Technology Collaboration Programme
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Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 32

Economical heating and cooling systems for low energy houses

Final Report – Part 2

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Preface

This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), which is a Technology Collaboration Programme 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 nearly 40 Technology Collaboration Programmes.

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Consistent with the overall objective of the HPT TCP, the HPC seeks to accelerate the implementation of heat pump technologies and thereby optimize the use of energy resources for the benefit of the environment. This is achieved by offering a worldwide information service to support all those who can play a part in the implementation of heat pumping technology including researchers, engineers, manufacturers, installers, equipment users, and energy policy makers in utilities, government offices and other organizations. Activities of the HPC include the production of a Magazine with an additional newsletter 3 times per year, the HPT TCP 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 Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:

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Final report Annex 32 part 1

IEA HPP Annex 32

Economical heating and cooling systems for low energy houses

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System solutions

Multifunctional heat pump systems for the application in low energy houses

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IEA HPP Annex 32 " Economical heating and cooling systems for low energy houses"

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Summary

The report gives an overview of marketable heat pump system solutions applied in low energy houses in the participating countries of IEA HPP Annex 32. In low energy houses, loads change significantly, in particular the space heating needs are notably reduced, and the share of DHW increases. Moreover, mechanical ventilation may be required to guarantee the necessary air exchange due to the air-tight building construction, and in recent years market development show an increasing integration of a comfort cooling option in the system layouts.
Therefore, integrated multifunctional heat pumps have advantages of covering different building functions at the same time, e.g. in simultaneous space cooling and DHW operation.
The report is intended to facilitate a system decision by giving tree depiction as overview of system solutions. Due to the above described different loads and building services the system classification is based on the integrated system functionalities.
First, an overview of heat source and heat emission systems is given. In Europe, outside air and the ground are the predominant heat sources used in the residential sector. However, in low energy building with mechanical ventilation system, exhaust air is increasingly used as heat source, in particular in ultra-low energy houses, where a mechanical ventilation is always installed. In Japan and the USA air-source heat pumps are very common. In the USA, central ducted systems are used, while in Japan, heat pump air conditioners or multi-split system for heating and cooling are mainly applied.
The top level system classification distinguishes between integrated ventilation function, cooling function, combined space heating and DHW functions and finally only a single functionality of the heat pump without integration, which are currently common on the market.
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 heat pump 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. So-called 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 hygienic ventilation rate to about 1.0-1.5 kW depending on the volume flow rate, so ground-to-air heat exchangers to increase the inlet temperature and an additional outdoor air volume flow for the heat pump evaporator are used to increase the heating capacity.
Systems with integrated cooling functions and no coupling to the ventilation can be differentiated in ground- or water-coupled passive cooling and active cooling by reverse operation of the heat pump and distinguished by the heat source.
For combined operating space and water heating heat pumps, alternate and simultaneous configurations exist. In Europe mainly alternate operation by switching the heat pump from space to DHW heating is found on the market, while in Northern America, simultaneous operation by desuperheater is more common.
In the category of systems with single functionality, standard configurations for space heating-only are given as well as heat pump water heaters are described, in particular CO_2 heat pump water heaters, which have reached a considerable market share in Japan.

Contents

IMPRINT 2

SUMMARY 3

CONTENTS 5

PREFACE 7

1 INTRODUCTION 9

2 SYSTEM CLASSIFICATION 11
2.1 SYSTEM CLASSIFICATION OF HEAT PUMPS FOR LOW ENERGY HOUSES 11
2.2 DISCUSSION OF HEAT SOURCES FOR HEAT PUMP SYSTEMS 11
2.3 DISCUSSION OF HEAT EMISSION SYSTEMS FOR HEAT PUMPS 15

3 VENTILATION AIR SOURCE HEAT PUMP SOLUTIONS 19
3.1 VENTILATION SYSTEMS 19
3.2 CLASSIFICATION OF VENTILATION AIR SOURCE HEAT PUMP SOLUTIONS 20
3.3 EXHAUST-AIR HEAT PUMP WATER HEATER 21
3.4 EXHAUST-AIR HEAT PUMP FOR SPACE HEATING AND DHW 21
3.5 ACTIVE HEAT RECOVERY BY THE HEAT PUMP 22
3.6 COMPACT UNITS 23
3.7 SYSTEMS FOR PREHEATING THE INLET AIR WITH THE GROUND 25
3.8 ADDITIONAL FUNCTIONS OF THE VENTILATION SYSTEM 25

4 HEAT PUMP SYSTEMS WITH SPACE COOLING OPTION 27
4.1 AIR-TO-AIR AIR-CONDITIONERS AND HEAT PUMPS 28
4.2 AIR-TO-WATER HEAT PUMPS 36
4.3 GROUND- AND WATER SOURCE HEAT PUMPS 37

5 HEAT PUMP SYSTEMS FOR SPACE HEATING AND DHW 39
5.1 SYSTEMS WITH ALTERNATE OPERATION 39
5.2 SYSTEMS WITH SIMULTANEOUS OPERATION 41
5.3 SYSTEMS WITH INTEGRATION OF SOLAR ENERGY 43

6 HEAT PUMP SYSTEMS WITH SINGLE FUNCTIONALITY 45
6.1 SPACE HEATING-ONLY HEAT PUMPS 45
6.2 HEAT PUMP WATER HEATERS 46

7 CONCLUSIONS 49

8 ACKNOWLEDGEMENT 51

9 REFERENCES 53

10 APPENDIX 55

A MARKET OVERVIEW ON HEAT PUMP COMPACT UNITS 56

B MARKET OVERVIEW ON RECENT MINI SPLIT UNITS 59

C SUMMARY OF COMMON HEAT PUMP TYPES 65
C.1 AIR-TO-AIR HEAT PUMPS – SUMMARY 65
C.2 EXHAUST AIR – VENTILATION AIR HEAT PUMPS – SUMMARY 66

C.3 BALANCED VENTILATION AIR HEAT PUMPS – SUMMARY 67
C.4 AIR-TO-WATER HEAT PUMPS – SUMMARY 68
C.5 BRINE- AND WATER-TO-WATER HEAT PUMPS – SUMMARY 69
C.6 COMPARISON OF VENTILATION AIR HEAT PUMPS IN NORWAY 70

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^{2}a)) 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

Energy needs in low energy buildings differ significantly from energy needs in the existing building stock. Space heating energy needs have been reduced significantly since the mid of the nineties. Thus, DHW energy needs constitute a bigger share of the total heating requirement. Further functionalities of the building technology have been added, such as a mechanical ventilation system, which is increasingly installed in low energy houses. Moreover, a cooling function may be added due to rising temperature in the course of climate change and increasing request for indoor comfort.

Therefore, system configurations have to be adapted to the changed situations and functionalities. Interesting concepts are integrated system configurations, since

- Waste heat, e.g. from the exhaust air, can be recovered for other building needs
- Different building needs can be covered simultaneously with efficiency gains, e.g. in case of a combined space cooling and DHW operation

Heat pumps have several advantages as core component of integrated systems in low energy houses.

- Highly-efficient with proper design of the system, use of ambient heat
- Available on the market down to very low capacity ranges
- Environmentally-sound technology, no dependency on fossil fuels (except for the electricity generation)
- With renewably generated electricity entirely CO_2-free operation possible
- Space heating and -cooling with one generator possible
- Simultaneous supply of different building services (e.g. space heating and DHW)
- Further reduction of building losses possible (e.g. exhaust-air heat pumps)
- Depending on the boundary conditions economically favourable
- Independent of rising oil and gas prices (as far as electricity prices are not affected)

This report gives an overview of marketable system solutions with multifunctional heat pumps. Due to the market introduction state, the report is restricted to electrically-driven heat pumps. The classification of system solutions is based on the functionality of the system.

In chapter 2 an overview of the system classification and a discussion of source- and sink systems are given.

In chapter 3, ventilation-based heat pump solutions are presented in more detail.

Chapter 4 treats system solutions with cooling option independent of the ventilation system.

Chapter 5 deals with integrated heat pump solutions for space heating and DHW operation, and gives an overview of the integration of solar and heat pump systems.

Chapter 6 shortly covers heat pumps with single functionalities, comprising CO_2 heat pump water heaters.

In the conclusion an outlook on further systems developments is given.

2 System Classification

2.1 System classification of heat pumps for low energy houses

In this chapter a basic system classification is presented. For the purpose of system choice, systems are distinguished with regard to the functionality, since the required functionalities are fixed first in the design process. Fig. 1 gives an overview of the system classification.
As first feature it is to be determined, if the building is equipped with a mechanical ventilation system which is coupled to the heat pump. System solutions containing a mechanical ventilation system with integrated heat pump are further classified in chapter 3. A coupling to the mechanical ventilation system generally leads to highly-integrated system solutions, which may have benefits of internal heat recovery.
Further on, it is to be decided, if a cooling function by the heat pump or the source system is to be included in the heat pump solution. Heat pump solutions with cooling function, which are not coupled to a mechanical ventilation system, are further classified in chapter 4.
As next step a decision has to be taken if a combined DHW-operation is accomplished with the heat pump. Heat pump system solutions without space cooling function and without coupling to a mechanical ventilation system are further classified in chapter 5.
Finally, in chapter 6, a short overview of heat pump solutions with only a single functionality like space heating-only or DHW-only system solutions is given. However, these systems are only discussed briefly, since they are well introduced in the market of many countries and are not in the focus of Annex 32.

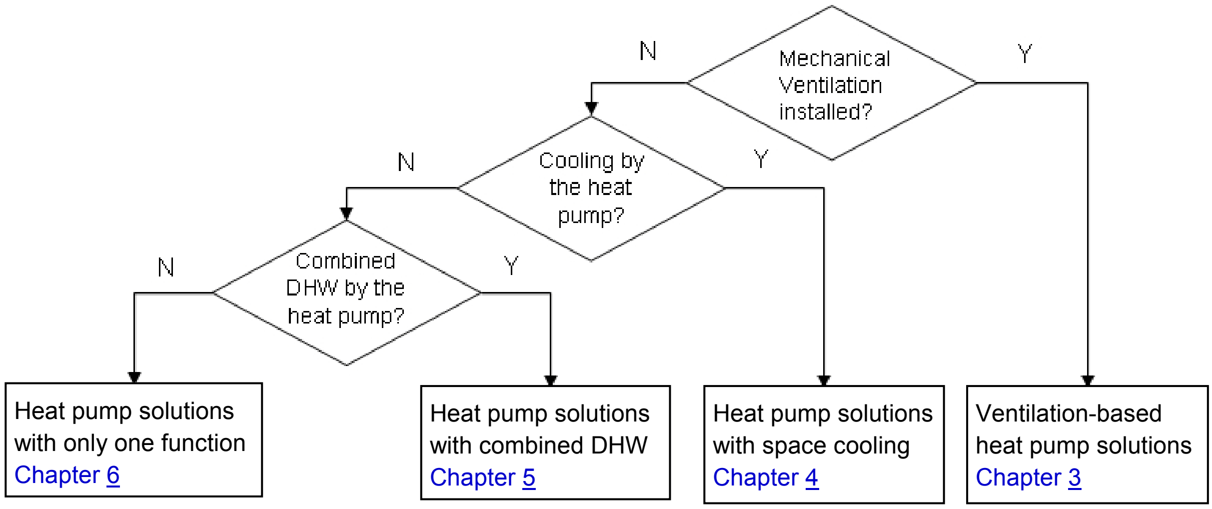


Fig. 1: Top-level system classification

2.2 Discussion of heat sources for heat pump systems

2.2.1 Overview of common heat sources

Main heat sources used for residential small-scale heat pump systems nowadays are outdoor air and the ground. In particular in low energy houses, however, exhaust air may be an increasingly used heat source due to installed mechanical ventilation systems. Where available, ground water and surface water are favourable heat sources. Use of gray water, solar energy and massive absorbers as heat source is still rare.

Regarding large-scale heat pumps for multi-family houses, blocks of flats or apartment houses, ground and surface water as well as borehole fields are common heat sources.

2.2.1.1 Outdoor air

Outdoor air is one of the most frequently used heat sources for residential heat pumps, since outdoor air is available everywhere and the connection of the source to the heat pump is generally easy and cheap. However, source temperature is opposite to the heating needs and in cold wintertime the capacity and performance is limited. Efficiency and capacity gains may be achieved, if the air is partly sucked from warm surroundings (uninsulated cellar, garage, exhaust air). Up to +7°C outdoor air temperature a defrosting operation has to be provided, and condensate has to be rejected in a frost secure pipe. Noise protection measures have to be carefully considered. Smaller systems (5-50 kW) are usually put inside the building unless no space in the building is available. Split systems have an outdoor (evaporator) and indoor (condenser) unit and are used, if the necessary air volume flow cannot be directly connected to the system placed inside the building.

2.2.1.2 Ground

The ground can be used both as heat source and heat sink for systems with space heating and space cooling operation. However, the annual energy balance has to be considered. Seasonal storage of larger amounts of energy in the ground is only possible for field of boreholes. In single borehole systems the stored heat escapes in the ground by heat conduction or ground water flow.
Most common systems of ground heat sources are horizontal ground collectors and vertical borehole heat exchangers.

Fig. 2: Horizontal collector and ditch collector (here as additional source for exhaust air heat pumps (Fehrm, 2005)

Horizontal collectors are usually buried in the ground at a depth of 1.2-1.5 m below the surface, i.e. under the level, where frosting of the ground occurs. They are easier to install, since no drilling is needed, but require quite a lot of digging and space in the garden. A variant are ditch collectors and ground baskets. Ditch collectors comprise a set of vertical tubes connected by a horizontal supply and return pipe, which are buried in a ditch in the ground. The used area is thus smaller than for horizontal collectors. Ground basket heat exchangers depicted in Fig. 3 are winded coils which are buried in the ground in 1.5-5 m depth.
Another variant are direct expansion (DX) systems, where the refrigerant is directly evaporated in the ground loop without an intermediate heat exchange fluid (open loop system). Advantages are less auxiliary energy consumption, since no source pump for the circulation of the intermediate heat exchange fluid is needed, and higher evaporation temperatures due to the direct evaporation without temperature drop in the evaporator. However, pipes have to be thoroughly sealed to avoid leakage of refrigerant into the ground and the atmosphere.

Fig. 3: Ground basket heat exchanger coil

Vertical borehole heat exchangers require the drilling of the borehole. Most common borehole heat exchangers are of double U-tube type, but also single U-tube and coaxial types are used. Main design aspects are the type of soil, the number of boreholes, the diameter and distance of boreholes and the pressure drop. To evaluate the ground characteristics, mostly for large-scale systems, so-called thermal response tests are accomplished. Most systems use brine, but with an adequate design to exclude freezing in the borehole heat exchanger, systems can also be operated with water. Cost of drilling is dependent on the ground characteristics. The drilling of borehole heat exchangers usually requires permission. Particular sites may be exempted of drilling, e.g. drinking water or geologically instable areas.

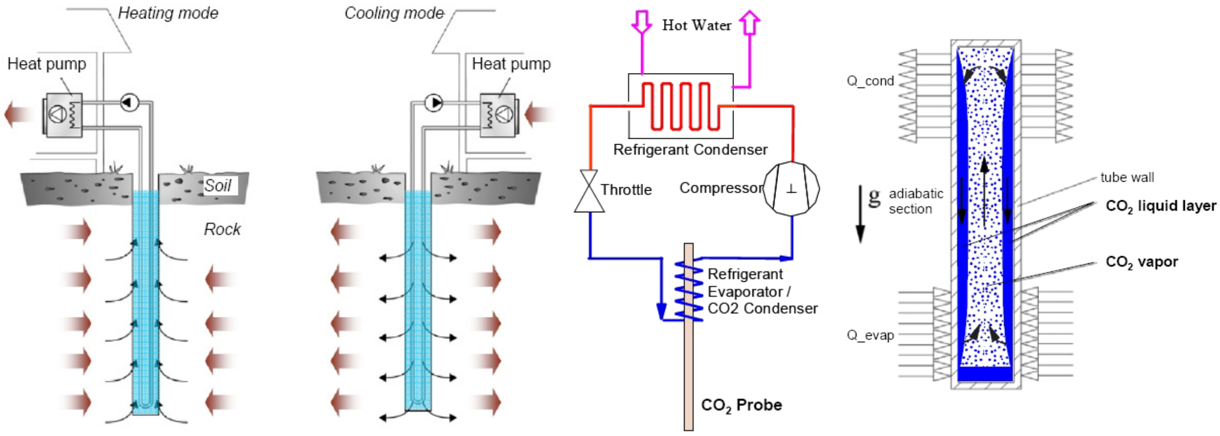


Fig. 4: Borehole heat exchanger in heating and cooling mode (left, Stene, 2007) and system layout and working principle of the CO_2 heat pipe (right, Heinz et al., 2007)

A recent development concerning vertical borehole heat exchangers is a heat pipe system with the working fluid CO_2. The working fluid CO_2 is evaporated in the heat exchanger below the ground flows to the heat exchanger at the top of the system, where the vapour is condensed by the evaporating refrigerant and returned to the lower end by gravity. As in direct expansion systems no source pump, which in conventional systems is one of the major consumers of auxiliary energy, is needed due to the natural heat pipe cycle, which increases the system performance. Additionally, the heat transfer is enhanced by the evaporation and condensation and due to the harmless working fluid CO_2, the system can also be installed in water protection areas. Fig. 4 right illustrates the system layout and the working principle of the CO_2 heat pipe. A pilot system is monitored in the Wattwerk® (http://www.wattwerk.ch), the first business building acc. to Swiss MINERGIE-P® standard.

2.2.1.3 Exhaust air

Exhaust air can be used as heat source in systems with a mechanical ventilation system. Since in many low energy houses, a mechanical ventilation system is installed due to the air tightness of the building, exhaust air is a common heat source in low energy buildings. However, due to volume flow rates restricted to the hygienic necessary air exchange the capacity is limited, in particular since most balanced ventilation systems are equipped with a passive ventilation heat recovery, i.e. a heat exchanger to preheat the outside air with the return air. In order to augment the capacity, variants with an additional ground source have been developed as shown in Fig. 2, or the exhaust air is mixed with an additional outdoor air flow at the inlet of the evaporator.

2.2.1.4 Water

The use of ground water depends strongly on the availability. Ground water has the best temperature conditions with a year-round nearly constant temperature in the range of 10°C. Normally, ground water is used directly by a source and sink well. Even though ground water is an attractive thermal heat source the cost for the connection to the source is the highest.
Surface water of lakes and rivers has lower temperatures and is normally used indirectly by an intermediate brine cycle either by a well or by a heat exchanger in the water source, which however has to be protected against pollution.

2.2.1.5 Grey water

Grey water is a promising heat source due to the temperature level, but is only used in larger buildings so far.

2.2.2 Choice of heat source system

The most important criteria for the choice of the heat source are

- availability
- temperature level
- capacity and
- cost.

The heat source with a constant availability and the highest temperature level should be chosen. The heat sources water and the ground are the most favourable, but are not available everywhere and have higher costs for the connection of the source to the heat pump. In low energy houses with low heat loads and installed ventilation systems exhaust air may become an interesting heat source, but its capacity is limited by the required ventilation flow rate. Thus, the use of hydrid sources, in particular the combination of exhaust air and outside air or the combination of exhaust air with the ground are under development and are partly available on the market. An overview of the characteristics of most common heat sources is given in Tab. 1.

Tab. 1 Characteristic of most common heat sources

Heat sources				
Criteria	**Outdoor air**	**Ground**	**(Ground) water**	**Exhaust air**
Availability	everywhere	high	restricted	in connection with ventilation system
Capacity of source	depending on volume flow rate	range of capacity: • Borehole: ≈50 $W/m_{groundHX}$ • Collector, dry soil: ≈10 W/m • Collector, wet soil: ≈35 W/m	range of capacity: • Ground water: 150-200 l/(h·kW) • Surface water: 300–400 l/(h·kW)	limited in case of hygienic necessary air exchange
Temperature range	-20°C - 40°C	1°C - 15°C	8°C – 13°C	20 - 28°C
Frosting risk	up to ≈7°C outdoor air temperature	in case of underdimensioned short ground HX	none	in case of coupling with ventilation heat recovery
Coherence SH need and source capacity	incoherent	low	middle	constant
Passive cooling possible	no	yes	yes	no
Required space	depending on type	• low (borehole) • high (collector)	low	low
Permission	none	required	required	none
Configuration	direct use	• intermediate cycle brine or water • direct expansion of refrigerant	• direct • intermediate cycle depending on water quality	direct use
Cost of heat source (CH)	low	average	high	low, if ventilation system is installed anyway
Further requirements	• consideration of operation limits of the heat pump • consideration of noise issues	access/permission for drilling required	• permission required • consideration of water quality	• consideration of operation limits of the heat pump • consideration of noise issues

2.3 Discussion of heat emission systems for heat pumps

2.3.1 Choice of emission system

The main criteria for the choice of the emission (or heating and cooling distribution) systems are the required temperature level and cost.

High efficiencies of the heat pump are mainly possible with emission systems which use temperature levels close to the indoor air temperature. While increasingly applied in office buildings, thermally-activated building systems (TABS) are still rare in residential buildings, so floor heating systems are the most common solution for the emission system in central Europe.

On the other hand, design and installation costs are the second argument, which is best for decentral air systems or central ventilation systems which are installed anyway and used for heating and cooling energy transport, since the hydronic distribution is saved.

Radiator and convector systems are not so common in low energy houses with heat pumps due to the higher required temperature by the reduced surface.

Tab. 2 gives a summary of the characteristic of different types of emission system for space heating and cooling based on Recknagel, Sprenger and Schramek (2006) and Baxter (2009).

Tab. 2: Overview of different space heating emission systems in low energy buildings

Space heating				
Criteria	**TABS**	**Floor heating**	**Radiators/ Convectors**	**Air heating**
Thermal Capacity	very high	high	rather low	low
Temperature requirements	below 30°C	30°C – 40°C	40°C – 70°C	Depending on volume flow Up to 50°C with only hygienically required air flow
Heating capacity	max ~40 W/m^2 (heating surface)	max. 80 W/m^2 (heating surface)	max. 1300 W/m^2 (heating surface)	max. 10 W/m^2 (energy reference area)
Use of solar gains	depending on control concept: (may be restricted due to hot floor)	depending on control concept: may be restricted (due to hot floor)	good	good
Controllability	• Slowest controllability due to the highest thermal mass • self regulation effect at low excess temperature	• Slow controllability due to the high thermal mass • self regulation effect at low excess temperature	• Fast control	• Fast control of the reheating of the air flow
Comfort				
Temperature asymmetry	low	low	depending on positioning	depending on air inlet
Radiative fraction	high	high	rather low (0.25 – 0.15, max. 0.4)	depending on air inlet
Air flow	low	low	depending on positioning and convective fraction high	depending on air inlet and convective fraction average
Other items				
Space demand	none	low	high	none
Specific advantages	Self regulation effect Very low supply temperature requirements	Self regulation effect Low supply temperature requirements	Fast control and therefore good use of solar gains due to cold floor	Cost advantages since no further installation for heat emission required
Restrictions	Restrictions regarding the floor covering	Restrictions regarding the floor covering	Restrictions regarding the location of the radiators	Restrictions with regard to the heating capacity
Application for SC	possible	possible	With convectors possible, with radiators supplementary, but rare	possible

Tab. 3: Characteristics of different space cooling emission systems (based on Recknagel-Sprenger, 2006, Baxter, 2009)

Space cooling					
Criteria	**TABS**	**Floor/Ceiling**	**Cooling panels**	**Central air distribution**	**Air convectors**
Thermal Capacity	very high	high	middle	low	low
Max. cooling capacity	40 W/m^2	95 W/m^2	120 W/m^2	40–60 W/m^2	50–200 W/m^2
Min. water temperature	17°C	16°C	16°C	~10°C for water-to-air fan coils 8-10°C refrigerant evaporating temperature for air-toair or water-to-air heat pumps	16°C
Controllability	poor	slow	good	fast	fast
Comfort	good at low loads	very good	very good	good	good at low loads
Use for heating and cooling possible	Base load, additional systems with fast control useful	depending on control concept: may be restricted (due to hot floor and exponent of the emission system)	good	good	good
Retrofitting	not possible	depending on circumstances	possible	depending on circumstances	possible

3 VENTILATION AIR SOURCE HEAT PUMP SOLUTIONS

3.1 Ventilation systems

With the higher air-tightness of low-energy buildings, low and ultra-low energy houses are increasingly equipped with mechanical ventilation systems in order to guarantee the hygienically necessary air exchange as well as for comfort reasons and to reduce ventilation losses. Ventilation systems can mainly be classified according to the following criteria:

- Exhaust-air-only or balanced ventilation systems (i.e. supply air flow equal to exhaust air flow)
- Central or decentral
- With and without ventilation heat recovery (also called passive heat recovery)

Exhaust air systems mainly guarantee an extraction of odour, germs and prevent building damage due to high moisture rates by extracting the exhaust air through an exhaust air duct system. The supply air gets into the house by infiltration through special fresh air wall valves.

Balanced ventilation systems with a separate supply air and exhaust air fan can guarantee a continuous supply of the hygienically necessary air volume flow rate. Exhaust air is extracted of the kitchen and bathroom areas, while the supply air enters the living and sleeping rooms. Air-quality is improved by filtering the inlet air and a passive ventilation heat recovery by an air-to-air heat exchanger in the ventilation ducts is possible. The ventilation losses can typically be reduced by about 60% by cross-flow heat exchanger, with highly-efficient cross-counterflow or counterflow heat exchangers above 80%. Rotary heat exchangers reach values about 75% and have the advantage, that also the moisture of the return air from the dwelling can be recovered, so-called enthalpy recovery. However, transfer of odour from the exhaust to the supply air flow may be critical. Other recuperative solutions with moisture transfer through membranes are in the market introduction, as well, see chap. 3.8.1 In most concepts balanced ventilation systems are used due to the better heat recovery conditions.
If a mechanical ventilation system is installed, different system concepts for the integration of the heat pump exist. Fig. 5 gives the basic system configurations of an exhaust air and a balanced ventilation system.

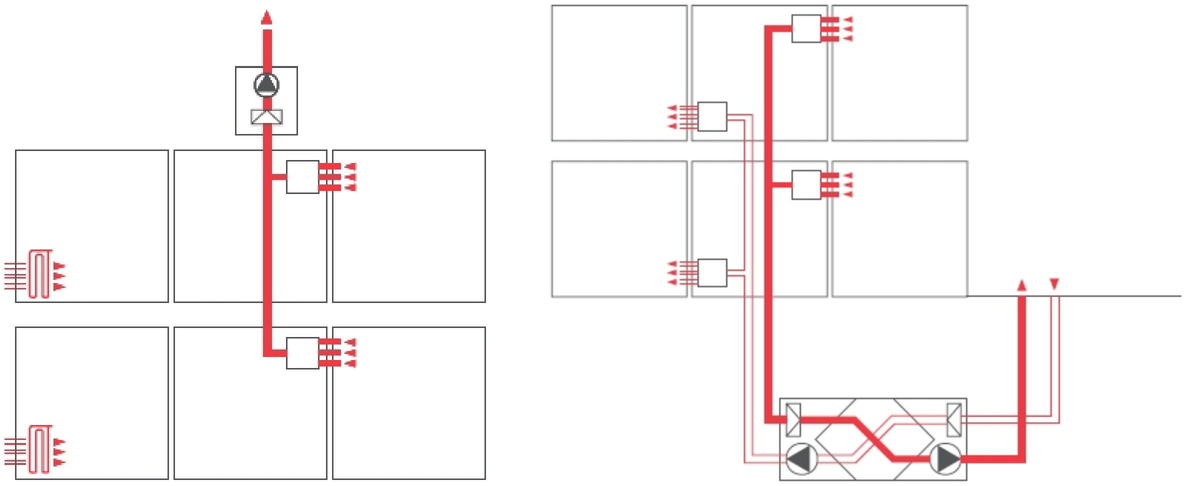


Fig. 5: Exhaust air ventilation (left) and central balanced ventilation systems with heat recovery (right) (source: MINERGIE®)

3.2 Classification of ventilation air source heat pump solutions

The main distinction is made according to the type of ventilation system.
In exhaust air systems a space cooling function cannot be realised by the ventilation system. Thus, exhaust air heat pumps can be differentiated in DHW-only operation, so-called exhaust air heat pump water heaters (HPWH) and combined space heating and DHW operation, where the space heating operation is coupled to a hydronic distribution system.
Since balance ventilation systems incorporate a supply air duct, as well, air conditioning functions of the supply air can be included. This leads to more system options.
Systems are further distinguished according to a passive ventilation heat recovery. Systems without passive ventilation heat recovery are often denoted as active heat recovery by the heat pump, where the heat pump is located between the supply air duct and the exhaust air duct. System solutions are further divided according to the coupling to a DHW integration.
Compact units include a passive ventilation heat recovery before the heat pump. Also these systems can be distinguished according to an integrated DHW function.
For each of these balanced ventilation systems a cooling option can be integrated by the use of a heat pump with reverse operation. This enables cooling operation by the supply air, while the extracted heat can be rejected to an installed DHW storage or is rejected to the exhaust air flow.
Fig. 6 gives an overview of ventilation air source heat pump solutions. The single system configurations are described in more detail in the following chapters.

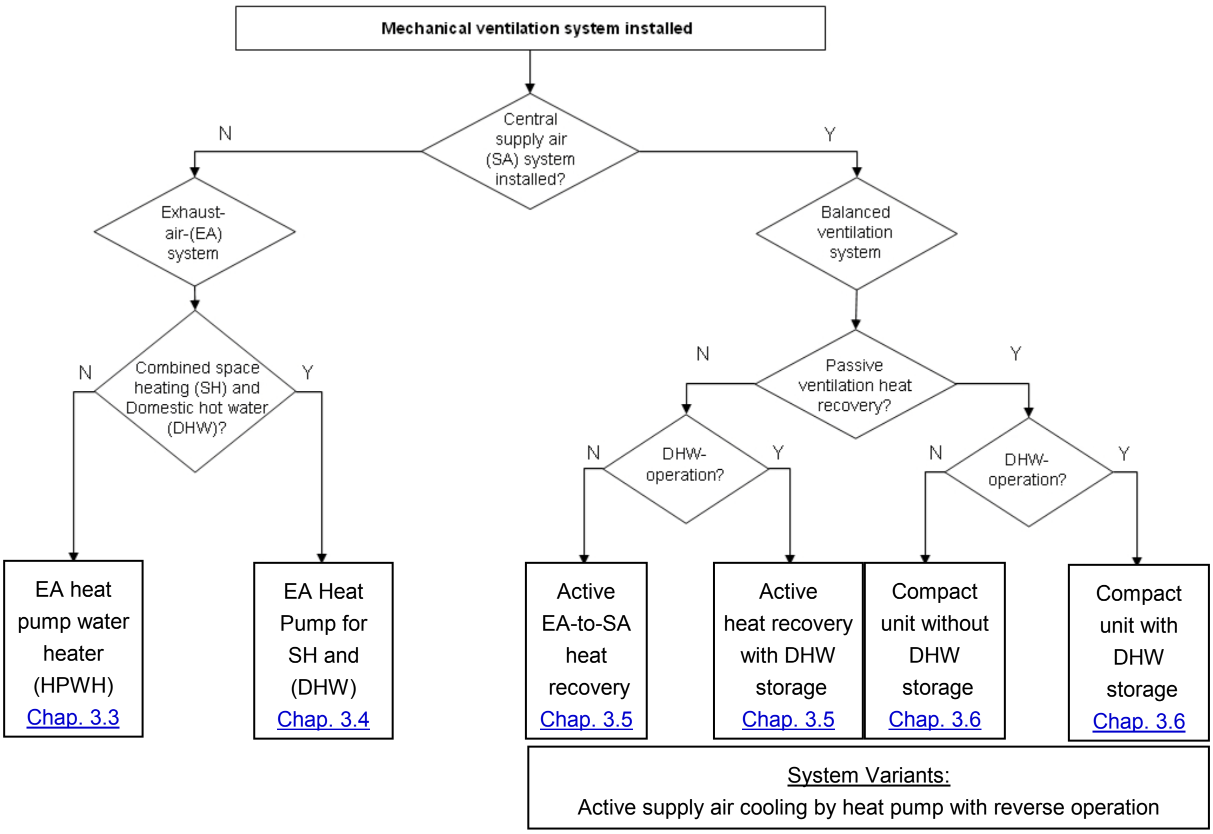


Fig. 6: Ventilation air based heat pump system classification and decision

3.3 Exhaust-air heat pump water heater

Exhaust air is a common heat source for DHW heating. The typical configuration of an exhaust air heat pump water heater is shown in Fig. 7. The return air from the house is cooled down by about 20°C to an exhaust air temperature of about 2°C.
Since the heat source exhaust air depends on the volume flow rate, the system is equipped with an additional electrical back-up heater.

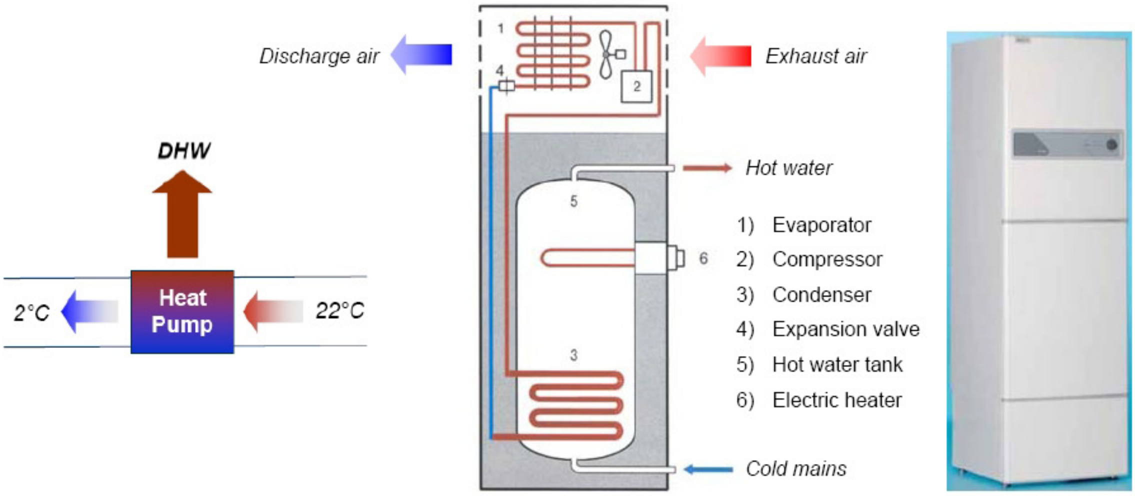


Fig. 7: Exhaust-air heat pump water heater (HPWH) (taken from Stene, 2007)

3.4 Exhaust-air heat pump for space heating and DHW

Heat recovered from the exhaust air ventilation system can also be supplied to a hydronic space heating system, thus covering both the space heating and DHW operation. However, due to the restriction of the air volume flow rate, the heating capacity is limited, so that only fractions of the needed energy for space heating and DHW operation can be covered. Therefore, these system solutions are typically equipped with an electrical back-up heating, and consequently the energy fraction covered by the heat pump has to be evaluated thoroughly to prevent excessive direct electrical operation by the back-up heating. Alternately the system is used as base heating and a second generator like a wood stove is used. Fig. 8 shows an example of a marketable system as picture/cut-away drawing of the German manufacturer Stiebel Eltron.

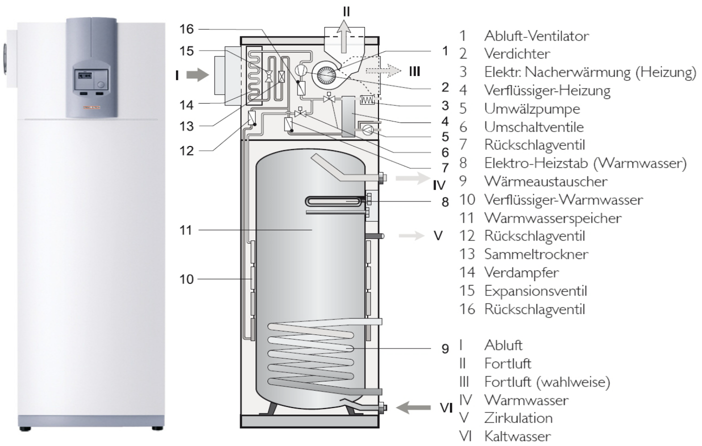


Fig. 8: Exhaust-air heat pump for space heating and DHW with hydronic distribution (Type LWA 303 by manufacturer Stiebel Eltron)

3.5 Active heat recovery by the heat pump

Systems with active heat recovery by the heat pump contain a central exhaust air heat pump in the ventilation duct without a passive heat recovery, i.e. the ventilation heat recovery is accomplished by the heat pump. In most cases the heat pump is of reverse type, so in winter operation an air heating and in summer operation an air cooling can be accomplished.

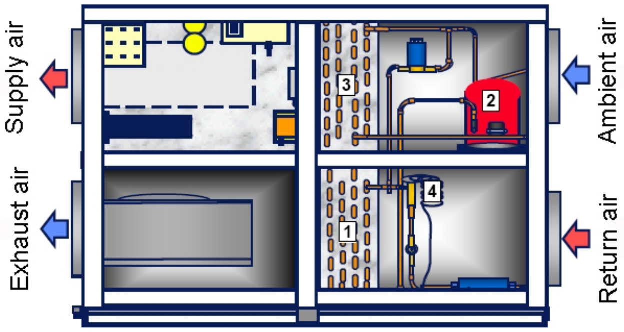


Fig. 9: Active heat recovery by a heat pump installed in the ventilation ducts (taken from NOVAP, 2007)

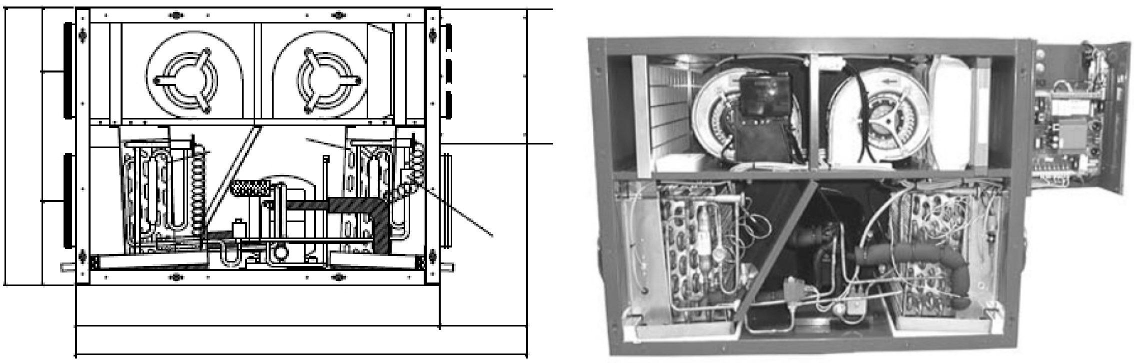


Fig. 10: Sample system of an active heat recovery by heat pump (Type mini C of manufacturer Genvex)

Fig. 9 shows a principle sketch of an active heat recovery with the heat pump, Fig. 10 gives a cut-away picture of a unit.
The active heat recovery by a heat pump can also be operated to produce space heating energy for a hydronic heat emission system and DHW. Fig. 11 shows a system concept, where the active heat recovery works on a storage where a desuperheater is located in the upper DHW part and the condenser works on the lower part of the storage for the space heating energy. Fig. 11 right, on the other hand, shows a system with active heat recovery which works on a storage for DHW heating and reheats the fresh air for air heating purpose. The system can be optionally equipped with a reverse operating heat pump, so that an optional fresh air cooling for the summer operation can be integrated. Moreover, the storage can be equipped with an additional hydronic space heating cycle.

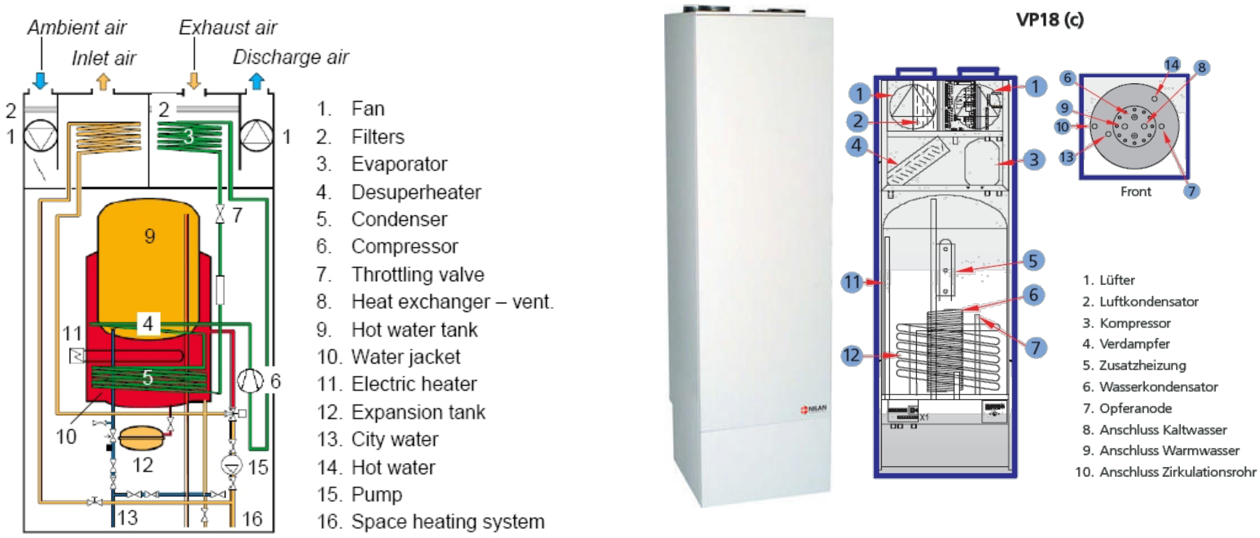


Fig. 11: Active heat recovery with DHW and hydronic heating system (taken from Stene, 2007) and with DHW and air heating (Type VP 18 of manufacturer Nilan)

3.6 Compact units

A ventilation compact unit with exhaust air heat pump (abbreviation: compact unit) consists of a balanced ventilation system with passive heat recovery, i.e. an air-to-air heat exchanger, and an exhaust air heat pump, of which the evaporator is located at the outlet of the ventilation heat recovery exhaust air path. The core components are the ventilation heat recovery (VHR) and the heat pump.

3.6.1 Compact unit for space heating and cooling

Compact units for space heating and cooling without DHW production can be installed directly in the ventilation ducts. The systems work in the same way as described in chapter 3.5 with the difference, that the passive ventilation heat recovery preheats the outdoor air, so the reheating by the heat pump only has to reheat the required supply air temperature. On the other hand the source temperature for the heat pump is lower due to the ventilation heat recovery, so that frosting may occur in the heat pump evaporator.

Fig. 12: Sample system of heat pump compact units for space heating and cooling (Type WRG 134 BP of the manufacturer BauInfoCenter)

As system variant a heat pump with reverse operation can be applied to cover active cooling operation, as well. For the cooling operation, however, the passive ventilation heat recovery has to be by-passed, and is sometimes replaced by a summer box for the direct connection, which is manually exchanged in the summer period.

3.6.2 Compact unit for space heating and cooling including DHW

Compact units for space heating and DHW storage with or without optional cooling mode are mostly found in tower configuration, where the ventilation unit is on top of the DHW storage. As for the system in the ventilation duct, the heat pump extracts heat of the exhaust air and supplies the heat to a hydronic or an air heating system or the DHW storage in alternate mode (by switching the heat pump condenser to the DHW) or simultaneous mode (heat pump work both for the DHW and space heating operation at the same time).
Moreover, further systems may be attached, for instance a ground-to-air heat exchanger and a solar collector and direct electrical back-up heaters for peak loads. A sample system layout containing most common system options is shown in Fig. 13.
Variants of system configurations can be classified concerning the following criteria

- Heat source (exhaust air VHR, mix exhaust air VHR-outdoor air)
- Heat emission system (air heating, hydronic floor heating, both options)
- Functionality (additional humidification, additional pre-heating/cooling option)
- Optional system extension (ground-to-air HX, solar collector, back-up heaters for pre-heating or reheating)

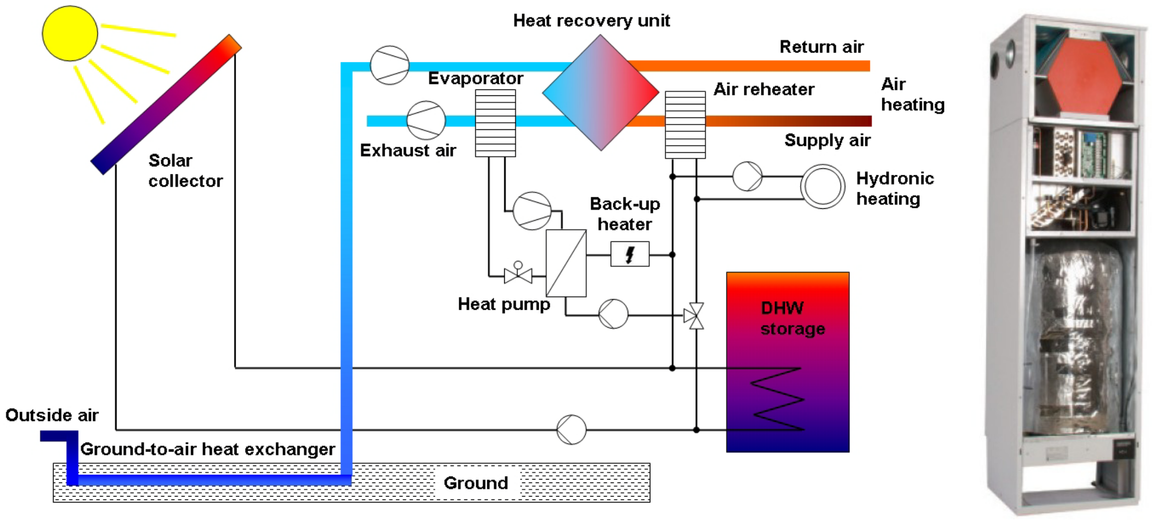


Fig. 13: Sample system configurations of heat pump compact units with additional components and cut-away of a compact unit (Type VP18-10P of manufacturer Nilan)

Solar energy is mostly used to support the DHW production. However, depending on the internal configuration of the compact unit, solar energy may also contribute to cover the space heating operation.
Ground-to-air heat exchangers, see also chap. 3.7, are often designed such that the outdoor air enters in the compact unit near 0°C to prevent frosting of the ventilation heat recovery. Furthermore, for units with only exhaust air of the ventilation heat recovery as heat source, the ground to air heat exchanger increases the heating capacity of the heat pump due to the higher outlet temperatures of the heat recovery and the thereby higher inlet temperatures to the heat pump evaporator.
In summer operation the ground-to-air heat exchanger can precool the inlet air. The ventilation heat recovery is often equipped with a bypass for summer operation to avoid a preheating of the air in summertime.

Tab. A 2 in Appendix A gives an overview of compact units on the market in Switzerland, Germany and Austria. Systems with a cooling option are marked in blue.
Investment costs of compact units are in the range of 5.000 – 12.000 €.

3.7 Systems for preheating the inlet air with the ground

For the preheating of the air, principally two system solutions are available on the market, the ground-to-air heat exchanger with and without an intermediate cycle. In systems without intermediate cycle, the inlet air is passed through Polyethylene or Polypropylene pipes of DN 160 (up to 125 m^3/h) or DN 200, which are buried in 1.5-2 m depth in the ground with an inclination of 1%-2% to drain condensate. The systems are normally designed to keep the ventilation heat recovery frost free, which often has a length of 20-30 m and offers the option of a precooling in summer operation.
In systems with intermediate brine cycle a horizontal ground collector, which is discussed in chapter 2.2.1.2, is connected to a heat exchanger installed in the inlet air duct of the ventilation system to preheat the outside air volume flow. Advantages of the ground-to-air heat exchangers can be the lower installation expense and material cost savings, no condensation drain and no cleaning requirements as well as no bypass in the temperature range of 7-20°C required (switch-off of the pumps). Fig. 14 shows the two system variants. In the case of new ulta-low energy houses with low heating capacity requirements the brine-to-air heat exchanger can be installed round the foundation of the houses, which saves the digging costs in the garden. the brine-to-air heat exchanger reach extremely high performance factors >100 in the operation to keep the ventilation heat recovery frost free. However, the primary energy savings in this operation mode is only about 1%.

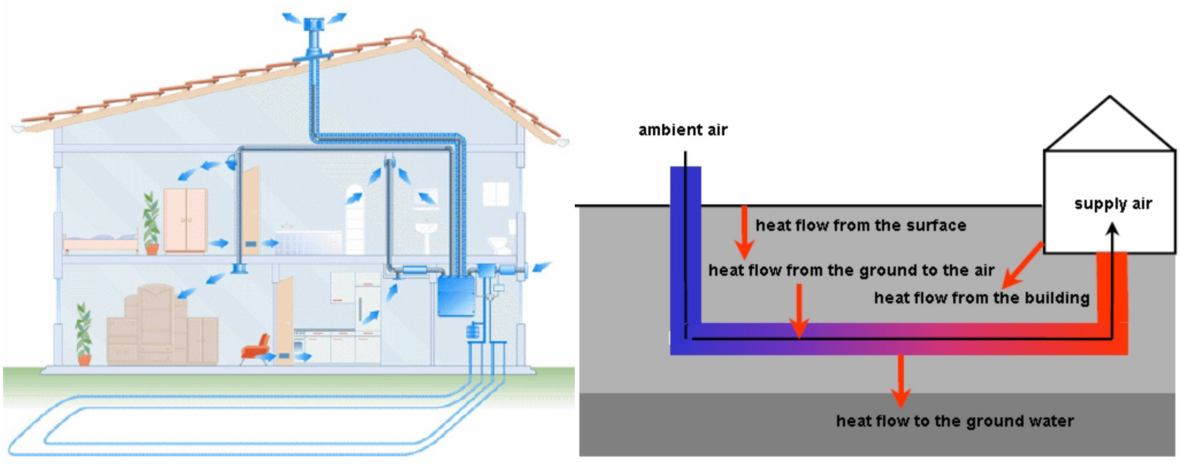


Fig. 14: Sample systems of brine-to-air (intermediate cycle) and ground-to-air heat exchangers coupled with the ventilation system for air preheating/-cooling and to keep the ventilation heat recovery frostfree (source: AEREX Haustechniksysteme)

3.8 Additional functions of the ventilation system

The ventilation system can also be used for further air conditioning function up to a full air conditioning system including a humidification and dehumidification function.

3.8.1 Enthalpy recovery

In wintertime, the inlet air is often quite dry in case of ventilation systems with heat recovery. Therefore, the manufacturer Zehnder has integrated a so-called enthalpy recovery in the

central heating unit Comfobox, which accomplishes a heat and a moisture recovery from the return air from the building to the inlet air. The principle is shown in Fig. 15 left. The membrane contains chemically bonded salt, which absorbs the water of the return air. By the osmotic difference due to the different water concentration in the inlet air and the return air, water molecules migrate through a membrane to the inlet air side. On the one hand, the membrane is advantageous for hygienic reasons, since the membranes retains pollutants in the return air stream, on the other hand, a latent heat transfer is accomplished.
Although the sensible heat recovery is a bit lower in comparison to the conventional Zehnder heat recovery, the overall heat recovery (sensible and latent) is higher, i.e. both the heat recovery is enhanced and the humidity problems is solved in a hygienic way by the enthalpy recovery (Kriesi, Schnyder and Tchui, 2006).
An example for an enthalpy recovery by a heat exchange with rotary regenerator on the market is depicted in Fig. 15 right (manufacturer Hoval).

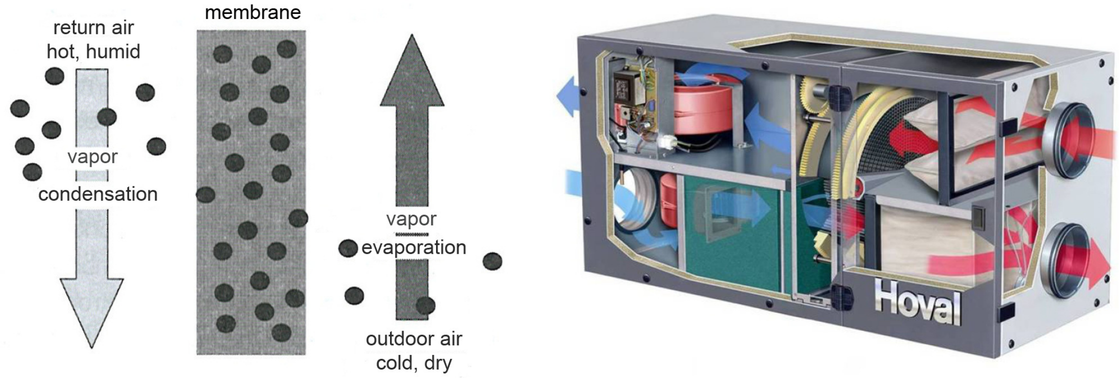


Fig. 15: Enthalpy plate exchanger by a membrane technology (left, manufacturer Zehnder) and enthalpy recovery by rotary heat exchanger (right, manufacturer Hoval)

4 HEAT PUMP SYSTEMS WITH SPACE COOLING OPTION

This chapter treats integrated heat pump solutions with space cooling option by the heat pump or heat pump source system which is not coupled to the ventilation system. Nevertheless a ventilation system might be installed, e.g. a decentral ventilation system with heat recovery, but the ventilation is not coupled to the heat pump or heat source system operation for space cooling. Examples are the heating centrals in Tab. A 1 in Appendix A, which contain a separate central balanced ventilation system, but neither the heating/cooling energy is distributed and emitted by the air nor is the exhaust air used as heat source of the heat pump. Thus, in these systems, a separate ventilation system is installed in the same casing without any integration.

Space cooling options can be distinguished into active and passive cooling.

Active cooling by the heat pump refers to a reverse operation of the heat pump cycle as already seen in the system variants of the last chapters.

Passive cooling is also called free, direct or natural cooling and refers to using the potentials of environmental sources colder than the indoor air temperature in summertime, i.e. the nighttime air, the ground or ground water. The term free cooling or passive cooling refers to the fact that no chiller but only auxiliary energy is needed for the space cooling operation. Most common passive cooling methods are

- Nighttime ventilation (by natural window airing or by the mechanical ventilation system with summer bypass)
- Ground-coupled cooling
    - With ground-to-air heat exchanger (as described in chapter 3.7, mainly for pre-cooling)
    - With borehole heat exchanger
- Direct water cooling with lake or ground water

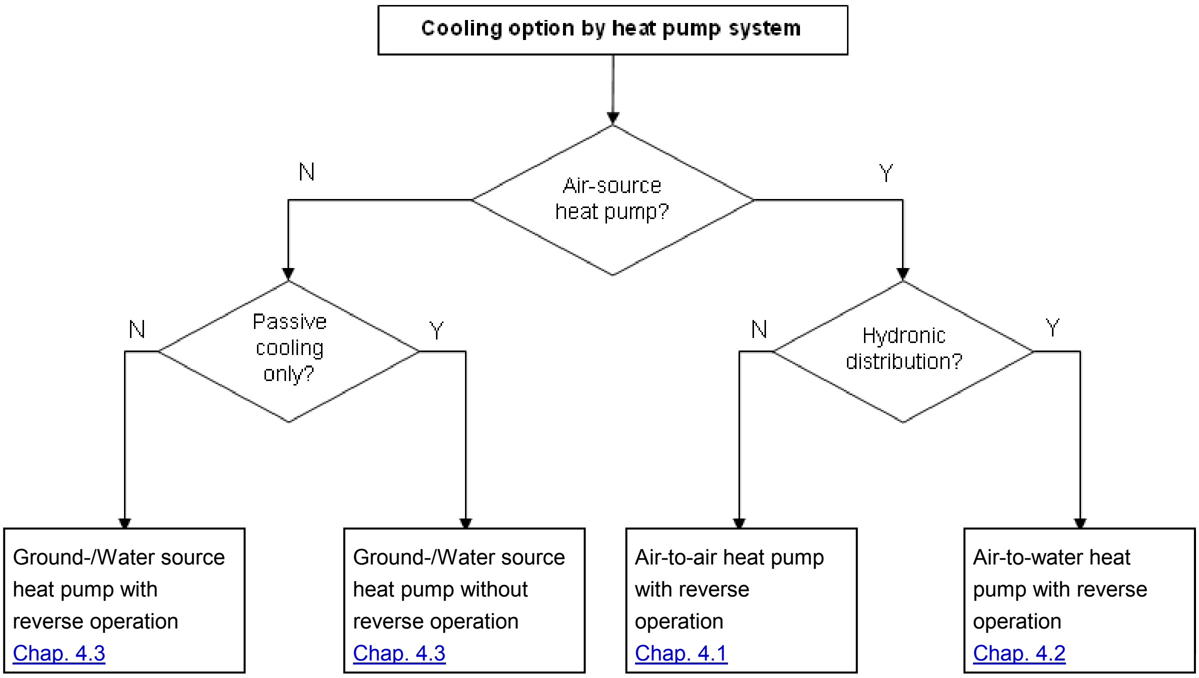


Fig. 16: Overview on heat pump solutions with active and passive space cooling options

4.1 Air-to-air air-conditioners and heat pumps

4.1.1 Overview of split air conditioners and system selection

Well-designed air-to-air split units can be an efficient means for heating or cooling of rooms, which, however, is only true for a small fraction of efficient units, while the market offers a whole bunch from almost useless to highly efficient and modern units. The following paragraphs give a short overview on available systems.
Mobile compact units for air conditioning with exhaust air tube (also called single tube air conditioning units, Fig. 17 left and middle) are cooling down the recirculated air and reject the hot air to the outside, but thereby, warm air can get into the conditioned space. Thus, the cooling effect in the room is diminished or even totally avoided, so single tube systems should not be used. In case of double tube system depicted in Fig. 17 right, the outdoor air for the heat rejection is let by the second tube. The application of such system is only possible with a heat exchanger on the outside. The efficiency of both system types is low.

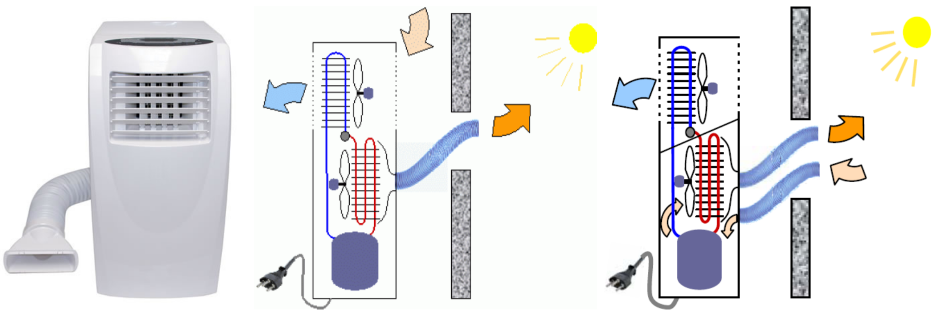


Fig. 17: Mobile compact split unit (left: single tube right: double tube) (source: www.topten.ch)

Split-units separate the cooling unit in one of more indoor units and one or more outdoor units, which are connected by refrigerant pipes. In the case of mobile split units in Fig. 18 only the condenser for the heat rejection in the outdoor unit is placed on the outside, the evaporator and compressor remain in the indoor unit. Thereby, the compressor heat and noise also remain on the inside. The units are often composed of prefabricated, mounted units. Also due to the strongly cost-oriented design, the efficiency of the units is often quite poor.

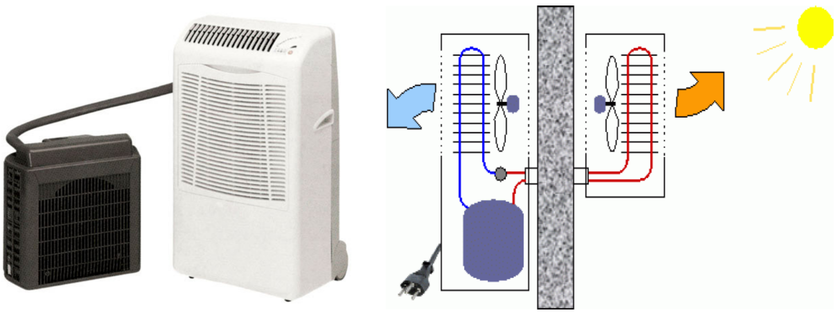


Fig. 18: Mobile split-units (source: www.topten.ch)

Constantly installed split- or multi-split-units shown in Fig. 19 are modular systems, so manifold indoor and outdoor units can be combined. The installation of such units requires a specific knowledge of refrigeration installations. The compressor is normally placed inside the outdoor unit. They are widely used for the professional cooling of buildings and reach the best performance values in the category of air-to-air air-conditioning units as well as the best thermal and acoustic comfort. The overall energetic efficiency is satisfactory to good.

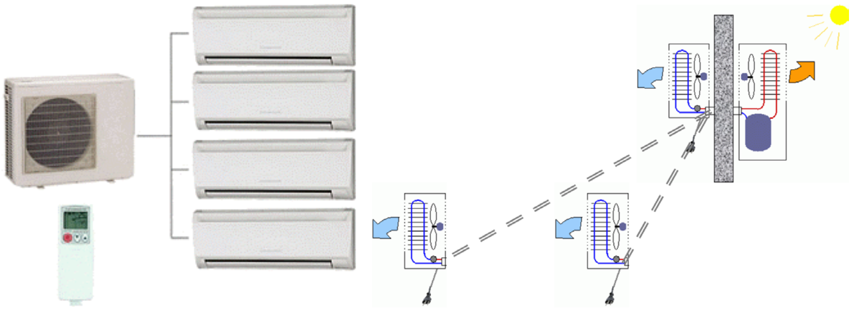


Fig. 19: Constantly-installed single split-/multi-split-units (source: http://www.topten.ch)

The energy efficiency of air-to-air split units is declared as efficiency, often as EER = Energy Efficiency Ratio or EEI = Energy Efficiency Index. Therefore, the generated cooling capacity is divided by the electrical expenditure of the cooling cycle including the air-side expenditure to overcome the pressure drop in the evaporator and condenser, i.e. according to the same system boundary as for the COP as instantaneous capacity ratio in the stationary operation state at defined standard rating conditions.

The efficiency for split-systems is on an energy label as depicted in Fig. 20. On the label it is denoted as „Energy efficiency metric“. The declared efficiency is measured at the following test conditions: inlet of the indoor air: 27 $°C_{DB}$, 19 $°C_{WB}$/ inlet of the outdoor air: 35 $°C_{DB}$/24 $°C_{WB}$.

The energy efficiency requirements according to the energy label are even for class A not particularly elevated as depicted in Tab. 4. With a COP above 3.2 class A is already reached. The best units on the market reach COP efficiencies higher than 5.0.

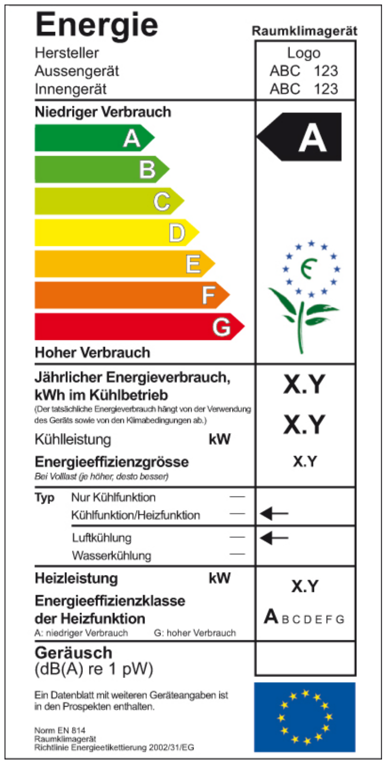


Fig. 20: Energy label for split units

A further normative requirement in Switzerland is contained in the Swiss standard SIA 382/1 which mainly deals with water-based cooling systems, but also defines requirements for air-cooled split units, which are listed in Tab. 4. The requirements are based on the operation at full load and 50% part load. Moreover, in chap. 5.6.5 design requirement is stated: „Most cooling system are characterised by variable power demand. The system should be designed, so that the part load efficiency at decreased cooling water temperatures is higher than in full load according to the part load efficiency characteristic curve.“ This requirement should also be applied to split units, since in particular in cooling operation, the systems are operated at part load for most of the time.

If a separate split unit is used as an additional unit to an independent space heating system, a simultaneous space heating and cooling operation must be avoided (exergy destruction). One possibility is a deactivation of the cooling operation during heating operation. If the split unit is also used for the heating mode, the efficiency characteristic should be evaluated carefully, since they are often related to the operation points with high outdoor air source temperatures (inlet state of indoor air: 20 $°C_{DB}$ / 15.5 $°C_{WB}$ inlet of outdoor air 7 $°C_{DB}$ / 6 $°C_{WB}$) and are thereby not very representative for effective operation in space heating mode. Also in the classification according to the energy label, this operation point is used.

Tab. 4: Efficiency / EER requirements according to the Swiss energy label in cooling mode

Cooling mode			
EER / efficiency		**Split-unit**	**Mobile compact unit**
Swiss standard SIA 382/1	< 12 kW cooling capacity part load 50% full load 100%	> 3.0 > 3.0	> 3.0 > 3.0
	> 12 kW cooling capacity part load 50% full load 100%	> 4.5 > 3.5	not applicable
Energy label	Recommended	> 4.0	> 3.0
	class A	> 3.2	> 2.6
	class B	3.0 – 3.2	2.4 – 2.6
	class C	2.8 – 3.0	2.2 – 2.4
Heating mode			
COP/ Efficiency		**Split-units**	
Energy label	recommended	> 4.0	not applicable
	class A	> 3.6	not applicable
	class B	3.4 – 3.6	not applicable
	class C	3.2 – 3.4	not applicable

As conclusion of the previous considerations only single split/multi split units with inverter controlled compressor should be applied, which comply with the requirement according to the energy label. The room/indoor units of multi-split air-to-air heat pumps have considerably higher capacity than the heat load. If only one outdoor unit is designed to the sum of the indoor units or even higher it would be massively over-dimensioned and would only be operated in part load operation. Therefore, the part load efficiency is of central importance for the evaluation of the seasonal performance. Fig. 21 gives and exemplary overview of the COP part load characteristic of three different capacity control methods of space heating heat pumps. Depending on the type of capacity control a reduction or an increase of the COP in part load are depicted. The on/off controlled units, which are currently the majority of residential space heating air-to-water and brine-to-water heat pumps in Europe, have lower COP values in part load operation. Inverter controlled heat pumps, on the other hand, show increasing COP values up to part load factors down to 20% (AC inverters) or even over the entire part load range (DC brushless inverters).

The heat rejection of air-to-air split heat pumps is mostly accomplished by convectors, which are supplied by refrigerant pipes from a central unit. Regarding a good thermal and acoustic comfort, units with variable fan speed and thereby variable volume flow are useful. The noise level of the indoor unit should be 30 dB or lower in normal operation and should be 30 dB or lower in enhanced operation. For condensate generation in cooling operation condensate a functional drain has to be provided.

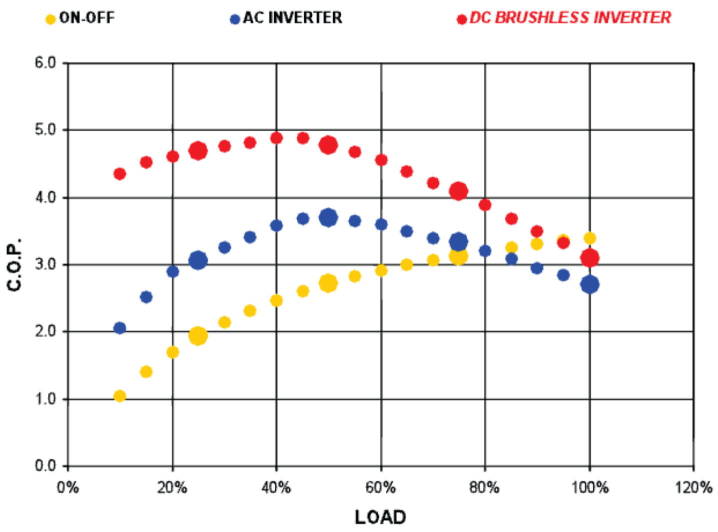


Fig. 21: Exemplary COP-part-load characteristic of three capacity control methods: (ON-OFF), capacity controlled AC-asynchroneous motor (AC INVERTER), capacity controlled brushless DC motor with rotor-integrated permanent magnet (DC BRUSHLESS INVERTER) (source: Lemanna)

4.1.2 Single-split air-to-air heat pumps for space heating

A common layout of an air-to-air heat pump is given in Fig. 22. Air-to-air heat pumps are used for space heating and/or –cooling and consist of an outdoor unit and one wall or floor mounted indoor unit (condenser, fan etc.) depicted in Fig. 22 right, which recirculates and heats/cools the indoor air. Efficient units mostly use R410A and inverter controlled compressors, other refrigerants used are R290 (propane), while units with R744 (CO_2) are not available on the market, yet (Stene, 2007).

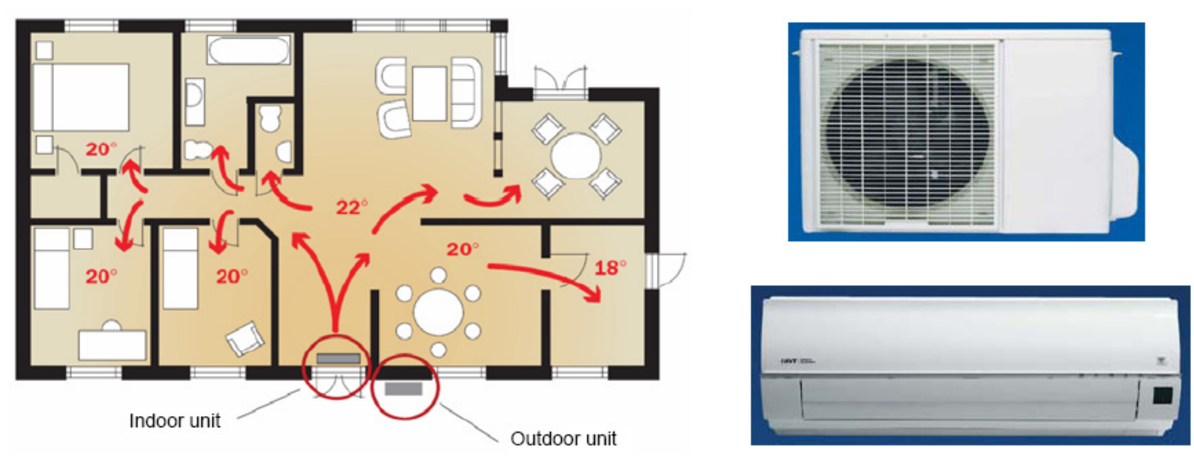


Fig. 22: Installation floor plan of an air-to-air heat pumps (left) and outdoor and indoor unit (right) (taken from Stene, 2007)

Single split units are a very common heating system in the moderate climate zone of Japan. Market development shows that 90% of the systems sold are single split, while multi-split systems have only a market share of 10%.

Thus, many Japanese manufactures offer single split systems. Recently, new functions were integrated into the units like automatic air filter cleaning, air flow control and air purification as well as improvement of efficiency, see Appendix B.

Air-to-air heat pumps are available with heating capacities from about 3 kW (at +7ºC ambient air temperature).

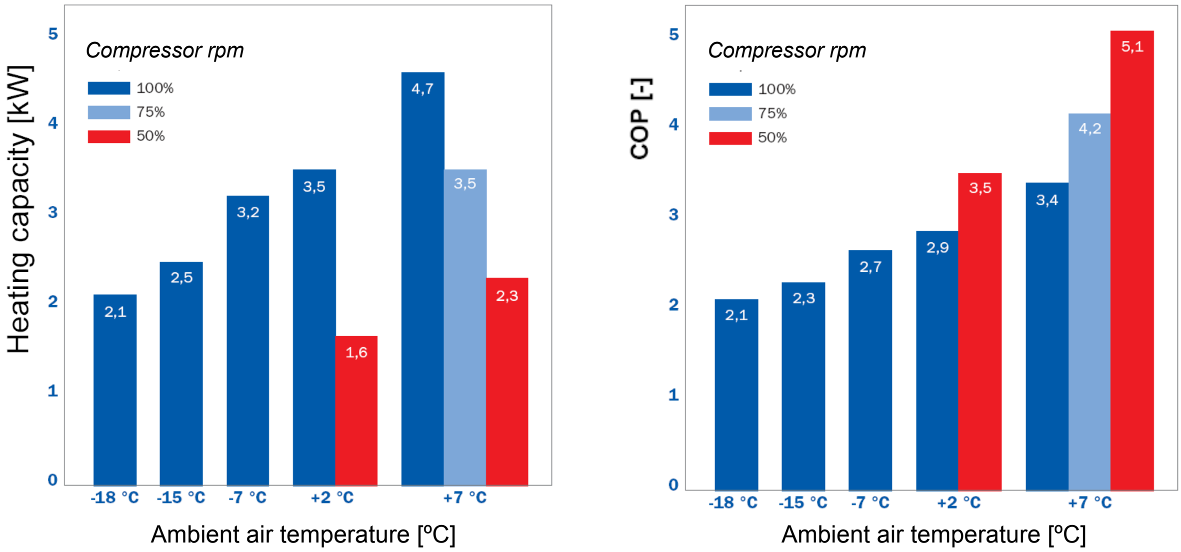


Fig. 23: Example of measured heating capacity and COP for a high-quality air-to-air heat pump at varying operating conditions (Karlsson et al., 2006).

The heating capacity and Coefficient of Performance (COP) for the heat pumps drop when the ambient air temperature is reduced. Example – the heating capacity at -15ºC is typically 45-55% lower than the heating capacity at +7ºC (Karlsson et al., 2006). The minimum temperature limit for operation of air-to-air heat pumps (stop temperature) ranges from -15 to -25ºC ambient air temperature.

Heat pumps with inverter controlled compressors achieve the highest COP at typically 30-60% of the max. rpm. Since the typical investment costs is lower than the maximum permissible investment cost (MPI), it is recommended that air-to-air heat pumps in low-energy houses and passive houses are designed to cover the entire space heating demand, even in relatively cold climate zones such as the Nordic countries. Fig. 23 shows, as an example, measured heating capacity [kW] and COP for a high-quality air-to-air heat pump at varying ambient air temperatures and 50-100% rpm for the compressor (SP, 2006).

Split system or single-package air-to-air heat pumps using single-speed compressors and fans with a centrally ducted air distribution network (or emission system) are the most common type of heat pump applied in the US (Fig. 24).

The single-package type may be installed in an attic or crawlspace location. In most existing systems the air distribution ductwork is mostly installed in unconditioned spaces (attics or crawlspaces) or semi-conditioned spaces (unheated basements). Most existing systems use R-22 refrigerant while all new systems now use R-410A. New systems are required to have a seasonal energy efficiency ratio (SEER) of 13 Btu/Wh (equivalent to a cooling SPF of 3.81 W/W) and a heating seasonal performance factor (HSPF) of 7.7 Btu/Wh (heating SPF of 2.26). However, high efficiency (or low-energy) home designs using air-to-air heat pumps usually feature systems with efficiencies considerably higher than the minimums and generally have the distribution ducts installed within the conditioned space to minimize duct losses. Air-to-air heat pumps with efficiencies exceeding SEER=20 (cooling SPF=5.86) and HSPF=9.5 (heating SPF=2.78) are available. Such units typically offer at least two compressor speeds or capacity steps and inverter-driven variable speed fans.

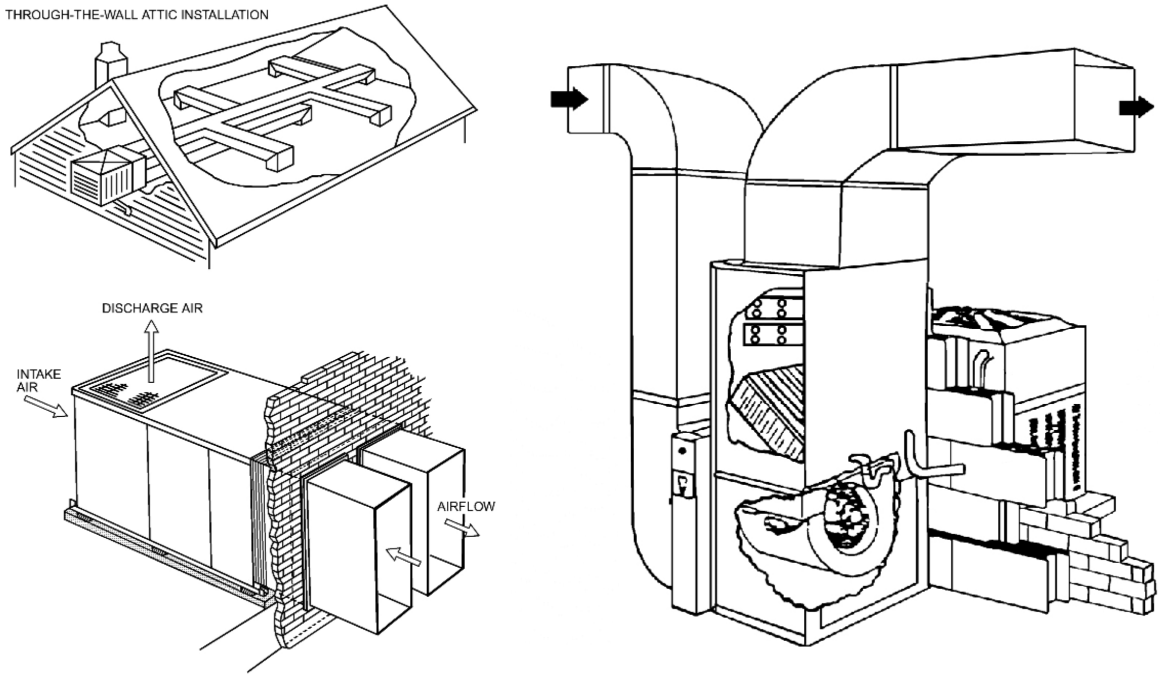


Fig. 24: Installation floor plan of an air-to-air heat pump and outdoor and indoor unit (source: Baxter, 2009)

4.1.3 Multi-split units in residential buildings

In multi-split system a single outdoor unit is combined with multiple indoor units, generally one indoor unit is installed per room to be conditioned. Components correspond to the ones used in single-split systems.

Fig. 25: Drawing of a multi-split system of an air-to-air heat pump with single outdoor unit and multiple indoor units in residential use (source: Ida, 2010) and types of indoor units (source: Timmer, 2009)

4.1.4 Multi-split units in non-residential buildings

While split system are standard system in Asia and the US, multi-split units are increasingly used in non-residential building in Europe, in particular office buildings, which have besides the space heating energy demand also considerable space cooling demand in moderate central European climates due to the high internal loads by higher occupancy (persons per areas) and rejected heat by equipment and illumination. Moreover, due to architectural de-

signs with high glazing fraction external loads augment the space cooling demands. In office building up to 40 indoor units can be connected to one outdoor unit. Conventional systems use a two pipe configuration. In order to integrate a heating mode in conventional cooling split system, either the entire cycle or part of the cycle can be reversed. If the entire cycle is reversed, all indoor units are either in heating or in cooling mode.
By modern 3 pipe configurations depicted in Fig. 26 to Fig. 29 simultaneous heating and cooling in different zones of the building is possible. COP values of up to 10 are reached in commercial buildings depending on the load conditions. The system configuration comprises 3 pipes, a suction gas pipe (1) with low temperature and low pressure, a discharged gas pipe (2) with high temperature and high pressure and a condensed refrigerant fluid pipe (3) with average temperature and high pressure.
All units in operation are connected to the fluid pipe (3), with serves in space heating operation as return and in space cooling as supply. In space cooling the suction gas pipe serves as return and the discharge gas pipe (2) is the supply in space heating mode.
In practical application not every indoor unit is connected to the three pipe configuration for reasons of complexity and cost, but there are always groups of indoor units which are operated in the same mode, either heating or cooling. These indoor units within the group are only connected by two pipes. The groups are interconnected with each other and the outdoor unit by the three pipe network by the switch boxes depicted below in Fig. 26 - Fig. 27.

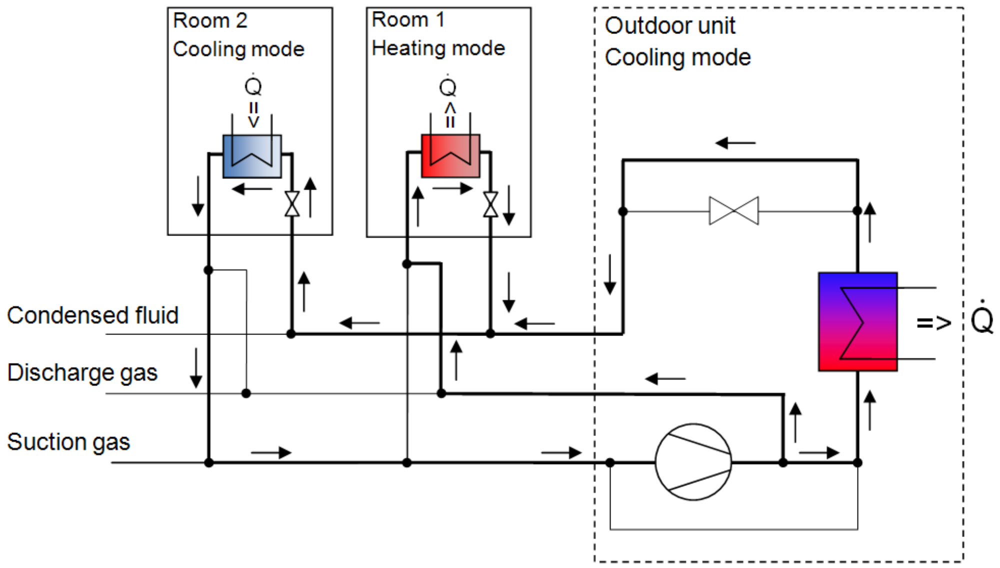


Fig. 26: Multi-split systems with 3 pipe configuration in operation mode of situations with higher cooling demand than heating demand

Fig. 26 depicts the situation with higher cooling load than heating load. In this case the heat pump operates in cooling mode. The arrows show the mass flow rate. Evaporated refrigerant is led to the compressor. Discharged refrigerant of the compressor is led on the one hand in the discharge gas pipe to the zone with heating demand, where it is condensed. The other share of discharge gas is led to the condenser of the outdoor unit, where the heat is rejected to the ambient. In this way the zones with heating demand serves as a recooling of the refrigerant for the cooling demand in the same way as the outdoor unit. Afterwards, both streams are mixed and flow to the zones with cooling demand, where they are expanded and evaporated for cooling the zones. The refrigerant gets back to the compressor by the suction gas line.
Fig. 28 shows a situation with higher heating demand than cooling demand. In this case the outdoor unit operates in heating mode. Discharged gas from the compressor is led to zones with heating demand. The condensed fluid (3) from the zones with heating demand is then split and flows on the one hand to the zones with cooling demand, where it is expanded,

evaporated while extracting the heat from the zones to cover the cooling load and led back to the compressor in the suction gas pipe. On the other hand, the second stream is expanded and evaporated in the outdoor unit and afterwards mixed with the suction gas of the zones in cooling mode. Thus, the cooling zones function as evaporator for the heating zones.

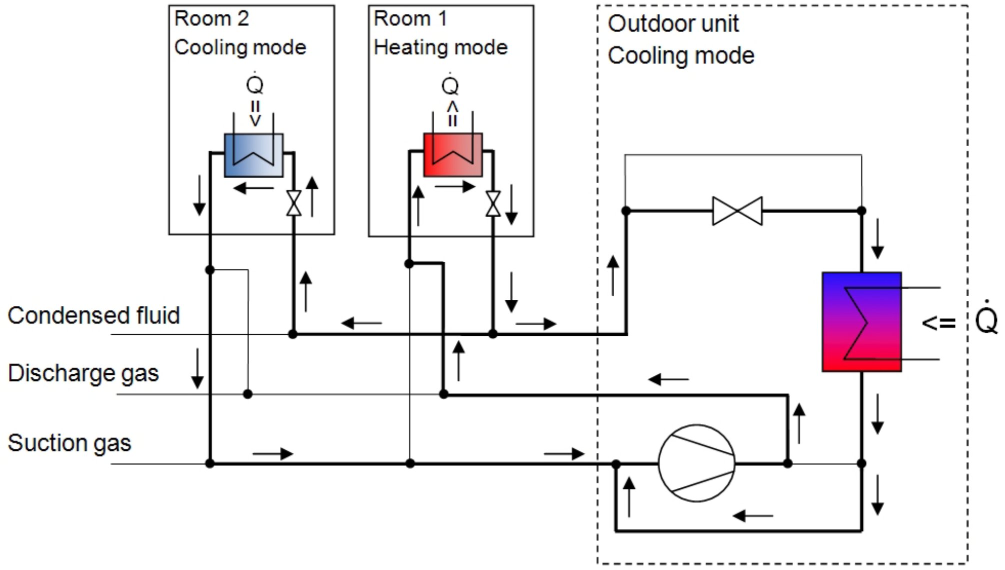


Fig. 27: Multi-split systems with 3 pipe configuration in operation mode of situations with higher heating demand than cooling demand

Finally, Fig. 27 depicts the ideal situation, where the heating and cooling load are the same. Then, the outdoor units functions as heat pump and takes the zones with cooling load as evaporator and the zones with heating mode as condenser. The heat exchanger and the expansion valve in the outdoor unit are bypassed and only the compressor is active. The discharge gas of the compressor is led to the zones with heating demand, which work as condenser and afterwards, the fluid flow to the zones with cooling load, which works as evaporator. The refrigerant is led to the compressor by the suction gas pipe.

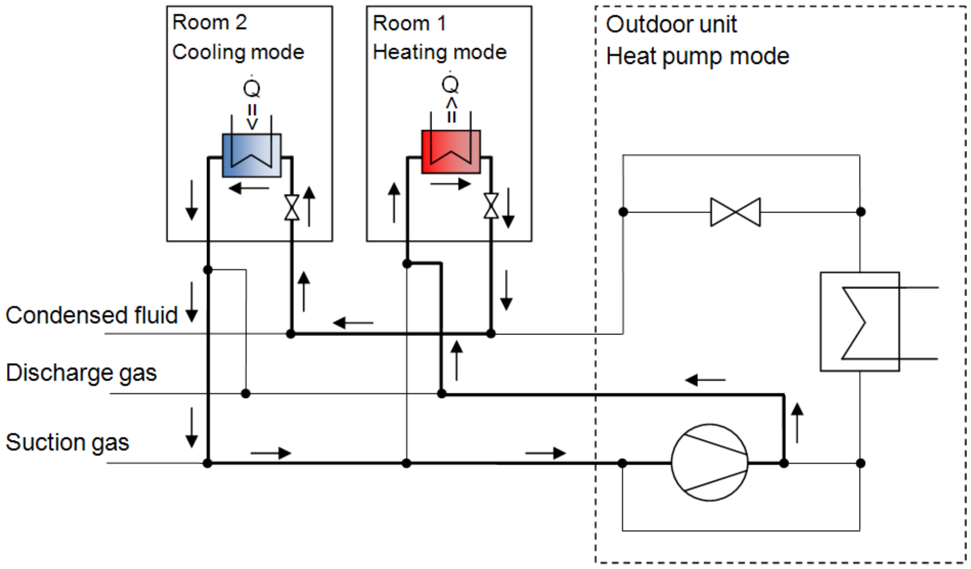
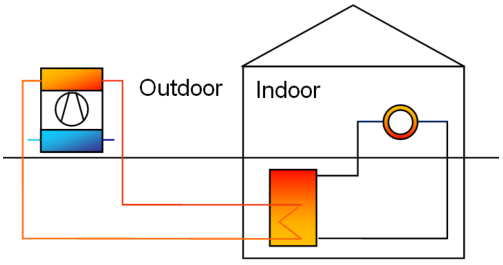


Fig. 28: Multi-split systems with 3 pipe configuration in operation mode of situations with equal heating and cooling demand

4.2 Air-to-water heat pumps

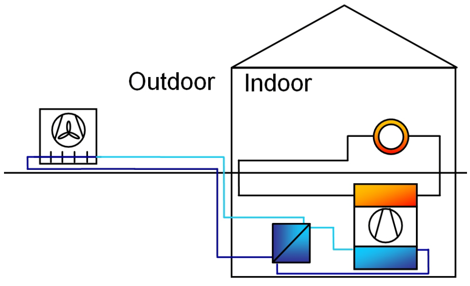
Air-to-water heat pumps are one of the most common heat pump systems for space heating and DHW production in Europe. There are different ways of an air-to-water heat pump installation.Besides the location entirely inside the building, three further variants exist:

- an entirely outside installation



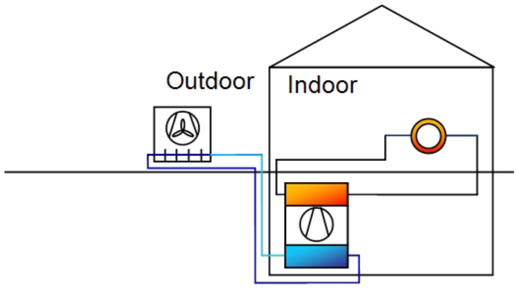
In case of an entirely location outside the refrigerant is directly evaporated, the heat is produced on the outside. This implies heat losses and the refrigerant cycle as well as the electronic are entirely placed on the outside.

- a variant with an intermediate brine cycle



In case of an intermediate brine-cycle, the evaporation is indirect. The heat pump is a brine-to-water heat pump using outside air as heat source. Due to the brine cycle a frost protection up to -20°C exists. The heat is produced on the inside and the refrigerant cycle and the electronic is protected.

- a split system with an outdoor and indoor unit



In case of a refrigerant split system, the evaporation is direct and heat is produced on the inside. However, for the installation a service technician is necessary.

Most A/W heat pumps use HFC refrigerants R407C, R410A, R134A, but some manufacturers offer propane (R290) systems, as well. Market available heating capacities are in the range of 5-40 kW, lower operation limits are between -15°C to -20°C, and as for air-to-air heat pumps, defrosting and noise protection must be provided. COP-values at the testing point A2/W35 range between 3.0 and 4.4 according the Swiss test centre WPZ (Eschmann, 2009). Investment costs are dependent on the capacity starting from 6000 € excluding the space heating distribution. Design in Nordic countries is usually between 40-60% of the design heat load of the building, while the rest is covered by electrical back-up heating (Stene, 2007). In Switzerland, use of electrical back-up for space heating was prohibited in 2008. Smaller A/W heat pumps for new residential single family house, are likely to be designed for the design heat load.
Active cooling operation with reverse operating air-to-water heat pumps is not common, yet. Thereby, the heat extracted from the building indoor air by the hydronic emission system can be rejected to the outdoor air with the outdoor unit of the air-to-water heat pump. Efficiency gains can be achieved, when active cooling operation is coupled with the DHW production in summertime (simultaneous cooling and DHW operation), i.e. the cooling load of the building is the source for the DHW operation, since in this case both the extracted evaporator heat for cooling operation and the condenser heat for DHW operations are used.

4.3 Ground- and water source heat pumps

Ground source heat pumps use an indirect brine (antifreeze) or water cycle to transport the heat of the ground source to the heat pump evaporator. Most common systems are horizontal collector and borehole heat exchangers as well as the source variants described in chap. 2.2.1.2. Brine-to-water heat pumps work with the refrigerants R407C, R410A and R134A, and some with propane (R290). While in Nordic countries, the heat pump is normally designed to 40-60% of the design heat load (Stene, 2007) and combined with electrical back-up heating, ground-source heat pumps are usually operated monovalently in the central European countries Germany, Austria and Switzerland. For low energy single family houses of about 5 kW design heat load, about 100 m borehole heat exchanger is required for monovalent combined SH&DHW operation. Ground source heat pumps including borehole heat exchanger have higher investment costs. However, by the higher source temperature, better seasonal performance is reached compared to air-source heat pumps. Therefore, ground source heat pumps have lower annualised costs in Switzerland (WWF, 2009).
In summertime, the borehole heat exchanger can also be used for passive cooling without heat pump operation. On the other hand, ground-source heat pumps with internal or external cycle reversal can be used for active cooling mode using the ground for heat rejection. Standard hydraulic system layouts including the cooling operation are given in the next chapters.

4.3.1 System configuration with only passive cooling option

Due to temperatures of the ground in summertime systems with borehole heat exchangers enable a passive cooling operation. Fig. 29 shows a hydronic integration of a ground-coupled heat pump with only passive cooling option. In comparison to system configurations for the space heating and DHW operation an additional heat exchanger to directly connect the borehole heat exchanger to the floor emission system is required. Design recommendations concerning the system integration and design of components are given in the field monitoring of the Annex 32 report.

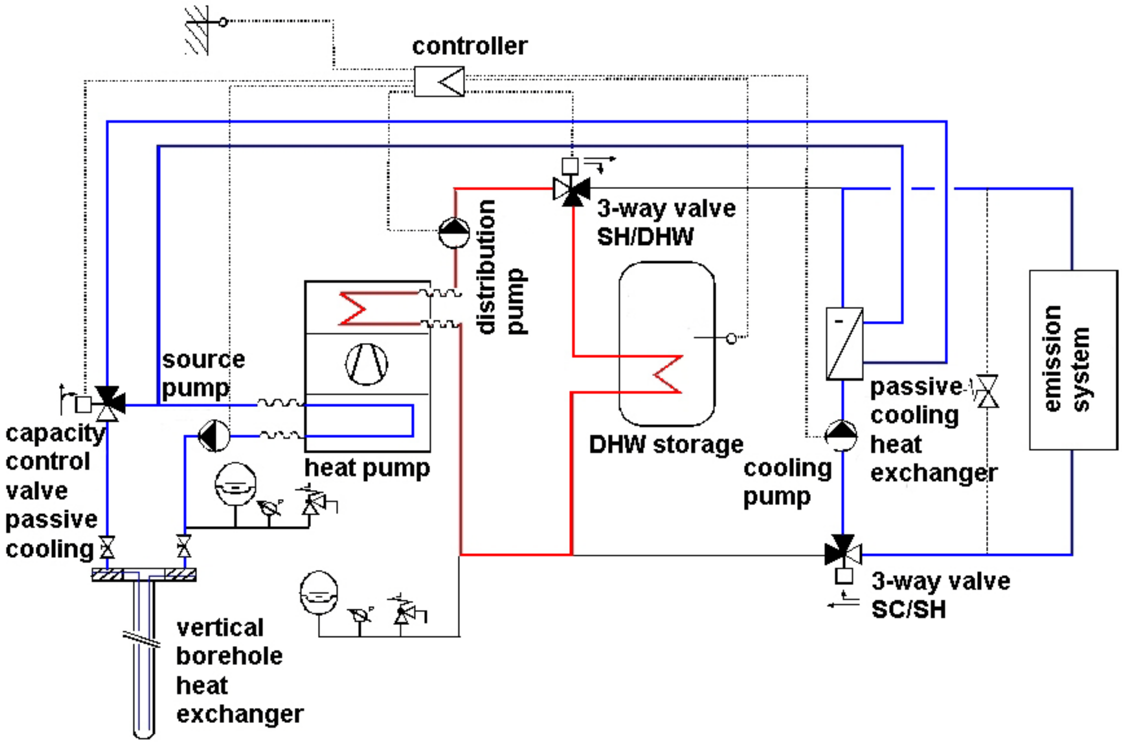


Fig. 29: Ground-coupled heat pump system with only passive cooling option (Dott, Afjei and Huber, 2007)

4.3.2 Brine- and water-source heat pumps with active cooling

The heat pump can also be used for active cooling by a reverse operation. This can be accomplished by an external hydraulic or an internal change of evaporator and condenser by a four-way valve in the refrigerant cycle.

In areas where active space cooling is a requirement or a strong desire (typical for almost all locations in the US for instance), a brine- or water-to-air heat pump (Fig. 30 left) with cycle reversal is the most common means used to provide space cooling. Most existing systems still use R-22 as the refrigerant, but all new ones use R-410A. The heat/cold emission system used for this type of equipment is a centrally ducted air distribution network. Very high efficiency systems featuring compressors with two speeds or multiple capacity steps, and inverter-controlled variable speed fans are available and are the systems usually favored in low energy home designs featuring ground-source heat pumps in the US.

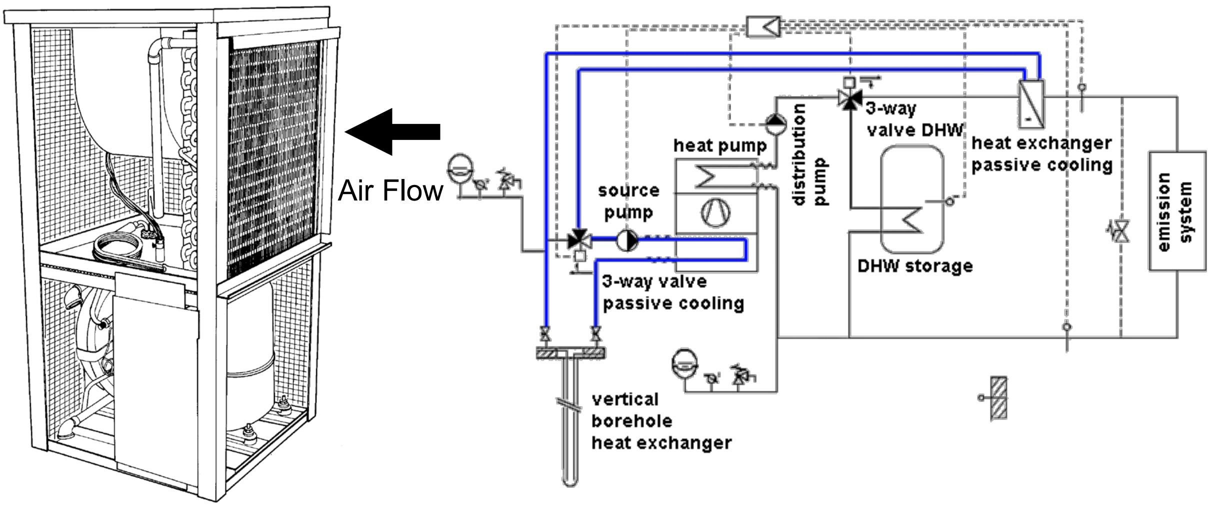


Fig. 30: Typical packaged water- or brine-to-air heat pump unit (left) and hydronic sketch of a brine-to-water heat pump system with passive and simultaneous cooling option (right)

Fig. 30 right shows a recommended system configuration for the integration of the heat pump with passive and simultaneous cooling/DHW option.

However, due to the short term storage of colder ground temperature due to the extracted heat in DHW operation, a daily decoupling of space cooling and DHW operation has no efficiency drawbacks. That means, the heat extracted from the ground in night-time DHW operation has a benefit for the next day's passive cooling operation. This is a major difference to air systems, where no storage effect exists.

5 HEAT PUMP SYSTEMS FOR SPACE HEATING AND DHW

Heat pumps for space heating and DHW operation are standard system solutions on the market and are commonly available for the heat sources outside air, ground and water. Exhaust air systems have already been treated in chapter 3.
Heat pump systems for combined space heating and DHW operation can be differentiated in alternate and simultaneous operating configurations.
Alternate operation refers to switching the heat pump from space heating to DHW heating, i.e. the space heating operation is interrupted until the DHW storage is charged to the set-point. Simultaneous system configurations produce the space heating and DHW energy at the same time.

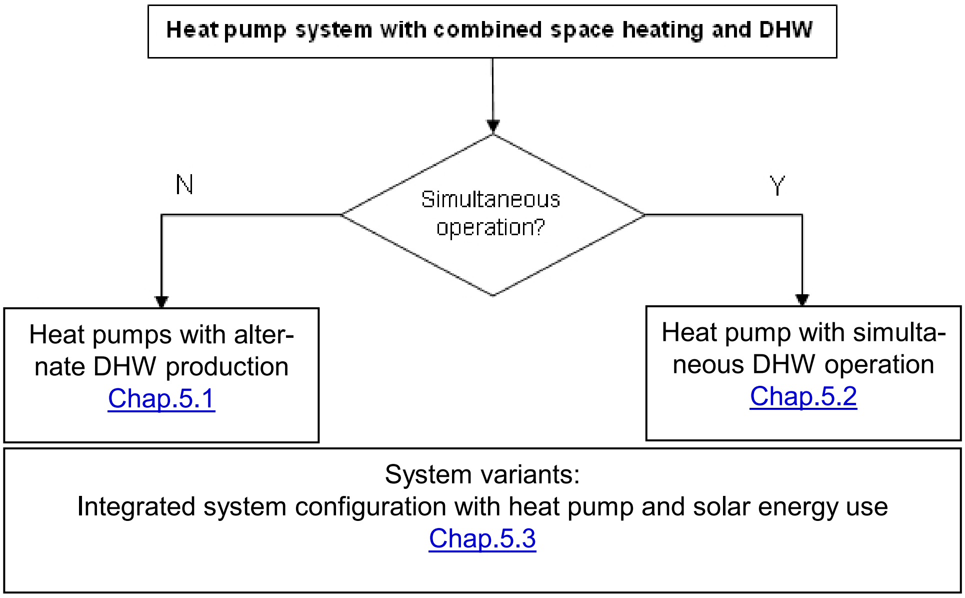


Fig. 31: Overview of heat pump systems with combined space heating and DHW production

5.1 Systems with alternate operation

In Europe systems in alternate configuration are the most common system configurations on the market.

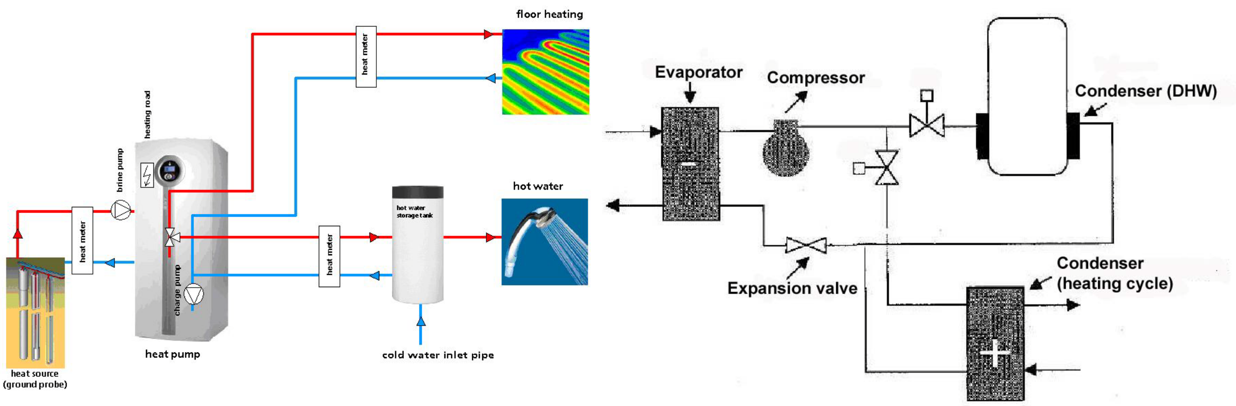


Fig. 32: Standard configuration of alternate systems (Miara et al., 2008) with parallel DHW storage and two condensers (Hantz et al., 2004)

This system configuration can be distinguished as well by the type of storage and the hydraulic integration of the storage. Configurations found on the market include the following:

- Intermediate circuit with external refrigerant/water heat exchanger for the DHW circuit
- DHW water/water heat exchanger around the storage tank (mantle storage tank)
- Condenser of the refrigerant inside the storage tank or around the storage
- Combined storage: a smaller DHW storage is integrated in a bigger heating buffer storage
- Fresh water system: Buffer storage with external heat exchanger for instantaneous DHW production

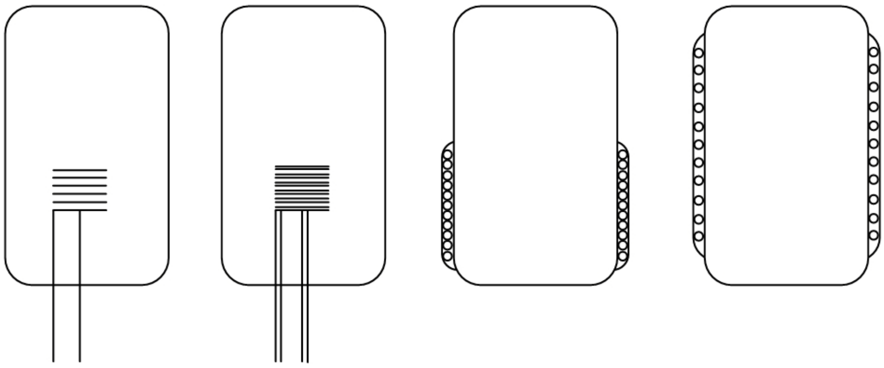


Fig. 33: Direct storage integration with condenser in storage (based on EN 255-3:1997)

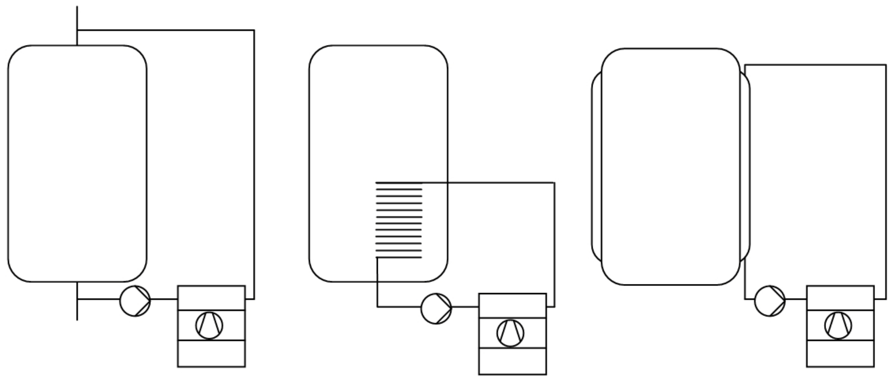


Fig. 34: Storage integration with intermediate cycle (based on EN 255-3:1997)

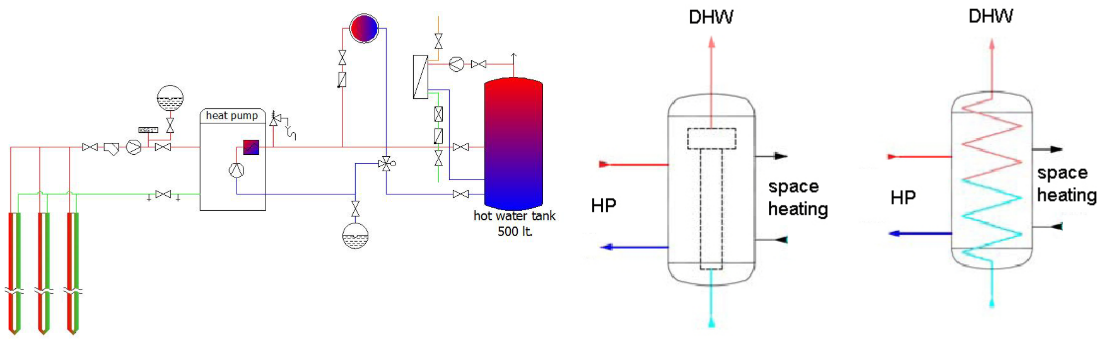


Fig. 35: Fresh water system (left, source: Zottl et al., 2010) and different types of combi-storages (source: FAWA, 2004)

Fig. 33 shows the direct integration into the storage, Fig. 34 shows configuration with an intermediate cycle.
Fig. 35 left depicts an example of a fresh water system with buffer storage and instantaneous water heating, which avoids problems with legionella. Fig. 35 right shows different types of combi storages for space heating and DHW operation.

5.2 Systems with simultaneous operation

Most common marketable systems with simultaneous operation use a desuperheater for the simultaneous DHW production.
Desuperheaters are common in North-American system configurations of air-to-air heat pump as shown in Fig. 36. The desuperheater is located on the outlet of the compressor and desuperheats the hot refrigerant down to the condensation temperature. The high temperature level of the desuperheating is favourable for the DHW production. The condenser is used to provide the reheating of the recirculated air. In case of a system with reverse operation the heat pump can also recool the recirculating air in summer operation. Note that the temperature level in the condenser defines the heat pump COP, while in alternate operation the higher temperature requirements of the DHW operation defines the COP of the heat pump.

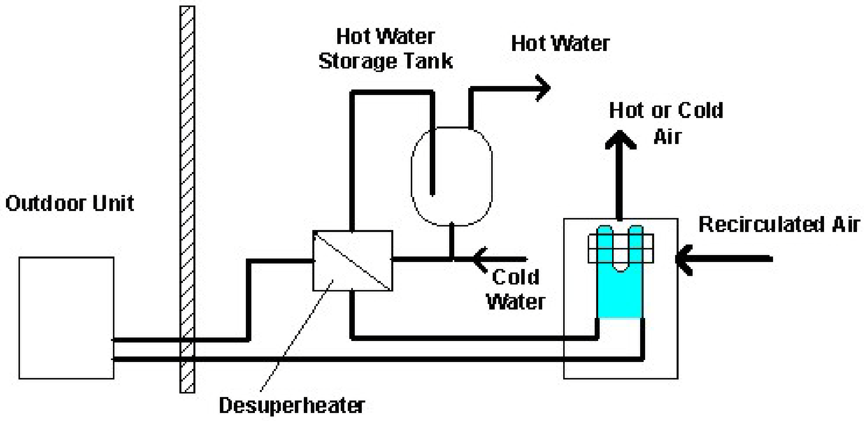


Fig. 36: Canadian air-to-air heat pump with desuperheater for the DHW production (Minea 2003)

A problem with the desuperheater could be that it is only active in case of space heating or cooling load of the dwelling, so a back-up heating for the DHW mode may be required for the times without space heating or cooling load.
Fig. 37 shows a Norwegian system configuration with simultaneous operation for space heating and DHW in monovalent configuration, which uses a desuperheater for the domestic hot water production both in summer and in winter operation.
In winter operation the condenser which is located in the lower part of a storage works on the heating cycle while a desuperheater is used for the domestic hot water production in the upper part. In summer operation, the domestic hot water is preheated in the lower part of the storage by the condenser heat and re-heated by the desuperheater. In this way the desuperheater can support the DHW production independent of the space heating energy needs.
Moreover, cascade solutions, where the upper stage extracts heat from the cycle of the lower stage are possible. An example from Switzerland is given in Fig. 38.

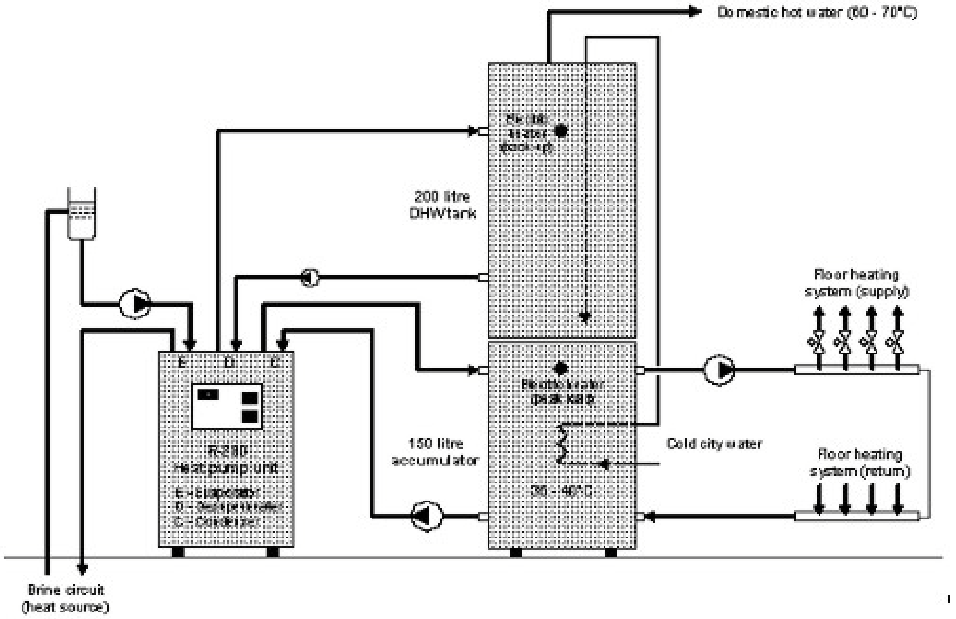


Fig. 37: Norwegian simultaneous heat pump with desuperheater (Jakobsen, 2003)

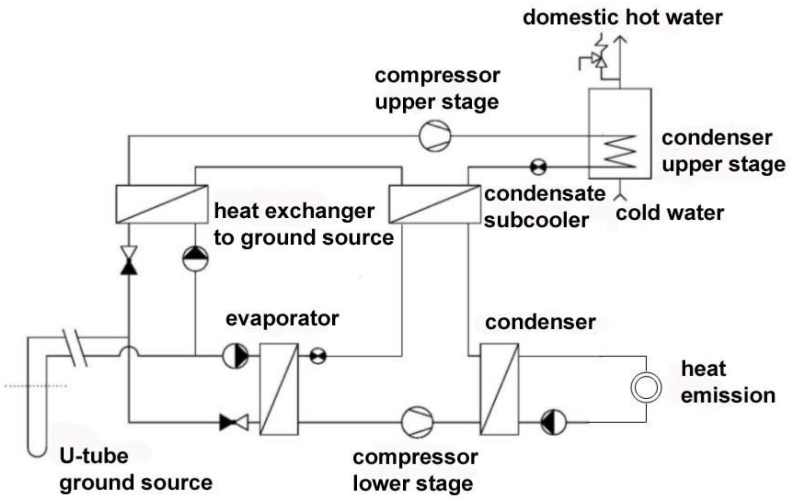


Fig. 38: Swiss two stage simultaneous operating heat pump concept with condensate subcooling of the lower stage heat pump for space heating

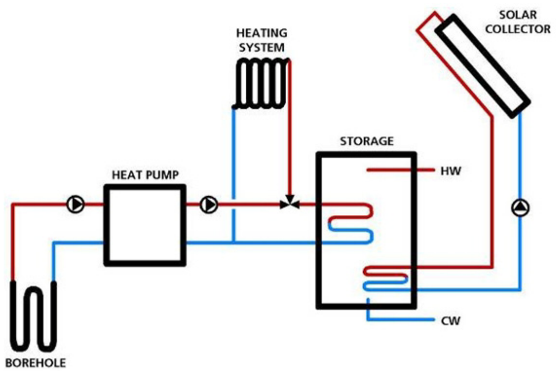
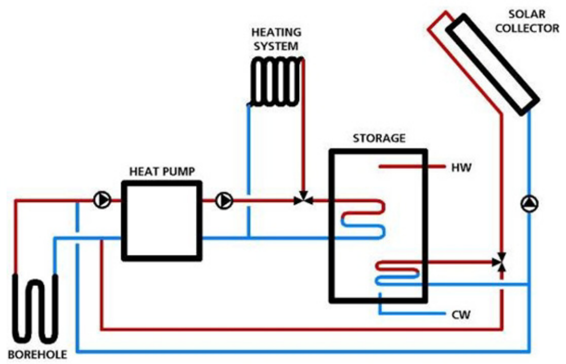
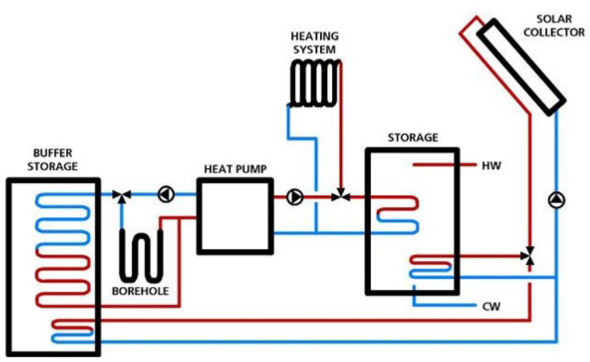
Summarising, simultaneous operating systems may have several efficiency benefits compared to alternate operating system solutions:

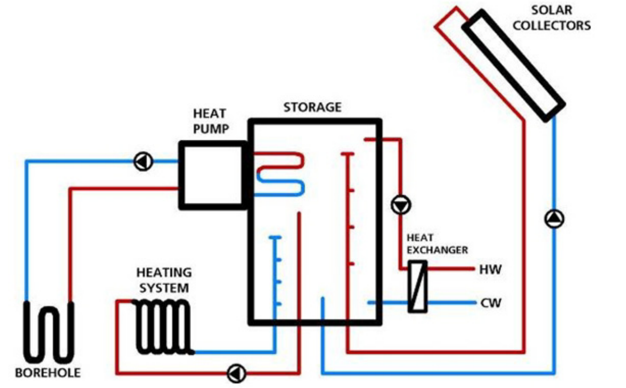
- Use of higher internal process temperatures as heat source (condensate subcooling).
- Higher COP by lower condensation temperature also in DHW operation (desuperheater).
- Better temperature match in a desuperheater, condenser or subcooler and thus reduced exergy losses for the heat transfer.
- Extended heat extraction from the process by use of subcooling heat as source or for preheating purpose.
- No interruption of the space heating operation during DHW production.
- Heat recovery in combined space cooling/DHW operation.

5.3 Systems with integration of solar energy

Presently, many systems combining heat pumps with solar thermal collectors are available on the European markets. But, since most of them were introduced recently, there is no experience about functionality, performance and operational behaviour of such systems. Therefore, a new joint IEA SHC Task 44/HPP Annex 38 has started in Jan. 2010 and will continue for a 4-year period until the end of 2013. The objective is to investigate marketable and new combinations of heat pumps and solar thermal collectors to quantify the benefits of the combinations. The overview given in Tab. 5 is a first classification of marketable system integrating heat pumps and solar themal collectors for space heating and DHW and was outlined in Henning and Miara (2008). In the table, also the main characteristics of the respective hydraulic integration are given.

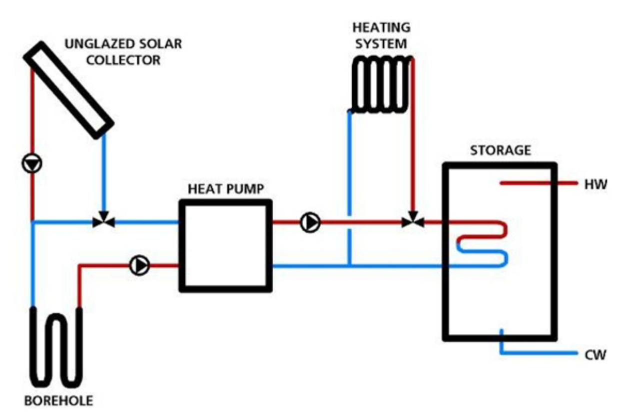
Tab. 5 Overview of integration of solar energy and heat pump (Henning and Miara, 2008)

System integration options of heat pump and solar thermal collector system	
System sketch	**Short description**
	**System with no interaction** • Use of solar energy only for DHW • No direct interaction between systems • Contribution of solar energy to higher overall SPF due to less DHW operation • No direct regeneration of the ground
	**Active regeneration** • Use of solar energy for DHW and regeneration of the ground • Eventually reduced length of borehole heat exchanger possible • Danger of drying-out of the ground • Seasonal storage with one borehole not possible => Rather suited for borehole fields • Higher solar contribution by elevation of source temperature possible • Reduction of stagnation operation of the collector
	**Big buffer storage** • Buffer storage as heat source for the heat pump • Borehole heat exchanger as back-up • Charging of buffer and DHW by solar energy • Higher inlet temperature possible at high solar irradiation level • No active regeneration of the ground



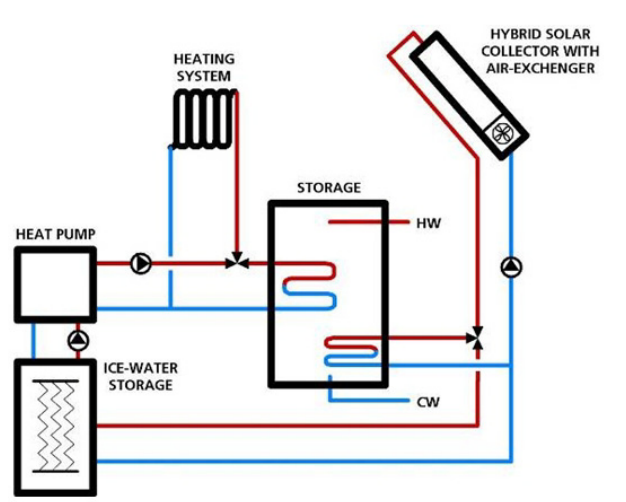
Maximum integration

- Integration of solar energy and heat pump by central stratified storage
- Heat pump as back-up of the solar system
- Condenser of heat pump placed in storage
- DHW by fresh water system
- No active regeneration of the ground



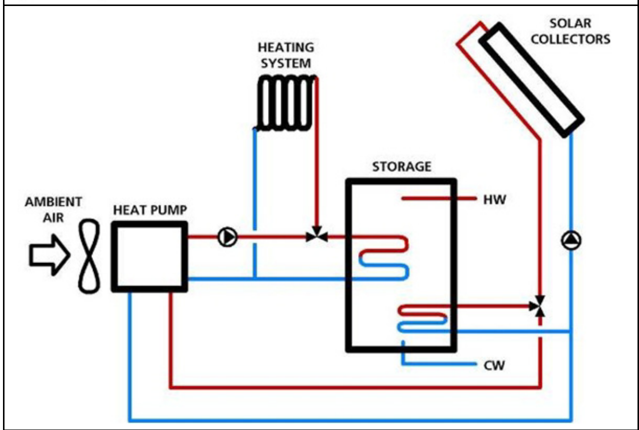
Unglazed collector

- Unglazed collector as elevation of the ground temperature
- Cost advantages by unglazed collectors
- Eventually reduction of borehole heat exchanger length possible
- No solar contribution for DHW operation



Solar heating system

- Special hybrid collector which uses solar energy and the outside air
- Hybrid collector connected to an ice storage, which stores the heat in the phase change ice - water
- Ice-storage is heat source of the heat pump
- Solar contribution to the DHW production
- No ground heat exchanger required



Outside air heat pump

- Separate solar collector and air-to-water heat pump (not integrated as hybrid collector)
- Heat pump uses solar source and outside air source
- Solar contribution to DHW production
- No ground heat exchanger required

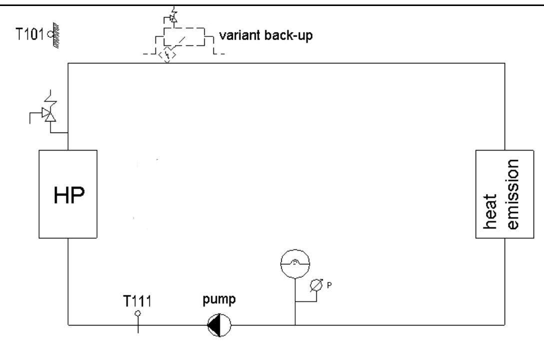
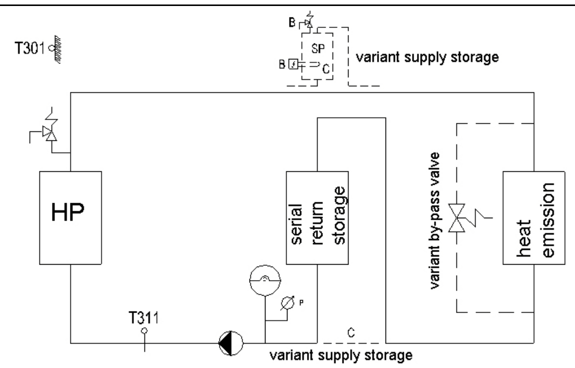
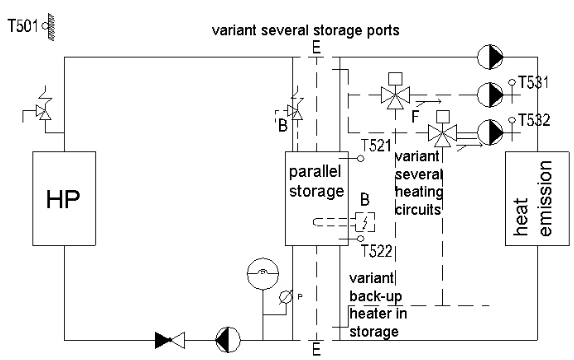
6 HEAT PUMP SYSTEMS WITH SINGLE FUNCTIONALITY

Heat pump systems with single functionality are the most common heat pumps on the market. In Europe heat pumps for space heating are the most common systems, in some countries, heat pump water heaters have a considerable market share, as well. In particular in Japan, the market of the heat pump water heaters with CO_2-refrigerant (so-called EcoCute systems) increased rapidly since their market introduction in the year 2000. In 2007 430.000 units were shipped, and the cumulated number in 2007 reached ~1'000'000 sold units (Ida, 2008). The target for 2010 is 5'200'000 sold units. Various systems of CO_2-HPWH of different manufacturers are on the market now.

6.1 Space heating-only heat pumps

System configurations can be distinguished by the integration of storages in the heating cycle and the number of heating cycles connected to the heat pump. The most common configurations and characteristics according to Gabathuler et. al. (2002) are given in Tab. 6.

Tab. 6 Overview of space heating-only heat pump systems (Gabathuler et. al., 2002)

Standard systems for space heating-only heat pumps	
System sketch	**Short description**
	**Systems without storage** • easiest solution • preferable due to robustness and costs
	**Systems with serial storage** • in the return of the heating cycle • required to augment thermal capacity of the space heating cycle • prevention of cyclic operation of the heat pump • mainly required in radiator systems
	**Systems with parallel storage** • heating buffer storage in parallel • hydraulic decoupling of heat pump and heat emission • useful, if more than one heating cycles is connected

6.2 Heat pump water heaters

6.2.1 Conventional heat pump water heaters

Common advanced designs of heat pump water heaters (HPWH) use up to four heat exchangers in order to best fit the temperatures of the heated DHW. In a desuperheater, the higher discharge temperatures of the refrigerant at the compressor outlet are used for reheating the DHW without increasing the condensation temperature. At the closest temperature spread (pinch point) the condensation of the refrigerant starts and a subcooling of the refrigerant for preheating the DHW have efficiency gains for the expansion process. Moreover, a suction gas heat exchanger can be used to transfer heat of the subcooled condensate to superheat the suction gas in order to increase desuperheating potential. Fig. 40 left shows the temperature difference in the heat exchangers for desuperheater, condenser and subcooler.

Residential HPWHs in the US come in two basic types, separate (or add-on) and integral. The add-on type has a separate, small heat pump package which is connected to a conventional water heater tank via hoses. A pump is used to circulate water to/from the storage tank to the water-to-refrigerant condenser in the heat pump unit. The integral type features a small heat pump unit mounted atop a conventional storage tank. This type may use a pump to circulate tank water to the heat pump condenser or the condenser may be inserted directly into the tank or wrapped around the tank exterior (Fig. 39).

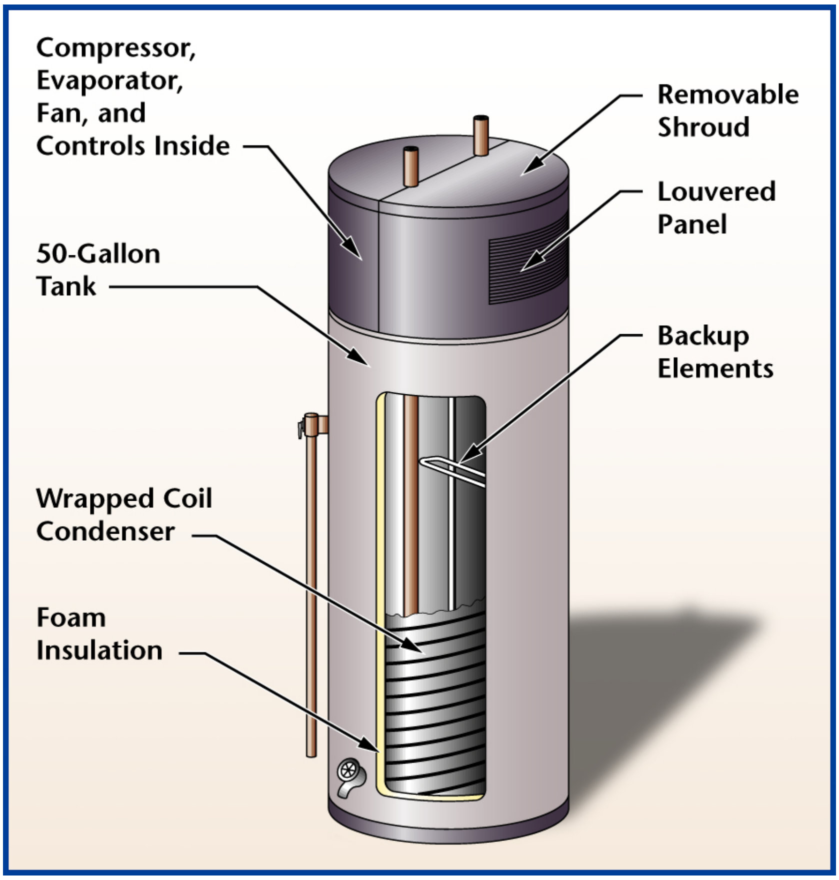


Fig. 39: Integral HPWH with wrapped tank condenser (source: Baxter, 2009)

6.2.2 CO_2 heat pump water heaters (EcoCute systems)

Heat pumps with carbon dioxide (CO_2, R744) refrigerant are a new and promising technology in particular for DHW heat pump water heaters (HPWH). CO_2 is a non-flammable and non-toxic fluid with a global warming potential (GWP) = 1 when used as refrigerant, in contrast to common HFC refrigerants. Due to the low critical temperature of 31.1 °C, a so-called trans-critical cycle is used for CO_2 heat pumps, where the heat is rejected by cooling down the superheated CO_2 in a single counter-flow gas cooler, see Fig. 40 right.

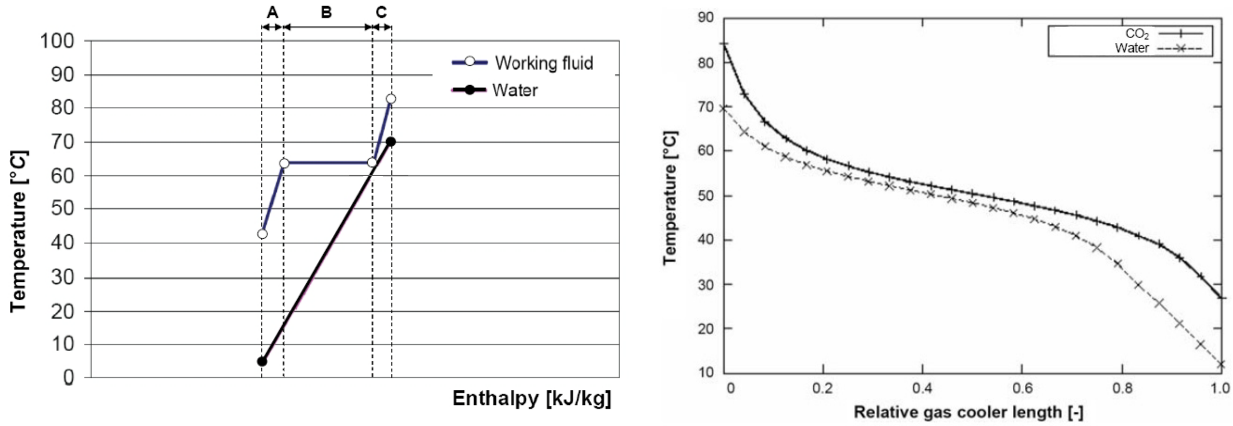


Fig. 40: Desuperheater-condenser-subcooler configuration used in common heat pump water heaters (right) and heating-up of DHW in counterflow gas cooler with superheated CO_2-refrigerant (left)(source: Stene, 2008)

Since the temperature fit reflects the exergy losses of the heat transfer, it becomes clear that the cooling of the CO_2 refrigerant in a counter-flow heat exchanger has exergetic benefits compared to the condensation at nearly constant temperature of other refrigerants. Thus, a higher COP for the DHW application can be expected, although very high DHW outlet temperatures of 60-85°C are reached.

The domestic hot water use in Japan is quite high compared to Europe due the tradition of taking a hot bath every evening. Therefore, the domestic hot water is stored at quite high temperatures. In particular for the applications of hot water at high temperature levels, CO_2-heat pumps have performance advantages compared other refrigerants. In Japan, DHW is normally produced during night-time, since the electricity tariff during nighttime is only ¼ of the daytime tariff.

Fig. 41 shows a common configuration of Japanese Eco Cute systems which usually uses the outside air as heat source. Units in the capacity range of 4-20 kW are on the market. Fig. 41 shows the outdoor unit and the DHW tank which is inside the white box.

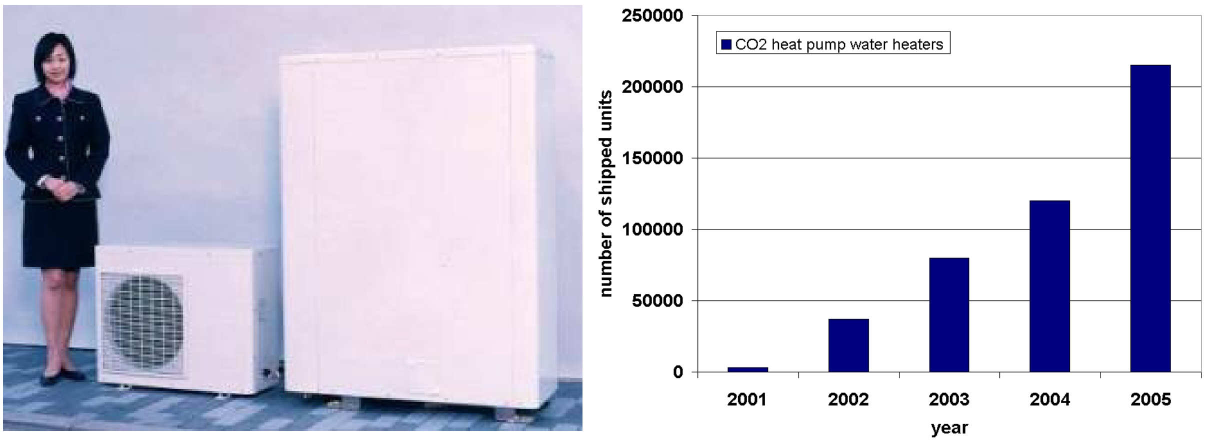


Fig. 41: CO_2-heat pump water heater on the Japanese market (called EcoCute systems)

7 CONCLUSIONS

The report gives an overview of marketable system configurations for the use in low energy houses. Due to the different energy needs, adapted system solutions have partly already been developed or are currently under development.
Compared to conventional new buildings in particular ventilation air based system solutions and integrated systems were developed, starting with integrated system for German passive houses. However, capacity of some marketable systems is also suitable for the application in low energy houses. Integrated systems mainly comprise the functions space heating, DHW and ventilation.
The report gives a categorisation which based on the integrated functionality of the systems. Mainly ventilation air based system solutions, system with cooling function independent of the ventilation and combined space heating and DHW functions can be distinguished.
Current heat pump market trends are driven by three issues: system integration, capacity control and natural refrigerants. In Europe heat pumps show a strong increase in some national markets (EHPA, 2009).
On the one hand system integration is related to the combination of heat pump with solar thermal collectors. Many manufacturers provide systems with heat pump and solar thermal collectors of different degree of integration. However, there is little information about the seasonal performance of these systems and whether higher investment costs are justified, since the heat pump and the solar collector performance may be in competition, e.g. if energy is covered by the solar collector in times of good heat pump performance. Therefore, these combinations are investigated in a joined IEA SHC Task 44/HPP Annex 38.
On the other hand system integration is related to the extension of the system configuration to the integration of the ventilation system or with a space cooling option.
More and more manufacturers have integrated options for passive ground-coupled cooling in their system configurations in the recent years.
Moreover, Japanese companies like Daikin and Mitsubishi are expanding into the European residential market with system concepts based on heat pump air conditioners as used in Japan. These units often have a space heating and space cooling operation mode, are normally inverter-controlled and are presently adapted to common emission systems on the European market like floor heating, leading to an increasing number of capacity-controlled heat pumps. Capacity controlled units may have advantages in part load conditions due to lower flow temperature and better COP in part load operation, and systems can be operated down to very low temperatures of – 20°C. This could be interesting for monovalent design and for the application in Nordic countries.
Last but not least, there is an ongoing discussion to phase-out the HFC refrigerants in Europe, and manufacturers are actively investigating options with natural refrigerants like CO_2 or propane. However, only a few manufactures offer heat pumps with natural refrigerants on the European market, while most of the systems use HFC refrigerants.

8 ACKNOWLEDGEMENT

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10 APPENDIX

- **A: Market Overview of heating centrals, compact units, exhaust air heat pumps in AT, CH, DE**

- **B: Overview of recent Japanese mini split units**

- **C: Summary of characteristics of common heat pumps**

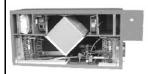
A MARKET OVERVIEW ON HEAT PUMP COMPACT UNITS

Tab. A 1 Market overview heating centrals with Ventilation Heat Recovery and heat pump without heat recovery by of the exhaust air

Manufacturer	Drexel & Weiss Kennelbacherstr. 36 A-6900 Bregenz drexel-weiss.at	Friap AG Ey 9 CH-3063 Ittingen friap.ch	Zehnder Comfortsystems Industriestr. CH-8820 Wädens-wil comfosystems.ch	Alpha-Innotec Logistikcenter Gäuerhof CH 6246 Altishofen calmotherm.ch	Siemens/Novelan AG Bucherstrasse 31 CH-8108 Dällikon novelan.ch
Type	Aerosmart XSL	Friap FM 3/FM 6	Comfobox	KHZ LW 60/80 (Calmotherm)	HLW 6M/8M (Novelan)
Figure					
Application	LEH, PH	LEH	LEH	LEH	LEH
Funktionality	VHR, SH, DHW	VHR, SH,DHW, SC (o), Sol (o)	VHR, DHW, SH, SC (o)	VHR, SH, DHW	VHR, SH, DHW
Capacity WP [kW]	2.5 (B0/W35)	3 or 6 (A2/B0/W35)	5-10 or 6-10	6 or 8 (A2/W35)	6 or 8 (A2/W35)
El. back-up heater [kW]	2 (WW)	2 (WW)	2	6	6
Heat source	S (hor.)	OA or S	OA or S	OA	OA
Abgabesystem	W	W	W	W	W
Volume flow rate [m^3/h]	160-230	150 – 500	45 - 500	50-300	50-300
Storage size [l]	200	external	400/500 l	265 l	265 l
DHW-Temperature [°C]	n.a.	Bis 67	54 (60 EH)	~48	~48
Refrigerant	R134a	R407C	R134a/R410C	R404a	R404a

Legend: LEH –low energy house, PH – Passive house, VHR – ventilation heat recovery, SH – space heating, SC – space cooling, Sol – Solar collector, o – optional, OA – outdoor air, W – PWW, blue backgruond – cooling option, B – Brine, n.a. – not available, DHW – Domestic hot water, hor. – horizontal ground collector

Tab. A 2 Market overview of ventilation compact units with heat recovery and exhaust air heat pump for space heating and/or DHW production

Manufacturer	Drexel & Weiss Kennelbacherstr. 36 A-6900 Bregenz www.drexel-weiss.at	AEREX HT-Systeme GmbH Steinkirchring 27 78056 Villingen-Schw. www.aerex.de	Stiebel-Eltron AG Netzibodenstr. 23c CH-4133 Pratteln www.stiebel-eltron.ch	Siemens/Novelan AG Bucherstrasse 31 CH-8108 Dällikon www.novelan.ch	Siemens/Novelan AG Bucherstrasse 31 CH-8108 Dällikon www.novelan.ch	Bau-Info-Center (BIC) Postfach 26 D-72530 Hohenstein www.bauinfocentrer.de	Bau-Info-Center (BIC) Postfach 26 D-72530 Hohenstein www.bauinfocentrer.de	NILAN AG Schützenstrasse 33 CH-8902 Urdorf Tel: +41-44 736 50 00 Fax: +41-44 736 50 09 www.nilan.ch	Effizionto Haustechnik GmbH Langwiesenstr. 8 D-74363 Güglingen www.effiziento.com
Type	Aerosmart S-L, mono	Aerex BW 175	LWZ 303 SOL THZ 303SOL	Genvex Combi 185 L	GE VP(C) Serie	WRG134 BP	WRG134LW WRG334LW	VP 18-10 P	Effiziento
Figure									
Application	U	U	L	U	U	U	U	U	L
Functionality	VHR, SH, DHW	VHR, SH DHW, Sol (o)	VHR, SH, DHW, Sol (o)	VHR, SH, DHW, SC (o), Sol (o)	VHR, SH, SC (VPC)	VHR, SH	VHR, SH (s), DHW, SC (o)	VHR, SH, DHW, SC(o), Sol (o)	VHR, DHW, SH, Sol (o)
Capacity HP [kW]	1.0(S)-1.7(L)	1.4	4.2	1.4	1.4	1.4	1.4	1.3	4
El. BU [kW]	2 (DHW)	2 (DHW)	6	1	none	none	none	1	2(-6 (o))
Heat source	EA	EA	Mix OA/EA	EA	EA	EA	EA	EA	OA/EA
Heat sink	A	A	W	A, W(o)	A	A	A	A, W (o)	W, A(o)
Air flow [m^3/h]	105-230	140-210	80-230 (VHR)	max. 260	100-260	80-250	100-265	75-240	70-350 (VHR)
Storage size [l]	200	Extern 320	200	185	none	none	External	180	External 500
DHW temp. [°C]	n.a.	n.a.	55	55	n.a.	none	n.a.	65	55
Refrigerant	R134a	R134a	R407C	R134a	R407C	R134a	R134a	R134a	R407C

Legend: L – low energy, U – ultra low energy house, VHR – Ventilation heat recovery, SH –space heating, SC – space cooling, Sol - solar collector, a – additional, o – optional, s –supplementary, EA - exhaust air, OA - outside air, W – water blue background – space cooling option

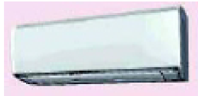
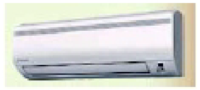
Tab. A 3 Market overview of exhaust air heat pumps (without a ventilation heat recovery) for space heating and/or DHW production

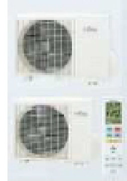
Manufacturer	Stiebel-Eltron AG Netzibodenstr. 23c CH-4133 Pratteln www.stiebel-eltron.ch	Stiebel-Eltron AG Netzibodenstr. 23c CH-4133 Pratteln www.stiebel-eltron.ch AEREX HT-Systeme GmbH Steinkirchring 27 78056 Villingen-Schw. www.aerex.de	NILAN AG Schützenstrasse 33 CH-8902 Urdorf Tel: +41-44 736 50 00 Fax: +41-44 736 50 09 www.nilan.ch	NILAN AG Schützenstrasse 33 CH-8902 Urdorf Tel: +41-44 736 50 00 Fax: +41-44 736 50 09 www.nilan.ch	NILAN AG Schützenstrasse 33 CH-8902 Urdorf Tel: +41-44 736 50 00 Fax: +41-44 736 50 09 www.nilan.ch	Siemens/Novelan AG Bucherstrasse 31 CH-8108 Dällikon www.novelan.ch
Type	LWA 100	LWA 203/303 SOL (AEREX TWIN Boxx)	VP 18	VGU 250 (EK 6/9)	VPL 15 EC	Vanvex 185 S/ 285 S
Figure		 				
Application	U, L (with s)	U, L (with s)	U	U	U	U
Functionality	V, DHW	V, SH, DHW, Sol (o)	VHR, DHW, SH, SC (o), Sol (o)	V, DHW, SH (EK)	V, SH, SC	V, DHW, Sol (o)
Capacity HP	0.8	1.5	2.1	1.2, 2.1 (EK)	2.1	1.5
El. BU [kW]	3	6.6 (DHW)	1 (o)	1, 9 (EK)	none	1
Heat source	EA	EA	EA	EA	EA	EA ; OA (a)
Heat sink	DHW	DHW, W	DHW, A, W (o)	DHW, W (EK)	A	DHW
Air flow rate	50-130	70-290, min. HP 120	max. 330	325	100 - 400	max. 280
Storage size [l]	100	300	180	230	none	185/285
DHW temp.	max. 55 (HP)	max. 60 (HP)	60	60	none	55
Refrigerant	R290	R134a	R134a	n.a.	R134a	R134a

Legend: L – low energy, U – ultra low energy house, V – Ventilation, SH –space heating, SC – space cooling, Sol - solar collector, o – optional, s –supplementary, EA - exhaust air, OA - outside air, W – water HP – heat pump blue background – space cooling option, a – alternate, min- minimum, max - maximum

B MARKET OVERVIEW ON RECENT MINI SPLIT UNITS

In the Japanese country report recent developments for marketable Mini Split Units of different manufacturers are outlined in the following overview.

Manufacture				DAIKIN INDUSTRIES			
Basic specifications	Model number			S40LTRXP	S40LTHXP	S40KTCXP	S40LTEP
	Release date			Nov-09	Nov-09	Mar-09	Jan-09
	Sales areas			Japan	Japan	Japan	Japan
	Image						
	Size	Indoor equipment		798Lx295Hx268D	798Lx295Hx268D	798Lx295Hx255D	795Lx290Hx248D
		Outdoor equipment		795(+63)Lx693Hx285(+46.9)D	795(+63)Lx569Hx285(+42)D	765(+63)Lx550Hx285(+42)D	765(+63)Lx550Hx285(+42)D
	Cooling Indoor: 27℃DB, 19℃WB Outdoor: 35℃DB, 24℃WB	Capacity [kW]	Minimum	0.6	0.6	0.9	0.9
			Rated	4.0	4.0	4.0	4.0
			Maxmun	5.3	5.3	4.5	4.5
		Power consumption [W]	Minimum	100	100	205	205
			Rated	885	885	985	1230
			Maxmun	1500	1500	1550	1760
	Heating Indoor: 20℃DB Outdoor: 7℃DB, 6℃WB	Capacity [kW]	Minimum	0.6	0.6	0.9	0.9
			Rated	5.0	5.0	5.0	5.0
			Maxmun	10.1	10.1	7.3	7.2
		Power consumption [W]	Minimum	100	100	175	175
			Rated	980	980	1055	1230
			Maxmun	3190	3190	2090	2370
	APF (Annual performance factor defined by JIS)			6.2	6.2	4.9	4.9
Striking function	Air flow control	A: On target automatically by perceiving human locus		B,C,D,E	B,C,D,E	B,C	B,C
		B: On target manually by remote-controller C: Ceiling-hugging for cooling / Floor-hugging for heating D: Deffusing for uniforming indoor temp. E: Other		Description: ●4 directions air flow control realizes an even comfort throughout the room. It also realizes people-friendly operation since it prevents the air blowing directly on to your body.	Description: ●4 directions air flow control realizes an even comfort throughout the room. It also realizes people-friendly operation since it prevents the air blowing directly on to your body.	Description: ●The comfort mode, which cold or warm air is prevented from being directly onto the body, is mounted. ●3D air flow, which combines vertical and horizontal auto-swing to circulate a stream of warm/cool air right to the corners of even large spaces.	Description: ●The comfort mode, which cold or warm air is prevented from being directly onto the body, is mounted.
	Automatic air filter cleaner (How to dispose the dust gathered)	A: Exhaust outdoors		B	B	B	
		B: Stock in a reciever C: Other		Description: ●Thanks to the dust Compression structure, you don't have to throw the dust out from the dust pocket for 10 years. ●"Heat exchanger with automatic cleaning function", which cleans dust attached to the heat exchanger, is mounted. ●Mold-proof operation, which prevents the generation of mould and mould odors inside the indoor unit.	Description: ●Thanks to the dust Compression structure, you don't have to throw the dust out from the dust pocket for 10 years. ●"Heat exchanger with automatic cleaning function", which cleans dust attached to the heat exchanger, is mounted. ●Mold-proof operation, which prevents the generation of mould and mould odors inside the indoor unit.	Description: ●Thanks to the dust Compression structure, you don't have to throw the dust out from the dust pocket for 10 years. ●"Heat exchanger with bacteria/mildew proof coating", which keeps it clean, is mounted. ●Mold-proof operation, which prevents the generation of mould and mould odors inside the indoor unit.	Description: ●Mold-proof operation, which prevents the generation of mould and mould odors inside the indoor unit.
	Air ventilation	A: Supply		A			
		B:Exhaust C: Other		Description: ●This model is available to be certified as a 24-hours ventilation product. (waiting for the certification.) ●Powerful ventilation with 32m/h in maximum per an hour. ●Cleaned outside air is taken in and supply the clean, heated air to the inside of the room. Keeps warm even a winter season.	Description: N/A	Description: N/A	Description: N/A
	Dehumidification	A: Cooling		B	B	A	A
		B: Reheat after cooling C: Other		Description: ●"SARARA dehumidification all-the-time mode", which automatically switches 3 dehumidification modes, is mounted. ●"Laundry drying operation" which dries a laundry quickly. ●"Mold-Proof operation", which prevents the generation of mold in your room, is mounted.	Description: ●"SARARA dehumidification all-the-time mode", which automatically switches 3 dehumidification modes, is mounted. ●"Laundry drying operation" which dries a laundry quickly. ●"Mold-Proof operation", which prevents the generation of mold in your room, is mounted.	Description: ●"Laundry drying operation" which dries a laundry quickly.	Description:
	Air purification			Description: ●"Double-block air purifying filter", which strongly removes bacteria and viruses, is mounted. (①Long-life Photocatalytic air-purifying filter② Long-life filter protecting against bacteria with silver and removing allergen.) ●"Bio-antibody filter(option)",which captures viruses with antibody, is mounted.	Description: ●"Double-block air purifying filter", which strongly removes bacteria and viruses, is mounted. (①Long-life Photocatalytic air-purifying filter② Long-life filter protecting against bacteria with silver and removing allergen.) ●"Bio-antibody filter(option)",which captures viruses with antibody, is mounted.	Description: ●"Double-block air purifying filter", which strongly removes bacteria and viruses, is mounted. (①Long-life Photocatalytic air-purifying filter② Long-life filter protecting against bacteria with silver and removing allergen.) ●"Bio-antibody filter(option)",which captures viruses with antibody, is mounted.	Description: ●"Double-block air purifying filter", which strongly removes bacteria and viruses, is mounted. (①Long-life Photocatalytic air-purifying filter② Long-life filter protecting against bacteria with silver and removing allergen.) ●"Bio-antibody filter(option)",which captures viruses with antibody, is mounted.
	Humidification			Description: ●"Ururu-humidification", which moisturizes throughout the indoor areas without water supply, is mounted. ●Moisturizing operation ,which moistens your skin throughout a year.	Description: N/A	Description: N/A	Description: N/A
	Status display (for energy saving)			Description: ●"Indication of Information", which inform you of an amount of power consumption, outdoor temperature etc..., is mounted. ●The eco-point can be saved by using the air conditioner unit in an eco-friendly operation. ●When you save a certain points and apply Daikin, we Daikin will perform an activity which contributes to the global environmental protection.	Description: ●"Indication of Information", which inform you of an amount of power consumption, outdoor temperature etc..., is mounted.	Description: N/A	Description: N/A
	Other			Description: ●"Handy remote controller with large display", which is simple to use by large buttons and LCD. ●"Comfort sleep operation", which keeps the room temperature comfortable enough for comfort sleep with V-shape temperature control, is mounted. ●"Deodorizing with water" function, which removes the odor components sticking to the wall or fabric with the moisture, is mounted.	Description: ●"Handy remote controller with large display", which is simple to use by large buttons and LCD. ●"Comfort sleep operation", which keeps the room temperature comfortable enough for comfort sleep with V-shape temperature control, is mounted.	Description: ●"Comfort sleep operation", which keeps the room temperature comfortable enough for comfort sleep with V-shape temperature control, is mounted. ●"Healthy Cooling Operation" , which Gentle cooling with automatic temperature setting which optimizes indoor and outdoor temperature difference, is mounted.	Description: ●"Good Sleep Operation" gives you comfortable sleep with natural fluctuation cooling.

Manufacture				Fujitsu General Limited								
Basic specifications	Model number			AS-Z71V2	AS-Z63V2	AS-Z50V2	AS-Z40V2	AS-Z28V	AS-S40V2	AS-S28V	AS-S25V	AS-S22V
	Release date			Mar-09	Mar-09	Mar-09	Mar-09	Mar-09	Feb-09	Feb-09	Feb-09	Feb-09
	Sales areas			Japan only	Japan only	Japan only	Japan only	Japan only	Japan only	Japan only	Japan only	Japan only
	Image											
	Size	Indoor equipment		880Wx250Hx286D	880Wx250Hx286D	880Wx250Hx286D	880Wx250Hx286D	880Wx250Hx286D	728Wx250Hx286D	728Wx250Hx286D	728Wx250Hx286D	728Wx250Hx286D
		Outdoor equipment		790Wx620Hx298D	790Wx620Hx298D	790Wx620Hx298D	790Wx620Hx298D	790Wx620Hx298D	790Wx540Hx290D	790Wx540Hx290D	790Wx540Hx290D	660Wx540Hx290D
	Cooling Indoor: 27℃DB, 19℃WB Outdoor: 35℃DB, 24℃WB	Capacity [kW]	Minimum	0.9	0.9	0.9	0.6	0.4	0.9	0.5	0.5	0.5
			Rated	7.1	6.3	5.0	4.0	2.8	5.0	3.6	2.8	2.5
			Maximum	7.4	6.6	5.9	5.5	4.3	8.6	7.2	5.8	5.5
		Power consumption [W]	Minimum	90	90	90	90	55	100	100	100	100
			Rated	2,900	2,015	1,425	930	495	1,135	690	485	435
			Maximum	3,200	2,600	1,750	1,600	1,100	2,850	1,980	1,460	1,460
	Heating Indoor: 20℃DB Outdoor: 7℃DB, 6℃WB	Capacity [kW]	Minimum	0.9	0.9	0.9	0.6	0.4	0.9	0.5	0.5	0.5
			Rated	8.5	7.5	6.3	5.0	3.6	4.0	2.8	2.5	2.2
			Maximum	12.0	12.0	11.5	11.5	7.9	4.8	3.7	3.5	3.3
		Power consumption [W]	Minimum	90	90	85	85	55	125	125	125	125
			Rated	2,190	1,675	1,335	935	605	1,100	610	525	455
			Maximum	3,785	3,785	3,695	3,695	1,980	1,500	980	980	980
	APF (Annual performance factor defined by JIS)			4.5	5.0	5.7	6.2	6.6	5.2	6.0	6.0	6.0

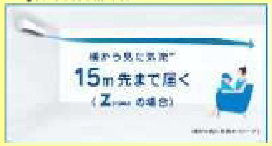
Striking function

Air flow control

A: On target automatically by perceiving human locus
B: On target manually by remote-controller
C: Ceiling-hugging for cooling / Floor-hugging for heating
D: Deffusing for uniforming indoor temp.
E: Other

Z series (AS-Z71V2 – AS-Z28V): A,B,C,D

Jet Cool Air Flow 15m

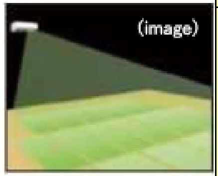


Jet & Wide Worm Air Flow 12m

Comfortable Automatic Swing

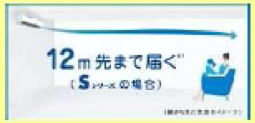
Sensor for Perceivinghuman locus ("Z" and "S" series) *Other function1

The sensor divides the room into 19, and it observes them.
The sensor check
1.The person's activity.
2.The person's existence.



S series (AS-S40V2 – AS-S22V): A,B,C,D

Jet Cool Air Flow 12m



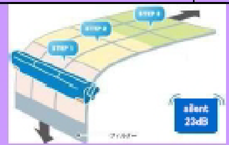
Jet & Wide Worm Air Flow 10m

Automatic air filter cleaner (How to dispose the dust gathered)

A: Exhaust outdoors
B: Stock in a reciever
C: Other

Z series: B

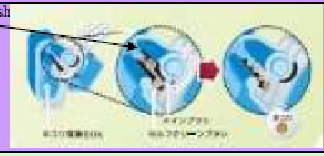
"Automatic Cleaner"



S series: B

3 step cleaning

Self cleaning of blush



Air ventilation

A: Supply
B:Exhaust
C: Other

Dehumidification

A: Cooling
B: Reheat after cooling
C: Other

Z series: A,B

Full season Dehumidification
"SaraSara Joshitsu" (Smoothly Reheat after cooling)
Laundry mode

S series: A,B

Full season Dehumidification
"SaraSara Joshitsu" (Smoothly Reheat after cooling)
Laundry mode

Air purification

Z series:

・Polyphenol Bacteria elimination odorization Negative air ion Air clean filter

・Metallic oxidation catalyst Odor removal filter

S series:

・Polyphenol Bacteria elimination odorization Negative air ion Air clean filter

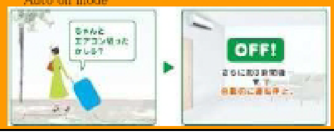
Humidification

Status display (for energy saving)

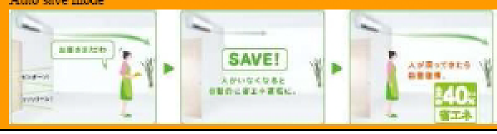
Other

Z series only
Voice information function

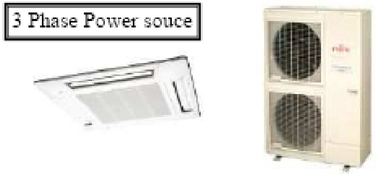
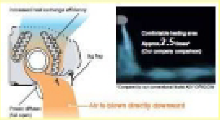
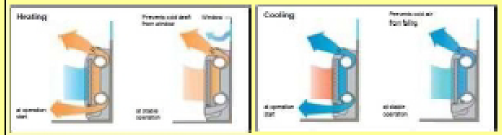
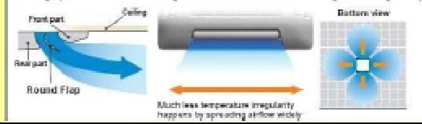
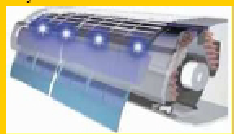
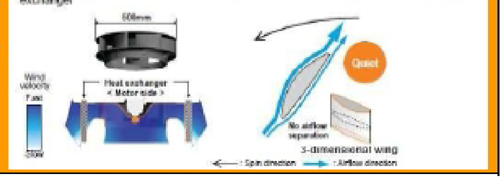
Sensor for Perceiving
Auto off mode

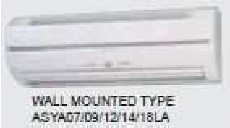


Auto save mode



nocria S series
The smallest WIDTH in Japanese market

Manufacture				Fujitsu General Limited								
Basic specifications	Model number (Inner/Outer)			AWYZ14LB / AOYZ14LB	AWYZ18LB / AOYZ18LB	AWYZ24LB / AOYZ24LB	AGYF09LA / AOYV09LA	AGYF12LA / AOYV12LA	AGYF14LA / AOYV14LA	AUYA36L	AUYA45L	AUYA54L
	Release date											
	Sales areas			Europa	Europa	Europa	Europa	Europa	Europa	Europa	Europa	Europa
	Image									3 Phase Power souce 		
	Size	Indoor equipment		899Wx250Hx298D	899Wx250Hx298D	899Wx250Hx298D	740Wx600Hx200D	740Wx600Hx200D	740Wx600Hx200D	(Unit) 840Wx288Hx840D (Panel) 950Wx 50Hx950D		
		Outdoor equipment		790Wx578Hx300D	790Wx578Hx300D	900Wx830Hx330D	790Wx540Hx290D	790Wx540Hx290D	790Wx578Hx290D	900Wx1280Hx364D		
	Cooling Indoor: 27℃DB, 19℃WB Outdoor: 35℃DB, 24℃WB	Capacity [kW]	Minimum	0.9	0.9	0.9	0.9	0.9	0.9	4.7	5	5.4
			Rated	4.2	5.2	7.1	2.6	3.5	4.2	10	12.5	14
			Maximum	5.3	5.9	8.0	3.5	4.0	5.0	11.4	14	16
		Power consumption [kW]	Minimum	0.09	0.09	0.11	0.25	0.25	0.25	-	-	-
			Rated	1.02	1.58	2.21	0.53	0.94	1.14	2.44	3.54	4.36
			Maximum	1.75	2	2.62	1.35	1.4	1.6	5.12	5.80	6.48
	Heating Indoor: 20℃DB Outdoor: 7℃DB, 6℃WB	Capacity [kW]	Minimum	0.9	0.9	0.9	0.9	0.9	0.9	5	5.4	5.8
			Rated	6.0	6.7	8.5	3.5	3.5	5.2	11.2	14	16
			Maximum	9.1	9.7	11.0	5.5	6.6	8.0	14	16.2	18
		Power consumption [kW]	Minimum	0.09	0.09	0.11	0.25	0.25	0.25	-	-	-
			Rated	1.35	1.63	2.35	0.79	1.19	1.44	2.56	3.58	4.43
			Maximum	2.95	3.2	3.68	2.1	2.15	2.95	5.12	5.80	6.48
	EER (Cooling)			4.12	3.29	3.21	4.91	3.72	3.68	4.10	3.53	3.21
	COP (Heating)			4.44	4.11	3.62	4.43	3.78	3.61	4.38	3.91	3.61
Striking function	Air flow control	A: On target automatically by perceiving human locus		B,C,D			C,D			C,D		
		B: On target manually by remote-controller		"Vertical airflow" provides powerful floor level heating 	"Horizontal airflow" does not blow cool air directly at the occupants in the room 					Improvement of the flap Making space between the ceiling, the air flows far wide and ceiling does not get dirty. 		
		C: Ceiling-hugging for cooling Floor-hugging for heating										
		D: Deffusing for uniforming indoor temp.										
		E: Other										
	Automatic air filter cleaner (How to dispose the dust gathered)	A: Exhaust outdoors		B								
		B: Stock in a reciever		Automatic filter cleaner Entire filter is cleaned automatically in approx. 2 minutes	Continuous Energy saving by preventing dust 							
		C: Other		WORLD FIRST								
	Air ventilation	A: Supply										
		B:Exhaust										
		C: Other										
	Dehumidification	A: Cooling		A,B								
		B: Reheat after cooling										
		C: Other										
	Air purification			Bacteria eliminating countermeasure Dirt and dust are bacteria-eliminated by photocatalytic filter Drives away bacteria and refreshes the air by UV (ultraviolet rays) illumination								
	Humidification									Adoption of high efficiency turbo fan High efficiency achieved by equaling the performance of the wing and air passing the heat exchanger 		
	Status display (for energy saving)											
	Other											

Manufacture				Example					
Basic specifications	Model number			AAA-BBB-C	※高級シリーズを中心に、数種類の容量をご紹介ください。 全館システムも是非・・・				
	Release date			Nov-09	※最新機種をご紹介ください。				
	Sales areas			Japan only	※輸出モデルがありましたら、ぜひご紹介ください。				
	Image								
	Size	Indoor equipment		800Lx300Hx250D					
		Outdoor equipment		800Lx600Hx300D					
	Cooling Indoor: 27℃DB, 19℃WB Outdoor: 35℃DB, 24℃ WB	Capacity [kW]	Minimum	0.5					
			Rated	2.2					
			Maximum	3.5					
		Power consumption [W]	Minimum	100					
			Rated	400					
			Maximum	800					
	Heating Indoor: 20℃DB Outdoor: 7℃DB, 6℃WB	Capacity [kW]	Minimum	0.6					
			Rated	2.8					
			Maximum	5.8					
		Power consumption [W]	Minimum	110					
			Rated	450					
			Maximum	1000					
	APF (Annual performance factor defined by JIS)			6.1					
Striking function	Air flow control	A: On target automatically by perceiving human locus		B,C,D					
		B: On target manually by remote-controller		Description: 気流制御機能をA～Eから選択(複数可)し、特徴について本欄に英語で自由記載してください。	Description:				Description:
		C: Ceiling-hugging for cooling Floor-hugging for heating							
		D: Deffiusing for uniforming indoor temp.							
		E: Other							
	Automatic air filter cleaner (How to dispose the dust gathered)	A: Exhaust outdoors		A					
		B: Stock in a reciever		Description: フィルター掃除機能をA～Cから選択し、特徴について本欄に英語で自由記載してください。	Description:				Description:
		C: Other							
	Air ventilation	A: Supply		B					
		B:Exhaust		Description: 換気機能をA～Cから選択し、特徴について本欄に英語で自由記載してください。	Description:				Description:
		C: Other							
	Dehumidification	A: Cooling		A,B					
		B: Reheat after cooling		Description: 除湿機能をA～Cから選択(複数可)し、特徴について本欄に英語で自由記載してください。	Description:				Description:
		C: Other							
	Air purification			Description: 空気清浄機能の特徴について、本欄に英語で自由記載してください。	Description:				Description:
	Humidification			Description: 加湿機能の特徴について、本欄に英語で自由記載してください。該当なしの場合は、"N/A"と記載してください。	Description:				Description:
	Status display (for energy saving)			Description: 省エネ関係の表示機能の特徴について、本欄に英語で自由記載してください。表示される場所についてもご記入お願いします。	Description:				Description:
	Other			Line up :	Description:				Description:

C SUMMARY OF COMMON HEAT PUMP TYPES

C.1 Air-to-Air Heat Pumps – Summary

Heat source	• Ambient air – large variations in average temperature and DOT[1] in Norway
Heat pump unit – components and design	• Heat pump system with one outdoor unit (evaporator, fan, compressor, expansion valve etc.) and one or several indoor units (condenser, fan etc.). The units are connected with flexible hoses (single or multisplit units).
Heating demands	• *Space heating* – Covered by the heat pump + possible auxiliary heating system • *Heating of ventilation air* – Reheating covered by the space heating system • *DHW heating* – Covered by a separate heating system
Heat distribution	• Air – recirculation and heating of indoor air by the indoor unit(s). Moderate supply air temperature (max. 30-35ºC) • Requires open floor plan in the residence in order to achieve satisfactory distribution of the warm air from the indoor unit • Bathroom and washing areas should have separate heating systems (floor heating)
Cooling demands	• Recirculation and cooling of indoor air by the indoor units. The heat pump runs in "reverse mode" which requires electricity, i.e. no free cooling.
Ventilation	• Can be used in residences with exhaust air ventilation or balanced ventilation
Design/ dimensioning	• The heat pump unit should be designed/dimensioned to cover the entire heat load (100 % coverage) for space heating in low-energy and passive houses
Average COP (SPF)	• Average COP in Norway ranges from *2.0 to 3.0,* defrosting included • Considerable variations in quality and performance for the different air-to-air-heat pump brands/models. R410A heat pumps with inverter controlled compressor achieve the highest COP. • Some models have poor defrosting systems without demand control
Indoor environment	• Heating of indoor air with moderate excess temperature in the exhaust zone. • Provides good thermal comfort in low-energy houses since windows and walls have low U-values (i.e. no large temperature gradients or drafts). • Heating of indoor air will lead to drier air which may irritate allergic persons. • The indoor unit is equipped with different filter types (synthetic fibre, zeolit, carbon, electrostatic), that clean the recirculated air. However, the fans may whirl up dust. • The fan of the indoor unit generates noise, typically 49-58 dB(A).
Miscellaneous	• The stop temperature ranges from -10 to -25ºC (ambient air temperature). • The evaporator in the outdoor unit must be regularly defrosted at ambient air temperatures below approx. +3ºC – requires energy and reduces the COP. • Requires correct installation of the indoor/outdoor units. • Requires regularly cleaning/replacement of the filter(s) in the indoor unit. • The compressor/fan in the outdoor unit generates noise, typically 58-63 dB(A).
Areas of application	• *Low-energy houses* – Air-to-air heat pumps applicable in all types of dwellings • *Passive houses* – Air-to-air heat pumps can be used in large residences, but will not be profitable in flats due to the very low space heating demand

[1] *Design Outdoor Temperature*

C.2 Exhaust Air – Ventilation Air Heat Pumps – Summary

Heat source	• Exhaust air, possibly in combination with ground (indirect system with a brine circuit connected to an air cooler and a ground-source heat exchanger).
Classification/design	• *Heat pump water heater (HPWH, Type A1)* – Compact heat pump unit with air cooled evaporator. Heat rejection to a hot water tank (direct or indirect system design). Reheating by electric immersion heaters, see chap. 3.3. • *Integrated units (Type A2)*– Compact heat pump unit with air cooled evaporator. Heat rejection to a hot water tank (direct or indirect design) and hydronic heat distribution system for space heating (floor heating, fan convectors etc.). Electric immersion heaters used for supplementary heating (peak load), see chap. 3.4 • *Integrated units (Type A3)* – Compact heat pump unit with air cooled evaporator with additional heat source, e.g. the ground acc. to Fig. 2.
Heating	• *Space heating* – Partly covered by the heat pump (Type A2, Type A3). • *Heating of ventilation air* – Covered by the space heating system. • *Hot water heating* – Covered by the heat pump. Reheating with electric immersion heaters located in the hot water tank (Type A2, Type A3).
Cooling	• The heat pumps cannot provide space cooling
Heat distribution	• Hot water – connection to single-shell or double-shell hot water tank. • Hydronic heat distribution system with floor or ceiling heating, fan convectors, heating boards or radiators (see Tab. 2).
Ventilation	• Used in dwellings with an exhaust air ventilation system
Dimensioning	• *HPWH (*Type A1*)* – Designed to cover the entire heating demand. • *Integrated (*Type A2, Type A3*)* – Designed to cool down the exhaust air to minimum 2-3ºC. Covers the entire hot water demand. The systems are normally not capable of covering the entire space heating demand due to limited energy content in the exhaust air. Supplementary heating (peak load) with electric immersion heaters.
Average COP (SPF)	• Hot water heating – COP typically *2.5.* • Space heating – COP typically *3.5* (requires low-temperature system).
Indoor environment	• Space heating with hydronic heating system. Air quality and thermal comfort is affected by the type of system (floor heating, fan convectors etc.).
Miscellaneous	• The relatively constant operating conditions and moderate temperature lift for the heat pump unit is favourable with regard to expected lifetime etc. • Compressor breakdown for propane heat pumps from some Swedish manufacturers, but the problems have been resolved. • Due to limited energy content in the exhaust air, integrated heat pumps are only capable of covering a part of the space heating demand, which means that the energy demand for supplementary heating can be relatively high.
Areas of application	The recommendations are based on the calculations of total annual specific energy demand for heating of a 150 m^2 low-energy house. • *Low-energy houses* – Type A1 in combination with air-to-air heat pump for space heating, (integrated system) and Type A3 (as chap. 3.4 + ground as additional heat source) are of current interest. • *Passive houses* – Only Type A1 is of current interest.

C.3 Balanced Ventilation Air Heat Pumps – Summary

Heat source	• Exhaust air, discharge air (passive house only) or a mixture of discharge air and ambient air. The ambient air can be preheated by a ground heat exchanger.
Design	• *Ventilation air heat pumps without heat recovery unit (System B1, see chap. 3.5)* – Units with air-cooled evaporator in the exhaust ventilation duct. Heat rejection to the supply ventilation air (direct system). Reheating by electric heater. • *Integrated heat pump without heat recovery unit (System B2, see chap. 3.5)* – Units with air cooled evaporator in the exhaust ventilation duct. Heat rejection to a hot water tank and the supply ventilation air. Auxiliary heating with electric heaters. • *Integrated heat pump with heat recovery unit (System B3, see chap. 3.6.2)* – Compact units with ventilation unit (fans, filters, heat exchanger), air-to-air/water heat pump unit, hot water tank and solar collector. Auxiliary heating with electric heaters.
Heating	• *Space heating* – Partly covered by the heat pump (Type B1, B2 and B3) • *Heating of ventilation air* – Covered by the heat pump (Type B1, B2 and B3) • *Hot water heating* – Covered by the heat pump (Type B1, B2, and B3). Reheating with electric immersion heaters located in the hot water tank.
Cooling	• Some of the heat pump systems are designed for space cooling
Heat distribution	• Hot water – connection to single- or double-shell hot water tank • Space heating by warm ventilation air (direct system) or by means of a hydronic heat distribution system (indirect system) • Ventilation air – direct or indirect heat system
Ventilation	• Used in dwellings with a balanced ventilation system
Dimensioning	• *Ventilation air heat pump (System B1)* – Cools down the exhaust air to minimum 2-3ºC. Do not cover hot water heating. • *Integrated heat pump (System B2)* – Cools down the exhaust air to minimum 2-3ºC. Covers the entire heating demand for hot water. • *Compact unit (System B3)* – Designed according to the available energy in the heat source. Covers the entire heating demand for hot water.
Average COP (SPF)	• Hot water heating – COP typically *2.5* • Space heating – COP typically *2.0-3.5* (depending on different factors)
Indoor environment	• Space heating with hot supply air (max. 50-55ºC) or hydronic heat distribution system. Hot ventilation air can lead to bad ventilation efficiency and poor indoor air quality. • A horizontal ground heat exchanger (GHE) for preheating of the ambient air may lead to poor indoor air quality due to bacterial growth in GHE.
Application of ventilation air heat pumps – balanced ventilation systems	The recommendations are based on the calculations of total annual specific energy demand for heating of a 150 m^2 low-energy house. • *Low-energy houses* – **Type B1** (heating of ventilation air), **Type B2** (integrated unit, as A2) and **integrated systems acc. to Fig. 2** (compact unit) are of current interest. • *Passive houses* – **Type B3** is of current interest.

C.4 Air-to-Water Heat Pumps – Summary

Heat source	• Ambient air – large variations in average temperature and DOT in Norway
Classification/design	• *Direct system* – Heat pump system equipped with an air-cooled evaporator (as in air-to-air heat pumps). Heat rejection from a water cooled condenser and possibly a desuperheater to a hydronic heat distribution system. • *Indirect system* – Heat pump system comprising a standard brine-to-water heat pump unit and air cooler connected by means of a brine circuit. Heat rejection as for air-to-water heat pumps with direct system design. • *Integrated units* – cover both space heating and hot water heating. • *Heat pump water heaters (HPWH)* – covers the DHW demand.
Heating	• *Space heating* – Covered by the heat pump (integrated units only). • *Heating of ventilation air* – Covered by the space heating system. • *DHW heating* – Covered by the heat pump (incl. electric heater).
Heat distribution	• Hydronic heat distribution system, e.g. radiators, fan convectors, floor heating systems, ceiling heating systems, radiant boards (Tab. 2). • Double-shell hot water tank or single-shell tank with integrated coil.
Cooling	• Some systems can provide cooling by reverse operation of the heat pump. • Some systems can accumulate low-temperature water or ice-slurry.
Ventilation	• Can be used in residences with exhaust air ventilation or balanced ventilation.
Dimensioning	• *Integrated heat pumps* – Designed to cover typically 40 to 60% of the maximum space heating demand at DOT. Peak load system required. • *Heat pump water heaters (HPWH)* – Covers the entire DHW demand.
Average COP (SPF)	• Average COP ranges from *2.0 to 2.5*, defrosting and auxiliary heating included. • The COP is highly depending on the design and control of the heat pump unit, the hot water system and the heat distribution system. • Integrated air-to-water heat pump systems achieve higher annual energy saving than air-to-air heat pumps, since they also are used for hot water heating.
Indoor environment	• Space heating with hydronic heating system. Air quality and thermal comfort is affected by the type of system (radiators, floor heating etc.).
Miscellaneous	• The stop temperature range from -10 to -15ºC (ambient air temperature). • The evaporator in the outdoor unit must be regularly defrosted at ambient air temperatures below approx. +3ºC – requires energy and reduces the COP. • The compressor and fan in the outdoor unit generates noise.
Areas of application	• *Low-energy houses* – Air-to-water HPWHs are applicable in all kinds of dwellings incl. single-family houses, row-houses and semi-detached houses as well as central systems in block of flats and apartment buildings. Integrated systems can be used in larger dwellings and as central systems in block of flats. • *Passive houses* – Air-to-water HPWHs can be used in all kinds of dwellings (as for low-energy houses). Integrated heat pump systems are not of current interest due to the extremely low space heating demand (<15 kWh/m^{2}year).

C.5 Brine- and Water-to-Water Heat Pumps – Summary

Heat source	• Brine-to-water – bedrock, soil, lake water (indirect system design). • Water-to-water – groundwater, grey water (direct system design).
Components, design	• Compact heat pump units equipped with plate heat exchangers as evaporator and condenser, and scroll or reciprocating compressor with variable speed or intermittent operation (on/off). Some units have integrated hot water tank, electric heater for supplementary heating, pumps, expansion tank etc. Indirect systems have a brine circuit (PEM tubes, antifreeze fluid, pump) that transfers heat between the heat source and the evaporator.
Heating	• *Space heating* – Covered by the heat pump (integrated units only). • *Heating of ventilation air* – Covered by the space heating system. • *DHW heating* – Covered by the heat pump (electric heater incl.).
Heat distribution	• Hydronic heat distribution system, e.g. radiators, fan convectors, floor heating systems, ceiling heating systems, radiant boards (Tab. 2). • Double-shell hot water tank or single-shell tank with integrated coil.
Cooling	• Heat pump units connected to boreholes in bedrock can provide free cooling where surplus heat from the house is rejected directly to the ground.
Ventilation	• Can be used in residences with exhaust air ventilation or balanced ventilation.
Dimensioning	• *Integrated heat pumps* – Designed to cover 40 to 60 % of the maximum space heating demand at DOT. Peak load system required. • *Heat pump water heaters (HPWH)* – Covers the entire DHW demand.
Average COP (SPF)	• Average COP ranges from *2.5 to 3.5*, supplementary heating included. • The COP is highly depending on the design and control of the heat pump unit, hot water system and heat distribution system.
Indoor environment	• Space heating with hydronic heating system. Air quality and thermal comfort is affected by the type of system (radiators, floor heating etc.).
Miscellaneous	• Quality gap between the various heat pump systems on the market. • Important with correct design and operation of the entire heat pump system, i.e. heat source system, heat pump unit, hot water system and heat distribution system, in order to attain high energy efficiency. • Ground-source systems have higher operational reliability and longer lifetime than ambient air heat pumps due to more stable operating conditions.
Areas of application	• *Low-energy houses* – Brine-to-water HPWHs can be used in all kinds of dwellings including single-family houses, row-houses and semi-detached houses as well as central systems in block of flats and apartment buildings. Integrated heat pump systems can be used in larger dwellings and as central systems in block of flats etc. • *Passive houses* – Brine-to-water HPWHs can be used in all kinds of dwellings (as for low-energy houses). Integrated heat pump systems are not of current interest due to the extremely low space heating demand (<15 kWh/m^2year).

C.6 Comparison of ventilation air heat pumps in Norway

The different ventilation air heat pumps for exhaust air ventilation air systems (A) and balanced ventilation systems (B), which are described in Chapter 4.5 and 4.6, have been simulated in order to estimate the seasonal performance factor (SPF) of the heat pump unit as well as the SPF and energy saving of the total heating system including supplementary heating. The hourly based simulations have been carried out for a 150 m2 single-family low-energy house located in Oslo, Norway. The dwelling has the same air-tightness and average U value as described in the new Norwegian building code, TEK 2007 Tab. C 1 shows the main basic data for the simulations.

Tab. C 1 Basic data for computer simulations of different types of ventilation air heat pumps in a low-energy dwelling. A – dwelling with an exhaust air ventilation system, B – dwelling with a balanced ventilation system.

Location, climate zone	Oslo, DOT=-20ºC, taverage=5.9ºC
Heated area	150 m2
Average UA value	70 W/K
Mean infiltration	0.08 air changes per hour
Indoor air temperature	21ºC
Internal heat loads, average	1190 W
Ventilation system	Air change rate 0.5 1/h Exhaust air ventilation – System A Balanced ventilation – System B SFP 2.0 kW/(m3/s)
Hot water heating	Annual heating demand – 4,000 kWh/year City water temperature – 10ºC Hot water temperature – 60ºC Heat loss from the hot water tank – not included
Heat pump – space heating	Maximum heating capacity – about 1380 W Supplementary heating – electric
Heat pump – hot water	Heats DHW from 10ºC to 55ºC At an average heating capacity of 410 W, the heat pump unit covers 90% of the annual heating demand Supplementary heating – electric
Heat pumps – no heat recovery **System A1, A1'[2], A2 and A3** **System B1 and B2**	Systems without heat recovery unit (air-to-air heat exchanger) The exhaust air is cooled down from 21ºC to 2ºC in the evaporator Possible additional heat sources – ambient air and ground
Heat pumps – with heat recovery **System B3**	Systems with heat recovery unit (air-to-air heat exchanger) The discharge air is cooled down by typically 10K in the evaporator Ambient air can be used as an additional heat source

The simulation results are presented in and. Dwellings with electric heating systems for space heating and hot water heating in combination with exhaust air ventilation (System A0) or balanced ventilation (System B0) are used as reference systems.

[2] *Exhaust air heat pump water heater (HPWH) + air-to-air heat pump unit for space heating.*

Tab. C 2 Specific energy demand for heating of a 150 m² low-energy house with different heat pump/ heating systems and ventilation systems. DHW – heating of domestic hot water, SH – space heating, VA – heating of ventilation air, HP – heat pump, HRU – heat recovery unit.

Type	Heating and ventilation system	Total heating demand[1)] [kWh/year]	Heat supply from HP [%]	COP, heating system[2)] [-]	Spec. energy demand[2)] [kWh/m²year]
A0	Electric heating (DHW + VA + SH) *Exhaust air ventilation – no HRU*	12,600	0	1.0	84
A1	Ventilation air HP (DHW) *Exhaust air ventilation – no HRU*	12,600	29	1.2	70
A1'	Ventilation air HP (DHW) + Ambient air-to-air HP (SH) *Exhaust air ventilation – no HRU*	12,600	97	2.4	35
A2	Ventilation air HP (DHW+SH) *Exhaust air ventilation – no HRU*	12,600	78	2.1	40
A3	Vent. air + ground HP (DHW+SH) *Exhaust air ventilation – no HRU*	12,600	94	2.5	33
B0	Electric heating (DHW+VA+SH) *Balanced ventilation – 75% HRU*	7,700	0	1.0	51
B1	Ventilation air HP (VA+SH) *Balanced ventilation – no HRU*	12,600	57	1.7	50
B2	Ventilation air HP (DHW+VA+SH) *Balanced ventilation – no HRU*	12,600	78	2.1	40
B3	Compact unit (DHW + VA + SH) *Balanced ventilation – 75% HRU*	7,700	90	2.2	24

1) Includes heat recovery in the ventilation system 2) Includes energy demand for the auxiliary (peak load) heating system(s)

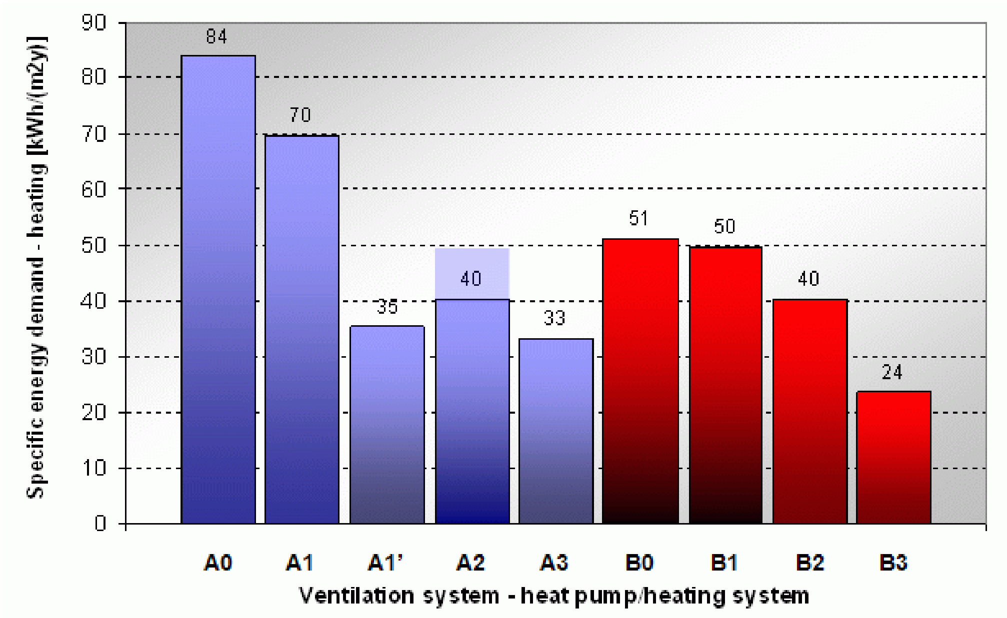


Fig. C 1 Specific energy demand for heating of a 150 m2 single-family low-energy house with different heat pump/heating systems and heat recovery systems (A0 to A3 and B0 to B3).

In , “Total Heating Demand” is calculated as the gross annual heating demand (i.e. space heating, heating of ventilation air and hot water heating) subtracted the annual heat supply from internal loads, i.e. lighting systems, electrical appliances, fans, people etc. When calculating “COP, Heating System” and “Specific Energy Demand”, energy for operation of both the heat pump and the supplementary heating systems have been included. It has been assumed that all supplementary heating is covered by electric heating systems. For system A1’, a combination of an exhaust air heat pump water heater (HPWH) and an air-to-air heat pump for space heating, it has been assumed that the air-to-air heat pump covers the entire space heating demand of the dwelling.

The different heating and ventilation systems are ranked according to the total annual energy demand:

1. System B3 – Compact unit (CVHD). The annual energy demand for heating is about 50% lower than that of a house equipped with a balanced ventilation system and direct electric heating (System B0) and about 4 times lower than that of a house with an exhaust air ventilation system and electric heating systems (System A0).
2. System A1’, A3 – A1’) Exhaust air heat pump water heater (HPWH) + air-to-air heat pump and A3) Integrated exhaust air heat pump with external heat source (ground), have more or less the same annual energy demand, i.e. about 35% higher than that of System B3 and 30% lower than that of System B0 (reference). The relatively high SPF for the total heating systems is due to the fact that the heat pump units cover a relatively large share (94-97%) of the total annual heating demand, which reduces the need for supplementary (electric) heating.
3. System A2, B2 – The two alternatives, i.e. integrated exhaust air heat pump installed in exhaust air and balanced ventilation systems, will achieve the same energy saving when assuming the same air exchange rate for the dwellings (see comment 6). The annual energy demands for the systems are about 65% higher than that of System B3, and 20% lower than that of System B0 (reference).
4. System B1 – This kind of ventilation air heat pumps are used as an alternative to conventional heat recovery units, and will be able to cover some of the space heating demand. However, due to the relatively short space heating season for a low-energy dwelling, the energy saving is more or less the same as for System B0 (reference), i.e. twice as high as for System B3.
5. System A1 – A dwelling equipped with an exhaust air heat pump water heater in combination with electric baseboard heaters for space heating, will have a relatively high annual energy demand, since the heat pump covers only 30% of the total heating demand of the residence. The energy demand is about three times higher than that of System B3, and about 40% higher than that of System B0 (reference).
6. In the calculations is has been assumed an air change rate of 0,5 1/h. However, in low-energy houses an air change rate of approx. 0.8-1.0 1/h will be required in order to provide sufficient ventilation in bedrooms located in the 2nd floor (Myhre and Dokka, 2004). The elevated air change rate will increase the ventilation loss, and with that the total heating demand of the dwelling. As a result, a house equipped with an integrated exhaust air heat pump (System A2) will have more or less the same energy demand for heating as a house with electric heating systems, balanced ventilation and 75% temperature efficiency for the heat recovery unit.

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