FOR THE SYSTEM COMPARISON

B.1 French study of system solutions in France

B.1.1 Characterisation of the Building

The selected BBC-individual house has a surface area of 115 m^2, which is characteristic of newly built houses in France. With breeze blocks and inside insulation, its construction mode is traditional.
Two thermal zones are defined (see *Figure 1*):

- "Day" living area corresponding to the ground level: kitchen, living room, hall and toilet (59.7 m^2),
- "Night" sleeping area corresponding to the first floor: three bedrooms, bathroom, toilet and corridor (55.9 m^2).

The detached house is built on a crawl space with an attached garage. The reference surface or the French SHON calculation method is 142.5 m^2. More details are provided in

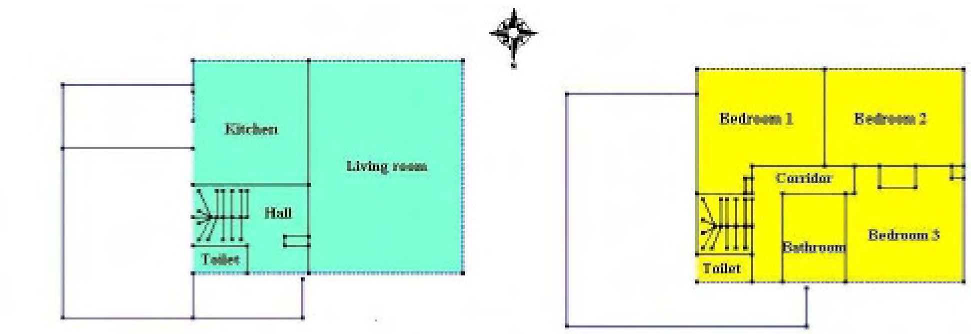

Fig. B 1: Floor plan of the house

Tab. B 1: Characteristic of the reference building envelope (26% better than RT2005)

Parameters	Description	Coefficients
External walls	20 cm thick breeze block with styrofoam and plaster sheet coating	U = 0.282 W/(m².K)
Ground level area	20 cm full concrete slab with 75 mm mineral wool insulation (R = 2.05 m². K/W)	U = 0.309 W/(m².K)
Windows	4/16/4 mm double glazing and PVC joinery Wooden shutters	Uw = 1.7 W/ (m².K), Ujn = 1.5 W/(m².K), SF² = 0.42
Doors	Entrance and garage doors	U = 1.5 W/(m².K)
Roof	26 cm mineral wool insulation	λ= 0.035W/(m.K)
U_{shell}	-26% of the standard RT2005 reference coefficient (in H1 Northern area of France)	U = 0.388 W/(m².K)
Air permeability	The flow of fresh air is of 62.8 m^3/h in the day living zone and 111.4 m^3/h in night zone	0.8 m^3/h/m² under 4 Pa, i.e. 0.6 vol/h

B.1.2 Ventilation system

A B-hygro modular system is used for ventilation. A B-hygro modular system is an efficient single flow ventilation system which adjusts inlet and outlet air flow rates in each room according to relative humidity of the air. Following air flow results for a standard system and a B hygro modular system:

- B-hygro modular: 20 m^3/h
- Standard system: 90 m^3/h

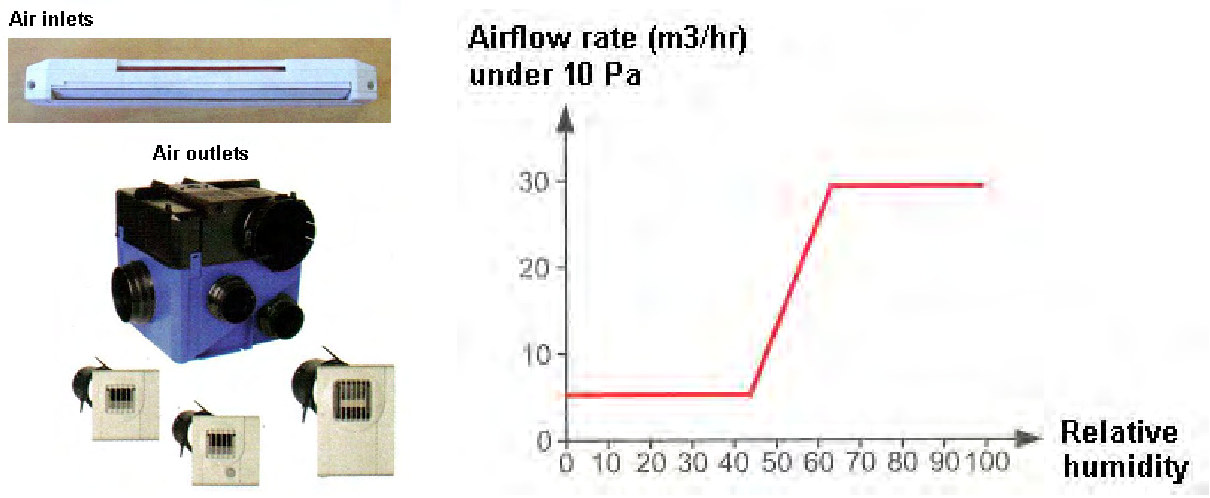

Fig. B 2: Ventilation system assumptions

B.1.3 Climate and design

The house is assumed to be located in the H1 cold climate zone, which accounts for the North, East and Centre of France. Therfore, its corresponding threshold value set by the BBC label is increased to 65 $kWh_{pe}/(m^2a)$.
Required power for space heating including losses through walls, infiltrations and air exchange is calculated for an outdoor design temperature of T_{OD} = -9 °C (in H1 area) and an indoor design temperature of T_{ID} = 20 °C.
By taking into account internal and solar gains, the required installed power is 5380 W (i.e. 46.5 $W/m^2_{living\ space}$) and the annual heating needs are 7666 kWh (i.e. 66.3 $kWh/m^2_{living\ space}$ per year).
The space heating setpoint temperature is of 19 °C during occupancy period (i.e. from 0 to 10 am and from 6 pm to 0 am during weekdays and all daylong during Saturdays and Sundays), while the setpoint temperature is 16 °C when the house is empty.
These temperature values are used to get the energy consumption. The heating period for H1 climate area lasts from the 14th of October to the 16th of June.

B.1.4 Internal gains

Lighting equipments and internal load by the user comply with the Th-CE calculation methods (CSTB (2006))
According to the RT2005 thermal regulation, internal gains are 5 W/m² during occupancy period. This period is defined by 16 hours during week-days (Monday to Friday from 0 to 10 am and 6 to 0 pm, from) and 24 hours during weekends. Resulting internal gains are 298.5 W in “day-living area” and 279.5 W in “night-living area”.
Moisture production is integrated over the same periods of occupancy with
0.002 $kg_{water}/(h{\cdot}m^2)$. Hence, the resulting latent input is 0.12 kg_{water}/h in the “day-living area” and 0.11 kg_{water}/h in the “night-living area”.
Regarding the residential sector, the RT2005 defines lighting input to 2 W/m² during occupancy periods, i.e. 5 hours from Monday to Friday (7 to 9 am and from 7 to 10 pm) and 15 hours on Saturdays and Sundays (from 7 am to 10 pm). Based on these assumptions, simulated lighting input is 119.4 W in the “day-living area” and 111.8 Watts in the “night-living area”.

B.1.5 DHW

The volume of daily tapping water draw-offs is given by the following formula

$V = a \cdot ah \cdot Nu \; [in \; m^3]$,

with
Nu area of living space [m^2]
a litres of needed water at 40 °C,
ah coefficient accounting for the daytime breakdown (see Tab. B 5).

However, to get the draw-off volume at the production temperature, i.e. 65°C, the temperature of fresh water provided in the Th-CE calculation method was used, so a draw-off volume of

60.3 l at 40°C
32.7 l at 65°C

Tab. B 2: DHW coefficient ah dependent on the time of day

Daytime	ah coefficient
7 to 8 am	0,028
8 to 9 am	0,029
9 am to 6 pm	0
6 to 7 pm	0,029
7 to 8 pm	0
8 to 9 pm	0,028
9 to 10 pm	0,029
10 to 11 pm	0
11 pm to 0 am	0

B.1.6 Characterisation of Best Available Technology (BAT)

B.1.6.1 Building envelope

Tab. B 3: Characteristic of the reference building envelope (26% better than RT2005)

Parameters	Description of the insulation	Coefficients
Walls	Polyurethane (PU)	λ = 0.023 W/(m.K)
Roof	300 mm mineral wool	λ = 0.032 W/(m.K)
U_{shell}	-44% of the standard RT2005 reference coefficient (in H1 Northern area of France)	U = 0.292 W/(m².K)
Air permeability	Value advised in BBC-Effinergie label	0.6 m^3/h/m² under 4 Pa

B.1.6.2 Characteristic of the space heating and DHW systems

Tab. B 4 and Tab. B 5 comprise the characteristics of the space heating and DHW systems.

Tab. B 4: Characteristic of the space heating systems

Name	Type of system	Performances
A/W HP	Air-to-water Heat pump (efficient)	COP = 3.4 at +7°C/35°C & COP = 2.4 at –7°C/35°C
A/W BHP	Best air-to-water Heat pump	COP = 4.1 at +7°C/35°C & COP = 2.24 at –7°C/35°C
W/W HP	Basic geothermal Heat pump	COP = 4,5 at 10°C/35°C
Joule	Direct electric convector	η (efficiency) = 1
A/A BHP	Air-to-air Heat pump (multi-split)	COP at +7°C/20°C = 4.8 & COP at –7°C/20°C = 3.4
BGas_Boiler	Condensation gas boiler	η (ICP[3]) = 96,8% at Pn,, η = 110 % at 0.3* Pn
BWood_Boiler	Wood pellet boiler (automatic)	η = 88% at Pn

Tab. B 5: Characteristic of the DHW systems

Name	Type of system	Performances
SWH	Solar Water Heater with electric auxiliary	Tank of 300 l, 4 m² of solar panel, η = 0,72
BSWH	Best Solar Water Heater with electric auxiliary	Tank of 300 l, 4 m² of solar panel, η = 0.82
SWH_gas	Solar Water Heater with gas auxiliary	Tank of 300 l, 4 m² of solar panel, η = 0,72
Thermo HW	Thermodynamic Hot Water boiler	Tank of 200 l – annual COP = 2,6

B.2 WWF –Study of the system comparison for Switzerland

Tab. B 6: Energy characteristic of the heating systems

Energy need heat (SH&DHW)				14400 kWh/a						
			oil	gas	B/W HP	A/W HP	pellet	pellet/ solar	oil/ solar	gas/ solar
			[l]	[m^3]	[kWh]	[kWh]	[t]	[t]	[l]	[m^3]
Energy consumption/system			1469	1426	4235	5538	3.4	2.7	1249	1212
Energy content/unit [Hu]		[kWh/...]	10	10.1	1	1	5200	5200	10	10.1
seasonal performance		SPF	0.98	1.0	3.4	2.6	0.82	0.82	0.98	1.00
auxiliary energy		kWh/a	191	144			263	311	262	222
fraction solar								20%	15%	15%
space requirement		m^3	10	2	2	6	10	10	10	3

Tab. B 7: Investment costs of the heating systems

Investment costs			**oil**	**gas**	**B/W HP**	**A/W HP**	**pellet**	**pellet/ solar**	**oil/ solar**	**gas/ solar**
		lifetime	[CHF]	[CHF]	[CHF]	[CHF]	[CHF]	[CHF]	[CHF]	[CHF]
fuel store/tank		30	3'000				3000	3000	3000	
connection network		25		4500						4500
boiler/heat pump		18	10000	4500	10000	12000	13000	13000	10000	4500
chimney		30	2500	2500			3500	3500	2500	2500
expansion		18	500	500	500	500	500	500	500	500
DHW storage		20	2000	2000	2500	2500	2000	4000	3000	3000
ground/air source		30			10000	1800				
heat distribution		30	2000	2000	2000	2000	2000	2000	2000	2000
thermal insulation		30	1000	1000	1000	1000	1000	1000	1000	1000
installation/wages		20	1500	1500	1500	1500	1500	1800	1800	1800
sanitary		25	1500	1500	1500	1500	1500	2000	2000	2000
electrical installation		18	2000	2000	2000	2000	2000	2500	2500	2500
surrounding, garden		20	1000	1500	3000	2500	1000	1000	1000	1500
dismantling, recycling		20	3000	3000	3000	3000	3000	3000	3000	3000
solar system		20						6000	5000	5000
Subsidies /tax reduction										
Total investment			**30000**	**26500**	**37000**	**30300**	**34000**	**43300**	**37300**	**33800**
average depriciation			22	23	23	21	22	22	22	22
Annuity [%] at interest rate	**3**	%	6.22	614	6.07	6.52	6.25	6.34	6.31	6.25
Total capital costs		**CHF/a**	**1867**	**1627**	**2247**	**1974**	**2126**	**2745**	**2352**	**2111**

Tab. B 8: Maintenance costs of the heating systems

Additional costs			**oil**	**gas**	**B/W HP**	**A/W HP**	**pellet**	**Pellet/ solar**	**oil/ solar**	**gas/ solar**
Service/repairs			400	300	100	200	500	500	400	300
Flue gas control			40	20					40	20
Chimney sweeper			190	47			190	190	190	47
Tank cleaning			90						90	
interest fuel			35				30	24	30	
total additional costs		**CHF/a**	**755**	**367**	**100**	**200**	**720**	**714**	**750**	**367**

Tab. B 9: Energy costs of the heating systems

Energy costs			**oil**	**gas**	**B/W HP**	**A/W HP**	**pellet**	**pellet/ solar**	**oil/ solar**	**gas/ solar**
		SPF	0.98	1.00	3.40	2.60	0.82	0.82	0.98	1.00
energy use		kWh/a	14694	14400	4235	5538	17561	14049	12490	12240
fuel costs										
heating fuel EL	80	Fr/100 ltr.	1176						999	
gas installation	300	SFr./a		300						300
gas	7.1	Rp/kWh		1012						860
Electr. installation	125	SFr./a			125	125				
electricity high tariff	20	Rp/kWh	25	19			34	41	34	29
electricity low tariff	8	Rp/kWh	5	4			7	8	7	6
el. winter HP-high tariff	15	Rp/kWh			426	557				
el. winter HP-low tariff	11	Rp/kWh			154	201				
Pellets blown in store	300	Fr./ton					1013	811		
Total energy costs		**CHF/a**	**1206**	**1335**	**704**	**883**	**1055**	**859**	**1040**	**1195**

Tab. B 10: Total annual costs of the heating systems

Total annual costs			**oil**	**gas**	**B/W HP**	**A/W HP**	**pellet**	**pellet/ solar**	**oil/ solar**	**gas/ solar**
capital costs			1867	1627	2247	1974	2126	2745	2352	2111
energy costs			1206	1335	704	883	1055	859	1040	1195
Add. Costs			755	367	100	200	720	714	750	367
Total annual costs		**CHF/a**	**3828**	**3329**	**3052**	**3057**	**3901**	**4319**	**4142**	**3673**
% difference to oil		%	100	87	80	80	102	113	108	96
price of heat		**Rp/kWh**	**26.2**	**23.1**	**21.2**	**21.2**	**27.1**	**30.0**	**28.8**	**25.5**

IEA Heat Pump Programme
Heat Pump Centre
c/o SP Technical Research Institute of Sweden
PO Box 857
SE-501 15 BORÅS
Sweden
Tel: +46 10 516 5512
Fax: +46 33 131 979
E-mail: hpc@heatpumpcentre.org
www.heatpumpcentre.org

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