Preparatory Studies for Ecodesign Requirements of EuPs (III)

ENER Lot 21 – Central heating products that use hot air to distribute heat
Task 6: Technical analysis BAT

Report to the European Commission, DG ENER
09 July 2012

European Commission

Developed by: bio Intelligence Service

Project description

CLIENT:	European Commission DG ENER
CONTRACT NUMBER:	TREN/D3/91-2007-Lot 21-SI2.521642
REPORT TITLE:	ENER Lot 21 – Central heating products that use hot air to distribute heat – Task 6: Technical analysis BAT
REPORT SUB-TITLE:	Final report
PROJECT NAME:	Preparatory Studies for Ecodesign Requirements of EuPs (III)
PROJECT CODE:	EUP21
PROJECT TEAM	BIO Intelligence Service
DATE:	09 July 2012

AUTHORS:

Mr. Shailendra Mudgal, BIO Intelligence Service
Dr. Adrian Tan, BIO Intelligence Service
Mr. Alvaro de Prado Trigo, BIO Intelligence Service
Mr. Sandeep Pahal, BIO Intelligence Service

KEY CONTACTS:

Shailendra Mudgal	Adrian Tan
+ 33 (0) 1 53 90 11 80	+ 33 (0) 1 53 90 11 80
sm@biois.com	adrian.tan@biois.com

ACKNOWLEDGEMENTS: TÜV Rheinland contributed to the first version of this report. Several stakeholders and experts have also contributed with many valuable comments during the course of the study. Dr. Otto Paulsen, Danish Technological Institute, supported the project team with the technical content of the final report.

Please cite this publication as:

BIO Intelligence Service (2012) Preparatory Studies for Ecodesign Requirements of EuPs (III), ENER Lot 21 – Central heating products that use hot air to distribute heat – Task 6: Technical analysis BAT. Prepared for the European Commission, DG ENER.

Photo credit: cover @ Per Ola Wiberg

Table of Contents

List of Tables

List of Figures

Task 6: Technical Analysis of Best Available Technologies (BAT)

Best-Available-Technology (BAT) is a technology or change in design that leads to less environmental impacts, and is already available in the market or whose technical feasibility has already been demonstrated (expected to be introduced at product level within 2-3 years). Best-Not-Yet-Available-Technology (BNAT) refers to a technology which has the potential to lead to further environmental performance improvements, but still is subject to research and development. BNAT is rather a future option or a long term trend.

The assessment of BAT and BNAT provides input for the analysis of improvement potentials in Task 7. Intellectual property, technical feasibility, and availability on the market in a strict sense are not judged here as the objective is to illustrate various technically available (or potentially available) options. However, Task 7 will take these issues into account when suggesting possible improvement options applicable to central heating that use hot air to distribute heat.

The results of this Task are predominantly based upon public sources such as technical journals, magazines and research publications, as well as other sources like interviews with technology experts, research institutes and the stakeholders of this project.

6.1 Best Available Products

The following section gives an overview of the best performing air-based central heating products currently available on the market. Best performing products are appliances whose environmental performance is significantly better than the average products on the market without compromising their functionality and capacity.

6.1.1 Warm air heaters

6.1.1.1 Gas warm air heaters

The best air heaters available on the market contain automatically modulating exhaust fans (draft inducers) to control the flow of combustion air and the disposal of flue gases, ensuring cleaner combustion and efficient operation. The fans are driven by modulating brushless permanent magnet motors[1], allowing energy efficient control of the blower speed and of the amount of introduced air.

Capacity modulating gas burners are able to modify the heat output capacity in a range of approximately 30% to 100% of the nominal capacity (see chapter 6.2.1.7). Burner ignition is

[1] Also often stated as electronically commutated motors (ECM) or variable speed drives (VSD)

achieved by electric spark igniters or "hot-surface-igniters" that eliminate the need for continuously burning pilot lights. The produced hot flue gas is introduced into the primary heat exchanger, usually made of stainless steel.

To increase heating efficiency, condensing technology is used, which means that the water vapour contained in the exhaust gas is condensed and additional heat (water latent heat) is extracted. To utilise the condensation heat, a secondary heat exchanger is necessary. Secondary heat exchangers for gas fired air heaters are usually made of stainless steel tubes that contain the flue gas. Aluminium fins are attached to the tubes to increase the heat exchange surface and the heat transfer to the passing air. In order to avoid jacket losses (losses from the warm air heater itself) at the installed location, recent warm air heater housings and combustion compartments are insulated with materials such as mineral wool.

Best available indirect-fired gas warm air heaters can reach thermal efficiencies up to 95% (gross) and 105% (net).[2] Table 6—1 shows the characteristics of the best available products found in the market in the category of the Base-Cases of warm air heaters.

Table 6—1: Best available gas warm air heaters

Application	Residential central heating	Non-residential central heating
Product type	Indirect-fired gas warm air heater	Indirect-fired gas warm air heater
Heating capacity	15 kW	120 kW
Fuel used	Natural gas N20	Natural gas N20
Burner type	Pre-mix burner	Pre-mix burner
Type of draught	Fan assisted: Type B22, C12, C32	Fan assisted
Control	Modulating	Ignition control
Efficiency (% net)	105%	95%
Efficiency (% gross)	95%	85.6%
Temperature rise (°C)	30°C-60°C	45°C-55°C
Purchase price (€)	2,200- 4,370	5,800

Compared to the Base-Cases analysed in Task 5, the best performing products include pre-mix burners, fan-assisted draught and capacity modulation. Other possible improvements such as better insulation or air distribution have not been described.

6.1.1.2 Oil warm air heaters

High efficiency oil warm air heaters also use condensing technology, meaning that additional heat (water latent heat) is retrieved from condensing the water vapour contained in the exhaust gas. Generally, oil contains less hydrogen than natural gas, which makes the potential amount of latent heat gain lower than in the case of gas warm air heaters and thereby decreases the overall efficiency. Additionally, the dew point of the flue gas is lower, so the warm air heater has to work harder to condense less. To achieve condensing, a secondary heat exchanger is needed. Since fuel oil contains a higher share of sulphur, the produced flue gases and condensate are even more acidic than in gas-fired condensing warm air heaters. For this reason, secondary heat exchangers have to be made from special corrosion resistive materials like stainless steel, which are costly.

High-efficiency oil warm air heaters also use brushless permanent magnet motors, allowing an energy efficient modulating control of the blower speed and of the amount of outside air introduced. For heat generation, high-efficiency oil warm air heaters use flame-retention head burners with a high-static pressure level.

Although condensing oil warm air heaters represent the best available type of heaters, there are only a few products available on the market. This is due to the price gap between non-condensing and condensing oil heaters and the lower efficiency ratings compared to condensing gas warm air heaters.

6.1.1.1 Electric warm air heaters

Compared to gas and oil warm air heaters, electric warm air heaters are cheaper and easier to install, and offer a thermal efficiency of 100%. But when the electricity consumed is converted into primary energy, the efficiency of electric warm air heaters is lower than the oil and gas ones, due to the electricity generation and distribution losses. Nevertheless, electric warm air heaters are not very widespread in the market, due to high electricity prices.

Other than the heat generation efficiency, the efficiency of electric warm air central heating is similar to the gas and oil warm air heaters, since the air distribution systems are similar.

6.1.2 Heat pumps

The ductless single split air-to-air heat pump is the state-of-the-art solution for heat pumps with a capacity under 30 kW. As already described in Task 4, single split heat pumps contain separated indoor and outdoor units that are connected via refrigerant lines. The best available products in the market use variable speed compressors optimised for heating to modulate the capacity and fitted with high efficiency motors and fans, advanced heat exchanger technology and working fluids. Notably, the majority of heat pumps under 30 kW are reversible and are used to provide cooling during the hot season. The SCOP of reversible units is substantially higher when using variable speed compressors that can over speed in heating mode.

Larger heat pumps are reversible and thus are used to heat and cool as required. The best performing air-to-air heat pump systems for larger capacities in terms of energy efficiency are variable refrigerant flow (VRF) systems. The term variable refrigerant flow means that the refrigerant flow of the system is modulated according to the heating or cooling demand of the indoor units, which represents an efficient way of reducing the energy consumption.

VRF systems are usually available in a wide capacity range, and can be built in a modular way, which means that two or more outdoor units can be combined to one system with a larger capacity. The outdoor unit contains the evaporator and the compressor(s) and is usually installed on building roofs. Depending on the number of rooms to be provided and the heating or cooling demand, multiple indoor units can be connected (up to around 60 units). The indoor units contain the condenser and the electronic expansion valve, and are available as wall-mounted, floor-standing, ceiling mounted devices with duct connection or cassettes. Indoor and outdoor units are connected with low diameter refrigerant lines, either two or three pipes depending on the type of VRF system. Two-pipe systems can supply all indoor units simultaneously with heating or cooling, while three pipe systems offer the versatility that each indoor unit can be run in heating or cooling mode independently.

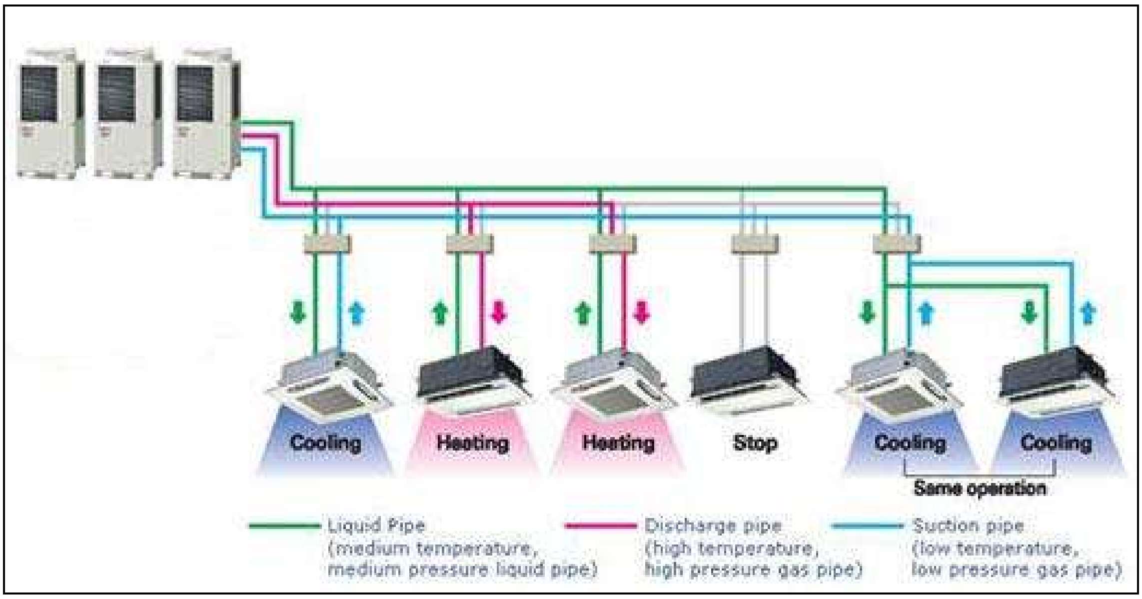
Recent VRF systems are driven by inverter controlled high efficiency compressors (scroll or rotary compressors) that offer modulation of the compressor rotation speed, which is accompanied by a modulation of the heating and cooling performance of the system. Typical VRF outdoor units contain more than one compressor to reach higher compression capacities. Fans are specially designed to deliver high static pressures with low noise levels. Brushless DC motors are used for driving the fans, which are also fitted with drives. R410A is the most often used working fluid in VRF systems, as it has a high volumetric cooling capacity. As a result, the components and refrigerant lines can be built in a more compact manner.

Table 6—2: Best available heat pumps[3]

Application	Non-residential heating	Non-residential heating
Product type	Single split heat pump	VRF
Heating capacity	16	56 kW
Heat source	Air	Air
Compressor type	DC twin rotary	Twin scroll
Refrigerant used	R410A	R410A
Number of units outdoor:indoor	1:1	1:9
Type fans	DC fan motor	DC fan motor
Control	Vector inverter control	Modulating
COP (EN 14511)	3.81	4.37
SCOP	-	-
Purchase price (€)	8,900	28,400

[3] For comparison, a recent study conducted by the Swedish Energy Agency (2011) evaluated 30 domestic air-to-air heat pumps under different load capacities and four different outdoor air temperatures (+7°C, +2°C, -7°C and -15°C, at 20°C indoor temperature). The best performing models reached COP values up to 5. At an outdoor temperature of –15°C, the heat pumps reached COP values between 2 and 3.
www.energimyndigheten.se/sv/Hushall/Testerresultat/Testresultat/Luftluftvarmepumpar/

Figure 6-1: Diagram of a 3-pipe VRF system[4]



Compared to the Base-Cases analysed in Task 5, the best available products present a higher COP but little technical differences. The best product of single split heat pump uses twin rotary compressors whereas the Base-Case of single split analysed in Task 5 uses a single scroll compressor. The best product of VRF uses twin scroll compressors, whereas the Base-Case in Task 5 uses a single scroll compressor.

Nonetheless, these differences on the compressor side might not be enough to explain the difference in efficiency (COP) noted between the Base-Cases and the best products. According to some stakeholders, the improvement potential in compressor construction and selection is negligible in heat pumps. In addition, the use of twin compressors instead of single compressors would achieve energy savings due to the capability of controlling the heating capacity delivered by the compressors, but this improvement would not be reflected in an increase of COP tested at full load.

One possible explanation of this improvement according to some manufacturers is that heat pumps are usually designed and constructed for a range of heating capacities, but are optimised for the lower capacity of the range. This means that the full load efficiency decreases slightly towards the higher capacity of the applicable range, as a consequence of having compressors, heat exchangers and other components sized for a different heating capacity. As different manufacturers use different capacity ranges in which the same casing is used, this might explain the COP differences between apparently similar products.

However, this COP drop induced by the same casing used for a range of capacities might be minimised if seasonal efficiency is compared (SCOP or SEER).

[4] All Four Seasons Ltd. Air conditioning showroom. 2011. www.allfourseasons.co.uk/products/vrfvrv/

6.2 Best Available Technologies

6.2.1 Warm air heaters

6.2.1.1 Heat generator

- **Electric heat generators**

As already explained in Task 4, electric heat generators generate heat by passing an electric current over a resistive element. Electric heating elements have a heat generation efficiency of 100% which means that all electric energy is transformed into heated air. Consequently, there cannot be made any further efficiency improvements from the heat generation perspective. With respect to gas and oil heaters, electric warm air heaters do not need a fuel supply or storage, and do not need exhaust gas (flue) systems. On the other hand, the losses of electricity generation and distribution make the overall efficiency in primary energy lower than gas and oil heaters.

- **Premix gas burners and flame cooling rods**

In the past years, research and development for gas burners has focused on the reduction of harmful NO_X emissions that enhance ozone formation and nitrate accumulation in the ground. Significant improvements concerning thermal efficiencies are not to be expected.

The current state-of-the-art technology is low-NO_X gas surface burners that reduce NO_X emissions significantly. Nitrous oxides emission levels are mainly influenced by the combustion temperature, retention time and oxygen levels of the combustion air. For example, the formation of NO_X rises exponentially above process temperatures of 1300°C. As the largest part of NO_X emissions is a result of such high temperatures, the primary measure is to lower the combustion temperature. This can be done with the following measures:

- Flame cooling with cooling rods is a technology that was used until the beginning of the 1990s and was replaced by premix burner technology. The flame cooling was achieved by installing cooling rods over the burner assembly. The rods take up heat from the core of the flames and emit thermal radiation to the combustion chamber walls. With cooling rods it was possible to reduce the NO_X levels by approximately 30%.
- Premix burners provide a complete mixing of fuel and combustion air before the ignition takes place. As a result, a consistent combustion can take place in several smaller flame holders and thereby form a larger burner surface with lower flame temperature. With premixing burners it is possible to achieve NO_X levels <30 mg/kWh and CO values <5 mg/kWh. Premixing burners represent the state-of-the-art technology for gas burners. However, according to one stakeholder the norm of premixing burners is around 50 mg/kWh NO_x emissions, which corresponds to class 5 of the standards EN 778 and EN 1319.

As fuel consumption and energy efficiency are largely determined by the controllability of heating devices, modulating premix burners and cooling rods play a key role in this context.

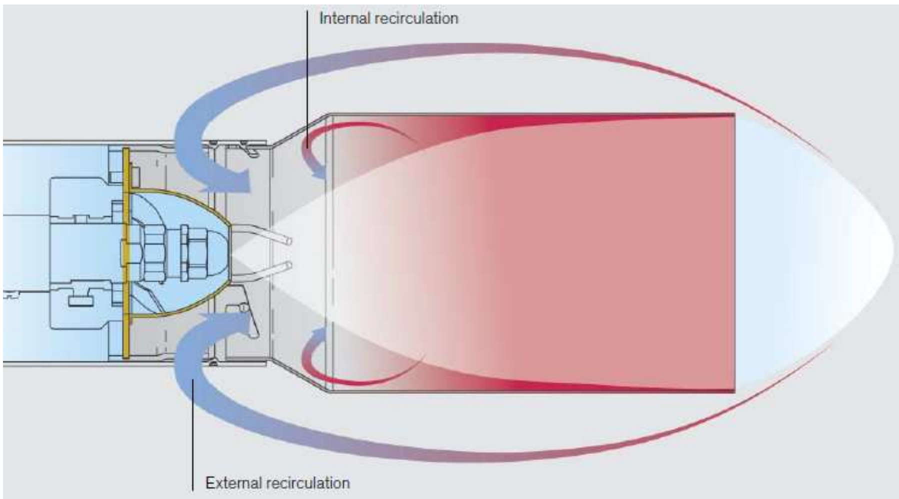
Low-NO_x oil burners

State-of-the-art developments in oil burner technology favour low-NO_X, pre-mix burners with lower combustion temperatures. Low-NO_X oil burners are usually called blue flame burners, and represent a further development of the traditional yellow flame burner. Blue flame burners use special mixing assemblies that allow flue gas recirculation to preheat the sprayed oil. Consequently, the oil vaporises more quickly even before being ignited and the flame forms a blue colour, comparable to a gas flame. A blue flame is an indicator for a clean combustion without the formation of smoke or soot and low-NO_X emissions. Furthermore, best available oil burners contain special mixing devices that create turbulence at the point of contact of air and oil vapour and improve mixing of the two.

Recent oil burners have additional components that make the combustion more efficient. Electric ignition devices help save energy, as only a small amount of electric energy is required for ignition. Furthermore, an oil preheating element helps to keep the provided oil at constant viscosity. Low viscosity leads to increased droplet size in the atomised oil spray and finally to lower combustion efficiency. Depending on oil characteristics and burner capacity, the preheating element needs to modulate its capacity. PTC heating elements are used for this purpose.

Manufacturers of blue flame burners state that blue flame burners consume up to 30% less energy than traditional yellow flame burners.[5] One general disadvantage of oil burners is that they are not appropriate for low capacity heating appliances and capacity modulation is not common in this kind of burner. The lowest capacity oil burners usually have a heating capacity of approximately 15 kW or more.

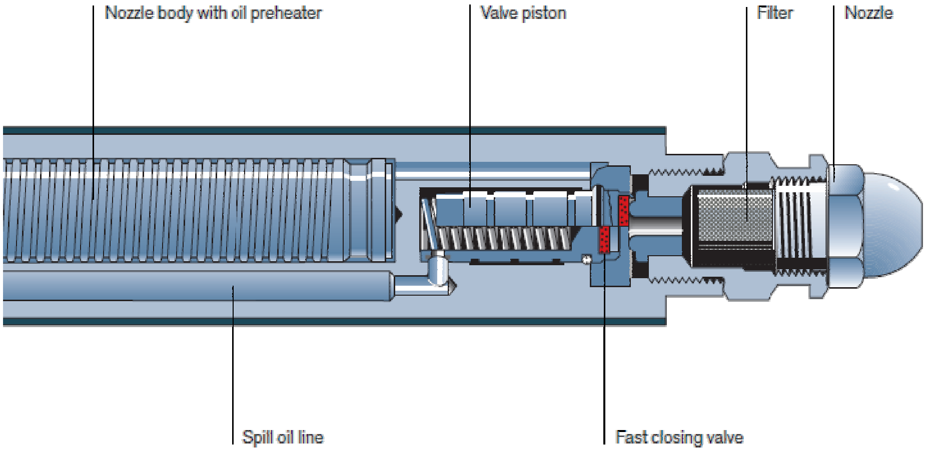
Figure 6-2: Diagram of a burner tube with flue gas recirculation (internal & external)[6]



[5] Scheer Heizsysteme & Produktionstechnik GmbH. 2004-2011. www.scheer-heizsysteme.de

[6] Max Weishaupt GmbH. Weishaupt purflam® burners. www.weishaupt.de

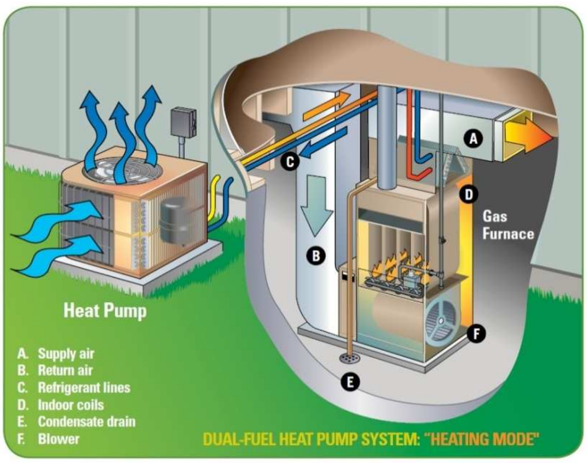
Figure 6-3: Diagram of an oil burner nozzle with oil preheating[6]



6.2.1.1 *Furnace-integrated heat pumps (Hybrid)*

Furnace-integrated heat pumps (also described as hybrid warm air heaters or dual-fuel systems) combine the benefits of an air-to-air heat pump system with the power of a high efficiency forced-air gas warm air heater. The heat pump operates as an air-conditioner in times of high temperatures (summer), and provides heat in times of moderate temperatures (transitional periods). The gas warm air heater takes over heating in peak load times (winter), as the heat pump is less efficient at these times. The exact set temperature for which the warm air heater would take over ranges between 0-10 °C, depending on the manufacturer, climate conditions, building specification etc. Typically, in a dual-fuel heat pump, the heat pump provides approximately 85% of the heating/cooling demand and the gas warm air heater covers the remaining 15%. Figure 6-4 shows a diagram of a typical warm air heater integrated heat pump system. Even though, the heat pump will be operating most of the time, the warm air heater would be of a bigger capacity from the heat pump. This can be a 1.5 – 2 times higher capacity for the warm air heater.

Figure 6-4: Furnace integrated heat pump system[7]



[7] KCP&L (2011) The efficient heat pump brochure. Available at: www.kcpl.com/brochures/heatpump.pdf

6.2.1.2 Improved heat exchanger

The primary heat exchanger in warm air heaters is responsible for heat transfer between the produced hot flue gas and the supply air, and thus finally for the overall performance of the warm air heater. In contrast to secondary heat exchangers, it only exchanges heat in the air, which means that no condensation takes place. The primary heat exchanger design of warm air heaters depends on the fuel used.

The best available primary heat exchangers for gas warm air heaters are tubular-shaped, made of aluminised steel or stainless steel. Aluminised steel behaves better against corrosion and keeps the properties of the base material steel for temperatures lower than 800 °C, but does not always withstand the thermal shock required for passing the test requirements of warm air heaters. Stainless steel is therefore more commonly used.

Primary heat exchangers consist of bended tubes, usually three or more in parallel. The tubes are bent in an 'S'-shape to lead the flue gas through the supply air stream at least three times. (See Figure 6-5) Additionally the tube diameter decreases towards the bottom. This has the effect of retaining the hotter flue gas longer in the upper part of the heat exchanger for better heat transfer, as it takes more time for the flue gas to pass the tubes with a smaller diameter.

Figure 6-5: Diagram of a high efficiency warm air heater with primary and secondary heat exchanger[8]

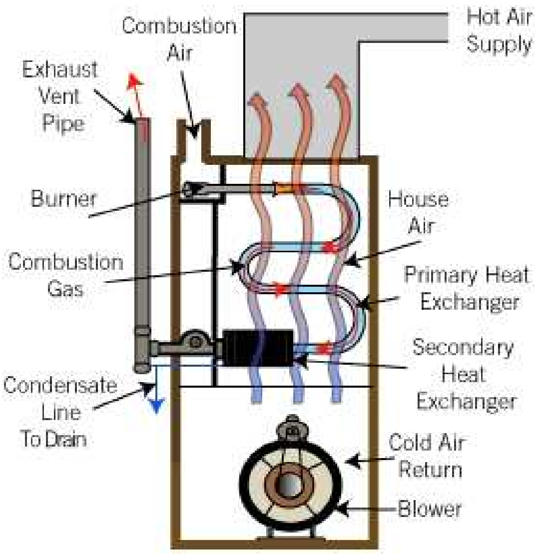
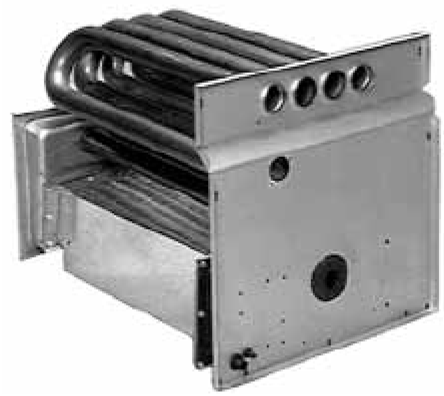


Figure 6-6: Stainless steel heat exchanger unit (primary heat exchanger with attached secondary heat exchanger)[9]



Best performing primary heat exchangers for oil warm air heaters are made of heavy gauge stainless steel or aluminised steel.

[8] Living With My Home. Forced Air Gas Furnaces. 2002-2008. www.livingwithmyhome.com/201-home-tips/pillar-to-post-forced-air-gas-furnace.aspx

[9] Rheem Manufacturing Company. RGRM Series. Specification Sheet. www.rheem.com

6.2.1.3 Secondary heat exchanger

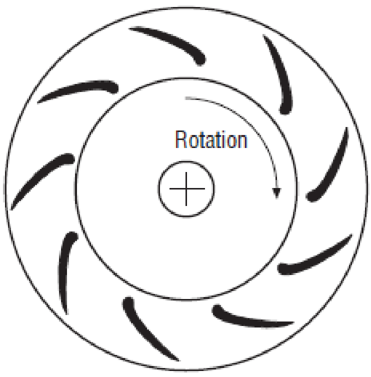
Secondary heat exchangers are additional heat exchangers found in condensing warm air heaters. Their purpose is to recapture latent heat out of the flue gas. Latent heat is the amount of energy that is inevitably used for evaporating the water contained in the fuel during the combustion process. A secondary heat exchanger regains latent heat by condensing the water vapour in the flue gas. The amount of latent heat can take from 12% to 16% of the total heat, thus achieving from 10% to 15% fuel saving at an extra cost of around € 400. By passing through the heat exchanger, the exhaust gases' temperature drops, causing the vapour to condense to water, releasing the latent heat, while the remaining cool gases are exhausted outdoors, and the water is disposed of by a condensate drain.

To obtain condensing, secondary heat exchangers need a large surface area which can be achieved by adding fins to the tubes that contain the flue gas (see Figure 6-5 and Figure 6-6).

6.2.1.4 Blowers/Fans & motors

The best performing warm air heater blowers/fans are centrifugal fans with backward-curved, airfoil-shaped blades. In centrifugal fans the air enters the impeller axially and is discharged in a radial direction into a volute-type casing. The airfoil blade design also reduces the noise level slightly. As the fan efficiency differs with the volume flow rate, the fan efficiency is usually quoted as "peak efficiency", or efficiency at the best operating point. Centrifugal fans with airfoil-shaped blades can reach peak efficiency up to 90%.[10] As a result of the higher efficiency, a 5% reduction in electricity consumption could be achieved at a cost increase from €50 to € 100.

Figure 6-7: Cross-section of an airfoil-shaped centrifugal impeller[11]



Fan efficiency has benefitted from recent brushless DC motor developments that can reduce by up to 40% the electricity consumed by a standard fan. As these motor types offer highly efficient operation and inverter controlled speed modulation according to heat demand, they are the best available fan motor technology to date. Fans with direct transmission from the motor also present higher efficiencies than belt-driven fans. The capacity to control the rotating speed allows both high efficiency and low noise emissions. Motors with two different rotation speeds

[10] Twin City Fan Companies Ltd. Engineering Data 2400. Fan Performance Characteristics of Centrifugal Fans

[11] US Department of Energy (US DOE) Energy Efficiency and Renewable Energy (2003) Improving Fan System Performance. Available at: www1.eere.energy.gov/industry/bestpractices/techpubs_motors.html

allow lower electricity consumption and lower noise emissions when the heater burners are off. The cost of such a high efficiency fan motor is around € 200

In the DG ENTR Lot 6 preparatory study[12], best available fans and motors were identified for non-residential and collective residential applications. These BATs can also be transferred to air-based central heating products.

6.2.1.5 Filters

In air-based heating products, filters are used to improve the indoor air quality by removing solid particulates from the warm air, as well as to protect the heat exchangers, humidifiers, etc. These filters are mostly fibre filters, which retain particles either on their surface (surface loading filters) or by using a higher volume (depth loading filters). Even though filters do not consume energy, their use causes a drop in the air pressure and this leads to higher energy consumption by the fans moving the air.

$$P = \frac{\Delta P * q}{\eta} \quad (1)$$

Where,

P is the power consumed by the fan

ΔP is the pressure drop

q is the velocity of the air flow

η is the efficiency of the fan

Filters are responsible of around 16% of the energy consumption of the fans, which could be reduced between 4 and 16% maintaining the same performance by using high efficient filters[13,14].

Eurovent manages a Certification Programme for air filters with the purpose of air handling and ventilation, as defined in the standard EN 779. In warm air heaters, filters are used in the ducts that distribute the warm air to the rooms, but these are not part of the warm air heater itself. Therefore, the manufacturers do not have decision capacity on the filter type used. For this reason, even though the influence of the filter on electricity consumption was included in the energy calculation in Task 5 of this preparatory study, no design improvement option is proposed on this regard.

---

[12] ARMINES (2012) Ecodesign preparatory study, DG ENTR Lot 6 - Air Conditioning and Ventilation Systems, Draft Report Task 5. Prepared for the European Commission, DG ENTR.

[13] ARMINES (2012) Ecodesign preparatory study, DG ENTR Lot 6- Air Conditioning and Ventilation Systems, Ventilation, Draft Report Task 6.

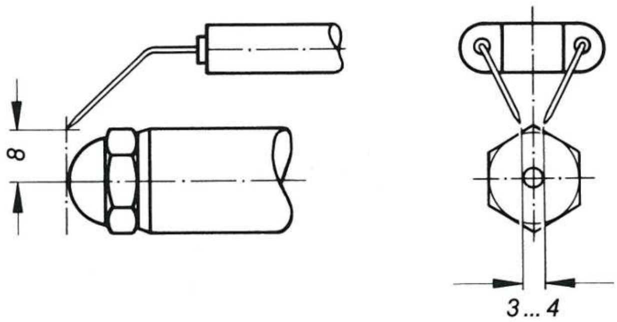
[14] Manufacturer's claim

6.2.1.6 Ignition device

Traditional appliances often have a continuously burning pilot light, which can consume between 100 and 500 Watts of gas power per hour. This form of heat loss can be eliminated by replacing the standard pilot lights with electric igniters.

Electric spark igniters provide a high voltage electrical spark between two electrodes. To do so, an electric transformer is required to generate a high electric voltage (approximately 12,000 Volts). The igniter is positioned close to the gas- or oil flow. The produced spark is blown into the flowing fuel-vapour in an arc-shaped form. As the fuel stream may not touch the electrodes, the distance between the electrodes and the nozzle exit is of great importance. Electric spark igniters are available for both gas and oil burners.

Figure 6-8: Electric spark igniter (oil burner)[15]



A different type of electric igniter is the hot surface igniter. Electricity passes through a filament usually made of silicon carbide or silicon nitride making it glow red hot. The igniter is positioned close to the fuel stream so that the vaporised fuel gets ignited on the hot surface. Hot surface igniters are less expensive than electric spark igniters and are therefore widespread in warm air heater technology.

Both types of electric igniters represent the best performing ignition devices available on the market, as they consume only very small amounts of electric energy for ignition and cost around € 20 to € 40. Electric igniters can increase the thermal efficiency by 5% resulting in a similar fuel efficiency of 5-6%.

6.2.1.7 Controls

The use of controls in central heating systems has increased in the EU, shifting the regulation of temperature and operation from the user to automated systems. In terms of energy consumption, controls can automatically turn off the heating system during the night or low-occupancy hours, modulate the amount of heat delivered, or distribute the heat differently in the building. There are however discrepant opinions on this topic. Some claim that programmable controls for central heating products can lead to an increase in the total energy consumption. The energy consumed is made "invisible" to the users and they are less responsible of the operating hours, settings and resulting energy consumption. In other words, a theoretical increase in efficiency due to smart controls of heating systems might lead to a rebound effect in

[15] Buderus Heiztechnik GmbH (2002) Handbuch für Heizungstechnik

which the total energy consumption is higher with controls[16]. This is not however in line with the findings of this preparatory study. When the seasonal efficiency is analysed, the capacity and zone controls achieve better performances, and they are already part of the functionality of central heating products.

- **Capacity controls**

Warm air heaters can include two-step or continuous capacity controls. These types of controls allow operation at less than 100% load when the heating demand decreases, reducing the fuel consumption and the start/stop cycling of the warm air heater. Two-step controls allow the warm air heater to work at reduced capacity or full capacity as required by varying the speed of the fan for gas and air input into the burner. Two-step controls are already included in most of the warm air heaters above 200 kW. Continuous modulation control allows adjusting the capacity delivered to match the heating demand by modulating the fans for the gas and air input into the burner similarly to the two step control.

These technologies provide energy savings throughout the year, but the thermal efficiency of warm air heaters does not reflect the improvements in seasonal performance.

- **Zone controls**

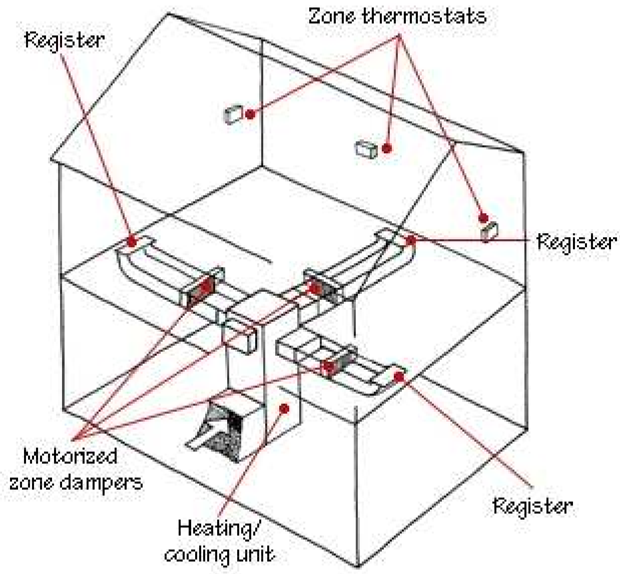
The installation of effective controls has a major impact on the energy consumption of air-based central heating products. The state-of-the-art control technology for central warm air heaters are programmable zone thermostats. Zoned heating is one of the best control concepts for an efficient energy usage of central air heating systems. A zoned heating system allows independent control of the air flow sent to various rooms or zones in the building, directing heating or cooling where and when it is needed. To do so, the central air heating system needs a special multi-zone programmable thermostat, additional thermostats for each room and a few motorised dampers. Recent programmable multi-zone thermostats allow for programming individual comfort patterns, vacation, night set-back and unoccupied settings for each zone. The damper in the ductwork opens or closes as needed based on each zone's thermostat settings. When a zone is at the selected temperature, and does not need to be heated or cooled, the dampers close to save energy and maximise comfort elsewhere. Depending on the overall demands, the heating capacity and air flow of the warm air heater can be modulated by the master controller.

Furthermore, the heating output of the warm air heater should be adjustable so it can adjust the amount of heating or cooling delivered throughout the house according to need. Zone heating can produce energy savings of more than 20% compared to heating both occupied and unoccupied areas of a building.[17] On average, at a cost increase of from € 20 to € 100, the investment would be paid back in a short period of time.

[16] Wallenborn *et al.* (2009) Integration of Standards, Ecodesign and Users in energy-using products “ISEU”. Final Report Phase 1., Belgian Science Policy (Research Programme Science for a Sustainable Development)

[17] US Department of Energy (US DOE) (2011) Energy Efficiency & Renewable Energy. Energy Savers. www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12520

Figure 6-9: Diagram of a zone control heating system[18]



This kind of controller only benefits large dwellings or non-residential buildings with low occupancy. According to a stakeholder, studies carried out in the UK for the revision of the buildings regulations, for dwellings smaller than 150 m^2 the cost of this provision outweighs the benefits in energy savings.

6.2.1.1 Mini duct systems

A mini duct system is a warm air delivery system where small diameter ducts work on delivering air on the principle of pressure rather than normal size ducts working on air velocity. A hi-velocity mini duct system can help improve the overall efficiency of a system where a conventional distribution system is used. Mini ducts are easier to install in existing buildings due to their small size. Mini-duct systems are a common technology in the US and Canada, but not common in the EU.

6.2.1.2 Material efficiency

In Task 5 it was shown that the amount of raw materials used in warm air heaters represent significant shares of process water consumption; waste generation (hazardous and non-hazardous), emissions of persistent organic compounds (POP), heavy metals and polycyclic aromatic hydrocarbons (PAH), and, eutrophication. This is largely due to the electronics and metals (particularly the non-ferrous) used in these products. The potential design improvements to reduce the resource consumption and environmental impacts of these warm air heaters are[19]:

[18] Don Vandervort's Hometips. How a Thermostat Works. 1997-2011. www.hometips.com/how-it-works/thermostats.html

[19] McAloone, T. & Bey, Niki, B. (2008) Environmental improvement through product development – a guide. Danish Environmental Protection Agency.

- Reducing the material intensity, i.e. using less material for the same functionality (product lightweighting)
- Eliminating or reducing the use of hazardous substances
- Increasing the amount of recycled and recyclable material, i.e. design for recycling
- Optimising the product's durability, i.e. increase the product's lifetime by making it durable, repairable and upgradeable (design for longevity)
- Substituting materials with alternatives having lower environmental impacts

Manufacturers claim that the costs of these heaters follow the amount of materials used. Manufacturers therefore have a self-interest in reducing the amount of materials used to a minimum without compromising the functionality or durability of the product. Designers already carefully consider the amounts of materials used in relation to the specified performance (e.g. insulation and energy efficiency) and durability (e.g. life time). The final choice is based on a trade-off between costs, performance and durability. According to manufacturers there is limited scope for using less material in the products currently placed on the market.

The Restriction of Hazardous Substance (RoHS) Directive[20] already covers the most harmful substances found in electronic equipment. The scope of this study did not allow further investigation to whether other harmful substances not covered by RoHS are used in central air heating products. Electronic manufacturers are already pushed to consider substituting harmful substances with other less harmful materials.

Warm air heaters already have relatively long life times. Although, it would be possible to increase their life further by making them more durable, repairable or upgradable, this would mostly likely come at the expense of energy efficiency. This study shows that the energy efficiency of warm air heaters will continue to increase over time with new developments. Increasing the lifetime of warm air heaters risks retaining less energy efficient models in the installed stock longer, and ultimately, reducing the overall potential for energy savings.

At present warm air heaters have a relatively high recycling rate. It would be possible to increase this further through better recyclability in design (e.g. information about the materials used, marking of parts, easier disassembly techniques, etc.), and as well as increasing the collection rates at the end of life. Most manufacturers claim that they already follow the best design practices related to recyclability, but it was not possible to verify this.

Another possible approach to material efficiency is to increase the recycled content in products. According to manufacturers, most of the metals used in their products are specified based on their specific performance requirements and already contain a large share of recycled content. Changing the specifications for materials based on recycling content could compromise the functionality of the product and would be practically difficult to implement.

Finally, manufacturers could consider substituting the materials currently used in warm air heaters with other materials that have lower environmental impacts. This is for example the case with changing refrigerants; using aluminium instead of copper in micro-channel heat exchangers

[20] Restriction of Hazardous Substances in Electrical and Electronic Equipment Directive (2011/65/EU)

(MCHX) for heat pumps; or, using plastic instead of stainless steel for the secondary heat exchanger (BNAT) in warm air heaters (see the following sections). Besides these improvement options, no other major material substitution potentials were identified.

6.2.2 Heat pumps

6.2.2.1 Compressors

Other than the system architecture and design, compressors have the highest contribution to the energy consumption. Therefore systems should be fitted with high efficiency variable speed compressors or a combination of variable speed and fixed speed compressors that can be alternated to achieve linear capacity modulation.

Compressors can be optimised for heating or cooling. For reversible systems, a compromise is achieved by using intermediate discharge valves, which are active during cooling providing good efficiency while maintaining a good heating performance in heating mode when the valves are inactive. Synchronous permanent magnet motors or other high efficiency motors present the highest efficiencies in this area.

Compressors are the focal component when assessing the energy efficiency of compression heat pumps. The efficiency of compressors can be assessed in two different ways: either by assessing the thermodynamic efficiency of the compressor itself, or by assessing the efficiency of the compressor as it performs in the system. In other words, a compressor that has highest thermodynamic efficiency (isentropic efficiency) is not automatically the best choice for every heat pump system. Therefore, several different compressor types can be the best performing, depending on the application area and capacity. Hence, as it is one of the most energy consuming parts of the system, there are more factors to be taken into account for the selection of the most suitable and efficient compressor. According to manufacturers, as progress in compressor efficiency has reached a plateau, it is important to make the right choice from the available options and thus match the function and environment (i.e. climatic conditioners) for which the appliance or system is destined for.

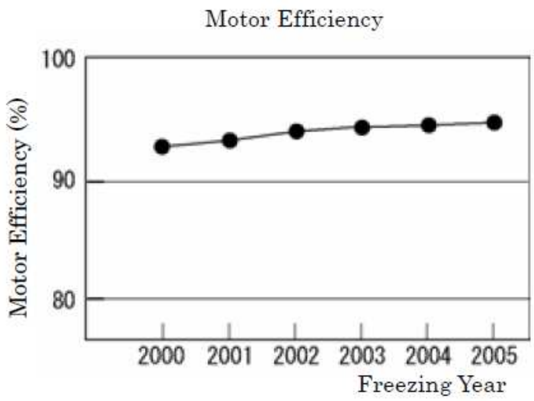
There are various conditions that influence the compressor's performance. For example, the state of operation (full-load/part-load operation) has a major influence on the efficiency as every compressor type has different part-load characteristics. By comparison, similar chillers with screw compressors have somewhat better full load efficiency, but are used only for hydronic (e.g. air-to-water) heat pumps, and do not achieve the part-load efficiency available with scroll compressors.[21]

Another important characteristic for compressor performance is the efficiency of the compressor motor. In recent years, compressor motor technology has evolved. By replacing highly efficient DC with AC motors, motor efficiency has improved significantly to approximately 95% (see

[21] Carrier Corporation (2004) Scroll Compressors - High efficiency compression for commercial and industrial applications. Available at: www.commercial.carrier.com

Figure 6-10).[22] Some of the highest efficiency motors are synchronous permanent magnet motors.

Figure 6-10: Compressor motor efficiency[23]



Furthermore, overall efficiency improvements were obtained by lowering mechanical losses of the moving parts (like friction or sliding losses) and by improving part-load efficiency. The latter was achieved by introducing capacity modulation control mechanisms, such as inverter technology and recent digital scroll technology.[24] The correct choice of a high efficiency compressor and motor could result in up to 45% reduction of energy consumption at an average cost of +500€ for residential single split units, and up to +1500€ for VRF non-residential applications.

According to manufacturers, rotary compressors offer the best performance for low-capacity heat pumps (up to 3 kW). For higher capacities, scroll compressors have a higher efficiency. Thus, for heat pump systems studied in this preparatory study, capacity modulating scroll compressors with high efficiency DC motors represent the best available technology, followed by inverter controlled twin rotary compressors, which are the best available technology for split and multi-split heat pump systems. For high capacity commercial and industrial hydronic heat pumps, the screw compressor represents the best technology. However, screw compressors are not used in air-based heat pumps.

- **Cascade compressor**

The cascade compressor has different tandem-connected membrane pumps, each of which has several stroke chambers and their volumes decrease with the fluid flow in the pumps. Each of those chambers has several input/output channels connected in parallel to connect individual membrane pumps and a check valve in every channel to stream fluid movement in a particular direction. By going through the compressor cascade's membrane pumps the fluid flow leads to its compression, and the volume reduction of each succeeding stroke chamber is caused by pressure at the end of the cascade.

---

[22] Energy Conservation Center Japan (ECCJ) (2008) Top Runner Program. Air Conditioners. Available at: http://www.eccj.or.jp/top_runner/

[23] Japan Refrigeration and Air Conditioning Industry Association

[24] Digital Scroll is a registered trademark of Emerson Climate Technologies

- **Tandem and Trio compressors**

Tandem (also called "twin") and trio compressors consist of two or three units connected in parallel. This configuration allows significant increase in equivalent capacity compared to single compressors, and high efficiencies.[25] Using parallel compressor units (to apply two or more compressors to a common suction header, a common discharge header and a common receiver) results in the potential for more effective load matching. Compressors are subsequently turned on or off in response to the changing load. Other advantages are diversification, flexibility, higher efficiencies, lower operating costs and less compressor cycling. The drawback of this kind of system is that any leaks affect the entire compressor rack.

- **Gas engine driven compressor**

Heat pumps with gas engine compressors (GEHP) were presented in Task 4 of this preparatory study. This is an alternative technology to all-electric heat pumps with capacity ranges from 20 kW to 80 kW of heating capacity.

The main benefits of this kind of compressor are the capability of recovering heat from the engine, and the lower primary energy consumed by gas compared to electricity. The average COP of GEHP is around 1.34 to 1.6, which compared to the COP of the Base-Cases of heat pumps presented in Task 5 may seem low. But when the COP is calculated in terms of primary energy, the efficiency of GEHP and all-electric heat pumps are similar. Gas engine heat pumps can also use inverter technology for implementing part load operation.

The heat recovery from the engine also enables a quick response at start-up and high heating capacity independent of the outdoor temperature (down to -20°C). This implies also a better sizing of the system according to the demand and the reduction of the need for over-sizing. When outdoor temperature is above 7°C, GEHP can also heat water (70°C). Gas engine heat pump do not need reverse cycles for defrosting since the heat used for the defrost process is taken from the engine and the heating function is not interrupted.

Nevertheless, gas engine heat pumps need a constant gas supply, which might increase the installation costs. The maintenance needed for the heat pump is similar to that of all-electric heat pumps, but the gas engine requires an additional inspection every 10,000 hours of work and has to be replaced every 30,000 to 40,000 hours, depending on the manufacturer.

Even though gas engine heat pumps can be an alternative technology to all-electric heat pumps, they cannot be presented as a direct replacement due to the need for gas supply installation. Therefore, GEHP will not be assessed in Task 7, but the analysis of the policy options to be carried out in Task 8 will include this type of heat pump.

6.2.2.2 Fans & motors

Besides compressors, fans represent the main consumers of electrical energy in air-based heat pump systems. Fans in air-to-air heat pump systems force the air over the heat exchangers in order to remove heat from the refrigerant (condenser) or to deliver heat to the refrigerant (evaporator). In air-source heat pumps, predominantly axial fans and centrifugal fans with

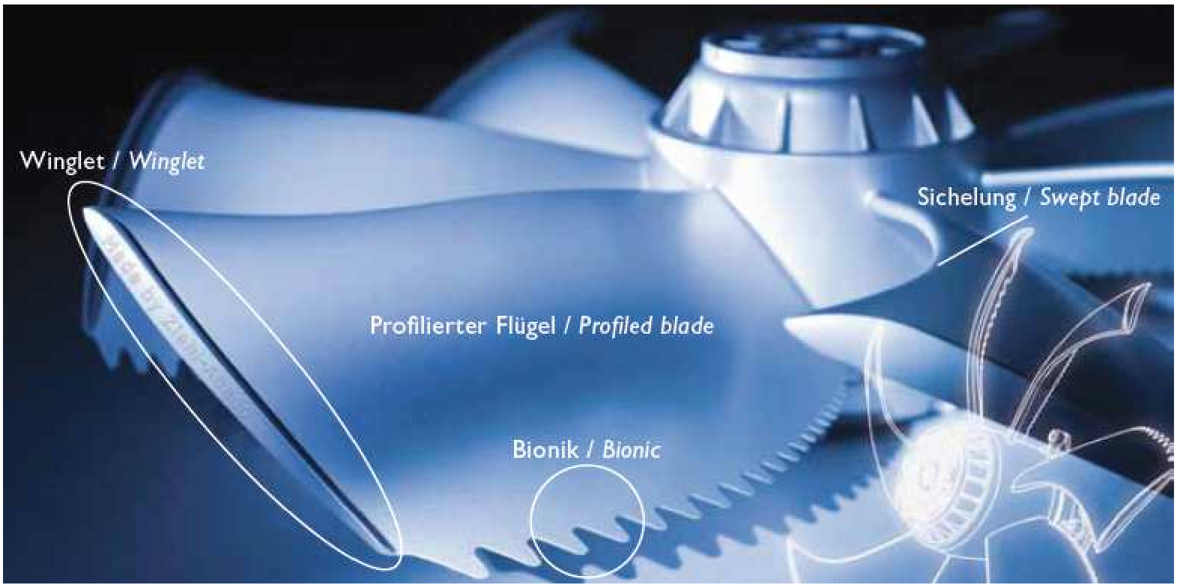
[25] BITZER Kuhlmaschinenbau GmbH

backward curved blades are used to pass air over the heat exchangers. The selection of a high efficiency fan could result in the reduction of electricity consumption by 5% at the cost increase would be from € 50 to € 100.

- **Axial fans**

Axial fans are named because they force air to move parallel to the ventilator shaft. The key advantages of axial airflow fans are their compactness, low cost, and light weight compared to centrifugal fans.[26] Recent axial fan blade design has progressively improved the volumetric efficiency and decreased the noise level. Figure 6-11 shows some examples for recent axial fan blade design options. Swept and airfoil-profiled impeller blades with attached winglets are typical examples of advanced designs.

Figure 6-11: A modern axial fan blade with advanced blade design[27]



Fan performance is influenced by many parameters. For example, the static pressure produced is proportional to the number of blades. Generally, fewer and wider blades result in better fan efficiency and a lower noise level. On the other hand, if the number of blades becomes too few, the fan becomes heavier, expensive and hard to balance. Therefore five to twelve blades are a good practical solution. Another example of a parameter influencing performance is the blade twist. Without it, the inner portion of the blade will stall and permit reversed airflow, which seriously affects the fan efficiency.[28]

- **Centrifugal fans**

As already mentioned in section 6.2.1.4, backward-inclined centrifugal airfoil fans offer low noise levels and high efficiencies. Because airfoil blades rely on the lift created by each blade, this fan type is highly susceptible to unstable operation because of stalling.

---

[26] US Department of Energy (US DOE) Energy Efficiency and Renewable Energy (2003) Improving Fan System Performance. Available at: www1.eere.energy.gov/industry/bestpractices/techpubs_motors.html

[27] Ziehl-Abegg AG (2011) Product Details Axial Fan FE2owlet design www.ziehl-abegg.com/us/fans-product-61-Axial-fan-FE2owlet-design.html

[28] BASF Corporation (2003) Basic guidelines for plastic conversion of metal axial flow fans

Cross flow fans

Cross flow fans, also called tangential fans or blower wheels, are cylindrical impellers in which the length of fan is longer than the diameter. Some of the advantages of cross flow fans are the low noise levels while serving big air volumes and the small size of the fan. The energy efficiency of cross flow fans is not as good as other types of fans, but the small size and low noise emissions make them suitable for indoor units.

Motors

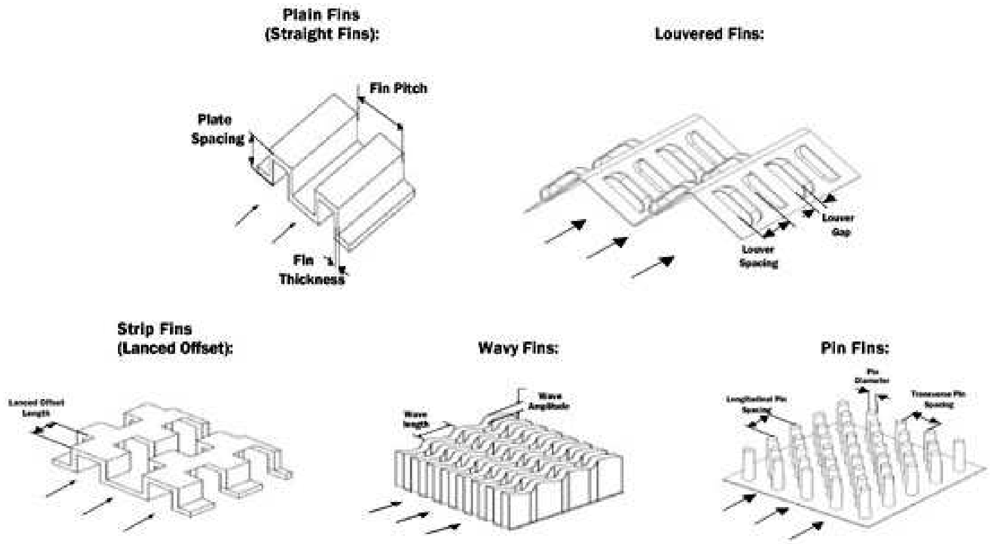
The best available fans are directly driven, meaning they do not use a belt or gear between the motor and the ventilator shaft. Direct drives have several advantages over belt drives, including higher efficiency, compact space requirements, and lower required maintenance efforts. In addition, they allow the fan to operate more reliably and more quietly. Motor efficiency was also progressively increased by using brushless DC motors. Another option of high efficiency motors are synchronous permanent magnet motors. The cost increase of this type of motors is around € 300. These motors offer highly efficient operation and inverter controlled speed modulation, which achieves electricity savings up to 40% over the year.

6.2.2.3 Heat exchangers

In the context of heat pump systems, the term heat exchanger stands for both evaporators and condensers of the system. Heat exchangers can influence the COP of a heat pump in different ways: by reducing the compressor pressure gap and by improving the evaporation temperature.[29] Furthermore, the efficiency of heat exchangers depends on many factors such as system size, primary and secondary medium characteristic (outside air, inside air, refrigerant). Thus it is not possible to identify one best available technology. The technology has to be assessed in a wider context. Therefore this section focuses on the technical improvement potential for evaporators and condensers in air-to-air heat pump systems that can lead to an increase in performance.

[29] European Heat Pump Association (EHPA), European Heat Pump News, No.1 - March 2011, Improving heat pump performance with a brazed plate heat exchanger

Figure 6-12: Different heat exchanger fin designs[30]



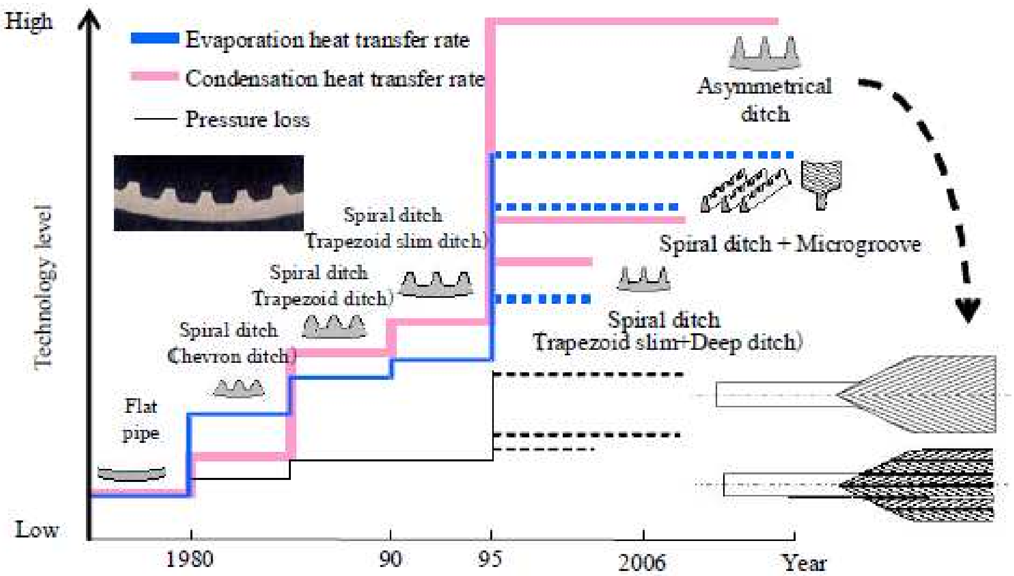
Evaporators and condensers of air-source heat pumps are usually built as finned tube heat exchangers, as the fins offer a large surface area. Generally, heat exchangers with low pressure loss and high heat transfer performance are needed to reach higher COP. To improve heat transfer, the heat transfer resistances of finned tube heat exchangers have to be lowered. These resistances are (1) the convective heat transfer resistance of refrigerant flowing inside the tube, (2) the thermal contact resistance between tubes and fins, and (3) the convective heat transfer resistance of air flowing through fins. The shares of heat transfer resistances are estimated to be about 15-20% for the refrigerant, 10-15% for the thermal contact of tube and fin, and 70-75% for air.[31] As can be seen, the highest improvement potential is on the air side, which is predominantly caused by the fin design and pressure loss due to the embedded tubes. More advanced fin types like wavy, louver or offset fins enhance the heat transfer on the air side (see Figure 6-12). The convective heat transfer inside the refrigerant tube was recently improved by introducing grooved tubes. A trend of tube design can be seen in Figure 6-13. Modern heat exchangers contain micro-fin tubes that have small fins on the inside that increases the heat transfer by generating turbulence.

According to some stakeholders COP increase of around 8% to 11% can be achieved by increasing the heat exchanger area by 50%. One stakeholder claims that an increase of the heat exchanger area of 50% for a 16 kW split heat pump would result in around € 120 increase of the price, due to the heat exchanger cost and the need of a bigger box and higher fan power. For a non-residential VRF system of 55 kW, a similar increase of the heat exchanger area would increase the price around € 400.

[30] ElectronicsCooling. Air Cooled Compact Heat Exchanger Design For Electronics Cooling (2004) www.electronics-cooling.com/2004/02/air-cooled-compact-heat exchanger-design-for-electronics-cooling/

[31] International Energy Agency (IEA) Heat Pump Programme (2010) Annex 33 Compact Heat Exchangers in Heat Pumping Equipment Final Report. Page 42

Figure 6-13: Trend in tube design of heat exchangers[32]



▶ Micro-channel heat exchanger

Micro-channel heat exchanger (MCHX) technology has been a proven technology since 1980, and is mainly used in air conditioning and the automotive sector. MCHXs are made of flat aluminium tubes with dimensions of 1 to 3 mm and louvered fins that pass between and are brazed to the tubes (see Figure 6-14). The sophisticated design of MCHX improves heat transfer while simultaneously lowering the air side pressure drop, leading to a reduced necessary fan power. Using MCHXs, gain of up to 10% COP can be reached at the equal front coil area or air volume, as compared to traditional finned tube heat exchangers[33], and gain of 30% more capacity can be reached keeping the same frontal area, air volume or COP. At the same time the refrigerant charge can be significantly lowered by 30% to 40% by replacing the condenser with MCHX, compared to a conventional heat exchanger of equal capacity.[34] However, some heat pump manufacturers are doubtful that this will increase COP, but agree that refrigerant charge could be reduced. Due to the smaller amount of material used, MCHXs are usually lighter in weight and smaller in size than traditional heat exchangers: a 2-row aluminium fin & copper tube heat exchanger is typically 44 mm wide, while an MCHX are about 6 mm wide.

The use of aluminium as a material in MCHX increases the lifetime of a product since no galvanic corrosion occurs between micro channels and fins. Aluminium is also less costly than copper, which can lower the cost of the materials for manufacturing. In the end-of-life phase, MCHX are easier to recycle than conventional heat exchangers, since there is no need to separate different materials.

[32] International Energy Agency (IEA) Heat Pump Programme (2010) Annex 33 Compact Heat Exchangers in Heat Pumping Equipment Final Report. Page 169

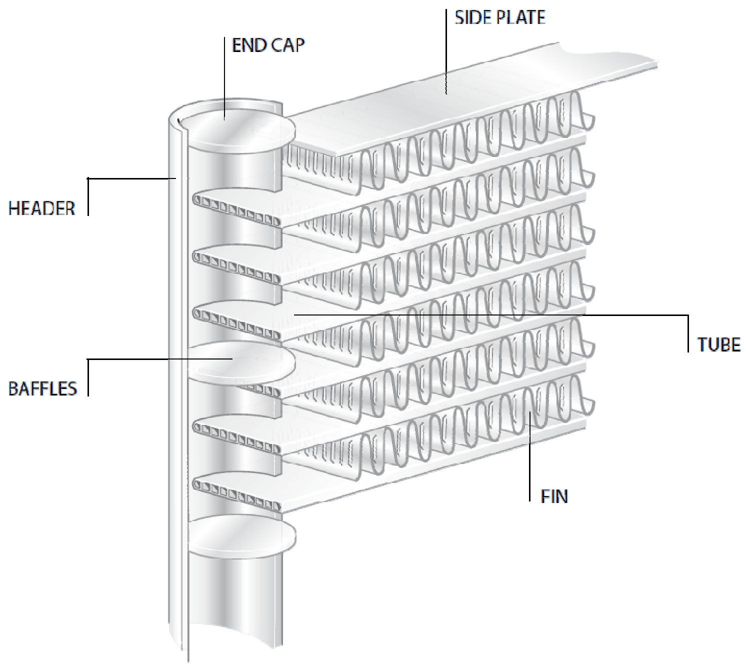
[33] Carrier (2007) Commercial documentation on micro-channel heat exchangers. www.carrier.com

[34] A stakeholder mentioned that replacing the condenser and the evaporator could potentially save up to 50% of the refrigerant charge, but there are issues with defrosting for outdoor units.

MCHXs are currently used in indoor units of heat pumps, but they are expected to be applied in outdoor units in the future. At present, the use of MCHX in outdoor models is difficult due to issues with defrosting.

According to some stakeholders, MCHX can achieve a gain of 10% in COP by keeping the same frontal area. Alternatively, MCHX can provide 30% higher capacity by keeping the same frontal area, the same air volume or the same COP. The third option would be the reduction of frontal area and the air volume by 25% while keeping the same capacity and COP.

Figure 6-14: Micro-channel heat exchanger[35]



The most important issue with the adoption of micro-channel heat exchangers is that the frictional pressure losses on the refrigerant side are higher due to reduction in diameter of channel or passage of flow. This prevents the uniform flow of the cooling material along the channels.

MCHX for air-to-air heat pumps are currently applied in low capacity products, up to 16 kW of cooling capacity. For higher capacities, this technology is not developed enough.

6.2.2.4 Expansion device

As already described in Task 4, the purpose of the expansion device is to reduce the pressure of the refrigerant and to regulate the refrigerant flow, before entering the evaporator. The best performing expansion devices are thermostatic expansion valves and electronic expansion valves, depending on the heat pump system.

Thermostatic expansion valves (TEV) regulate refrigerant flow by maintaining a nearly constant superheat at the evaporator outlet. As the superheat at the evaporator outlet rises due to increased heat load on the evaporator, the TEV increases refrigerant flow until the superheat

[35] Danfoss-Sanhua Inc. Inside an MCHE(2011) www.danfoss-sanhua.com/coils003.aspx

returns to the valve's setting. Conversely, the TEV will decrease refrigerant flow when the superheat lowers as a result of a decreased heat load on the evaporator. The effect of this type of regulation is it allows the evaporator to remain nearly as fully active as possible under all load conditions.[36] TEVs are the most widespread type of expansion valve.

Electronic expansion valves (EEV) control the refrigerant flow at the evaporator by means of a pressure sensor and a temperature sensor, which are both installed at the outlet of the evaporator. A regulator controls the valve opening in real-time. EEVs with adaptive control algorithm allow good evaporator control especially for systems with high capacity variations (e.g. variable capacity compressors). According to some stakeholders, this can lead to 5-7% higher COP compared to TEV for single split heat pumps. For VRF heat pumps, EEV is already considered a common component. This increase of COP is due to utilising 30% more area of the outdoor heat exchanger.

Recent developments include combined electronic injection and distribution systems. These systems allow optimised evaporator usage and control. Due to their control characteristics, these combined electronic injection and distribution systems can provide energy savings.

6.2.2.5 Refrigerants

- **Traditional refrigerants**

Concerning traditional refrigerants like hydrofluorocarbons (HFCs), the most efficient heat pump systems use either use R134a, R407C or R410A as a refrigerant, as they offer a significant gain in compactness due to their high volumetric cooling capacity.

Hydrofluorocarbon R410A is recognised as the best performing refrigerant in use in heat pumps. Intentionally introduced as the main replacement for the restricted R22 refrigerant, R410A is nowadays widespread in heat pump technology. Also R410A has an ozone depletion potential of zero (ODP = 0), it has a global warming potential (GWP) of 1725[37]. As all HFCs contribute to the greenhouse effect, the aim for traditional refrigerant heat pumps is to lower the total refrigerant charge.

The substitution of R410A with R134a is a topic where views differ. Many stakeholders have expressed their concerns regarding the adoption of R134a as being inappropriate and the level of performance of the system is reduced considerably. On the other hand, according to some with appropriate modifications, units using R134a could achieve the same performance of conventional units. According to the same stakeholders, when R134a is applied, the entire system needs to be redesigned resulting in an increase of at least 25% of the unit size. This increase in size is due to the difference in operating temperature and the pressure of the refrigerant. Such changes would result in increasing the product price around 40%.

- **Natural refrigerants**

[36] Sporlan Valve Compay (2001) Thermostatic Expansion Valves - Theory of operation - Application - Selection

[37] Compared to CO_2, which has GWP =1. Also measured in kg CO_2-equivalent per kg of refrigerant

Besides the traditionally used refrigerants like HFCs, natural refrigerants are an alternative for heat pump systems. The main benefit of natural refrigerants is their lower GWP compared to HFC refrigerants. Examples of natural refrigerants that may be used in heat pump systems are propane (R290), ammonia (R717), and CO_2 (R744).

As some of these alternatives present a risk to human health (ammonia: high toxicity, difluoromethane and propane: flammable) they are usually not used in split heat pump systems in Europe.

Table 6—3: Critical temperatures and pressures of natural refrigerants

Refrigerant	Critical Temperature in [°C]	Critical Pressure in [bar]
CO2 (R744)	31.0	73.8
Propane (R290)	96.7	42.4
Ammonia (R717)	132.0	113.0

- *Propane*

R290 is the common name for high purity propane, which is mainly used in commercial and industrial refrigeration technology. As with all natural refrigerants, propane has zero ozone depletion potential (ODP = 0) and low global warming potential (GWP = 3). Propane can serve as a functional replacement for R-12, R-22, R-134a, and other chlorofluorocarbon or hydrofluorocarbon refrigerants in conventional stationary refrigeration and air conditioning systems. As propane is highly inflammable, devices using R290 need additional safety devices, which could result in lowering overall efficiency compared to the Base-Case. In addition, due to propane's flammability, the amount allowed is limited, making it a suitable option only for small units. In some Member States, the use of propane is totally prohibited.

A recently introduced refrigerant with high potential of substituting R410A and actually even increasing the performance of units slightly, is R32. With the GWP of 100 years at 675 and a possible performance increase up to 10%, R32 is the BAT of refrigerants that could help reduce the direct and indirect emissions of heat pump units.

Another promising refrigerant especially concerning its GWP is R1234yf. R1234yf is currently in the research stage concerning heat pump applications. Nevertheless, either being used purely or in combination with other refrigerants (a mix), it could potentially result in even lower direct emissions as it has a GWP for 100 years of 4 according to IPCC. The first commercial application of R1234yf appears to be implemented soon by the automotive industry. Some concerns have been raised concerning the flammable nature of R1234yf, which will require that safety measures are taken and this could affect its performance significantly.

- *Ammonia*

Refrigerant ammonia is a clear, colourless liquid or gas, free from visible impurities. It has a purity of at least of 99.95%. Ammonia has zero ozone depletion potential (ODP = 0) and also zero global warming potential (GWP = 0). The properties of ammonia make it an ideal refrigerant. If properly applied, it is very efficient to use.

The dominant characteristic of ammonia is its penetrating smell, its acute toxicity and its incompatibility with copper materials. Despite these drawbacks, ammonia was been widely used for refrigeration systems until it was substituted by HFCs. When ammonia is being used as a refrigerant, the efficiency of the unit is slightly reduced and the entire unit has to be redesigned

- *Transcritical CO2 heat pump*

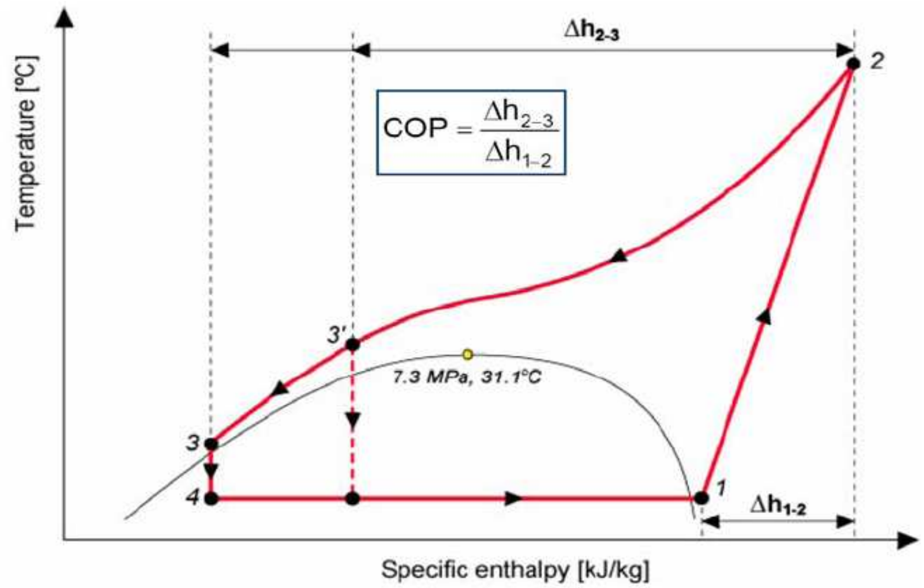
As the name already implies, the transcritical CO2 heat pump uses carbon dioxide as a refrigerant. CO_2, which is also known as R744, has no ozone depletion potential (ODP = 0), a negligible global warming potential (GWP = 1), high volumetric cooling capacity (which leads to small compressors and suction lines) and is non-flammable and non-toxic.

These criteria would make CO2 an attractive choice, if there was not a major drawback. Due to its specific thermodynamic properties (relatively low critical temperature, 31°C, and relatively high critical pressure, 73.8 bar), carbon dioxide involves operating in so-called transcritical[38] mode, with evaporation at subcritical pressure and heat rejection at supercritical pressure.

As can be seen in Table 6—3, the critical temperature is relatively low, compared to other natural refrigerants. Above the critical point, liquefaction is not possible anymore, which means that the CO2 cycle becomes transcritical and only sensible heat can be rejected in the gas cooler, as no phase change of the refrigerant occurs.

As a consequence, the operating pressure in CO2 heat pump systems will typically be five to ten times higher than that of traditional HFC systems, i.e. 20 to 40 bar in the evaporator and 80 to 130 bar during heat rejection in the gas cooler.[39] Resulting from the specific thermodynamic properties of CO2, the complete system design and controls have to be changed. Figure 6-15 shows the principle of the transcritical CO2 heat pump cycle in a Temperature-Enthalpy diagram.

Figure 6-15: Principle illustration of the transcritical CO2 heat pump cycle in T-h diagram[39]



---

[38] Transcritical operation means operation at temperatures higher than the critical temperature.

[39] Stene (2007) Integrated CO2 Heat Pump Systems for space heating and hot water heating in low-energy houses and passive houses.

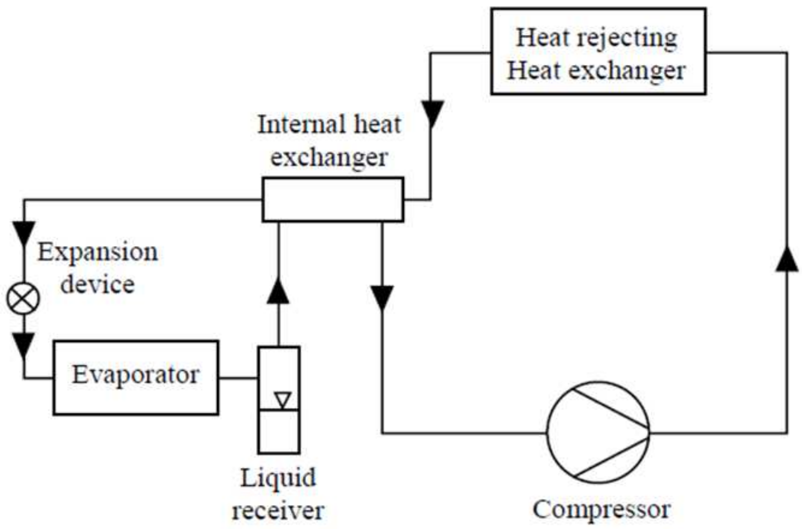
Legend: 1-2: Compression; 2-3: Heat rejection in a gas cooler; 3-4: Expansion/throttling; 4-1: Evaporation.

The major differences in system design are different compressor design, gas coolers, expansion device and internal heat exchanger. The compressor of transcritical CO2 heat pump systems has to be designed to withstand high pressures. Due to the high volumetric refrigeration capacity of CO2, compressors can be designed with smaller volumes. This also holds true for other components.

The gas cooler corresponds to a conventional condenser. As in transcritical operations, the refrigerant cannot condense. The gas cooler cools the CO2 discharged from the compressor at a high pressure. Because of this high pressure, the tubes in which the vaporised CO2 flows are strengthened compared to a conventional heat exchanger. Specifically, each tube is made five to ten times stronger than a conventional tube by optimizing the tube diameter and wall thickness. In addition, the gas cooler uses a unique tank structure, which allows refrigerant to flow more efficiently in the gas cooler to exchange heat with the air.

While in subcritical applications, refrigerant is metered by a capillary tube or thermostatic expansion valve, transcritical CO2 systems use high pressure expansion valves (HPEV). HPEVs work similarly to thermostatic expansion valves (TEVs) in traditional heat pump systems, with the difference that they control the refrigerant flow from the high pressure side of the system. Unlike a TEV, an HPEV does not control evaporator superheat. As HPEVs are designed to control gas cooler pressure, they must withstand high CO2 pressures that can easily reach up to 100 bar, at the same time accurately controlling gas cooler pressure. Slight changes in gas cooler pressure will have significant influence on the system cooling capacity and energy efficiency (COP).[40]

Figure 6-16: Flow diagram of a transcritical CO2 cycle[41]



CO2 air conditioning systems incorporate an internal heat exchanger installed between the outlet of the gas cooler and the evaporator. The internal heat exchanger helps to further cool the high pressure CO2 refrigerant that leaves the gas cooler by exchanging heat with refrigerant flowing out of the evaporator before entering into the compressor.

[40] Staub, Rasmussen, Robinson (2004) CO_2 As Refrigerant: The Transcritical Cycle

[41] Adriansyah (2001) Combined Air-conditioning and Tap Water Heating Plant, Using CO_2 as Refrigerant for Indonesian Climate Condition

The practical feasibility of transcritical CO2 heat pump systems has been investigated in many projects and studies. Nevertheless, research is still ongoing with respect to overall system performance, heat exchange component and compressor development. Some results showed that transcritical CO2 heat pumps can reach COP values comparable to traditional HFC heat pump systems, especially when being built as integrated heat pump systems with hot water heating, but could also prove promising for air-based heating systems.[42] According to some stakeholders, R744 performance can be greatly affected by climatic conditions. For R744, it is possible to reach COP values of traditional systems only in cold climates; where for not suitable climatic conditions, this could result in an increase in electricity consumption of up to 20%.

The introduction of transcritical CO2 systems in the market has been very slow. This is mainly due to the significant upfront investments for manufacturers, when changing to a drastically new technology, and the associated high costs for customers.[43]

6.2.2.6 Controls

State-of-the-art control solutions for air-to-air heat pumps contain weather compensated control mechanisms and allow an independent zone temperature control. A typical modern control system might include:

- programmable time and temperature thermostats in each zone;
- an external temperature sensor;
- an intelligent defrost control of the external airside heat exchanger and auxiliary heaters; and,
- a central control unit, which controls the compressor and all other system components on information it receives from the programmable thermostats.

Recent systems are self-adaptive, which means that they can "learn" the thermal characteristics of the building and heated spaces and intelligently adapt themselves based on weather conditions to ensure that a particular zone or zones are heated to the required temperature at the set time.

Besides weather compensated controls many manufacturers state that fuzzy logic control strategies may allow better performance, reduced reaction time and smaller overshoot temperature. On the other hand, the reaction time of heat pumps is usually short, hence, limiting the additional gains of such controls systems.

In VRF heat pump systems, each individual indoor unit can be controlled by a programmable thermostat, or multiple indoor units serving the same zone can be controlled by one master thermostat. Most VRF manufacturers offer a centralised control option, which enables the user to monitor and control the entire system from a single location or via the Internet. These controls

[42] Stene (2007) Integrated CO2 Heat Pump Systems for space heating and hot water heating in low-energy houses and passive houses

[43] Eckhard A. Groll & Jun-Hyeung Kim (2007) Review of Recent Advances toward Transcritical CO_2 Cycle Technology, pp. 499-520. Available at: http://dx.doi.org/10.1080/10789669.2007.10390968

optimise system efficiency and refrigerant flow, matching capacity to the load in each of the zones.

Even though controls increase the seasonal efficiency of central heating systems, they might lead to increased total energy consumption, as explained in section 6.2.1.7. However, the findings of this preparatory study point to an increase of the seasonal efficiency, when automated controls are used in central heating systems. Furthermore, these controls are part of the functionality of the products, and the energy saving strategies are more focused on increasing product efficiency rather than reducing their use or functionality.

6.2.2.1 Mini VRF

The majority of manufactures provide a mini VRF option to the market with a range of 11-18 kW heating capacity. As the name suggest, mini VRFs can be up to 70% smaller than standard VRF systems, and can be used for small buildings, where the heating need is low. Mini VRF can have COP values of over 4. At partial load of less than 50%, some systems are able to reach up to 6.41 COP. Depending on the manufacturer and capacity, up to 12 indoor units can be supplied from a single outdoor unit. A common refrigerant for mini VRF systems is R410A.

6.2.2.2 Noise reduction

As explained in Task 4 and Task 5, noise emissions in heat pumps are produced by the evaporator and condenser fans. Some manufacturers offer products with silent modes of operation, mostly for indoor units, as it is a usual request from customers. The state-of-the-art in sound power level for indoor units is around 38 dB, and for outdoor units is around 67 dB. However, the sound power level of outdoor units usually increases with the heating capacity.

According to some stakeholders, the reduction of the noise power levels in heat pumps has a drawback of the reduction of the energy efficiency of the product.

6.2.2.3 Air quality

Although some technologies were identified for improvement of the air quality (e.g. low NOx oil burner) no information was available regarding the exact emissions levels of both warm air heater and gas driven heat pumps. However, the Blue Angel labelling scheme in Germany provides information regarding the emissions of both gas driven heat pumps and gas boilers. As the criteria of the labelling scheme are based on the “best in class” products, the levels set for air quality (NOx, CO, etc.) can be assumed to be achieved only by the BATs. It is assumed that similar level of emissions can be achieved by gaseous warm air heater and gas boiler BATs. Therefore, the air quality requirements proposed later on in Task 8 are based on the requirements recommended by UBA[44] and DG Environment.

[44] The Federal Environmental Agency (UBA) of Germany.

6.3 Best Not yet Available Technologies

The following section deals with technology perspectives that may increase energy efficiency or lower the environmental impacts of the product Base-Cases. These technologies and components may not yet be available on the market, or represent an alternative technology that is currently in a research or prototype testing phase.

6.3.1 Warm air heaters

6.3.1.1 Low capacity modulating oil burners with catalytic vaporisation

With the specific heat demand of new buildings getting lower in recent years, demand for low capacity oil burners with capacities below 12 kW has grown. Besides, the growing use of alternative energies like solar thermal energy may influence the heat demand, due to seasonal effects and climate conditions. This fluctuating heat demand requires burners that can vary their heating output, so called modulating burners.

Low capacity modulating burners are being developed at the moment, and offer such advantages. The key technology that makes it possible to build low capacity modulating oil burners is the catalytic vaporisation of oil. This means that the liquid oil is completely evaporated before it is mixed with air and ignited. With this advanced pre-mixing technology it is possible to build easy modulating oil burners with a reduced number of start/stops and lower emissions of unburned hydrocarbons and NO_X. Heating capacities as low as 3 kW can be achieved, with prototypes already being available.[45]

6.3.1.2 Cool flame technology

Cool flame technology (CFT) is a patented process[46] of liquid fuel warm air heaters, where a mixture of fuel and air undergo a partial low-temperature-oxidation. Cool flames are exothermal reactions, where a small fraction of the fuel (oil) and air reacts with each other and generates heat. A particular feature of the cool flame is that there is no visible flame, which is self-regulated at a constant temperature in the region of 350 to 480 °C depending on the operating parameters. The heat generated in the exothermic reaction is used to fully evaporate the fuel and make it suitable for combustion. Because of the lower temperature combustion, lower NO_X emissions can be achieved.[47]

Cool flame technology is an interesting candidate for future burner technology, where prototypes are already available and it allows use of low capacity modulating burners.

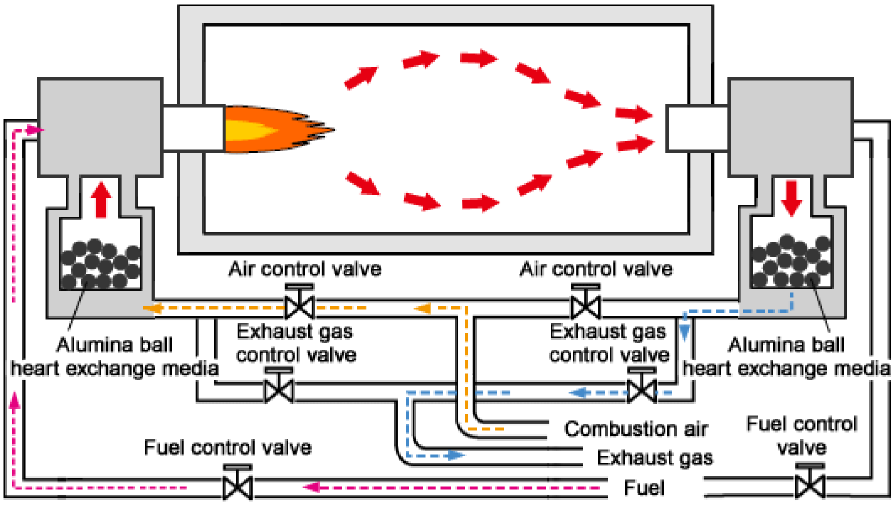
[45] CATVAP project, www.fhnw.ch/technik/itfe/forschung/projekte/catvap-katalytische-verdampfung-von-heizoel
[46] Patent-no. EP 1 102 949 / US 6.793.693, PKF GmbH & Co. KG, Aachen
[47] Cool Flame Technologies (2011). www.coolflame.no

6.3.1.3 Regenerative burners

Besides the recent technological developments for the residential sector, there are also a lot of emerging technologies for the commercial and industrial sector of indirect and liquid fired gas warm air heaters. These technologies could possibly serve as examples for future technologies in the residential sector as well.

Regenerative burners use a pair of burners which cycle to alternately heat the combustion air, or recover and store the heat from the warm air heater exhaust gases. When one regenerative burner is firing, the other is exhausting the warm air heater gases. Exhaust gases pass through the regenerative burner body and into a media case, which contains refractory heat exchange material such as alumina or ceramic balls. This refractory media is heated by the exhaust gases, thus recovering and storing energy from the flue products. When the media bed is fully heated, the regenerative burner currently firing is turned off and begins to exhaust the flue products. The regenerative burner with the hot media bed begins firing. Combustion air passes through the media bed and is heated by the hot refractory material. Due to this air preheating, temperatures within 150°C and 260°C are achieved, resulting in exceptionally high thermal efficiency with very low NO_X emissions.[48]

Figure 6-17: Regenerative burner mechanism[49]



6.3.1.4 Recuperative burners

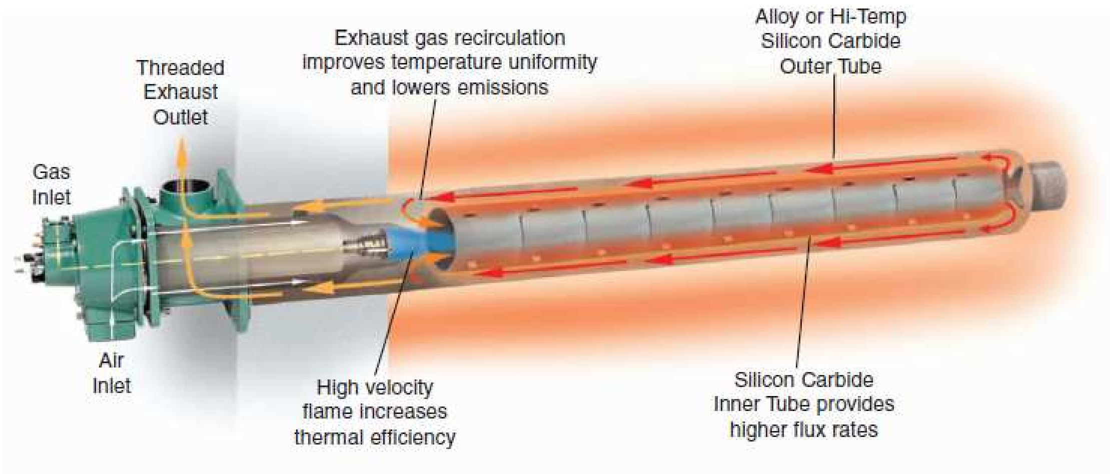
Recuperative burners are usually built as single-ended burners (SER-burners). This kind of burner is currently available for industrial applications in both indirect fired and liquid fuel gas warm air heaters. It contains a counter-flow heat exchanger that is positioned concentrically in a protective radiant tube. The produced flue gases are drawn backwards over the heat exchanger (recuperator) and transfer heat back through the recuperator wall, where it is picked up by the incoming combustion air. These re-circulated flue gases contain less oxygen than combustion air, which leads to lower flame temperatures and significantly lower NO_X levels - up to 50%.

[48] Bloomengineering Company Inc.. Regenerative Burners. 2001-2007, www.bloomeng.com/regenerative.html

[49] TipTon Ceram Corp.. Regenerative Burner Mechanism. www.tiptonceram.com/oil_refining/burner.html

The major advantage of the SER system over a regenerative system is that it only requires access to the warm air heater from one side, which allows it to facilitate horizontal as well as vertical heating systems.

Figure 6-18: Diagram of a recuperative industrial warm air heater burner[50]



6.3.1.5 Secondary heat exchanger improvement

Plastic is discussed as a cost-effective alternative to stainless steel as a material for secondary heat exchangers. Specially developed plastics can be highly corrosion resistant while still holding good heat conducting characteristics. Some warm air heater manufacturers have already tried to combine conventional steel with corrosion resistive plastic coatings. Nevertheless, a widespread market introduction for plastic heat exchangers or plastic coated exchangers seems to be difficult.

6.3.1.6 Improved insulation

Jacket losses and duct losses in warm air heaters can account for up to 17% of the total energy delivered by warm air heaters (see Task 5 of this preparatory study). Thus, there is significant potential for reducing these heat losses by improving the casing and ducts insulation. However, it can be assumed that some minimum heat losses are unavoidable, and that the maximum energy savings would never reach that limit. Ducts and heater jackets can be insulated with fibreglass or reflective insulating materials, but as seen in Task 5, this addition of materials to the product might increase the environmental impact of the materials needed and the production phase. Therefore, it would be relevant to find a compromise between the energy savings of insulation and the environmental impacts of the materials required.

[50] Eclipse Combustion Ltd.. Products page. AutoRecupe SER Burners. www.eclipsenet.com/products/

6.3.2 Heat pumps

6.3.2.1 Solar-assisted compressor heat pumps

Solar-assisted heat pump systems combine the working principles of a solar power system with a heat pump. Solar energy is harnessed in a solar collector at a higher temperature relative to the ambient temperature, and is used to vaporise the refrigerant in the heat pump evaporator. This utilisation can be achieved directly or indirectly with the use of additional heat exchangers.

- **Indirect expansion solar-assisted heat pumps**

Indirect expansion solar assisted heat pump systems use solar collectors that are usually installed on roof tops of buildings to collect solar radiation. The collectors are usually made of evacuated glass tubes with embedded piping. A special liquid is pumped through the collector and is heated as a result of the incoming solar radiation. Afterwards, the warmed liquid enters a heat exchanger, and raises the temperature of the refrigerant in the heat pump cycle, that is also passed through the secondary side of the heat exchanger. In this configuration both solar collector and heat pump evaporator are separate units, but coupled through a heat exchanger.

- **Direct expansion solar-assisted heat pumps**

In a direct expansion heat pump, the solar collector also acts as the heat pump evaporator, thus reducing the number of components as well as the inefficient thermodynamic processes across the two eliminated units. In direct expansion solar-assisted heat pump (DX-SAHP), the liquid refrigerant from the condenser is flashed through a throttle valve into the tubes of the solar collector panel for vaporisation and superheating of the refrigerant.

Recent development in the integration of heat pump and solar technology lies in the use of direct-expansion solar collectors to replace the standard air-source evaporator in a heat pump system. The advantage of this system is the higher evaporating temperature of the refrigerant at the evaporator-collector, owing to the solar heating effect. This increases the coefficient of performance (COP) of the heat pump.[51]

- **Other solar configurations**

As there are many other possible system configurations using solar assistance, the performances and relevance of such combined systems using solar thermal energy and heat pumps are actually being assessed in a joint project by the IEA Heat Pump Programme (Annex 38) [52] and the IEA. Solar Heating and Cooling Programme (Task 44) [53].

---

[51] P. Gang et al. (2007) Performance of Photovoltaic Solar Assisted Heat Pump System in Typical Climate Zone. Journal of Energy & Environment. Vol. 6

[52] International Energy Agency (IEA). Heat Pump Programme (HPP). Annex 38 Solar and Heat Pump Systems. 2010-2013

[53] International Energy Agency (IEA). Solar Heating & Cooling Programme (SHC). Task 44 Solar and Heat Pump Systems. 2010-2013

6.3.2.2 *Thermally driven heat pumps*

The most important types of thermally driven heat pumps are closed liquid absorption and solid adsorption cycles. Both technologies are based on a working pair of refrigerant and a sorption medium. In absorption devices, the refrigerant is dissolved in a liquid sorption medium. Today's most common working pairs are Lithium Bromide/Water and Ammonia/Water. In the case of adsorption heat pumps, the refrigerant is adsorbed in the pores of a solid adsorption medium. Today's most common working pairs are Zeolite/Water, Silica Gel/Water, Activated carbon/Ammonia and Activated carbon/Methanol.[54] Compared to traditional vapour compression systems, thermally driven heat pumps can result in benefits in terms of reduced energy consumption and mitigation of global warming potential due to low GWP of the refrigerants used.[55]

Table 6—4: Overview of available refrigerants/sorbents and performance[56]

Process	Adsorption		Absorption		
Refrigerant/sorbent	Water Silica gel	Water Zeolite	Water/LiBr Single-effect	Water/LiBr Double-effect	Ammonia Water
Temperature heat source [°C]	60 - 90	75 - 150	75 - 110	135 – 200	100 - 180
Capacity [kW]	7.5 - 500	7 - 15	15 - 12,000	200 - 6,000	18 - 700
COP	1.4 - 1.6	1.3 - 1.5	1.4 - 1.6	1.8 - 2.2	1.4 - 1.6
EER	0.5 - 0.7	0.4 - 0.6	0.6 - 0.7	0.9 - 1.3	0.5 - 0.7

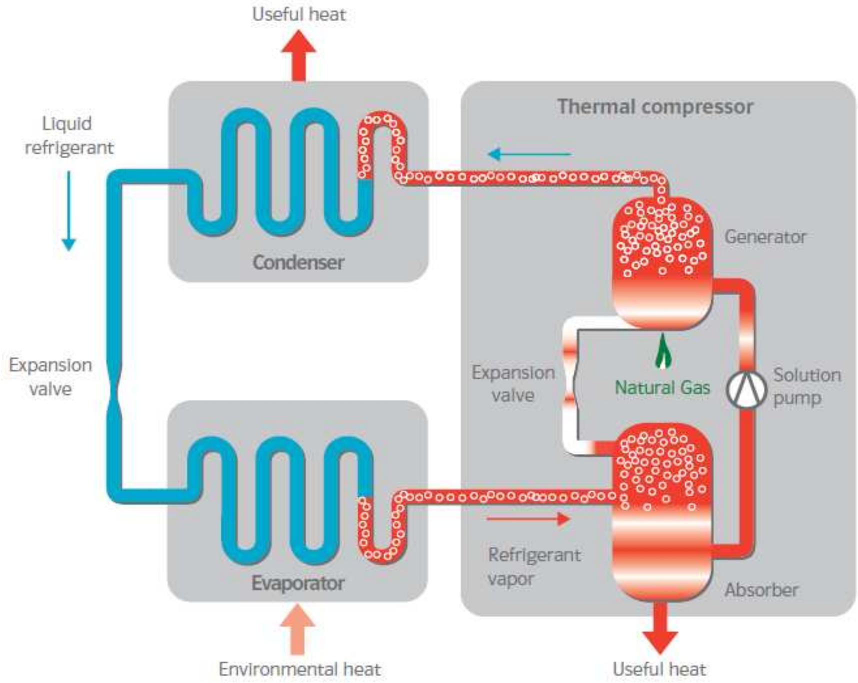
Absorption heat pumps for the residential sector are often gas-fired, which means that the thermal energy for the sorption process is delivered directly or indirectly by traditional heat generators; i.e. gas burners or condensing gas boilers.

[54] Wang, L.W., Wang, R.Z., Oliveira,R.G. (2009) A review on adsorption working pairs for refrigeration. Renewable and Sustainable Energy Reviews Vol. 13 pp. 518–534

[55] Meunier F. (2001) Adsorptive cooling: a clean technology. Clean Products and Processes. Vol.3 pp. 8–20

[56] International Energy Agency (IEA). Heat Pump Centre Newsletter. Volume 27 – No. 4/2009. Thermally driven heat pumps in future energy systems.

Figure 6-19: Diagram of a gas-fired absorption cycle[57]



Larger capacity thermally driven heat pump systems are available for commercial and industrial buildings. Compact devices with lower capacities and high efficiencies are still being developed and tested in many research projects and field test trials. There are no air-to-air gas absorption heat pumps available yet.

6.3.2.3 Recent refrigerant developments

The recently developed unsaturated HFCs (e.g. HFO-1234yf[58]) represent an alternative to HFC refrigerants with almost no environmental impacts. It has zero ozone depletion potential (ODP = 0) and an almost negligible global warming potential (GWP = 4). HFO-1234yf was intended as a replacement for R134A and offers comparable properties. It is slightly flammable, which means that it cannot be ignited under normal working conditions.

Originally developed for mobile air conditioning (MAC) industry, HFO-1234yf and its blends may represent candidates for replacing HFC refrigerants like R410A in stationary HVAC equipment such as heat pumps. The conditions and the technical barriers are being examined.

Another alternative refrigerant is R32, also called difluoromethane. R32 is an HFC single component refrigerant. It is commonly used as the primary composition of some mixed refrigerant gases such as R402. R32 has zero ozone depletion potential and its GWP100 is 650. In

[57] International Energy Agency (IEA). Heat Pump Centre. Volume 29 – No. 1/2011. Gas-driven sorption heat pumps; a potential trend-setting heating technology

some experimental tests R32 has shown a higher efficiency than R410A, and the refrigerant charge needed is lower than in the case of R410A.[59]

6.3.2.4 Compressors

- **Linear compressors**

Linear compressors are similar to reciprocating compressors (also called piston compressor), but use a linear motor to drive the compression piston instead of a standard rotating motor with a crankshaft. Linear motors can operate with variable stroke, allowing even better capacity modulation than recent compressor types. Also linear compressors have less friction loss and wear problems than conventional compressors. As linear compressors have already been commercialised for refrigerators, they represent a potential improvement option for heat pump technology as well. However, there are no linear compressors commercially available yet as they are still being evaluated and tested.[60]

- **Oil-free compressors**

As in heat pump systems the refrigerant gets compressed, inevitably coming into contact with the compressor's lubrication oil. If oil is carried out of the compressor to the evaporator or condenser, it may deteriorate the heat transfer and can lead to a decrease of efficiency. Oil-free compressors eliminate this problem by eliminating conventional lubricated bearings. In an oil-free compressor, the impellers and the rotating shaft form a single moving part that is suspended on magnetic bearings. With no mechanical bearings, oil-free compressors promise improved reliability and reduced maintenance.

- **Small radial compressors**

Radial micro-compressors are a futuristic compressor technology designed for domestic heat pump appliances, but could possibly be relevant for larger heat pump systems. They consist of a small scale radial impeller that rotates at very high speeds (up to 200,000 rpm). Small radial compressors are still in the testing phase, but promise significant performance improvements in the domestic heat pumps field by allowing the use of oil-free specific technologies in the heat pumps circuits and reaching very high compressor efficiencies (isentropic efficiencies up to 85%).[61]

---

[59] Taira Shigeharu, Yajima Ryuzaburo, Koyama Shigeru (2001) Applied technology of new refrigerants. The Performance Evaluation of Room Air Conditioner using R32 in the Case of Cooling and Heating Mode. Transactions of the Japan Society of Refrigerating and Air Conditioning Engineers Vol 18 N 3

[60] Xie et al. (2011) Study on characteristics of the linear air-conditioner compressor at varied operating conditions. Available at: http://www.scientific.net/AMR.201-203.632

[61] École Polytechnique Fédérale de Lausanne (EPFL) (2011) Oil-free domestic heat-pumps based on oil-free direct driven variable speed radial compressors. Available at: leni.epfl.ch/research/leniorc/Oil-free-domestic-heat-pumps-based-on-oil-free-direct-driven-variable-speed-radial-compressors

6.3.2.5 Other system improvements

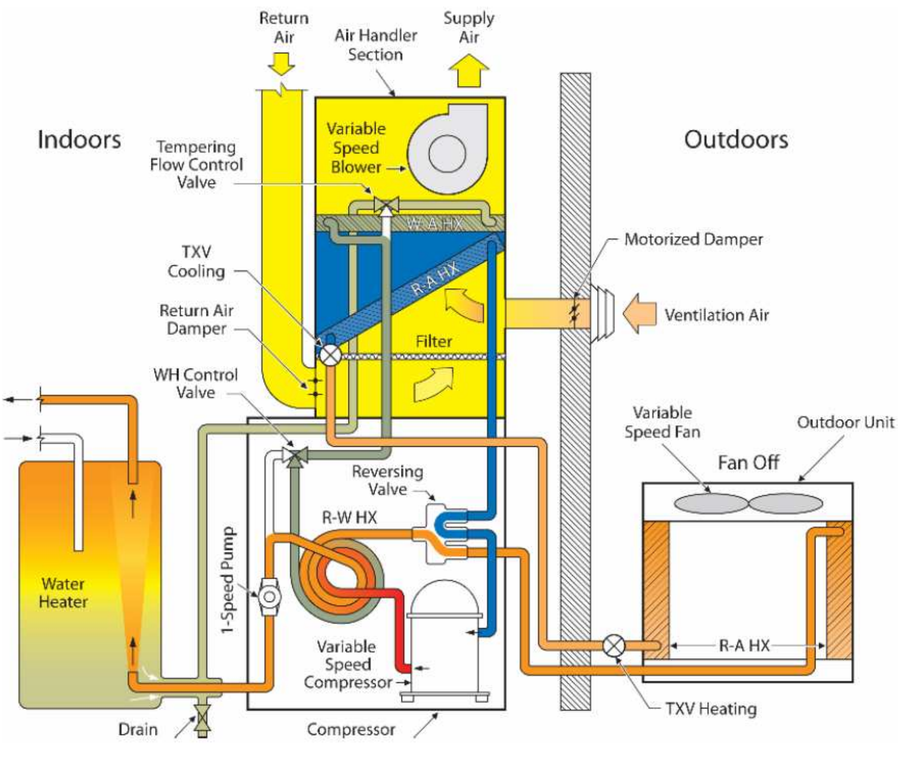
- **Integrated heat pump systems**

Integrated heat pump (IHP) systems combine multiple functions like space heating and cooling, water heating, dehumidification and ventilation. As hot water is usually needed throughout the whole year, a heat pump with integrated hot water heating can reach higher seasonal efficiencies than standalone heating/cooling heat pumps.

Air-source IHPs are being developed at the moment as a future heating and hot water heating alternative for low-energy and zero-energy buildings. As illustrated in Figure 6-20, first technical concepts use one variable-speed modulating compressor, two variable speed controlled fans, a single-speed circulator pump, and a total of four heat exchangers (two air-to-refrigerant, one water-to-refrigerant, and one air-to-water). A water heater tank is included for hot water storage.

First prototype test results have been used to set parameters of a heat pump model system simulations for 5 major climate zones, yielding a reduction of energy consumption in the range of 47% to 67% for the air-source IHP compared to a baseline system consisting of an air-source heat pump, a water heater, ventilation fan and dehumidifier. For the different climate zone, payback times range between 5-10 years for the air-source heat pump systems.[62] However, in the opinion of some stakeholders the future of such technology is limited due to its application.

Figure 6-20: Concept of an air-to-air integrated heat pump system[63]



[62] International Energy Agency (IEA). Heat Pump Programme (HPP) Annex 32, www.annex32.net

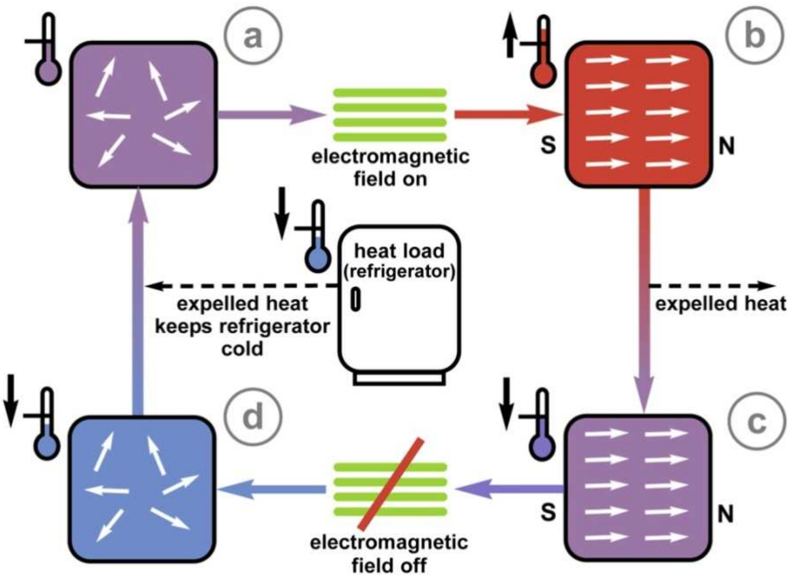
[63] Van D. Baxter, Dr. C. K. Rice, Dr. R. W. Murphy (2008) Small integrated heat pumps (IHP) for net zero energy homes (ZEH) - development status, Country report USA Task 2, Oak Ridge

Magnetic Refrigeration Cycle

The traditional compression/expansion cycle in heat pump technology utilises compression of a gas, extraction of heat, expansion of the gas, and injection of heat. The two processing steps, extraction of heat and expansion, are responsible for a cooling process in two steps. The main cooling usually occurs by the expansion of the gas. The magnetic refrigeration process works in an analogous manner. In Figure 6-21 one can see that instead of compression of a gas, a magneto caloric material is moved into a magnetic field and that instead of expansion, it is moved out of the field. The magneto caloric effect was discovered by Emil Gabriel Warburg in 1881 in an iron sample. When moved into a magnetic field, the iron heated a few millikelvins, and cooled down again when removed out of the magnetic field.[64]

Recently, various groups of scientists and physicists are working on implementing the magnetic refrigerant cycle in commercial refrigerators, air conditioning and heat pump appliances for space heating purposes.

Figure 6-21: Diagram of the magnetic heating/refrigeration cycle[65]



Solar thermal collectors

Solar thermal collectors consist in solar panels that use solar energy for space or water heating. Combined with an air-based heating system such as a heat pump, solar thermal collectors can represent an alternative method for central air heating. The solar thermal collectors preheat outside air before it is introduced into the building. This warm air can be directly distributed into the rooms, further heated in the building's primary heating system, or used as combustion air for warm air heaters.

Solar air heating systems contain special solar panel absorbers made of perforated dark metal claddings, usually made from unglazed corrugated aluminium. These absorbers are installed

[64] Egolf et al. (2008) An Introduction To Magnetic Refrigeration

[65] National Institute of Standards and Technology (NIST). Talbott. January 27, 2009. www.nist.gov/ncnr/refrigeration_012709.cfm

about 20 cm away from a south-facing building wall, which creates a small space between the facade and the building wall. Outside air is drawn in through the perforations in the panels by ventilation fans located at the top of the wall. Warmed by the solar panels, the trapped air rises to a plenum (duct) at the top of the wall; from there it is routed to the nearest dedicated ventilation fan or HVAC system. In high temperature times, the solar panel absorbers can be bypassed, to avoid overheating. Typical solar air heating systems can produce 500 to 700 kWh of thermal energy per meter of solar cladding per year, depending on the solar irradiation.[66]

Additionally the solar panels reduce heat loss over the building shell, especially at night, and lower the radiation heat gain into the building in summer.

- **Dual fuelling heat pumps (hybrid)**

When ground source heat pumps are adopted, the installation cost (i.e. drilling) and/or space limitation can have a negative impact, affecting the competitiveness and performance of the system. Imbalance of the heat rejection or heat extraction from the ground can result into changing of the ground temperature with time and hence deteriorating the performance of the system. A way of overcoming the problem is the introduction of a second heat source such as air. The use of a second heat source would allow for the optimisation of the system and a better performance during intermediate periods, where the ground water heat pumps are less efficient. According to some research carried out for the optimisation of such hybrid systems, heating COP and SCOP values are typically higher compared with air-source heat pump systems, with further room for improvement.[67,68]

- **Correct sizing**

The European climate shows great variation. This is one of the common problems HVAC designers face, and the incorrect sizing of heating and cooling systems is one of the major issues of energy efficiency in buildings.

On the other hand, heat pumps are designed and manufactured to operate at certain heating capacity ranges, and are usually optimised for the lower end of each range. Thus, the efficiency at full load of a unit decreases when it is used for the higher capacities of the range it is designed for. This difference in capacity can be up to 30% of the COP from the lower end to the higher end of the capacity ranges. Nonetheless, in the case of variable capacity heat pumps, the seasonal performance of the product is not affected as much as in on/off heat pumps.

- **Heat recovery ventilation**

Heat recovery systems use counter current heat exchange between the exhaust air stream and the supply air stream. This leads to energy savings, reduction of heat losses and increase of ventilation cost-effectiveness. Heat recovery ventilation captures 60-80%[69] of the heat in the air

---

[66] www.solarwall.com/en/home.php

[67] Lubis L.I. *et al* (2011) Thermodynamic analysis of a hybrid geothermal heat pump system. Geothermics 40 , pp. 233-238

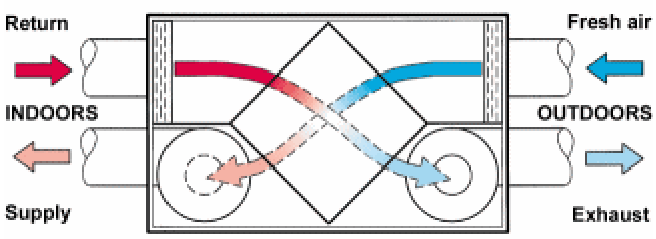
[68] Nam Y., Ooka R., Shiba Y. (2010) Development of dual-source hybrid heat pump system using groundwater and air. Energy and Buildings 42, pp. 909-916

[69] www.toolbase.org/TechInventory/techDetails.aspx?ContentDetailID=748

to use them as heating, which would otherwise be lost. For reduction of humidification costs some heat exchangers are able to recover moisture during the winter.

The typical unit consists of highly efficient supply and extraction air fans, and a heat exchange with up to 99%[70] efficiency. This kind of system is especially appropriate for well-insulated low energy houses where there is a need for ventilation. Due to the nature of the system, it is useful mainly in buildings, where a ventilation system it is used. Heat recovery ventilation can be also useful, when there is a need for cooling and heating of different rooms/parts of the buildings simultaneously.

Figure 6-22. Heat recovery ventilation[71]



The mode of operation is presented in Figure 6-22. Outdoor fresh air passes through the heat exchanger where it is warmed (cooled for air conditioning) and distributed to the rooms by a ducts system or directly emitted to a room. The stale air goes through the exhaust ducts and pre-conditions the incoming air.

- **No defrost**

For air source heat-pumps, defrosting is a necessary function with current technologies. If the outdoor temperature falls near or below the freezing point, the moisture of the air will condensate and freeze on the heat exchanger. This decreases the efficiency of the heat exchanger and the frost has to be removed by a defrost cycle. Defrost cycles increase energy consumption and lower the efficiency of the heat pumps, since it is achieved by reversing the system or by means of electrical heating. The reduction of energy consumption and the need for defrost cycles might be one of the important developments in the future for heat pumps. According to some stakeholders, the overall energy gains would be around 20-30%.

However, the potential of this hypothetical improvement option would not be reflected in terms of energy efficiency parameters, such as COP or SCOP, which are based on heating capacity and power input of the heat pump at different conditions. Therefore, different analysis and policy options should be foreseen in order to allow the development of this type of options in the future.

[70] www.paulventilation.co.uk/

[71] Air Infiltration and Ventilation Centre; www.aivc.org/frameset/frameset.html?../Publications/Vips/vip06.htm~mainFrame

6.3.3 Summary of improvement options

In the following section the best available technology options at component level are summarised for each Base-Case of Lot 21 air based central heating products. Additionally, the efficiency improvement of each BAT option is quantified compared to the Base-Case. The basis for this comparison exercise is the current technology used in the Base-Case and the current product prices. These prices might be subject to change in the future due to economies of scale from mass production of new products and technologies.

Table 6—5: Summary of improvement options for BC1A: residential warm air central heating

	Residential warm air heater				
Improvement options for indirect-fired gas warm air heaters	**Electricity consumption change [%]**	**Thermal efficiency change [%]**	**Annual fuel savings [%]**	**Annual fuel savings [kWh]**	**Consumer price increase**
Electric ignition device	0%	0%	2%	780	€ 200
DC variable speed fan for controlling hot air flow	-33%	N/A	N/A	N/A	€ 80 to € 100[72]
High efficiency condensing furnace: Primary and secondary heat exchanger and electric ignition device	0%	+ 16%	17%	8,250	€ 500[73]
Continuous modulating burner	0%	N/A	9%	4,100	€ 450 to € 750; Maintenance costs from 10% to 25% higher[73]

[72] DG ENER Lot 10 Preparatory study on residential air conditioning and ventilation

Table 6—6: Summary of improvement options for BC1B: non-residential warm air central heating

	Non-residential warm air heater				
Improvement options for indirect-fired gas warm air heaters	**Electricity consumption change [%]**	**Thermal efficiency change [%]**	**Annual fuel savings [%]**	**Annual fuel savings [kWh]**	**Consumer price increase**
Electric ignition device	0%	0%	1%	1,600	€ 200
DC variable speed fan for controlling hot air flow	- 33%	N/A	N/A	N/A	€ 80 to € 100
High efficiency condensing furnace: Primary and secondary heat exchanger and electric ignition device	0%	+ 16%	17%	35,300	€ 600
Continuous modulating burner	0%	N/A	8%	16,900	€ 2,200 to € 3,700; Maintenance costs from 10% to 25% higher
Thermostat and damper control: control the temperature in the room and the warm air flow	0%	N/A	13%	28,300	€ 20 to € 100

Table 6—7: Summary of improvement options for BC2: single split heat pumps

	Single split			
Improvement options	Electricity consumption change [%]	Efficiency change (COP) [%]	Efficiency change (SCOP) [%]	Consumer price change [€]
Increased heat exchanger surface in outdoor unit	- 7% to - 10%	+ 8% to 11%	+6%	+ € 120
Micro-channel heat exchanger in indoor unit(s)	- 9%	+ 10%[73]	+7%	+ € 0[73]
Increased heat exchanger surface in indoor unit(s)	- 7% to - 10%	+ 8% to 11%	+6%	+ € 120
Noise reduction	+ 30%	- 23%	-21.5%	€ 0[73]
Reduce crankcase heater time	Less than - 1.8%[74]	NA	+1.2%	€ 0
Improved electronic expansion valve control	- 5% to - 7%	+ 5% to 7%	+4%	€ 0[73]
Refrigerant R134a and 25% increase of over all unit	0	0	0	Up to +40%
Refrigerant R290	- 5%	+ 5%	+3%	+ € 40 to € 200
Refrigerant R32	-10%	10%	+10.1%	Up to +16%

[73] Source: Stakeholders' comments

[74] Source: own estimate based on Base-Case inputs and prEN 14825 working hours

Table 6—8: Summary of improvement options for BC3: VRF heat pumps

	VRF			
Improvement options	Electricity consumption change [%]	Efficiency change (COP) [%]	Efficiency change (SCOP) [%]	Consumer price change [€]
Increased heat exchanger surface in outdoor unit	- 7% to - 10%	+ 8 to 11%	+6%	+ € 400
Micro-channel heat exchanger in indoor unit(s)	- 9%	+ 10%[73]	+6%	+ € 0[73]
Increased heat exchanger surface in the indoor unit	- 7% to - 10%	+ 8 to 11%	+6%	+ € 400
Noise reduction	+ 30%	- 23%	-21.5	+ € 0
Reduce crankcase heater time	Less than - 0.7%[74]	NA	+0.6%	+ € 0
Refrigerant R134a and 25% increase of unit	0	0	0	Up to +40%
Refrigerant R744	+20% / 0%[75]	0	0	+ 100%
Refrigerant R32	-10%	10%	+10.1%	Up to +16%

75

6.4 Conclusion

In this report, best-available-technologies (BAT) and best-not-yet-available (BNAT) technologies for central heating products that use hot air to distribute heat have been analysed and described. As the main environmental impacts of such products are caused by high energy consumption, new technologies (at product and component level) were analysed that could possibly reduce the products' environmental impacts, especially the impacts related to energy consumption.

Especially for air-to-air heat pumps there are several research activities being conducted to examine future product technologies and components. Alternative refrigerant heat pumps (like CO_2 or propane driven systems) represent promising technologies to lower the impact of greenhouses gases, while on the component level, manufacturers and research institutes are mainly working on compressor technology, heat exchanger design and sophisticated control strategies.

The greatest barriers for highly efficient air-based central heating products like sophisticated air-to-air heat pump systems are high initial capital costs - even though they may be cheaper to run on a lifetime basis.[76] These barriers can be overcome by raising consumer awareness of the often lower life cycle costs as well as introducing supporting financing mechanisms.

Other air-based central heating products like forced-warm air heaters mainly benefit from recent component developments like efficient condensing burner technology, capacity controls and smart controls. In warm air heaters, the fans, motors and controls consume auxiliary energy in the form of electricity. Some of these components can also be improved to reduce their energy consumption. However, the share of the electricity consumption in relation to the total annual energy consumption of the product is very low, as shown in the Task 5 of this preparatory study.

As the amount of raw materials used in warm air heaters contributes to significant environmental impacts, various material efficiency design options were considered. Manufacturers claim that the scope for using less material is limited without compromising the performance and durability of their products. Besides changing to a less harmful refrigerant, some of the energy efficiency improvement options identified are also material efficient as they replace some materials with materials that have lower environmental impacts.

In Task 7, the different design options presented in this task will be analysed in terms of environmental impacts and life cycle costs. This analysis will help to select the best improvement options regarding their environmental benefits and the consumer expenditure through the product's life cycle.

[76] International Energy Agency (IEA) (2010) Heat Pump Centre Newsletter, Vol. 28 – No. 3/2010.

09 July 2012

20-22 Villa Deshayes
75014 Paris

+ 33 (0) 1 53 90 11 80

biois.com