DAIKIN altherma

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Daikin Altherma Hybrid heat pump systems

- X Environmentally friendly
- X Flexible in use
- X Affordable renewable energy

… A POWERFUL TOOL TO CONTRIBUTE TO THE 20/20/20-TARGETS

The Daikin Altherma hybrid heat pump: a heating solution that maximises environmental friendliness and cost-effectiveness

Daikin Altherma hybrid heat pump technology:

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replacing the combustion boiler with affordable renewable heating in dwellings

Since 40% of all primary energy use in the EU can be assigned to buildings (of which 70% is used for space heating and the production of domestic hot water), and since the renovation market represents over 85% of the total market, replacing combustion boilers with hybrid heat pumps might be the holy grail of cost-efficient solutions for providing renewable energy.

A hybrid heat pump pairs a heat pump with a gas condensing boiler, both of which can be employed to provide the necessary space heating of a house. Depending on the required set flow temperature and the outdoor temperature, the appliance can operate in boiler only mode, hybrid mode (in which the boiler and the heat pump work together) or heat pump only mode. The appliance is designed to minimise energy costs, taking into account energy prices or primary energy use, depending on the user's preferences. The benefits arising from these energy savings make a hybrid heat pump an ideal solution for the replacement of combustion boilers in dwellings.

The hybrid is highly flexible, both towards the type of building and the type of emitters (both underfloor heating and radiators are possible). It is also highly environmentally friendly and can reduce CO_2 emissions at a lower investment cost than other existing renewable technologies. As further explained, the hybrid can be considered a very cost-efficient solution to contribute to the EU's "20-20-20" targets.

Also the hybrid is featured by a state-of-the-art design that optimises efficiency, compactness and noise. It allows for both easy operation and energy monitoring.

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1

Benefits of the use of a hybrid heat pump

1.1. Environmental benefits: savings in CO_2 emissions and primary energy use with respect to EU 20-20-20

In the EU about 40% of all primary energy use can be assigned to buildings, of which residential houses constitute a vast majority. In these dwellings, the energy use for space heating and hot water production accounts for 70%. Because the majority of all homes in the EU is still being heated by fossil fuels, a changeover to a domestic renewable heating system that reduces primary energy consumption and CO_2 emissions could drastically contribute to the EU's 20-20-20 objectives, i.e. a 20% reduction in the EU's greenhouse gas emissions compared to 1990 levels, an increase in the share of renewable energy in the final EU energy consumption to 20%, and a 20% reduction in the EU's primary energy use (EU Directive for Renewable Energy, Directive 2009/28/EC).

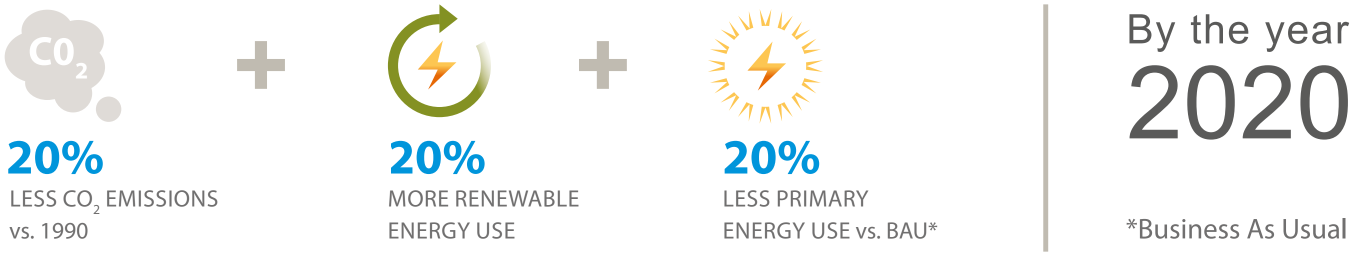


Figure 1: Illustration of EU's 20-20-20 objectives.

Air source heat pumps (ASHPs) have become a well-established renewable technology for the heating and cooling of buildings. Throughout the years, their design has been optimised in order to increase efficiency (and lower electricity consumption) and the refrigerants being used have been replaced by substitutes, which are - thanks to their lower Global Warming Potential (GWP) - more environmentally friendly. Because ASHPs use air, they can be used as a renewable heating source. The major drawback of ASHPs, however, is that their efficiency decreases at higher flow temperatures: more power is required for a certain heating output, resulting in a lower coefficient of performance (COP) and a higher energy bill. Higher flow temperatures are needed if radiators are used in the house as heat emitters. Combining heat pumps with condensing gas boilers, hybrid heat pumps provide a solution for this.

1.2. Savings in running costs due to intelligent switching between heat pump mode, hybrid mode and boiler operation

The Daikin Altherma Hybrid heat pump meets the 3 basic requirements of the 20-20-20 directive:

1. **Less CO_2 emissions**: The hybrid saves on CO_2 emissions in case the CO_2 emission of the gas boiler exceeds the CO_2 emission of the heat pump.

› CO_2 emission of gas boiler: $\frac{\text{emission rate of gas}}{\eta}$

- η = efficiency of the boiler [-]
- Emission rate of gas [kg CO_2/kWh] (this is the amount of CO_2 emitted per kWh of burned gas) e.g. 180~0,230 kg CO_2/kWh for natural gas

› CO_2-emission of the heat pump: $\frac{\text{emission rate of the electricity grid}}{\text{COP}}$

- Emission rate of the electricity grid = the amount of CO_{2e} emitted per kWh produced electricity [kg $C0_{2e}$/kWh]. A typical value is 0,5 kg $C0_{2e}$/kWh, but this depends on the electricity production mix and also varies in time.
- COP = Coefficient Of Performance (efficiency of the heat pump) [-]

The example below reveals the CO_2 emissions savings if for a home with an annual gas consumption of 20.000 kWh the condensing gas boiler would be replaced by a hybrid heat pump. The assumptions are the direct result from a specific field test measurement.

- Condensing gas boiler: 4.444 kg $C0_2$
- Daikin Altherma Hybrid heat pump: 3.449 kg $C0_2$

This represents a saving of almost 1.000 kg CO_2 on an annual basis for one specific home, or a saving of more than 22%.

2. **More renewable energy use**: When the hybrid operates in heat pump or in hybrid mode, the heat pump uses air as a renewable energy resource and hence provides renewable energy.

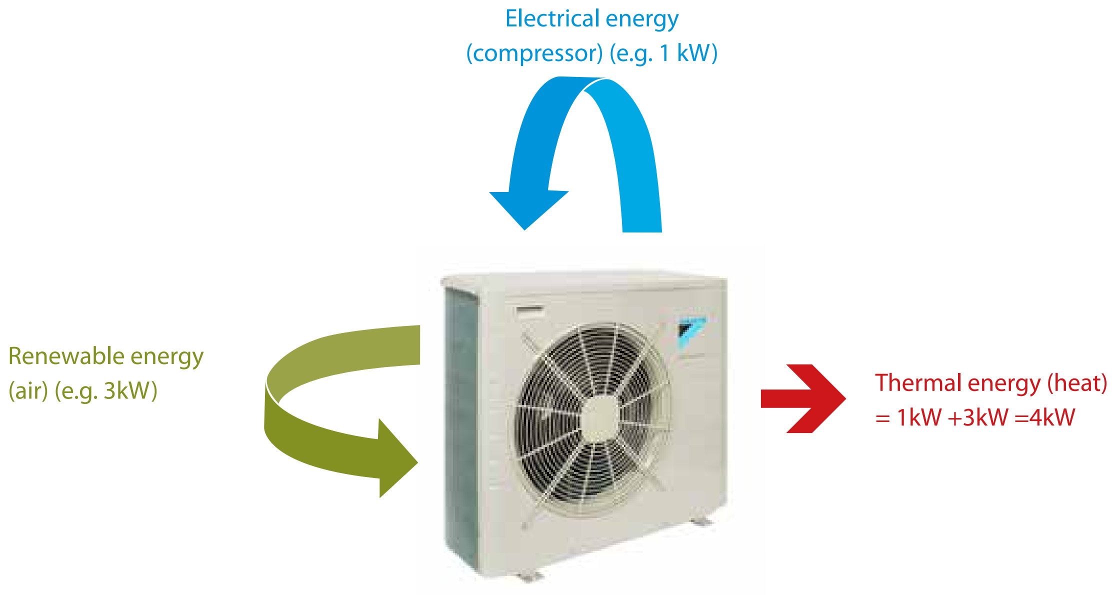
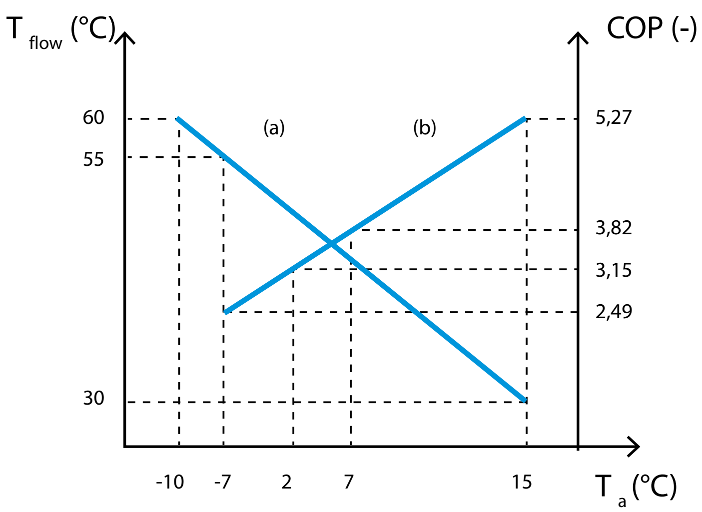


Figure 2: Illustration of how a heat pump uses air as a renewable energy source to provide heat (note that for this example the COP of the heat pump equals the thermal energy output (4kW) over the electrical input (1kW) and is hence equal to 4.

3. **Less primary energy use vs. BAU (Business As Usual):** The Primary Energy Seasonal COP (PE-sCOP) measures how much primary energy is used to obtain a certain amount of heating output during a heating season. Figure 19 shows the result of a specific simulation, revealing that the Daikin Altherma hybrid heat pump reached a PE-sCOP of 1,2 ~1,5, whereas the condensing gas boiler only reached 0,88 ~ 0,98.

   The Daikin Altherma hybrid heat pump avoids running at low COPs by switching over to hybrid heating mode, in which the heat pump is assisted by a condensing gas boiler to deliver the required amount of heating. Even at lower ambient temperatures, the unit finally switches to a mode in which the condensing gas boiler takes over the entire heat load. The working principle of the hybrid technology and the points at which the Daikin Altherma hybrid heat pump switches from one mode to another are elaborated in more detail in the second section of this document.



Legend:
- T_{flow} = Flow temperature (°C), i.e. the temperature to which the system is heating the water
- T_a = Ambient temperature (outdoor temperature, (°C))
- COP = Coefficient Of Performance (heating output / Power input)

Figure 3: Typical heat pump characteristics showing (a): A weather-dependent set point curve (the required flow temperature T_{flow} [°C] as a function of the ambient temperature T_a [°C]) and (b): A typical COP curve (the obtained COP [-] as a function of the ambient temperature T_a [°C]).

1.3. Flexibility in use with respect to both the heating system and the age/insulation quality of the building

Daikin Altherma hybrid heat pump is flexible towards both the type of building in which it is installed and the heat emitter type used. Because it combines the technology of a gas condensing boiler with an air source heat pump, it can be installed in any building, regardless of the year it was built or the quality of the insulation. Furthermore, the Daikin Altherma hybrid heat pump can produce water flow temperatures ranging from 25°C to up to 80°C, making it suitable for use in dwellings with any type of heat emitter, including fan coils, underfloor heating and radiators. The hybrid can be used in any climate, with any type of heat emitter, and in any type of house.

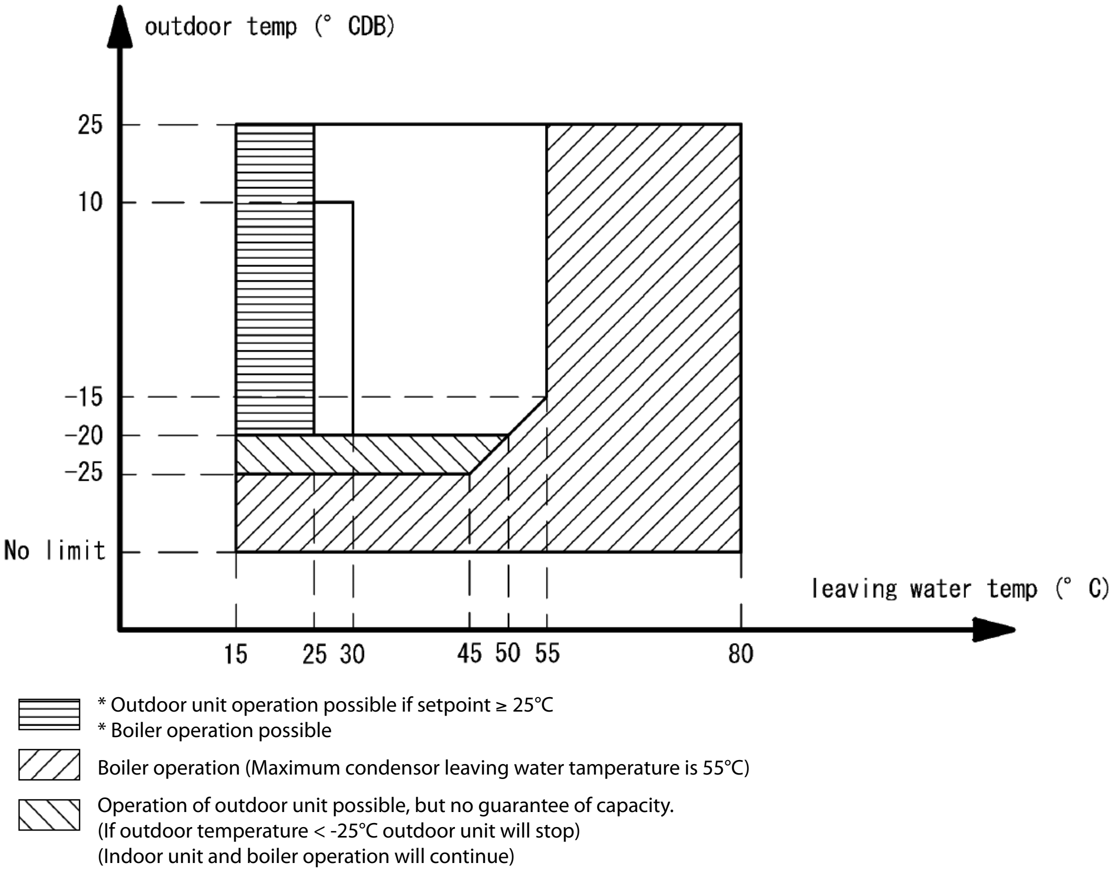


Figure 4: Daikin Altherma HYBRID heat pump operating range, for the hybrid operating in heating mode.

Figure 4 shows the operating range for the Daikin Altherma hybrid heat pump operating in heating mode. Depending on the value of the outdoor temperature (°C DB) and the Leaving Water Temperature (LWT, °C), four zones can be distinguished:

1. A pull up area (for which the heat pump is not dimensioned to operate), but if leaving water temperatures are too cold, it can still start and pull up the leaving water temperature to normal operating values and continue normal operation);
2. A boiler operation zone, with LWT down to 15°C for screed dry-out;
3. A boiler operation zone;
4. A heat pump operation zone (in this zone both the heat pump and/or the boiler can operate) .

2

Principles

of hybrid operation

The Daikin Altherma hybrid heat pump continuously monitors system parameters and temperatures. It maximises system efficiency in real-time and operates the system in the most efficient way at all times. Four different operation modes for space heating are embedded.

2.1. Distinction of different modes of operation

Four different modes of operation can be distinguished:

1. Heat pump only operation mode;
2. First hybrid operation mode;
3. Second hybrid operation mode;
4. Boiler only operation mode.

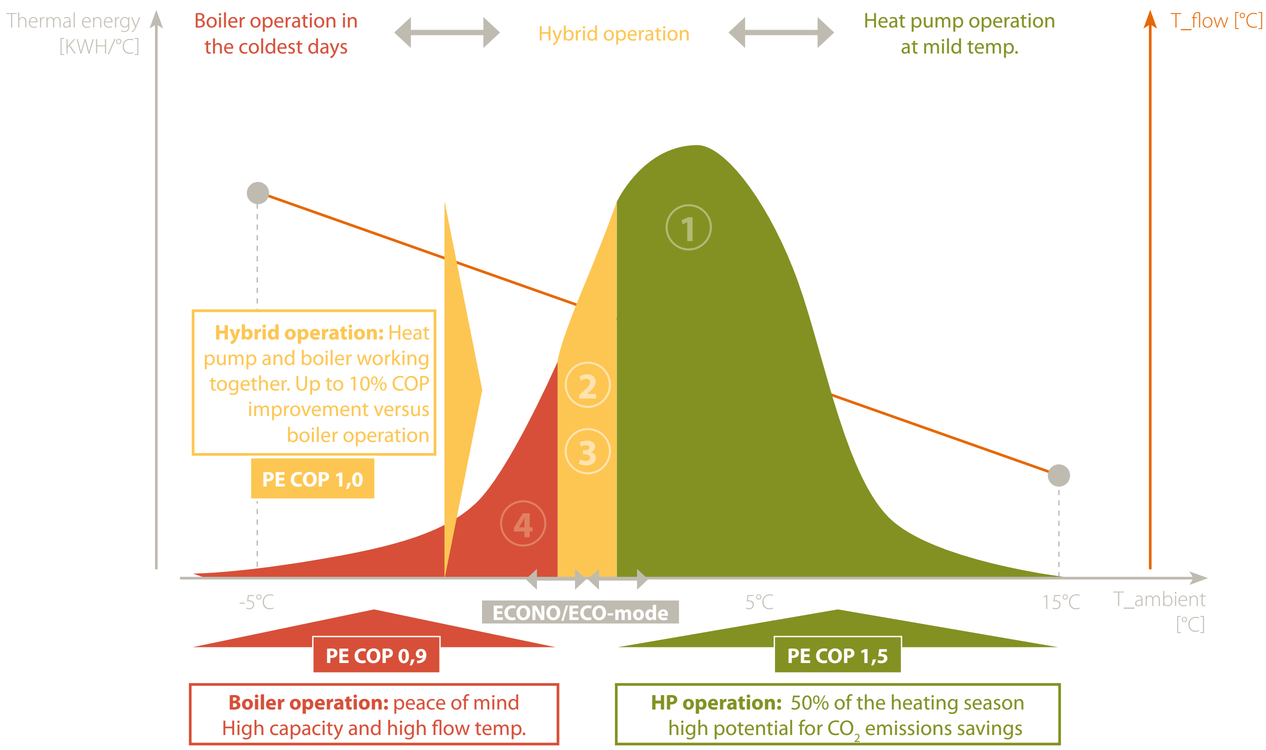


Figure 5: Distinction of the four different modes of operation, also showing the thermal energy [kWh/°C] and flow temperature T_{flow} as a function of the ambient temperature $T_{ambient}$.

Legend:

- Thermal energy [kWh/°C]: the amount of thermal output [kWh] the Daikin Altherma hybrid heat pump generates at a certain ambient temperature.
- PE COP [-] : Primary Energy COP: Indicates how much thermal energy output can be generated by making use of 1 unit of primary energy input.
- T_{flow}: The flow temperature, i.e. the temperature [°C] at which the water leaves the Daikin Altherma hybrid heat pump.
- HP = heat pump

The user can choose whether switching between operation modes is either economically ("ECONO-mode") or ecologically ("ECO-mode") optimised. In "ECONO-mode", the system will in all operating conditions select the energy source (gas or electricity) based on the active energy cost. In "ECO-mode", the heat source will be selected based on ecological parameters (minimisation of primary energy).

2.2. Determination of the set flow temperature and calculation of the Break-even COP

The break-even COP is required to determine the operation mode of the hybrid.

A temperature sensor measures the ambient temperature T_a (outdoor temperature), out of which the required set flow temperature (T_{flow}) is calculated. To achieve this, the installer defines the weather-dependent set point curve in the system. To heat the house to a comfortable temperature, this curve defines the required leaving water temperature for each outdoor temperature (see Figure 6). Based on heat pump characteristics the system will then calculate in real-time both the heat pump efficiency (COPSet Flow Temperature) and the required leaving water temperature.

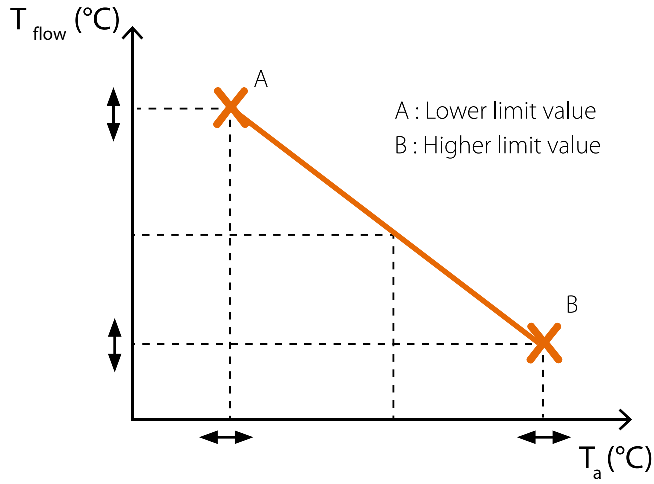


Figure 6: Weather dependence curve: by fixing two points (to both of which the installer assigns a value for T_{flow} [°C] and T_a [°C] (outdoor temperature)), the required leaving water temperature for each outdoor temperature is defined.

In ECONO-mode: When the heat pump operates at the break-even COP, the cost of 1 kWh thermal output produced by the heat pump is equal to the cost of 1 kWh thermal output produced by the boiler. The break-even COP is dependent on the electricity price [€/kWh], the gas price [€/kWh] and the boiler's thermal efficiency [%] (considered as a fixed value, independent of flow temperature, return temperature and ambient temperature). The energy prices are set by the user or installer and can be adjusted.

$$COP_{\text{Break-even, ECONO}} = \frac{\text{Electricity price} \left[\frac{€}{kWh}\right] \times \eta_{boiler} [-]}{\text{Gas price} \left[\frac{€}{kWh}\right]}$$

In ECO-mode: When the heat pump operates at the break-even COP, the pimary energy use to produce 1 kWh thermal output by the heat pump is equal to the primary energy use to produce 1 kWh thermal output by the boiler. The break-even COP is dependent on the Primary Energy coefficient (the amount of primary energy input that is needed to generate a kWh of electricity, here assumed to be 2,5) and the boiler's thermal efficiency.

$$COP_{\text{Break-even, ECO}} = \text{Primary Energy coefficient} [-] \times \eta_{boiler} [-]$$

2.3. Mode 1: Heat pump only operation mode

When the efficiency of the heat pump is high enough to realise economical or ecological savings for the user, the Daikin Altherma hybrid heat pump will operate in heat pump only mode. More specifically, this happens if COPSetFlowTemperature (the COP that is obtained if the working fluid is entirely heated by the heat pump, from the return temperature to the set point temperature) is higher than COPBreak-even (see formula above) and if the heat pump is capable of delivering the required heating capacity. This will typically occur at mild temperatures.

The boiler is not operated unless domestic hot water production is required.

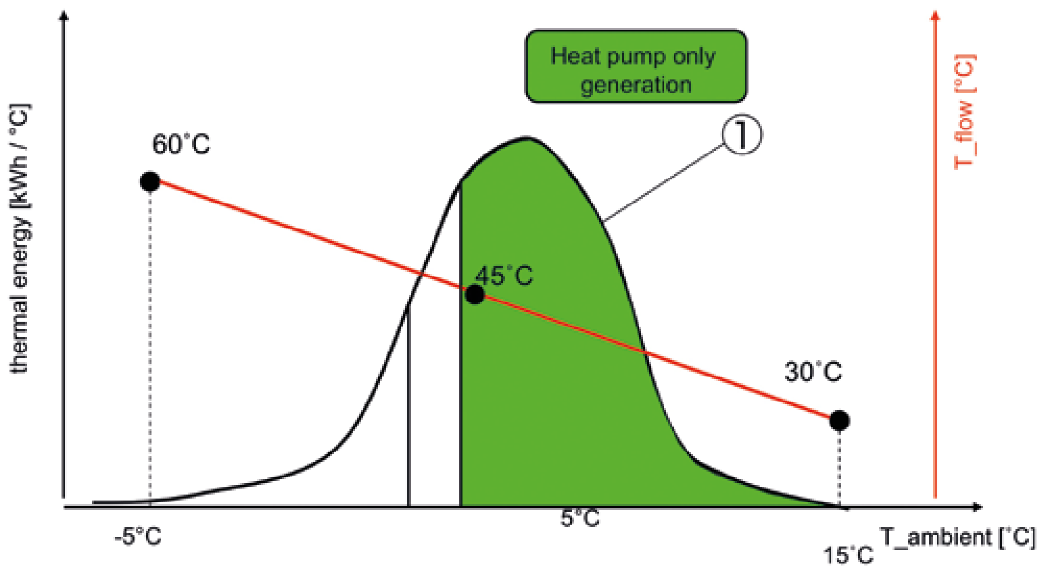


Figure 7: Heating degree curve where the active mode is heat pump only operation mode.

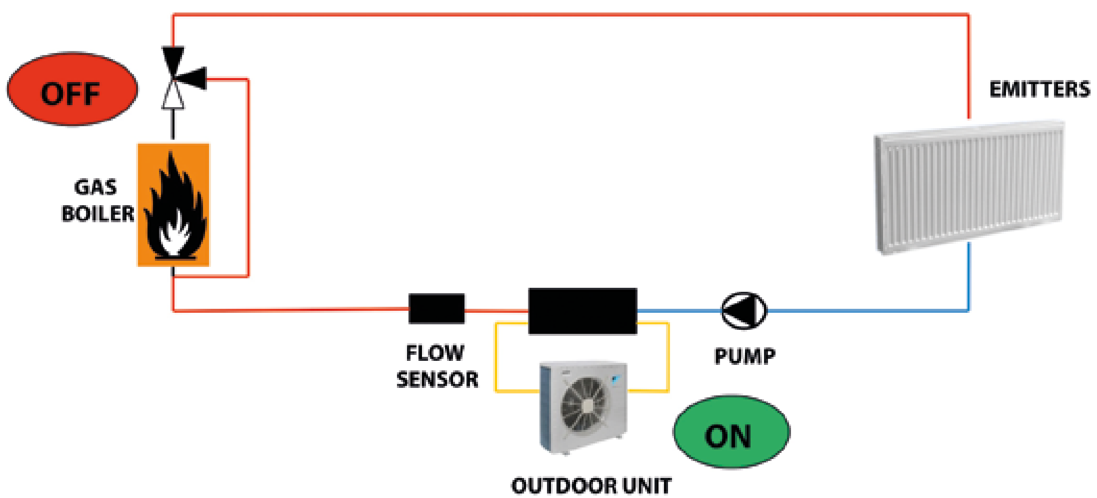


Figure 8: Illustration of the flow pattern in heat pump only operation mode.

2.4. Mode 2: Hybrid operation mode (patented technology)

If $COP_{Heat\ Pump}$ is lower than $COP_{Break\text{-}even}$, a conventional bivalent heating system will immediately switch entirely to boiler only mode. This is one point where the Daikin Altherma hybrid heat pump differentiates itself from a bivalent heating system.

The hybrid's software calculates the flow temperature at which the heat pump's COP would equal the break-even COP. If such an intermediate flow temperature exists (i.e. the temperature at the point between the first heat pump heat exchanger and the second boiler heat exchanger – at the exit of the first heat exchanger), both the heat pump and the gas condensing boiler will operate in hybrid operation mode. The temperature after the first heat exchanger (heat pump) will equal the intermediate flow temperature. The temperature after the second heat exchanger (boiler) will equal the set flow temperature. If such an intermediate flow temperature does not exist, the working fluid is heated entirely – from the return temperature to the set flow temperature – by the gas condensing boiler (see previous section).

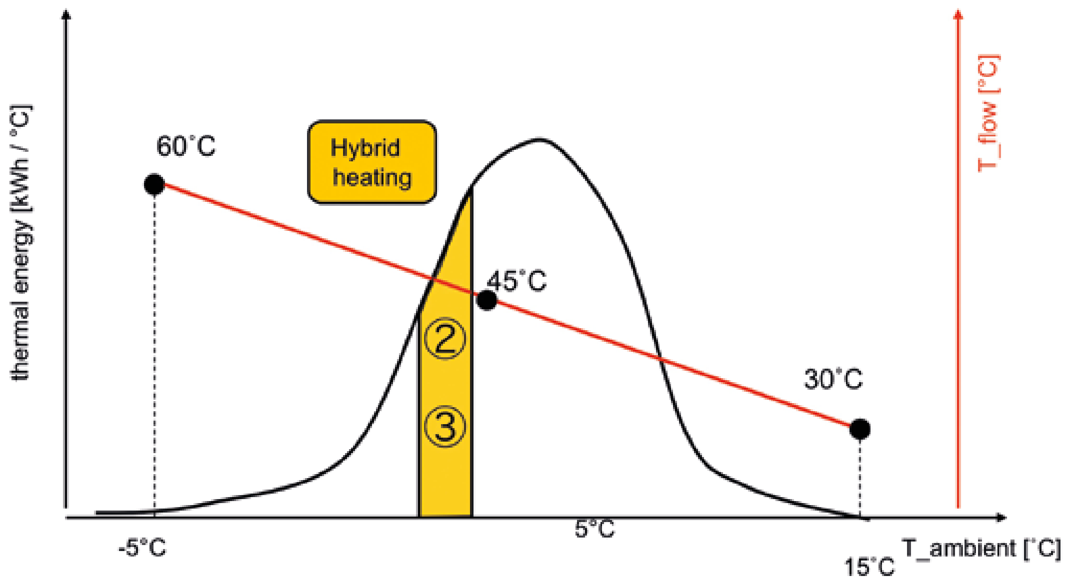


Figure 9: Heating degree curve where the active mode is (first or second) hybrid heating mode, in which both the gas condensing boiler and the heat pump are active.

During hybrid operation mode, the heat pump heats the working fluid from the return temperature to an intermediate flow temperature, after which the gas boiler takes over, heating the fluid to the set point temperature. The Daikin Altherma hybrid heat pump is thus operating in so-called hybrid mode.

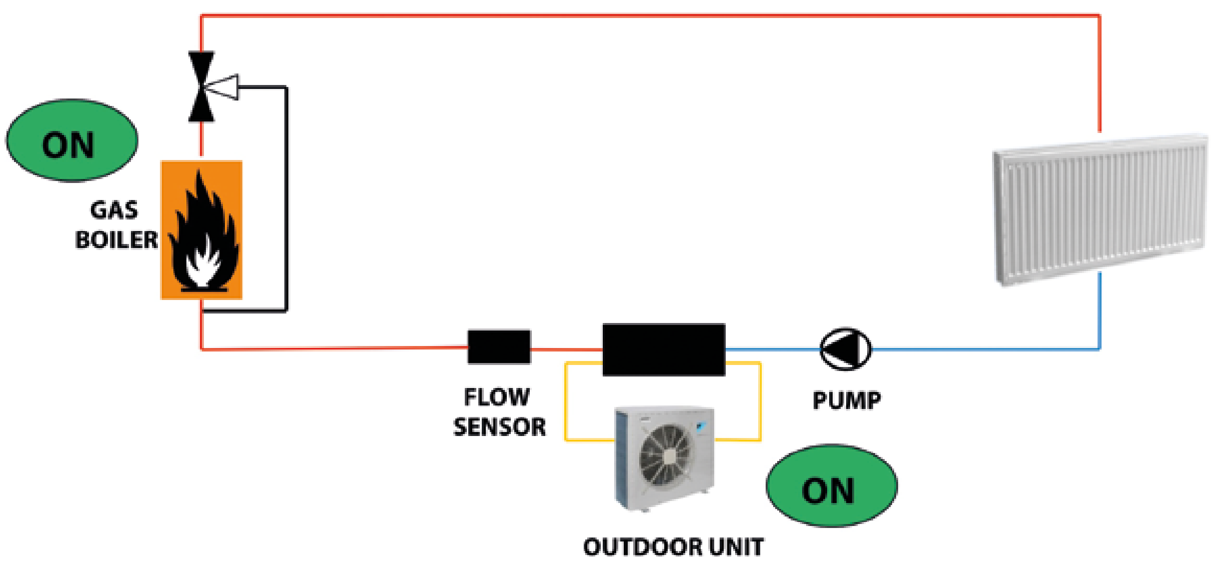


Figure 10: Illustration of the flow pattern in hybrid operation mode.

Extra increase of the heat proportion provided by the heat pump during hybrid mode

In order to further increase the proportion of the heat load provided by the heat pump in first hybrid mode, a flow control function is added. The hybrid heat pump is able to control a variable flow pump and to reduce the flow rate of the working fluid. During hybrid operation, the heat pump will work at a reduced flow rate. This makes it possible to further decrease the intermediate flow temperature, so that $COP_{Intermediate\ Flow\ Temperature} > COP_{Break\text{-}even}$. The temperature difference (and accordingly the heat load provided by the heat pump) increases. This way, the proportion of heat provided by the heat pump can be optimised, dependent on the customer's preferences either to increase cost-effectiveness (economical mode) or environmental friendliness (ecological mode).

However, if the return temperature is decreased, the temperature of the emitting section (the average temperature of the incoming and outgoing working fluid) is lowered, which decreases the heating capacity. To compensate for the loss of heating capacity, the set flow temperature is increased. This is done stepwise with a certain time interval, so that the time to reach the required emission capacity is extended. Hence the return temperature can be kept lower during a longer time interval and the proportion of heat provided by the heat pump (which decreases with an increasing set flow temperature because increasing the set flow temperature increases the return temperature) can be maximised during a longer period of time.

2.5. Mode 3: Hybrid operation mode in case of capacity shortage

If $COP_{Heat\ pump} > COP_{Break\text{-}even}$, use of the heat pump is preferred over use of the gas condensing boiler. If, however, the heat pump is not capable of delivering the required capacity, the control is configured to operate the Daikin Altherma hybrid heat pump in hybrid mode, wherein the heat pump heats the working fluid as much as possible under full load and the gas boiler provides the remaining heat load (the above pictures, Figure 9 and Figure 10 still apply).

2.6. Mode 4: Boiler only operation mode

In case the efficiency of the heat pump is too low to realise economical or ecological savings for the user, the Daikin Altherma hybrid heat pump will operate in boiler only mode. More specifically, this happens if $COP_{Heat\ Pump}$ (the COP that is obtained if the working fluid is entirely heated by the heat pump, from the return temperature to the set point temperature) is lower than $COP_{Break\text{-}even}$ (see formula above) and if no intermediate flow temperature exists at which the heat pump's COP equals the break-even COP (because then the hybrid will operate in Mode 2, as previously mentioned).

The heat for space heating is then only provided by the boiler and the heat pump is not operating. This will typically occur when ambient temperatures are low.

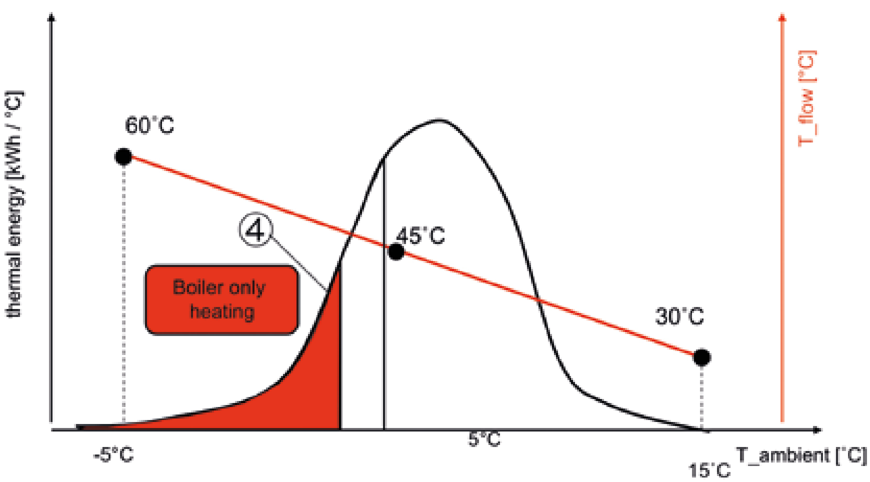


Figure 11: Heating degree curve where the active mode is gas boiler only operation mode.

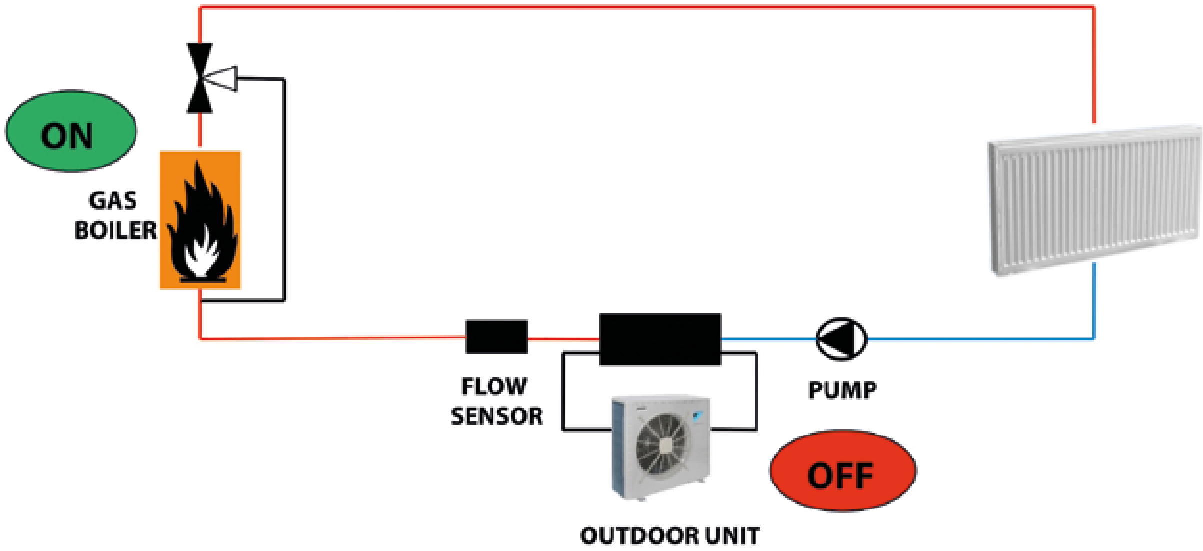


Figure 12: Illustration of the flow pattern in boiler only operation mode

2.7. Domestic hot water operation

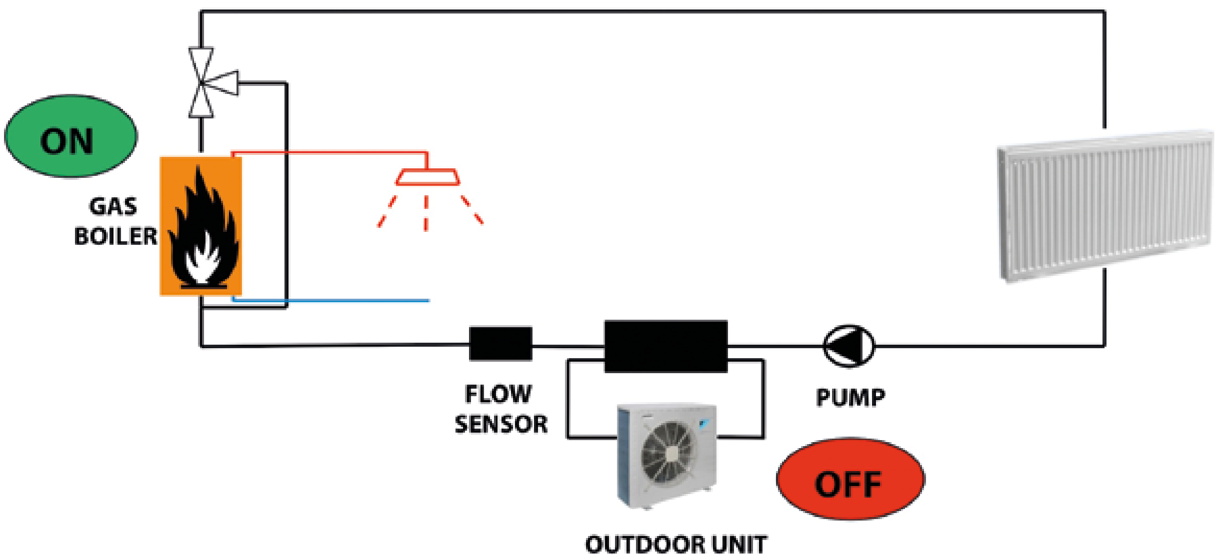


Figure 13: Illustration of the flow pattern in domestic hot water operation mode

If domestic hot water (DHW) production is required, the control operates the burner and DHW is instantly produced. If a domestic hot water storage tank is connected, heat exchange with this tank is performed.

The heat demand for domestic hot water is entirely covered by the boiler. When a space heating demand simultaneously occurs, it will be answered by the heat pump. Next to hybrid mode (mode 2) and hybrid mode in case of capacity shortage (mode 3), this can be considered as a third hybrid operation.

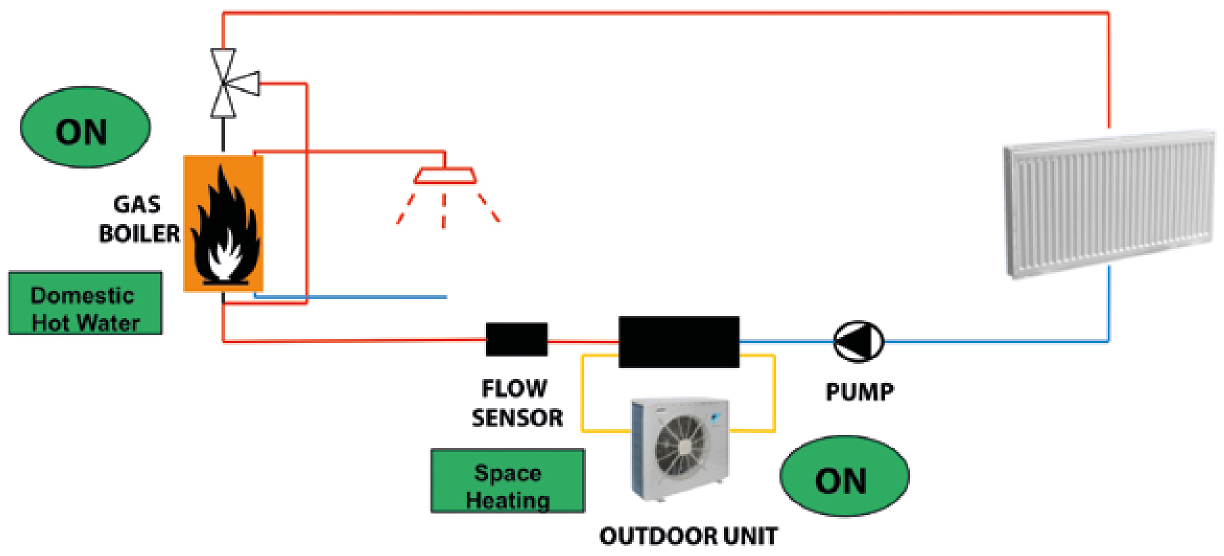


Figure 14: Illustration of the flow pattern, in which the domestic hot water demand is covered by the condensing gas boiler and at the same time the space heating demand is covered by the heat pump.

Figure 15 shows the configuration in case a DHW tank is added to the set-up.

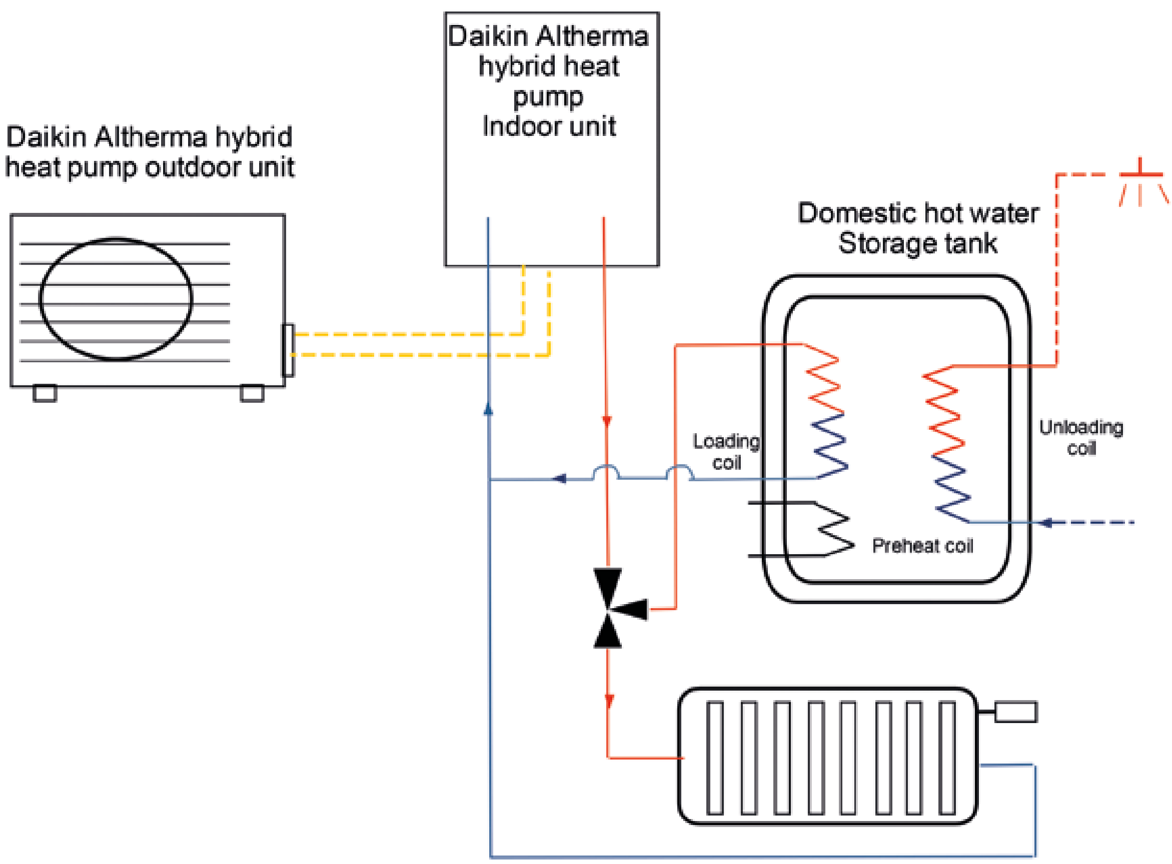


Figure 15: Configuration showing the connection of a storage tank to the Daikin Altherma Hybrid heat pump.

3

Definitions of efficiency

3.1. Efficiency definitions related to gas boilers

Definition of Higher and Lower Heating Value

The burning of methane (CH_4, the main component of natural gas) generates water, CO_2 and heat. The chemical reaction is as follows:

$$CH_4 + 2\,O_2 \longrightarrow 2\,H_2O + CO_2 + \text{heat}$$

Higher Heating Value (HHV, sometimes also referred to as gross calorific value), means that all the products of combustion are brought back to the original pre-combustion temperature. This is particularly important because all vapour has then condensed and thus released all of its latent heat of vapourisation. The Lower Heating Value (LHV, sometimes also referred to as lower calorific value) is obtained by subtracting the heat of vapourisation of the water vapour from the higher heating value. Typical values for different types of natural gas for the HHV and LHV (note that these are country and region dependent), as well as theoretical values for condensed water volume, can be found in the table below.

Table 1: Higher Heating Values (HHV), Lower Heating Values (LHV) and theoretical condensed water volumes for different kinds of fossil fuels.

	HHV [kWh/m³]	LHV [kWh/m³]	HHV/LHV	Theoretical condensed water volume [kg/m³]
City gas	5,48	4,87	1,13	0,89
Natural gas E Natural gas LL	9,78	8,83	1,11	1,53
Natural gas E	11,46	10,35	1,11	1,63
Propane	28,02	25,80	1,09	3,37
Domestic fuel oil [all values in kWh/l or kg/l]	10,68	10,08	1,06	0,88

Because in the past gas boilers did not allow for the condensation of flue gases, the Lower Heating Value was used as a reference to calculate obtained efficiency. Nowadays, however, though condensation of flue gases is possible, the Lower Heating Value is still used as a reference. Hence, as such calculated efficiencies can exceed 100%.

Condensing versus non-condensing boilers

The difference in efficiency between condensing gas boilers and conventional non-condensing ones is most distinct at low capacity use. Because conventional boilers – even at low capacity - have to maintain a constant temperature, the fraction of radiation losses compared to the total provided energy is high, resulting in a low efficiency. Condensing gas boilers, however, need lower water temperatures at lower capacities. In this way, the temperature difference between the colder return water and the flue gases is increased, causing the boiler to profit from the condensation effect [1].

Typical efficiency values for different kinds of gas boilers (both w.r.t. LHV and HHV):

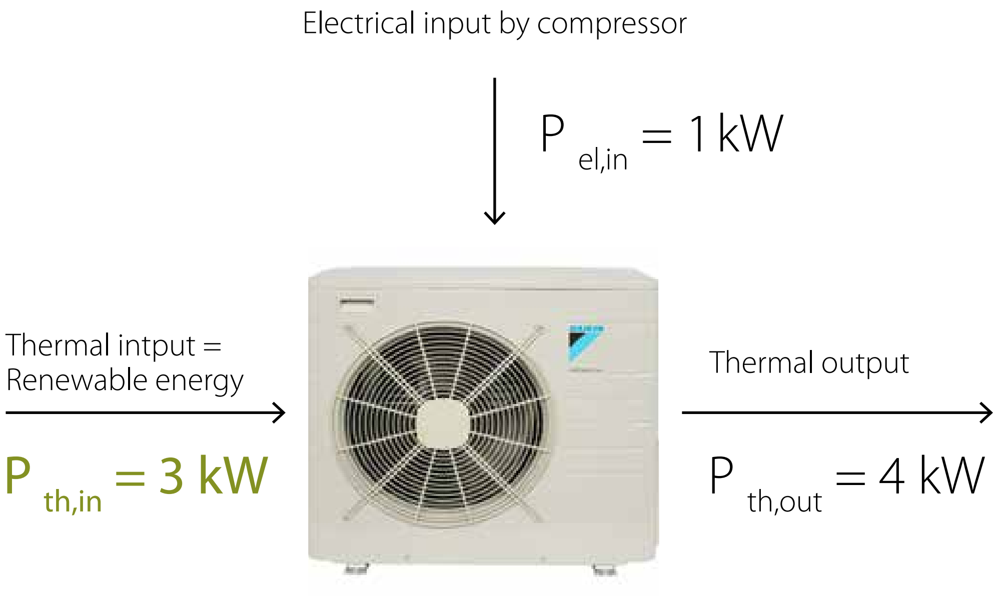
Table 2: Typical values for the Lower Heating Value (LHV) and the Higher Heating Value (HHV) for an 'old' and 'new' non-condensing gas boiler, a condensing gas boiler and the Daikin wall hung condensing boiler.

	LHV	HHV
'Old' non-condensing gas boiler	± 70%	± 62%
'New' non-condensing gas boiler	± 78 ~ 89%	± 69 ~ 79%
Condensing gas boiler	± 98 ~ 109%	± 87 ~ 97%
Daikin wall hung condensing boiler	107%	98%

[1] Source: Viessman, Expertise series on condensation technology, "Condensation technology for energy savings and a clean environment"

3.2. Efficiency definitions related to heat pumps

The efficiency of a heat pump is characterised by the Coefficient Of Performance (COP). The COP indicates the fraction of thermal output over electric power input and is a function of the ambient temperature, the leaving water temperature and the flow. Because the COP is dependent on the outdoor temperature and the required heat load, it varies in time. If one wants to have an indication of the energetic performance of a heat pump for a whole year, the seasonal COP (sCOP) is to be used.



$$COP = \frac{P_{th,out}}{P_{el,in}} = \frac{4\ kW}{1\ kW} = 4$$

Figure 16: Illustration of how renewable energy is used by a heat pump, e.g. for COP = 4

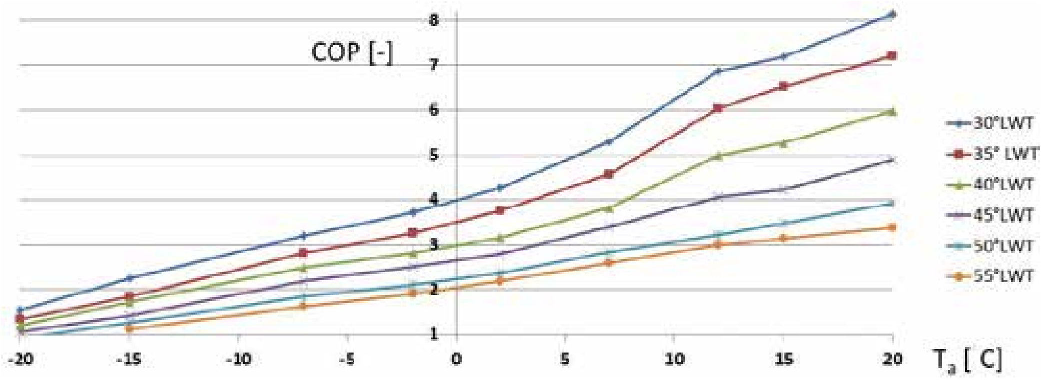


Figure 17: The graph makes clear that a heat pump's COP is dependent on the ambient temperature and the required heat load by showing the dependence of the COP from the Leaving Water Temperature [°C] and the ambient Temperature [°C].

To calculate the sCOP, one needs appropriate input data: the occurrence (number of hours for a whole year) of a certain ambient temperature and the required heat load [kW] as a function of that temperature. As the COP for each ambient temperature is known, the sCOP can be calculated. The seasonal energy efficiency ratio (SEER) equals the fraction of the annual cooling output over the required electric power input and is the equivalent of the sCOP for cooling operations.

3.3. Efficiency definitions for a hybrid system

To quantify the efficiency of a hybrid system, the Primary Energy Coefficient Of Performance (PE-COP) is used. The PE-COP indicates the thermal output that is generated per unit of primary energy input. Natural gas is a primary energy source (with a primary energy coefficient equal to 1), while electricity is a secondary energy product. Assuming an average electricity production efficiency (including transportation losses) of 40%, the primary energy coefficient for electricity equals 2,5[2] . Note that the boiler's efficiency needs to be expressed in terms of higher heating value, because only this value represents the true energetic content of natural gas.

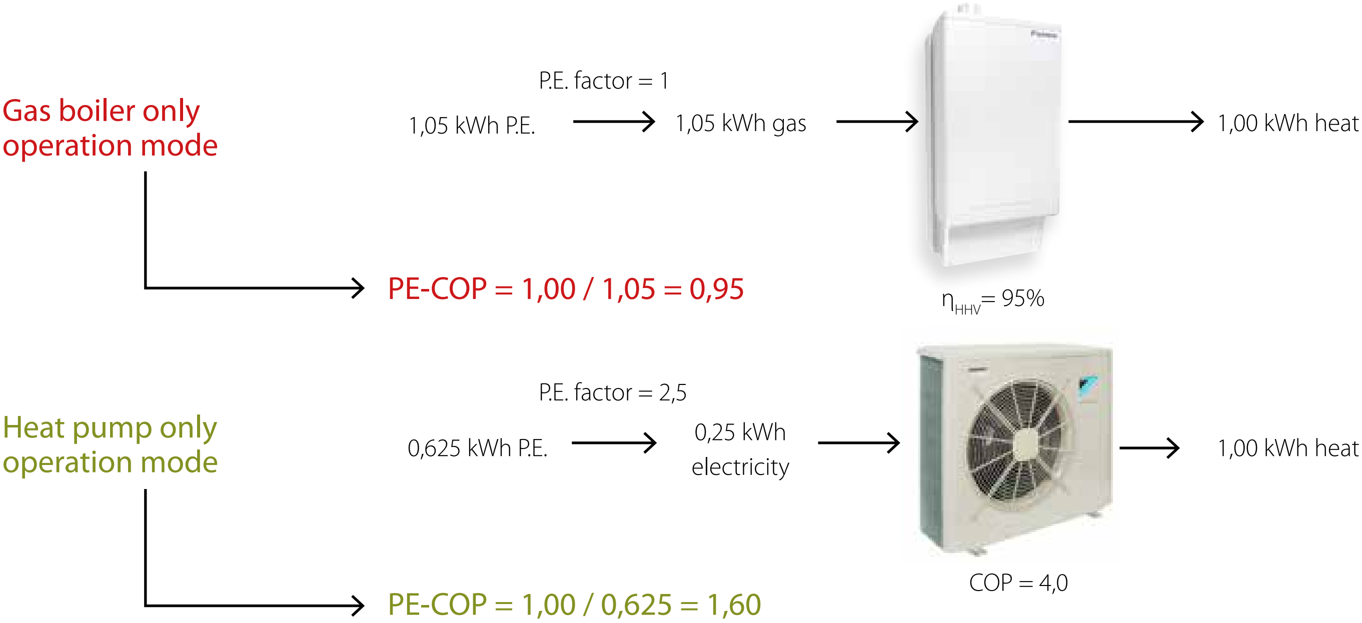


Figure 18: Illustration of the PE-COP for a gas condensing boiler and for a heat pump.

The Primary Energy seasonal Coefficient of Performance (PE-sCOP) is used to characterise the efficiency of a system regarding its annual primary energy use. It takes into account the PE-COP of the different operation modes (boiler only operation mode, hybrid operation mode, and heat pump only operation mode) and the frequency at which each operation mode occurs throughout the year. This results in a value for the PE-sCOP, which is a reliable indicator for the efficiency of the Daikin Altherma hybrid heat pump in terms of annual primary energy use.

2 The conversion coefficient of 2,5 is adopted by the Erp – Ecodesign Directive LOT 1.

3.4. Efficiency comparison of a gas boiler, a condensing gas boiler and a hybrid heat pump

Figure 19 shows the PE-sCOP assuming different heating sources. As explained before, the PE-sCOP indicates how much thermal energy output is generated by making use of 1 unit of primary energy input. The higher the value, the less primary energy is needed to heat up a space, and the more CO_2 is saved. The heating systems compared are an old non-condensing gas boiler, a new non-condensing gas boiler, a condensing gas boiler, a heat pump and a hybrid system. For all boiler types, a certain efficiency range is considered. It is clear that the hybrid system saves huge amounts of primary energy (and hence of CO_2), even when compared to the condensing gas boiler.

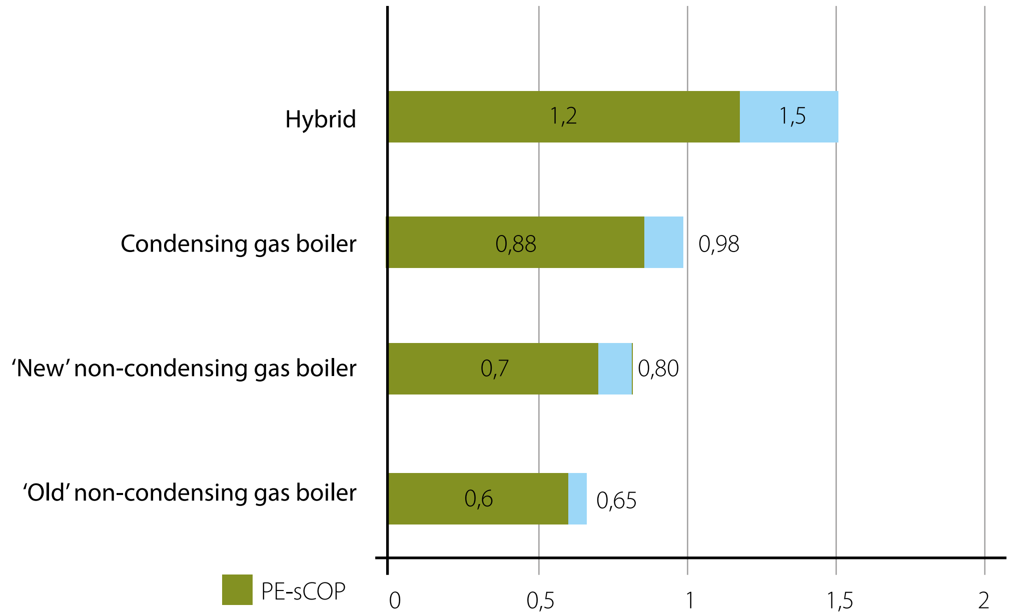


Figure 19: PE-sCOP (Primary Energy seasonal COP) for different heating systems. The figures are based on simulations, for which the following assumptions hold: The climate data used are those for London (UK), for a house with a 12 kW heat load at the design temperature and a LWT of 65°C/45°C. The calculation was done for a house with a space heating demand, excluding the DHW demand. The efficiency of the gas condensing boiler module in the hybrid is assumed to be ηLHV=107% (so ηHHV=98%). For an old non-condensing gas boiler, it is assumed that ηHHV~= 60-65%. For a new non-condensing gas boiler, ηHHV is assumed to be 70-80%. The electricity price is assumed to be €0,150/kWh; the gas price €0,050/kWh.

Figure 20 shows the annual running costs for space heating of the different heating systems. The costs for a hybrid heat pump are set to 100; those for the other systems are expressed relative to this value. From the graph it is clear that the non-condensing gas boiler is 66 to 80% more expensive in terms of annual energy costs for space heating than the Daikin Altherma hybrid heat pump. For the new non-condensing gas boiler, this excess ranges from 35 to 54%. The condensing gas boiler, finally, is 10 to 23% more expensive. The efficiencies used for the calculation of these figures are based on measured values of a field test in Wigan, UK.

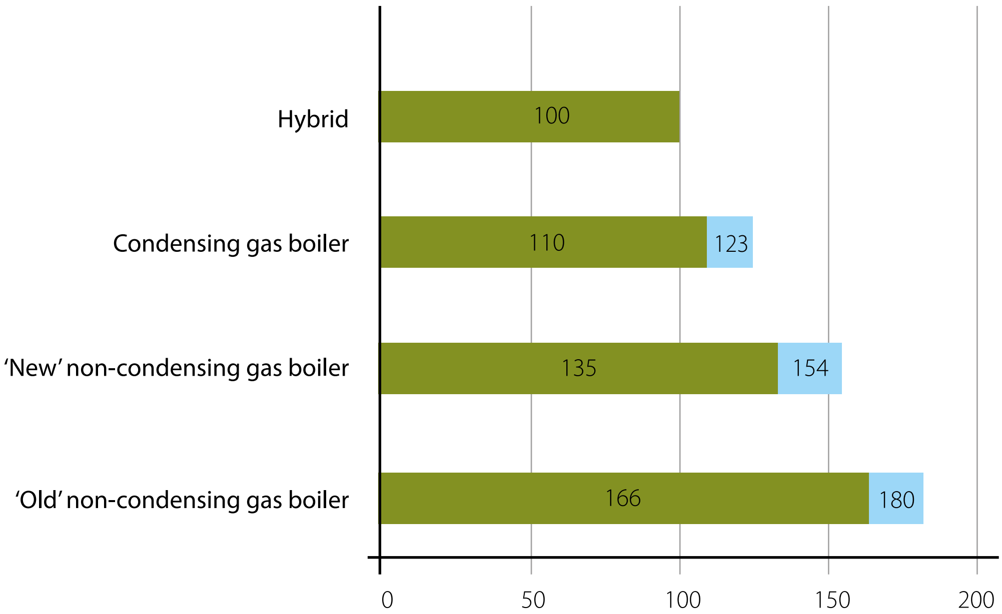


Figure 20: Annual running costs for space heating of the different heating systems. The running costs are expressed relative to the one for the Daikin Altherma hybrid heat pump, which is assumed to be 100. The energy prices used are the same as in Figure 19 (electricity price = 0,150€/kWh; gas price = 0.005 €/kWh). For the Daikin Altherma hybrid heat pump the results from the UK (Wigan) field test are used. The sCOP of the boiler is equal to 0.98 and the sCOP of the heat pump to 3.325. The thermal output was generated for 20% by the boiler and for 80% by the heat pump.

4

Major components

of the Daikin Altherma hybrid heat pump system

The figure below shows the hydraulic scheme of the Daikin Altherma hybrid heat pump system in case no domestic hot water tank is connected. The domestic hot water is heated up by passing through a heat exchanger inside the boiler unit. As regards space heating, the return water, coming from the emitters, passes through the heat pump heat exchanger and the boiler heat exchanger. By which heat exchanger(s) the water is heated up, depends on the active operation mode.

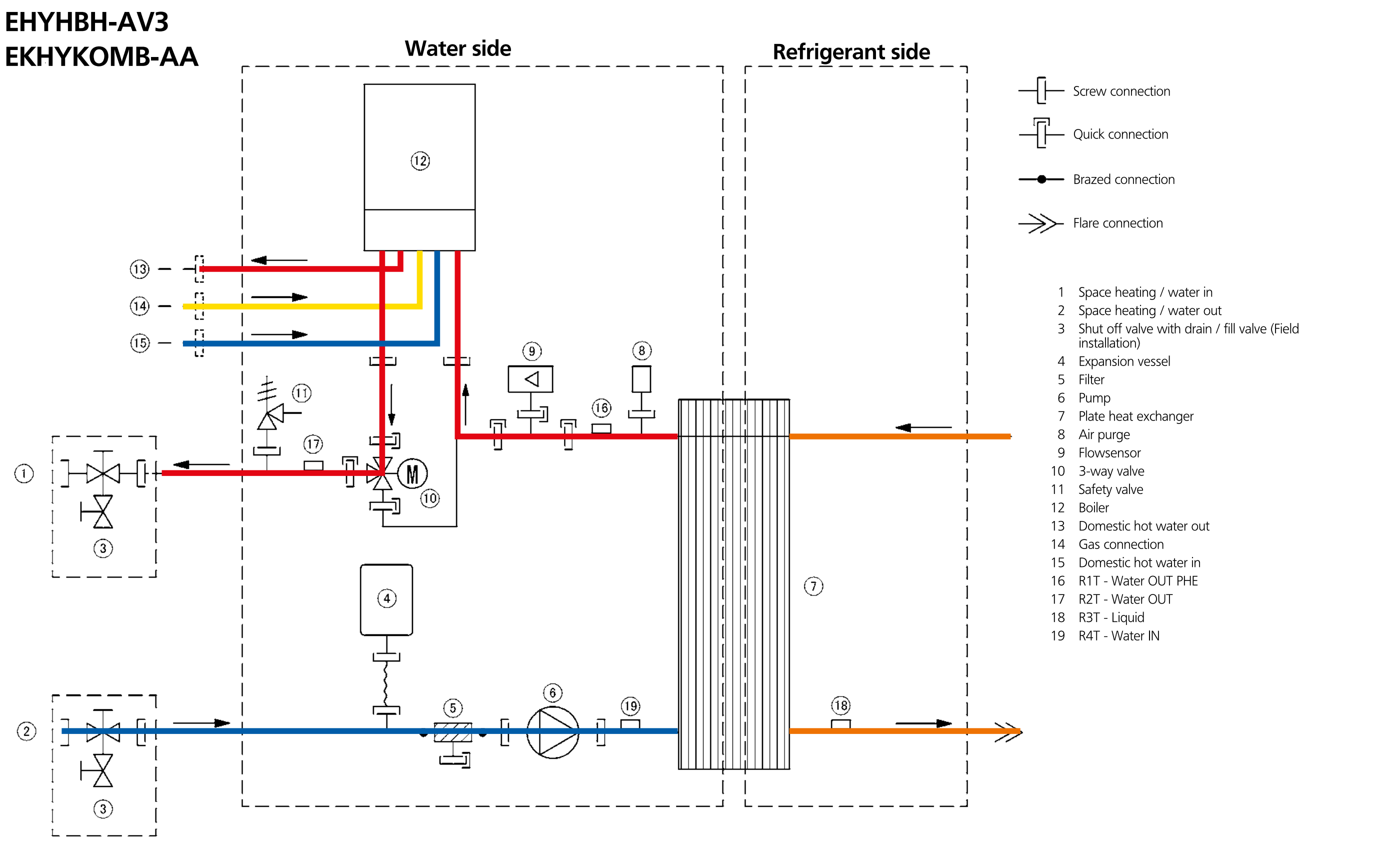


Figure 21: This figure shows the hydraulic scheme of the Daikin Altherma hybrid heat pump in case no domestic hot water (DHW) tank is connected. The blue lines represent cold water, the red lines represent warm water, and the orange ones represent refrigerant lines.

The Daikin Altherma hybrid heat pump system (see Figure 22) consists of an outdoor unit, a gas boiler and a hydrobox (heat pump module). The following paragraphs describe each component in deeper detail.

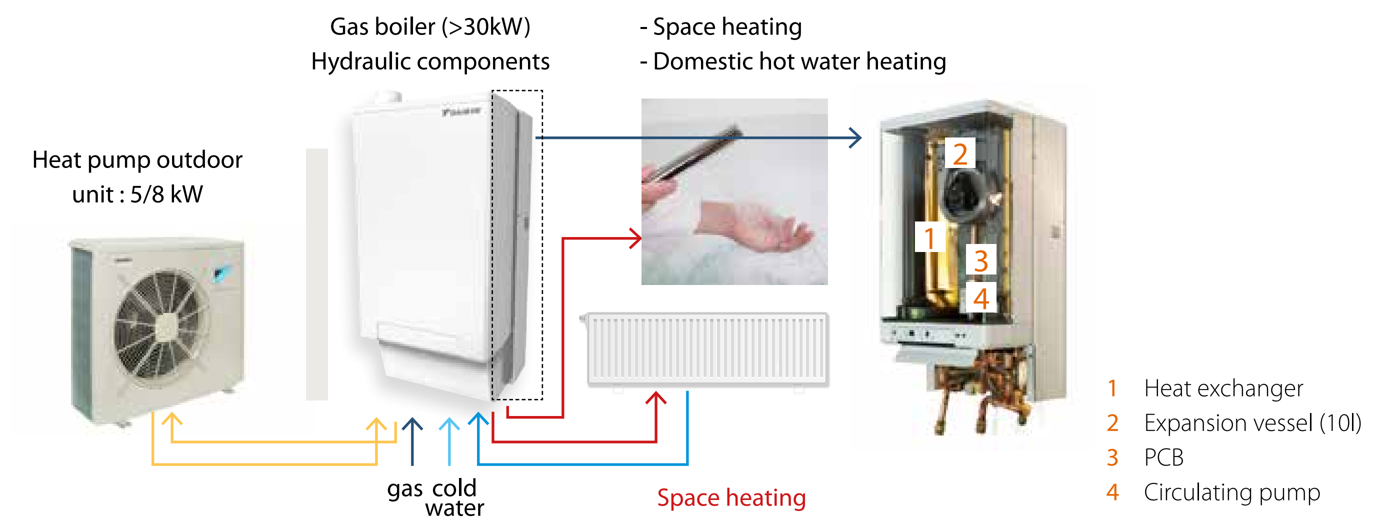


Figure 22: 3Dview of the configuration of the Daikin Altherma Hybrid heat pump: a heat pump outdoor unit (5 / 8 kW), a gas boiler and a hydraulic module (situated behind the gas boiler). A 3Dview with the indication of the main components is shown on the right.

4.1. Outdoor Unit: the Daikin Altherma hybrid heat pump module

The inverter principle

When the heat load of a space is lower than the maximum capacity a heat pump can deliver, traditional non-inverter heat pump systems have on/off full load cycles, resulting in low efficiency. In inverter-controlled heat pumps, however, the compressor frequency is reduced, increasing both its efficiency in part-load operation and its operation life cycle. The efficiency is increased by a higher compressor efficiency and the fact that the heat exchangers in the refrigeration cycle (one for condensation and one for evapouration) are relatively oversized. Admittedly, the inverter needs to operate at a high enough frequency before maximum efficiency is reached; at too low frequencies, inverter losses result in a negative impact on the efficiency. Be that as it may, though, and even with inverter losses taken into account, inverter compressors are still considerably more efficient than non-inverter heat pump systems with full load operation.

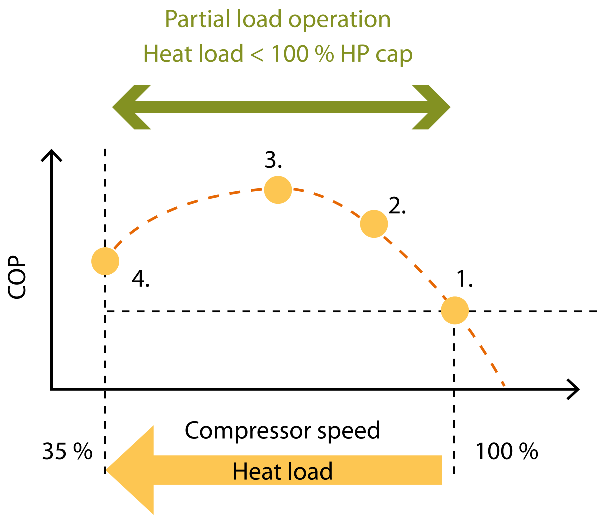


Figure 23: The Coefficient Of Performance as a function of the compressor speed showing the efficiency advantage of inverter heat pumps in comparison to non-inverter heat pumps.

Resistance to ice buildup

A heat pump's outdoor heat exchanger will inevitably ice up at ambient temperatures lower than 2°C. Due to air (with a certain relative humidity) entering the unit and cooling down, water vapour will condense into liquid water and freeze on the fins of the heat exchanger. As a result, the air passage through the openings of the fins is less effective, and the evapourative capacity of the outdoor unit is decreased. This results in a drop in heating capacity and in the general efficiency of the heat pump. Therefore, the cycle can be reversed.

The indoor unit serves as an evapourator (the fan is turned off) and the outdoor unit as a condenser, accepting hot refrigerant to melt the ice.

The outdoor unit is especially designed to prevent ice-up as much as possible.

This is achieved by a number of design measures.

Test conditions: ambient temperature -20°C - relative humidity 99%

Before optimisation of resistance against icing

Melted ice dripping down from the coil and freezing on the cold bottom plate. Also, ice accumulating on the side grill.

After optimisation of resistance against icing

In the new set-up, the coil is free-hanging (no bottom plate underneath the coil). In this way, ice buildup on the bottom of the unit can no longer occur, preventing coil damage, fan damage and capacity decrease. The side grill is also removed, preventing ice accumulation on the side of the unit.

- First, there's the "**free hanging coil concept**", which minimises the buildup of ice.
- Secondly, the outdoor unit uses a **new discharge grill** (the grill at the front side of the outdoor unit, through which air is blown out), preventing ice buildup in the area around the fan.
- Thirdly, **the top plate of the outdoor unit** protrudes sideward, so that if snow falls, it will fall next to the heat exchanger, without making contact with the heat exchanger itself.
- Furthermore, there is **no bottom plate** underneath the heat exchanger, so that cold water cannot freeze on it and initiate the formation of ice.
- Finally, the **control** has been optimised with a strong focus on reducing ice-up.
- All these efforts have resulted in a unit that deals with ice-up in an excellent way. There is no steady ice accumulation in any climate condition within its operation range.

Low electrical inputs and low standstill losses

Low electrical inputs are achieved by making use of a high **efficiency circulating pump**. The pump has an EEI smaller than 0,23 (which corresponds to an A energy label), qualifies for incentive schemes and future regulations (e.g. ErP2015), and requires a low power input (75W lower than conventional pumps), increasing the COP and sCOP. If the pump operated for 6000 hours per year, this would account for an annual difference in energy consumption of 450 kWh (savings of € 77/year, for an average electricity price throughout the EU of € 0,17/kWh).

Also, thanks to its intelligent design, the indoor unit does not require a bottom plate heater, which further reduces the electrical input. Normally, to prevent ice-up, a bottom plate heater would start functioning when the ambient temperature drops below 4°C. However, by not making use of a bottom plate heater, the outdoor unit avoids its use during approximately 2800 hours per year, resulting in annual electricity savings of 168 kWh or € 29.

Low standstill losses are attained **by reducing the standby losses of the inverter drive PCB**. By making the indoor unit PCB switch off the inverter drive PCB during standby operation, the power input of the inverter drive PCB is reduced by 20W. Assuming 3000 hours of standby mode per year, this results in an annual difference of 60 kWh per year, accounting for an annual saving of approximately € 10.

[3] EEI is the Energy Efficiency Index. This score is an indication for the efficiency of a circulating pump. It results in an energy label ranging from class A (best score) to class G (worst score). The requirement for 2013 is EEI < 0,27. From 2015 onwards, an EEI < 0,23 is required, which means that only variable speed circulators with a permanent magnet motor will be allowed on the market.

4.2. Hydrobox

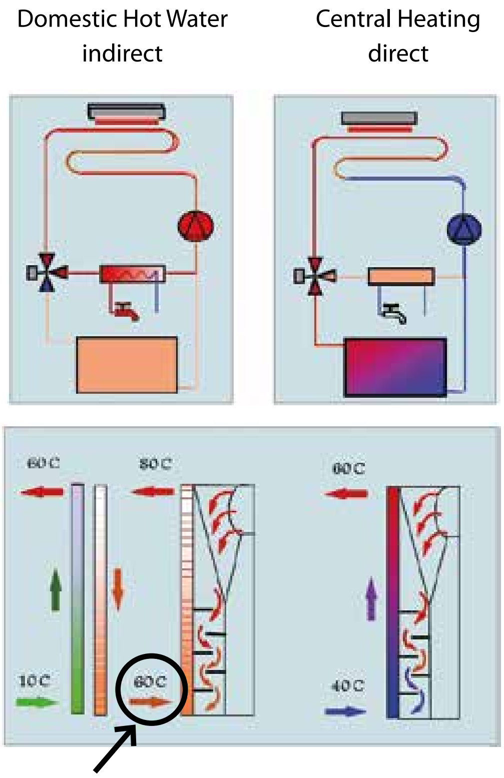
The main functionality of the hydrobox is to exchange heat between the refrigerant and the water. Its internal logic decides, dependent on the savings setting (ecological or economical), whether it is better to use the heat pump or the condensing gas boiler to provide a certain space heating load. The hydrobox acts as a master over the outdoor unit and the gas boiler and controls them. It has been designed to be as compact and silent as possible.

Figure 24: Hybrid indoor module – view of the hydrobox, through the gas boiler.

4.3. Hybrid gas boiler module

The hybrid gas boiler module is a highly efficient boiler with an efficiency of 107% (compared to the Lower Heating Value).

The hybrid boiler module is a gas condensing boiler. In low temperature boilers, the condensation of flue gases is technically impossible. In condensing boilers, however, the condensation of flue gases is possible, so that the latent heat in the water vapour of flue gases can be used to preheat the working fluid for space heating.



Standard condensing boiler: During domestic hot water operation, the temperature of the entry water is higher than the dew point of the flue gases, so no condensation is possible.

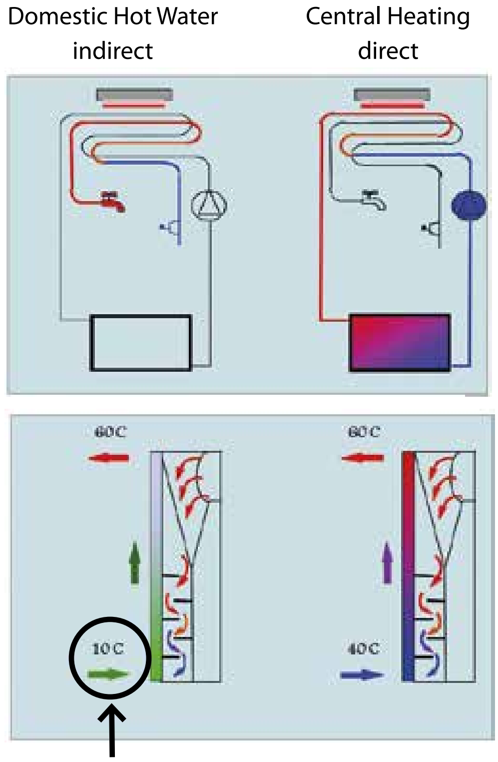
Thanks to its unique heat exchanger, The DAIKIN Altherma gas boiler not only condenses in space heating operation, but also in domestic hot water operation.

This allows the boiler to generate domestic hot water in a more efficient way.

In conventional gas condensing boilers, the working fluid for domestic hot water cannot be preheated by the condensation of flue gases because heat is not directly exchanged to cold tap water but via a plate heat exchanger.

As a result, the temperature of the water entering the condensing gas boiler is higher (60°C), as mentioned in Figure 25 than the dew point temperature of the flue gas (57°C for natural gas; 47 °C for heating oil) making condensation for domestic hot water purposes impossible, even for 'condensing' gas boilers.

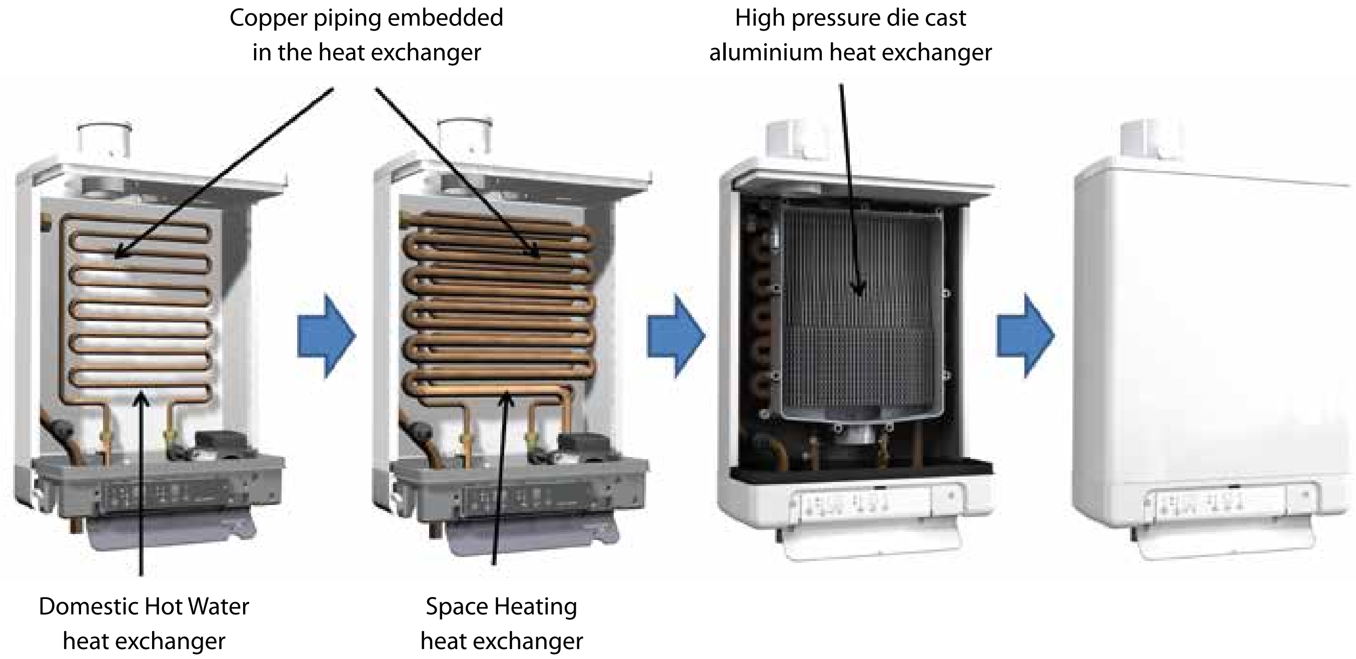
Figure 25: How conventional gas boilers work: due to indirect heating of domestic hot water, no benefit can be taken from the condensation of flue gases



Hybrid condensing boiler: During domestic hot water operation, the temperature of the entry water is lower than the dew point of the flue gases, so condensation of flue gases is possible.

The boiler used in the hybrid produces domestic hot water differently. The burner consists of a double pass heat exchanger (see Figure 27), through which both the water for space heating purposes and that for domestic hot water pass directly. As the working fluid for domestic hot water is not exchanged via a plate heat exchanger, but passes directly through the burner at a temperature of 10°C (see Figure 26), flue gases condense and will heat up the domestic hot water. This causes a big increase in efficiency.

Figure 26: How the hybrid gas boiler module works: due to the direct heating of domestic hot water, a benefit can be taken from the condensation of flue gases.



Opposed to a conventional standard combination boiler, in which domestic hot water is indirectly heated by a plate heat exchanger and no benefit is taken from the condensation of flue gases, the hybrid boiler module heats domestic hot water and water for space heating through a double pass heat exchanger. The two flow circuits are perfectly separated and can both benefit from the condensation of flue gases (because for both flow circuits the inlet temperature is lower than the dew point temperature of the flue gas), which results in an increased efficiency compared to conventional standard combination boilers. Thanks to the condensation effect and the design of the heat exchanger, the efficiency of the double pass heat exchanger is up to 30% higher compared to a conventional one.

Figure 27: The hybrid gas boiler module, consisting of a double pass heat exchanger (both the coil for space heating and that for domestic hot water are directly heated by the burner), and covered by aluminium ribs and a sheet metal cover plate.

5

Environmental performance

and evaluation of

the cost efficiency

of CO_2 emission reductions of the hybrid technology compared to other renewable technologies

In order to compare different renewable technologies, a quantitative indication of the investment cost per kWh of renewable energy is required. This can be obtained by dividing the investment price of a certain renewable energy producing technology by the total production of renewable energy over its entire lifetime. The cheaper this price, the more renewable energy can be produced for a certain investment in that technology and the more cost-efficiently the technology can contribute to achieving the EU's 20-20-20 targets. Below, a comparison is performed between solar thermal energy, solar PV and the Daikin Altherma Hybrid heat pump.

Solar thermal energy is a technology for harnessing solar energy for heat by using solar thermal collectors. Assuming that the solar equipment – 4 m^2 flat panels, as well as a solar storage tank – and its installation cost about € 3500 and that the equipment has a lifespan of 20 years and would annually yield 1.000 kWh (for an average climate), this results in a renewable energy investment cost of €0,175/kWh produced renewable thermal energy.

Solar PV systems produce about 850 kWh per year per kWp for an average climate. As their cost is about € 2000 per kWp and their lifespan is approximately 20 years (10 years for the inverter), this results in a renewable energy investment cost of €0,117/kWh produced renewable electric energy.

Assume that the **Daikin Altherma Hybrid heat pump** annually provides 15.000 kWh of thermal energy (10.000 kWh by the heat pump and 5.000 kWh by the boiler), of which 2.500 kWh is delivered by an electrical input, so that 7.500 kWh is actual renewable heat. Also assuming the hybrid costs € 1.500 more compared to the average gas condensing boiler, and its lifespan is 12 years (its lifetime expectancy, however, is 15 years), this results in a renewable energy investment cost of **0,017/kWh**.

[4] Note that if the electricity cost to run the hybrid is taken into account (€0,161/kWh, price according to info from the Flemish Energy Agency), this will result in a total renewable energy cost of €0,070/kWh.

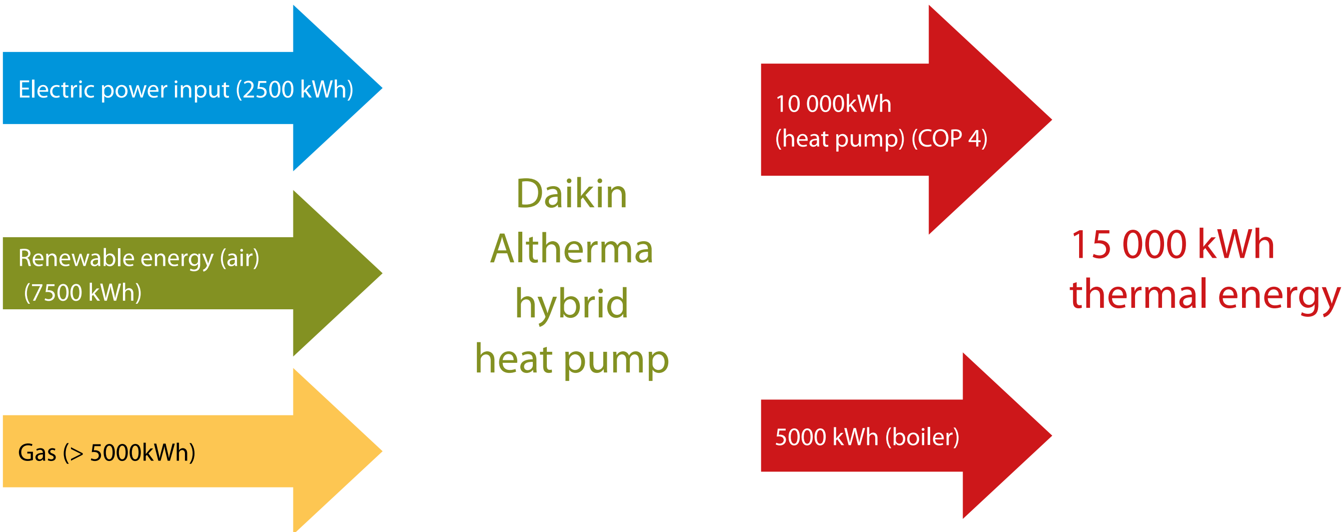
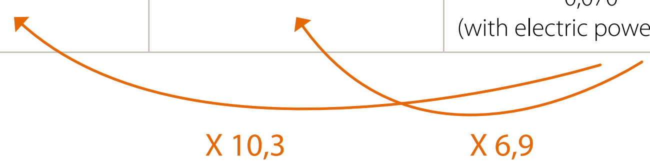


Figure 28: Yearly energy inputs and outputs for the production of 15.000 kWh of thermal energy. From the 10.000 kWh thermal energy produced by the heat pump , 7.500 kWh can be considered as actual renewable heat. This requires 2.500 kWh of electric power input (COP =4).

Comparison of the investment cost for renewable energy [€/kWh]		
Solar Thermal Energy	Solar PV	Daikin Altherma hybrid heat pump
0,175	0,117	0,017 (investment cost, without electric power input) 0,070 (with electric power input)



As regards the production of renewable energy, this makes using the hybrid 10,3 times cheaper than using solar thermal energy, and 6,9 times cheaper than using solar PV. That is why hybrid heat pumps can be considered as a valuable and promising technology to contribute to the EU's 20-20-20 targets in the most cost-efficient way.

Figure 29: Comparison of the investment cost for renewable energy: Solar thermal energy, solar PV and the Daikin Altherma hybrid heat pump.

6

The hybrid technology: case studies

The Daikin Altherma hybrid heat pump has been installed and tested at different field sites, in various climates and house types (size, age and energy rating), and with different heat emitters. Three field tests are described in deeper detail below. Each time, the characteristics of each test house are described and the measured results are explained.

6.1. UK field test – Wigan

6.1.1. Characteristics of the house

Figure 31: Picture of the house in Wigan, UK (1).

Figure 30: Picture of the house in Wigan, UK (2).

The house is owned by Mr. James Jennings and is located in Wigan, UK. It is terraced and occupied by 3 people. As it is 110 years old, has no insulation (the 30mm cavity walls were considered too hard to treat) and has high flow temperatures to the radiators (70°C), it could be considered as a 'worst case scenario' from an efficiency point of view.

A gas boiler has been replaced by a Daikin Altherma hybrid heat pump. The heat emitters were radiators and have been kept. The heating capacity at the design temperature (-7°C) is 9 kW. The heating control is weather-dependent , with 70°C leaving water temperature at the design temperature. The heating area equals 140 m^2.

Figure 32: Picture of the installed hybrid heat pump module.

Figure 33: Picture of the indoor hybrid gas boiler and heat pump module (field test setup).

6.1.2. Results

The test results show that of the 16 300 kWh used for space heating, 13 060 kWh (or >80%) was produced by the heat pump. This clearly shows that, even in older properties with radiators, the heat pump in a hybrid system will supply most of the energy for space heating, with the boiler acting as a 'supporting' heat source. This confirms that the hybrid system is suitable for any type of house: small or large, new or old, with underfloor heating or radiators.

Furthermore, the measured seasonal efficiency in the house, based on the primary energy source, is 1.26 for space heating and 1.2 for the total energy supply (space heating and hot water production combined). This is 37% higher than a state-of-the-art gas condensing boiler, based on an efficiency of 90% for space heating operation (seasonally based) and 70% for domestic hot water.

The graph below (Figure 34) shows the theoretically required heating capacity to heat the house to a good comfort level as a function of the ambient temperature (blue line). This line is based on two points: the required heating capacity at the design temperature (-7°C) , which is set to 9 kW, and the assumption that no more heating capacity is required at 16°C. The blue dots scattered around it result from field test measurements. These show measured values for the heating capacity at a certain value for the ambient temperature.

The figure also shows the leaving water temperature (LWT, [°C]) as a function of the ambient temperature (red line). The LWT is fixed at 70°C at the design temperature and at 30°C at an ambient temperature of 16°C.

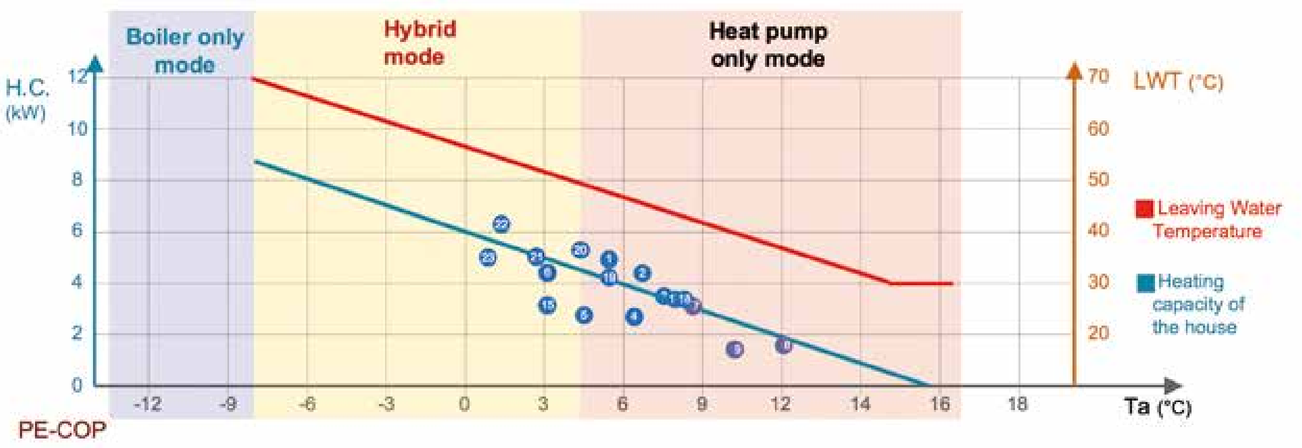


Figure 34: Graphs concerning the field test in Wigan, UK: 1) Heating capacity [kW] as a function of the ambient temperature Ta [°C] (blue line); 2) Leaving water temperature [°C] as a function of the ambient temperature Ta [°C] (red line).

Figure 35 shows the thermal energy demand of the house per degree Celsius [kWh/°C] as a function of the ambient temperature T_a [°C] (green line). The area under the green line is a measure of the total annual space heating energy demand of the house. The yellow line and yellow dots show the system efficiency, in terms of the PE-COP, as a function of the ambient temperature T_a [°C]. The black dots show the boiler efficiency. It can be seen that as the ambient temperature rises, the yellow dots move farther away from the black ones. This is because, as the ambient temperature rises, the heat pump effect increases and so does the PE-COP.

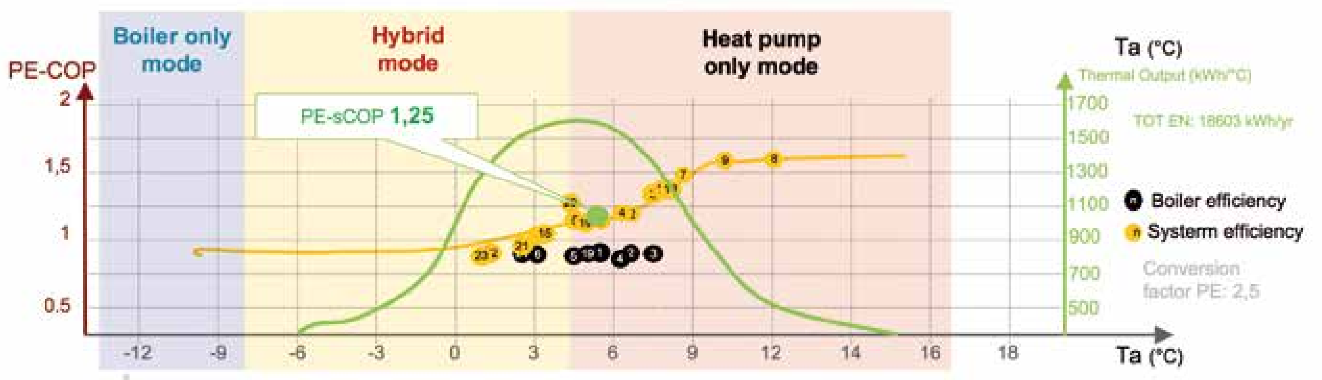


Figure 35: Graphs concerning the field test in Wigan, UK: 1) Thermal output per degree Celsius [kWh/°C] (green line); 2) System efficiency (yellow line and dots) and boiler efficiency (black dots); both in terms of the PE-COP.

Figure 36: James Jennings, Susie and daughter Olivia: owners of the Hybrid field test house in Wigan, UK.

James Jennings, owner of the house in Wigan, stated that thanks to the hybrid, he feels that he has future-proofed his house:

> Due to this technology I feel I have future-proofed my house, as whichever is cheaper, gas or electricity, I know I will always be running as efficiently as possible without having to think about it. It also ensures I play my part in being as environmentally friendly as possible, with the latest most efficient technologies working together as one.

James Jennings and family,
ownersof the Hybrid field test house @Wigan, UK

6.2. Germany field test – Stuttgart

6.2.1. Characteristics of the house

The house is located near Stuttgart, Germany. It is occupied by 2 adults and 2 small children. The house is semi-detached and the heating area is 208 m^2. The heating capacity at the design temperature (-12°C) equals 8 kW. The heat emitters are radiators and have been kept during the refurbishment of the old gas boiler.

The heating control is weather-dependent, with 60°C leaving water temperature at the design temperature.

Figure 37: Picture of the house near Stuttgart, Germany.

Figure 38: Picture of the installed indoor unit of the hybrid.

6.2.2. Results

Figure 39 shows the leaving water temperature as a function of the ambient temperature (red line). It goes from 60°C at an outdoor temperature of -12°C to 35°C at an outdoor temperature of 16°C.

The blue line shows the theoretically required heating capacity of the house and rises from the assumption that the required capacity is 8kW at -12°C and no heating capacity is required anymore when the outdoor temperature exceeds 16°C.

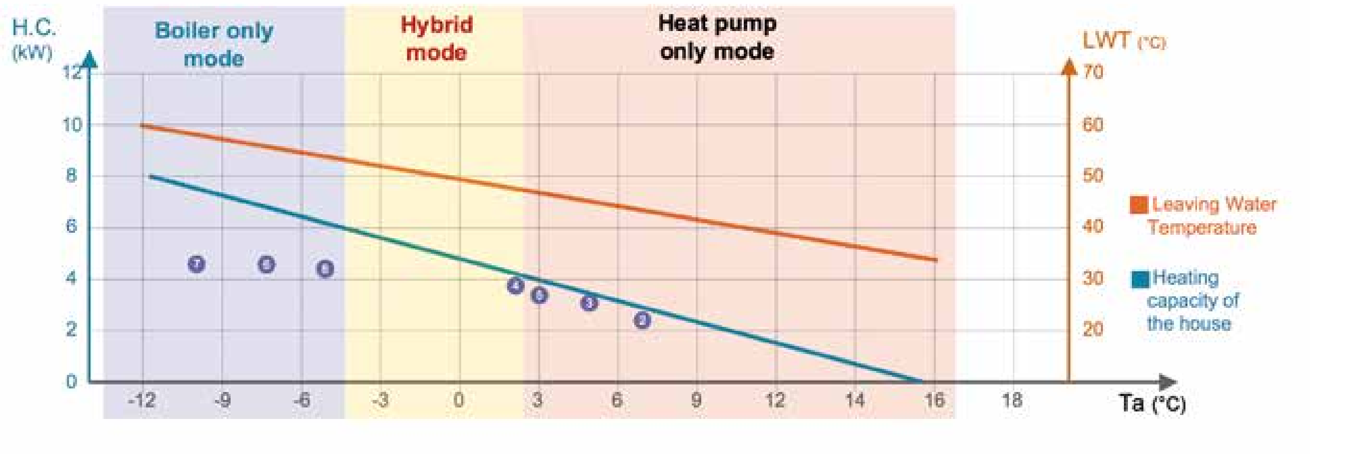


Figure 39: Graphs concerning the field test near Stuttgart, Germany.: 1) Heating capacity [kW] as a function of the ambient temperature Ta [°C] (blue line); 2) Leaving water temperature [°C] as a function of the ambient temperature Ta [°C] (red line).

In winter time, the occupant combined a wood stove with the Daikin Altherma Hybrid heat pump, which explains the lower measured capacities in comparison with the expected capacity (see the three leftmost blue dots on Figure 39).

The graph below (Figure 40) also shows that the system efficiency increases with increasing ambient temperatures (i.e. as the heat pump provides a larger part of the heat load). The boiler efficiency can be considered as constant, as can be seen from the black dots. The annual PE-sCOP is 1,25, which is 40% higher in comparison with the replacement system.

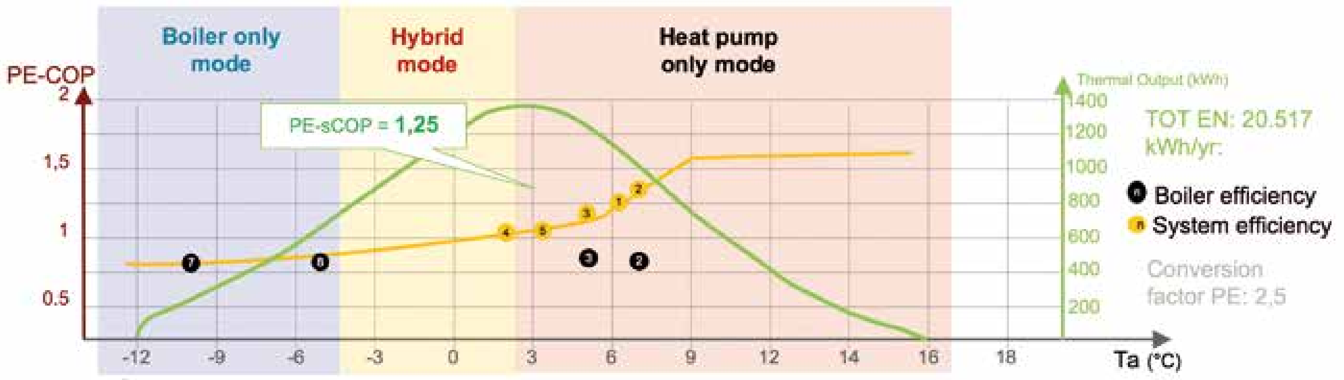


Figure 40: Graphs concerning the field test near Stuttgart, Germany: 1) Thermal output per degree Celsius [kWh/°C] (green line); 2) System efficiency (yellow line and dots) and boiler efficiency (black dots); both in terms of the PE-COP.

6.3. Italy field test – Rimini

6.3.1. Characteristics of the house

A third field test has been performed in Rimini, Italy. The house is terraced and occupied by 2 people. In it, an old gas boiler has been replaced by a Daikin Altherma hybrid heat pump while keeping the existing radiators. The heating capacity at the design temperature (-5°C) equals 6 kW and the heating area is 140m^2. The heating control is weather-dependent, with 55°C leaving water temperature at the design temperature.

Figure 41: Picture of the house in Rimini, Italy.

6.3.2. Results

The weather-dependent leaving water temperature curve shown on Figure 43 ranges from 55°C at an outdoor temperature of -5°C to 30°C at about 16°C. The heating capacity of the house was estimated at about 6kW at the design temperature. The measured values of the heating capacity of the hybrid again scatter around this line.

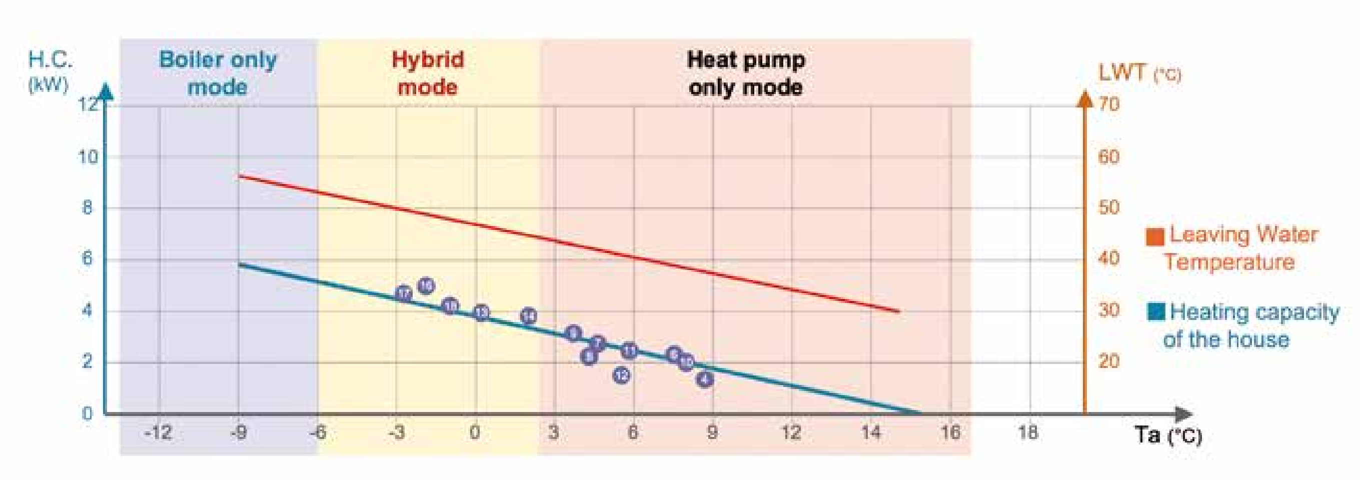


Figure 43: Graphs concerning the field test in Rimini, Italy.: 1) Heating capacity [kW] as a function of the ambient temperature Ta [°C] (blue line); 2) Leaving water temperature [°C] as a function of the ambient temperature Ta [°C] (red line).

Figure 44 also shows the increase in efficiency of the Daikin Altherma hybrid heat pump as the heat pump provides a larger portion of the heat load (as ambient temperatures increase). See the yellow line.

The green line again indicates the thermal energy output per degree Celsius, which reaches a maximum at about 5°C. The PE-sCOP in this house is 1,3.

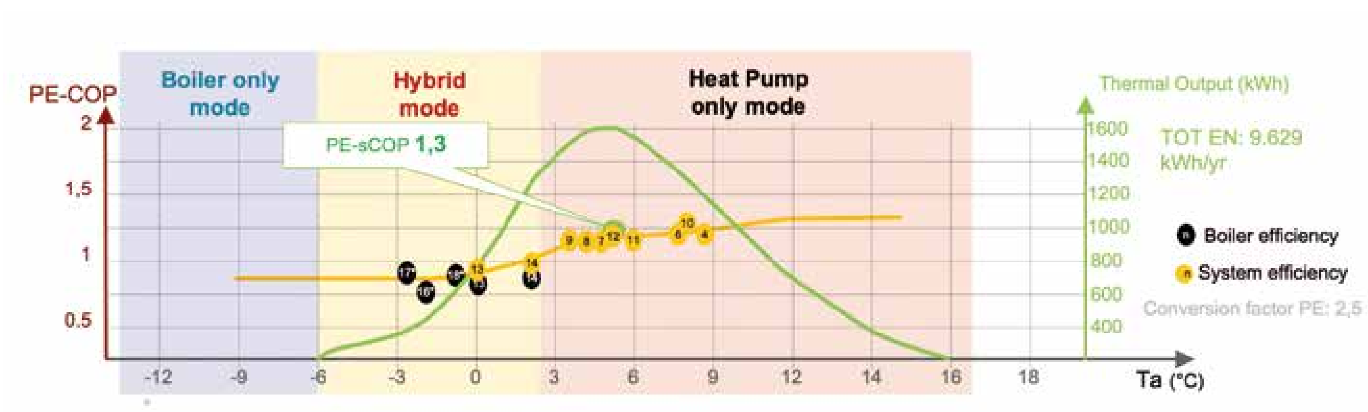


Figure 44: Graphs concerning the field test near Rimini, Italy: 1) Thermal output per degree Celsius [kWh/°C] (green line); 2) System efficiency (yellow line and dots) and boiler efficiency (black dots); both in terms of the PE-COP.

7

Conclusion: why the Daikin Altherma hybrid heat pump is to be considered the heat source of the future

The Daikin Altherma hybrid heat pump differentiates itself from other conventional heat sources in several aspects.

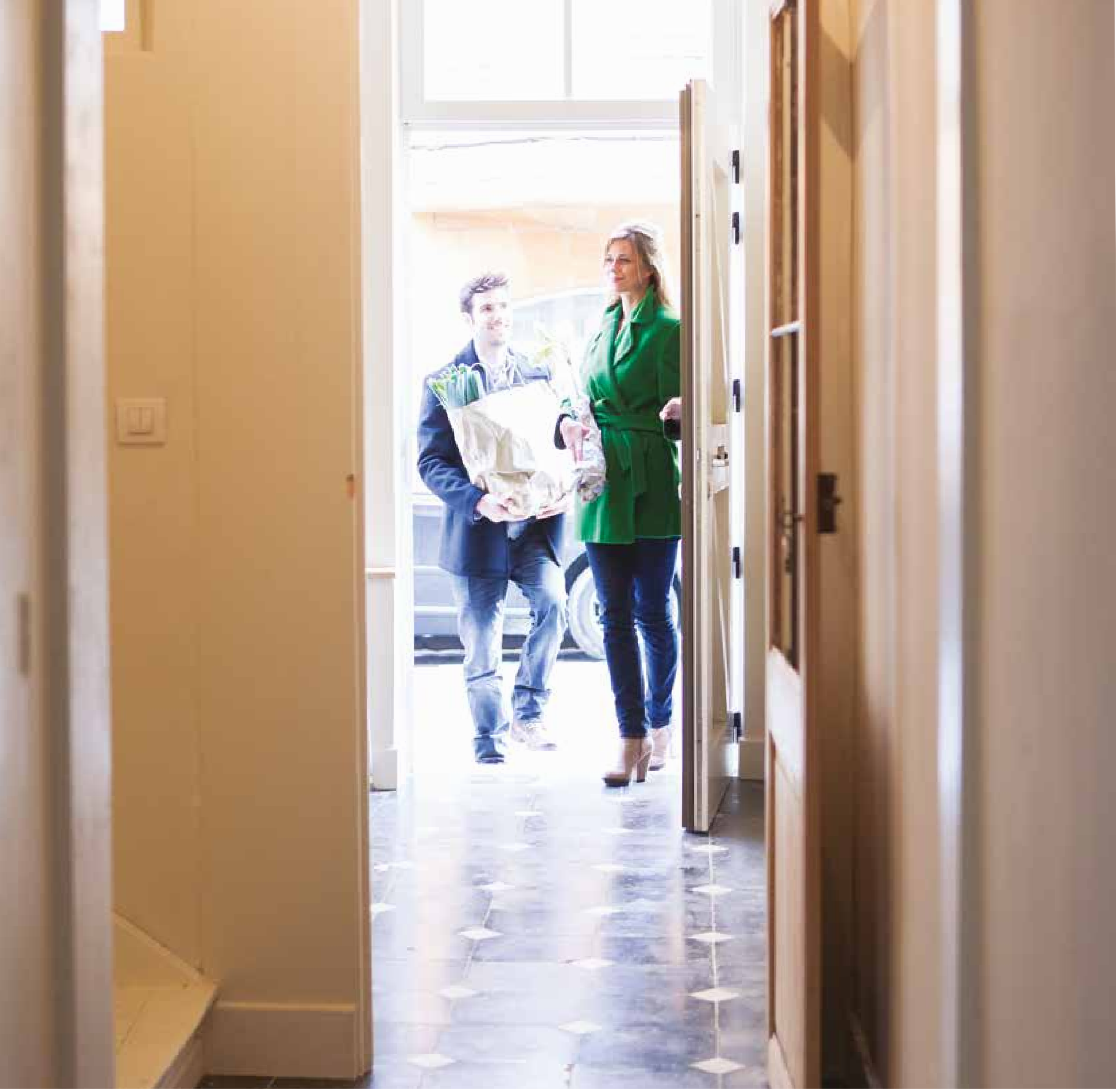
First, the hybrid is highly flexible, both towards the type of house and the type of heat emitters. Water flow temperatures from 25°C up to 80°C are possible, which makes the hybrid suitable for providing excellent comfort levels in any type of house, both through underfloor heating and radiators.

Secondly, the hybrid is highly environmentally friendly, because it can reduce CO_2 emissions and provide renewable energy at an investment cost of €0,017 per kWh, making it the most affordable renewable energy source available.

Thirdly, the hybrid is featured by a state-of-the-art design that optimises efficiency, de-icing, compactness and sound. The hybrid contains an inverter controlled outdoor unit with minimal electric power consumption, low standstill losses and optimal resistance against icing. The heat pump module exchanges heat between refrigerant and water and is designed to be as compact and silent as possible. The gas condensing boiler contains a double heat exchanger for the highly efficient production of domestic hot water and water for space heating.

Finally, the hybrid allows for easy operation through an intuitive user interface. Energy monitoring can be performed, where the energy production through gas and electricity for both space heating and domestic hot water can be read out separately. The hybrid is also the perfect tool for electricity grid management: depending on the load of the grid, the system can switch between boiler and heat pump operation via a voltage free contact.

The combination of the heat pump and the gas condensing boiler, which are both designed to be highly efficient and represent the best available technologies on the market, together with the possibility to switch from heat source to heat source in an economically optimal way, reduces running costs and provides an affordable renewable technology for any type of house with any type of emitters. The Daikin Altherma hybrid heat pump has all the assets to become a mainstream heating system.



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