(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 361 531 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
01.05.2024 Bulletin 2024/18

(21) Application number: **23201646.9**

(22) Date of filing: **04.10.2023**

(51) International Patent Classification (IPC):
F25B 41/31 *(2021.01)* ***F25B 49/02*** *(2006.01)*

(52) Cooperative Patent Classification (CPC):
F25B 41/31; F25B 49/02; F25B 2600/2513

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

(30) Priority: **26.10.2022 IT 202200022080**

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(54) **HEAT PUMP WITH EXPANDED MODULATION OF THE EXPANSION DEVICE**

(57) A heat pump (1) comprises a circuit (2) for circulating a refrigerant fluid, a first heat exchanger (3) placed in the circuit (2) and forming an evaporator (4), a compressor (5) placed in the circuit (2) downstream of the first heat exchanger (3), a second heat exchanger (6) placed in the circuit (2) downstream of the compressor (5) and forming a condenser (7), an expansion device (8) placed in the circuit (2) downstream of the second heat exchanger (6), an electronic control system (9) which controls the compressor (5) and the expansion device (8),
where the electronic control system (9) and the expansion device (8) are configured so as to achieve a ratio (Aexv_max / Aexv_min) between the upper total opening area limit (Aexv_max) and the lower total opening area limit (Aexv_min) of the expansion device (8) greater than 15, or in the range from 22 to 70, or greater than 70.

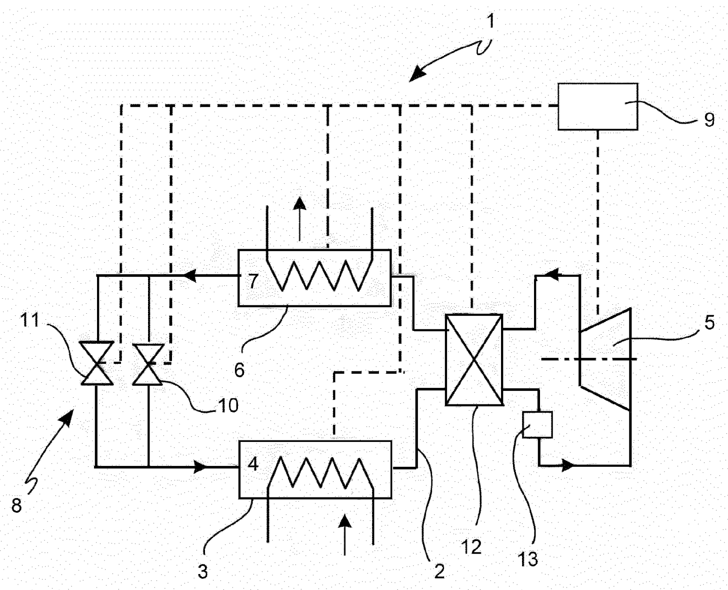

FIG. 7

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Description

[0001] The invention relates to a heat pump, for example for heating and/or cooling air and/or water, e.g., in a plant for heating and/or cooling rooms and/or water.

[0002] A heat pump comprises a circuit for the circulation of a refrigerant fluid, an evaporator (consisting of a first heat exchanger) placed in the circuit, a compressor placed in the circuit downstream of the evaporator, a condenser (consisting of a second heat exchanger) placed in the circuit downstream of the compressor, and an expansion valve placed in the circuit downstream of the condenser and upstream of the evaporator. The indications "downstream" and "upstream" refer to the circulation direction of the refrigerant fluid in at least one operating mode. The compressor is operable to take in the refrigerant fluid in the gaseous phase and at low pressure from the evaporator, compress the refrigerant fluid, and push it into the condenser. Inside the condenser, the compressed refrigerant fluid releases heat and condensation at high pressure. After the exit from the condenser, the refrigerant fluid passes through the expansion valve which decompresses it, bringing the refrigerant fluid into a depressurized liquid phase with a possibly lower amount of gaseous phase. Still due to the suction effect of the compressor, the depressurized liquid refrigerant fluid is conveyed into the evaporator where the refrigerant fluid absorbs heat and evaporates at low pressure, before being taken in and compressed again by the compressor.

[0003] The refrigerant fluid changes state inside the evaporator, switching from liquid to gaseous by absorbing heat, and inside the condenser, switching from gaseous to liquid by yielding heat. The air or fluid in contact with the evaporator (or, in other words: the space where it is located) is thus cooled, whereas the air or fluid in contact with the condenser (or, in other words: the space where it is located) is heated.

[0004] It is further known to connect the compressor in the circuit by the interposition of a (four-way) switching valve which allows inverting the compression and circulation direction of the refrigerant fluid and thus switching the first heat exchanger from evaporator to condenser and the second heat exchanger from condenser to evaporator, allowing both cooling and heating the air or fluid in contact with the first and second heat exchangers (or the spaces in which they are located).

[0005] Known heat pumps, described above, can be used in a heating mode, e.g., in winter months, taking heat from the external air and bringing heat into a building.

[0006] In this case, the refrigerant fluid crosses the expansion valve and becomes a liquid-vapor mixture at low pressure, then enters into the evaporator, placed outside, where it absorbs heat until it becomes vapor at low temperature, which vapor is then taken in and compressed by the compressor with the consequent temperature increase, and the hot and compressed vapor is pushed from the compressor outlet into the condenser, which can for example be a fan coil unit placed inside the building (close to the boiler for example), and changes phase again from gas to liquid releasing the liquefaction heat. The liquid refrigerant fluid returns to the expansion valve and the cycle is repeated.

[0007] By inverting the cooling cycle, e.g., through the (four-way) switching valve, the same heat pump can be used in a cooling mode, e.g., in the summer months, where the refrigerant fluid evaporates in the indoor fan coil unit and condenses in the outdoor heat exchange battery.

[0008] Heat pumps use greenhouse gas as a refrigerant fluid. The F-gas regulation introduced by the European Union, and similar legislation or initiatives in other countries, aim to reduce the emission of greenhouse gases and are pushing manufacturers of heat pumps to reduce the global warming potential (GWP) of their products. The reduction in global warming potential can be carried out using refrigerant fluids with low greenhouse effect properties, or by adopting technical solutions that reduce the mass of fluid required for the individual heat pump with equivalent thermal performance levels.

[0009] Many refrigerant fluids with low global warming potential (GWP) are classified as flammable (e.g., R32, propane). For safety reasons, for these flammable refrigerant fluids, allowable amount limits are set or recommended in a heat pump present inside a house (or at least also extending thereto). In particular, heat pumps known as splits (with units inside the house) which use flammable refrigerant fluids must thus operate with low charges of refrigerant fluid with respect for example to single-block heat pumps completely located outdoors.

[0010] However, heat pumps have to operate in a wide range of outdoor temperatures and water (or indoor) temperatures and it is known that a refrigerant fluid charge reduction in the same heat pump also reduces the operating temperature range.

[0011] Therefore, it is the object of the invention to provide an improved heat pump and a method of operating the heat pump which allow reducing the mass of refrigerant fluid used (with respect to a known heat pump with optimized refrigerant fluid charge), with at least almost equal performance in terms of COP (coefficient of performance) and thermal capacity and with at least almost equal operating interval/range, and keeping most of the main components of the heat pump cooling circuit unchanged.

[0012] These and other objects are achieved by a heat pump according to claim 1. The dependent claims relate to advantageous and preferred embodiments.

[0013] According to an aspect of the invention, a heat pump comprises:

- a circuit for circulating a refrigerant fluid,
- a first heat exchanger placed in the circuit and forming an evaporator,
- a compressor placed in the circuit downstream of the first heat exchanger,

- a second heat exchanger placed in the circuit downstream of the compressor and forming a condenser,
- an expansion device placed in the circuit downstream of the second heat exchanger,
- an electronic control system controlling the compressor and the expansion device,

where, during operation of the heat pump with the expansion device open, the electronic control system controls an upper total opening area limit (Aexv_max) of the expansion device and a lower total opening area limit (Aexv_min) of the expansion device,
where the electronic control system and the expansion device are configured so as to achieve a ratio (Aexv_max / Aexv_min) between the upper total opening area limit (Aexv_max) and the lower total opening area limit (Aexv_min) of the expansion device greater than 15, or in the range from 22 to 70, or greater than 70.

[0014] Particularly advantageously, this ratio (Aexv_max / Aexv_min) between the upper total opening area limit (Aexv_max) and the lower total opening area limit (Aexv_min) of the expansion device (8) is in the range from 22 to 26, or from 23 to 25, or 24.

[0015] The configuration of the expansion device and of the control system extends the total area range of the expansion device with respect to the adjustment of the opening area ranges of expansion devices during the operation of heat pumps of the prior art. As will be explained hereinafter, the expansion of the total opening area range of the expansion device, during its operation with the expansion valve open, allows using a smaller amount of refrigerant fluid with substantially the same thermal and energy performance of the heat pump.

[0016] According to a further aspect of the invention, a heat pump comprises:

- a circuit for circulating a refrigerant fluid,
- a first heat exchanger placed in the circuit and forming an evaporator,
- a compressor placed in the circuit downstream of the first heat exchanger,
- a second heat exchanger placed in the circuit downstream of the compressor and forming a condenser,
- an expansion device placed in the circuit downstream of the second heat exchanger,
- an electronic control system controlling the compressor and the expansion device,

characterized in that:

- the expansion device comprises a plurality of electric expansion valves (e.g., a first electric expansion valve and a second electric expansion valve) placed in parallel in the circuit,
- the electric expansion valves each have an individually adjustable opening area (e.g., the first electric expansion valve has a first adjustable opening area and the second electric expansion valve has a second adjustable opening area) which together define a total opening area of the expansion device,
- the control system is configured to control the plurality of electric expansion valves in a total opening area range delimited by a lower total opening area limit and an upper total opening area limit,
- the upper total opening area limit is greater than an upper individual opening area limit of each of the electric expansion valves.

[0017] The configuration of the expansion device and the control system allows extending the total opening area range of the expansion device, with respect to the individual opening ranges of known and commercially available expansion valves. As will be explained hereinafter, the extension of the total opening area range of the expansion device allows using a smaller amount of refrigerant fluid with substantially the same thermal and energy performance of the heat pump.

[0018] The configuration of the expansion device and of the control system also allows a sufficiently fine adjustment within, and in particular at the margins, of the entire extended total opening area range, using known and commercially available expansion valves notwithstanding the known disadvantage of adjustable valves, according to which as the maximum opening area increases, the adjustment of the smaller opening areas becomes more approximate and less certain.

[0019] As will be explained later, the combination of both aspects (extension of the opening range of the expansion device controlled by the control system + two expansion valves in parallel individually controlled by the control system) allows obtaining synergistic effects in relation to overcoming the disadvantages of the prior art.

Brief description of the drawings

[0020] Some advantageous aspects and considerations of the invention, as well as some non-limiting exemplary embodiments thereof will be described below with reference to the drawings, in which:

Figure 1 shows the operating range (in temperature) in a heating mode for an exemplary heat pump with R32 refrigerant fluid, where T_water indicates the water temperature at the outlet of the heat exchanger of the condenser, T_air indicates the air temperature external to the heat exchanger of the evaporator, and CR (compression ratio) is the ratio of the absolute delivery pressure to the absolute suction pressure of the compressor.
Figure 2 shows the operating range (under pressure) in a heating mode for an exemplary heat pump with R32 refrigerant fluid, where P_cond indicates the pressure of the refrigerant fluid in the condenser,

P_eva indicates the pressure of the refrigerant fluid in the evaporator, and CR (compression ratio) is the ratio of the absolute delivery pressure to the absolute suction pressure of the compressor.

Figure 3 shows the operating range (in temperature) in a cooling mode for an exemplary heat pump with R32 refrigerant fluid, where T_water indicates the water temperature at the outlet of the heat exchanger of the evaporator, T_air indicates the air temperature external to the heat exchanger of the condenser, and CR (compression ratio) is the ratio of the absolute delivery pressure to the absolute suction pressure of the compressor.

Figure 4 shows the operating range (under pressure) in a cooling mode for an exemplary heat pump with R32 refrigerant fluid, where P_cond indicates the pressure of the refrigerant fluid in the condenser, P_eva indicates the pressure of the refrigerant fluid in the evaporator, and CR (compression ratio) is the ratio of the absolute delivery pressure to the absolute suction pressure of the compressor.

Figure 5 shows the thermodynamic cycle of the heat pump for different masses of refrigerant fluid charged without and with the extension of the opening area of the expansion device, where the ordinate indicates the pressure of the refrigerant fluid and the abscissa indicates the specific enthalpy of the refrigerant fluid,

Figure 6 shows the variation of the coefficient of performance (COP) of a heat pump for different charge percentages of refrigerant fluid and for different total opening areas of the expansion device (Area EXV). The values are expressed as percentages with respect to a nominal reference situation (100%).

Figure 7 shows a heat pump according to an embodiment of the invention,

Figure 8 shows a heat pump according to a further embodiment.

[0021] Prior to the detailed description of the embodiments of the invention, there will be provided a more detailed explanation of the problems of the prior art, the scientific basis of the inventive idea, and the reasons why the heat pump according to the invention solves at least part of the problems of the prior art and allows reducing the amount of refrigerant fluid required for the operation of the heat pump.

[0022] Figures 1 - 4 show typical operating ranges for a heat pump operated with R32 refrigerant, where operating points are observed in a heating mode (figures 1 and 2) with high compression ratios CR (>8) at points of operation in a cooling mode (figures 3 and 4) with low compression ratios CR (about 1).

[0023] If we consider a heat pump working with an optimized nominal charge of refrigerant fluid, setting the parameters:

- outdoor temperature,
- water flow rate in a primary water circuit in a heat exchange relationship with an internal heat exchanger (inside a house),
- water temperature entering the internal heat exchanger,
- working frequency of the compressor,
- working frequency of a blower of an external heat exchanger,
- opening area of an expansion valve,

and having optimally chosen the parameters working frequency of the compressor, working frequency of the blower and opening area of the expansion valve, optimal performance in terms of heat capacity and COP are obtained and the heat pump reaches a state of equilibrium of operation or stationary operation, where the compressor delivery pressure depends on:

- the temperature of the water leaving the internal heat exchanger which characterizes the condensation of the refrigerant.
- the charge of refrigerant fluid because the more the charge of refrigerant fluid increases, the more the amount of liquid present in the condenser increases and the more the condenser will tend to flood. Therefore, if the refrigerant charge increases, the compressor delivery pressure also increases, whereas if the refrigerant charge decreases, the compressor delivery pressure also decreases.

[0024] The suction pressure of the compressor also depends on the refrigerant fluid charge, since an increase in the refrigerant fluid charge increases the amount of liquid phase in the evaporator and reduces the volume of the vapor phase that can be taken in by the compressor. Therefore, if the refrigerant charge increases, the suction pressure (absolute value) of the compressor also increases, whereas if the refrigerant charge decreases, the compressor suction pressure (absolute value) also decreases.

[0025] Therefore, with all other variables of the thermodynamic process being equal, a desired decrease in the refrigerant fluid entails a decrease in the suction and delivery pressures of the compressor (figure 5).

[0026] Figure 5 shows the results of simulations carried out by varying the R32 refrigerant charge in a heat pump operating with an example thermodynamic cycle, in a heating mode, with an outdoor air temperature of 7°C and a water temperature of 30°C.

[0027] In a second simulation ("80% nominal charge") the refrigerant charge was decreased by 20% compared to a first simulation ("nominal charge"). In a third simulation, the refrigerant charge was decreased by 20% compared to the first simulation ("nominal charge") and, moreover, the opening area of the expansion valve was increased with the aim of compensating for the decrease in compressor suction pressure.

[0028] Through the same simulations, the variation of the coefficient of performance (COP) was also determined for the different simulated situations (figure 6).

[0029] Figure 6 shows the coefficient of performance (COP) values of the exemplary heat pump being simulated as the refrigerant fluid charge varies. Leaving the opening area of the expansion valve unchanged and decreasing the refrigerant charge to 80% of the nominal charge, a decrease in the COP coefficient of performance of more than 5% is observed compared to the simulation with the nominal refrigerant charge. It is also observed that, by increasing the opening area of the expansion valve (but keeping the refrigerant charge low) the COP coefficient of performance can be re-increased to 99% of the nominal COP.

[0030] Still with reference to figures 1 - 4, at the points of minimum compression ratio CR, already with a nominal refrigerant charge (therefore undesirably high) it is necessary to adjust the expansion valve of the known heat pump up to its upper opening area limit, thus making it impossible to operate the known heat pump with a low refrigerant charge at these same points of the thermodynamic cycle, or making it necessary to use an expansion valve with an increased upper opening area limit, but with the same fine adjustment features. However, expansion valves with these features are not commercially available to date.

[0031] Still with reference to figures 1 - 4, at the points of maximum compression ratio CR (heating), with a nominal refrigerant charge (therefore undesirably high) it is necessary to adjust the known heat pump expansion valve up to its lower opening area limit, and a surplus charge of refrigerant fluid is accumulated in a storage vessel. At these operating points of the thermodynamic cycle, a desired decrease in refrigerant fluid charge would have less impact and the expansion valve opening area remains close to that needed for a nominal refrigerant fluid charge and would be manageable by known expansion valves already commercially available today.

[0032] However, in order to continue to operate in the maximum compression ratio points CR even with a low charge of refrigerant fluid, it is necessary to obtain very small opening areas and adjust them finely and with certainty.

[0033] Commercially available expansion valves do not allow solving a sufficiently broad opening area range. Commercially available adjustable expansion valves do not allow an increase in the maximum opening area without also increasing the minimum opening area limit and without losing the fine adjustment capability at the margins of the opening area range.

[0034] This limitation of the prior art is overcome by the heat pump according to the invention.

Description of embodiments

[0035] With reference to figures 7 and 8, a heat pump 1 comprises:

- a circuit 2 for circulating a refrigerant fluid,
- a first heat exchanger 3 placed in the circuit 2 and forming an evaporator 4,
- a compressor 5 placed in the circuit 2 downstream of the first heat exchanger 3,
- a second heat exchanger 6 placed in the circuit 2 downstream of the compressor 5 and forming a condenser 7,
- an expansion device 8 placed in the circuit 2 downstream of the second heat exchanger 6,
- an electronic control system 9 controlling the compressor 5 and the expansion device 8,

where:

- the compressor 5 is operable to take in the refrigerant fluid in the gaseous phase and at low pressure from the evaporator 4, compress the refrigerant fluid, and push it into the condenser 7,
- in the condenser 7, the compressed refrigerant fluid releases heat and condenses at high pressure,
- after leaving the condenser 7, the refrigerant fluid passes through the expansion device 8 which depressurizes it,
- the refrigerant fluid depressurized by the expansion device 8 enters into the evaporator 4 where it absorbs heat and evaporates at low pressure, before being taken in and compressed again by the compressor 5.

[0036] The expansion device 8 comprises a plurality of electric expansion valves 10, 11 (e.g., a first electric expansion valve 10 and a second electric expansion valve 11) placed in parallel in the circuit 2.

[0037] The electric expansion valves 10, 11 each have an individually adjustable opening area Aexv1, Aexv2 (e.g., the first electric expansion valve 10 has a first adjustable opening area Aexv1 and the second electric expansion valve 11 has a second adjustable opening area Aexv2) which together define a total opening area Aexv of the expansion device 8.

[0038] The control system 9 is configured to control the plurality of electric expansion valves 10, 11 in a total opening area range delimited by a lower total opening area limit Aexv_min and an upper total opening area limit Aexv_max, where the upper total opening area limit Aexv_max is greater than an upper individual opening area limit Aexv1_max, Aexv2_max of each of the electric expansion valves 10, 11.

[0039] According to an embodiment, the control system 9 is configured to adjust the individual opening areas Aexv1, Aexv2 of the electric expansion valves 10, 11 to assume different values at the same instant of time. This makes it possible to adjust at least one of the plurality of expansion valves 10, 11 to a valve position with good adjustment resolution.

[0040] According to an embodiment, the control system 9 is configured to completely close at least a first expansion valve 10 of the expansion valves 10, 11 and to adjust the individual opening area Aexv2 of at least a second expansion valve 11 of the electric expansion valves 10, 11 in a lower half of an individual opening area range of the second electric expansion valve 11. This makes it possible to avoid situations in which all the expansion valves 10, 11 are positioned close to their lower individual opening area limit Aexv1_min, Aexv2_min, in which the adjustment resolution is notoriously less fine and the adjustment itself more uncertain.

[0041] According to an aspect of the invention independent of the number of individual expansion valves (but synergistic in combination with a number of two expansion valves in parallel), during operation of the heat pump (1) with the expansion device (8) open, the electronic control system (9) controls an upper total opening area limit (Aexv_max) of the expansion device (8) and a lower total opening area limit (Aexv_min) of the expansion device (8),
where the electronic control system (9) and the expansion device (8) are configured so as to achieve a ratio (Aexv_max / Aexv_min) between the upper total opening area limit (Aexv_max) and the lower total opening area limit (Aexv_min) of the expansion device (8) greater than 15, or in the range from 22 to 70, or greater than 70.

[0042] Advantageously, said ratio (Aexv_max / Aexv_min) between the upper total opening area limit (Aexv_max) and the lower total opening area limit (Aexv_min) of the expansion device (8) is in the range from 22 to 26, or in the range from 23 to 25, or 24.

[0043] The embodiments described herein are particularly advantageous when referring to a heat pump providing a thermal power greater than 12 kW, e.g., 15 kW in heating at T_air = 7°C and T_water = 35°C.

[0044] This makes it possible to reduce the amount of refrigerant fluid as previously explained.

[0045] According to an embodiment, the upper total opening area limit Aexv_max of the expansion device 8 is greater than 2.5 mm^2, preferably from 3.14 mm^2 to 11.45 mm^2, for example **5.09 mm^2,** whereas the lower total opening area limit Aexv_min is less than 4% of the upper total opening area limit (Aexv_min < 0.04*Aexv_max), for example **0.21 mm^2.**

[0046] According to an embodiment, the upper total opening area limit (Aexv_max) of the expansion device (8) is in the range from 4.9 mm^2 to 5.2 mm^2, or from 5.04 mm^2 to 5.13 mm^2, or **5.09 mm^2.**

[0047] Advantageously, the total opening area range (Aexv_max - Aexv_min) expressed as the difference between the upper total opening area limit (Aexv_max) and the lower total opening area limit (Aexv_min) of the expansion device 8 is greater than 2.5 mm^2, preferably between 4.83 mm^2 and 11 mm^2, for example **4.88 mm^2.**

[0048] According to an embodiment, the total opening area range (Aexv_max - Aexv_min) expressed as the difference between the upper total opening area limit (Aexv_max) and the lower total opening area limit (Aexv_min) of the expansion device (8) opened and controlled by the electronic control system (9), is between 4.6 mm^2 and 5.18 mm^2, or between 4.83 mm^2 and 4.93 mm^2, or **4.88 mm^2.**

[0049] According to a further embodiment, a ratio Aexv1_max / Aexv1_min, Aexv2_max / Aexv2_min between the upper individual opening area limit Aexv1_max, Aexv2_max and the lower individual opening area limit Aexv1_min, Aexv2_min of one or each of the electric expansion valves 10, 11 is in the range from 10.5 to 13.5, preferably from 11.5 to 12.5, for example **12.**

[0050] According to an embodiment, the upper individual opening area limit Aexv1_max, Aexv2_max of one or each of the electric expansion valves 10, 11 is greater than 2.13 mm^2, preferably from 2.54mm^2 to 4.52 mm^2, for example **2.54 mm^2,** whereas the lower individual opening area limit Aexv1_min, Aexv2_min of one or each of the electric expansion valves 10, 11 is less than 0.25 mm^2, preferably from 0.106 mm^2 to 0.25 mm^2, for example **0.21 mm^2.**

[0051] According to an embodiment, the upper individual opening area limit (Aexv1_max, Aexv2_max) of one or each of the electric expansion valves (10, 11) is in the range from 2.4 mm^2 to 2.7 mm^2, or from 2.5 mm^2 to 2.6 mm^2, or **2.54 mm^2,** whereas the lower individual opening area limit (Aexv1_min, Aexv2_min) of one or each of the electric expansion valves (10, 11) is in the range from 0.20 mm^2 to 0.30 mm^2, or from 0.207 mm^2 to 0.213 mm^2, or **0.21 mm^2.**

[0052] According to an embodiment, the individual opening area range Aexv1_max - Aexv1_min, Aexv2_max - Aexv2_min expressed as the difference between the upper individual opening area limit Aexv1_max, Aexv2_max and the lower individual opening area limit Aexv1_min, Aexv2_min of one or each of the electric expansion valves 10, 11 is less than 5.27 mm^2, preferably between 1.22 mm^2 and 2.9 mm^2, for example **2.33 mm^2.**
According to an embodiment, the individual opening area range (Aexv1_max - Aexv1_min, Aexv2_max - Aexv2_min) expressed as the difference between the upper individual opening area limit (Aexv1_max, Aexv2_max) and the lower individual opening area limit (Aexv1_min, Aexv2_min) of one or each of the electric expansion valves (10, 11) is between 2.18 mm^2 and 2.48 mm^2, preferably between 2.30 mm^2 and 2.36 mm^2, for example **2.33 mm^2.**

[0053] According to a further embodiment, a ratio Aexv1_max / Aexv1_min,
Aexv2_max / Aexv2_min between the upper individual opening area limit Aexv1_max, Aexv2_max and the lower individual opening area limit Aexv1_min, Aexv2_min of one or each of the electric expansion valves 10, 11 is less than the ratio Aexv_max / Aexv_min between the upper total opening area limit Aexv_max and the lower total opening area limit Aexv_min of the expansion device 8, preferably the ratio Aexv_max / Aexv_min of the expansion device 8 is greater than or equal to **200** % of the ratio Aexv1_max / Aexv1_min , Aexv2_max / Aexv2_min

of each of the single expansion valves 10, 11.

[0054] According to a further embodiment, the individual opening area range Aexv1_max - Aexv1_min, Aexv2_max - Aexv2_min expressed as the difference between the upper individual opening area limit Aexv1_max, Aexv2_max and the lower individual opening area limit Aexv1_min, Aexv2_min of one or each of the electric expansion valves 10, 11 is less than the total opening area range Aexv_max - Aexv_min expressed as the difference between the upper total opening area limit Aexv_max and the lower total opening area limit Aexv_min of the expansion device 8, preferably the total opening area range Aexv_max - Aexv_min of the expansion device 8 is greater than or equal to **110%** of the individual opening area range Aexv1_max - Aexv1_min , Aexv2_max - Aexv2_min of each of the single expansion valves 10, 11.

[0055] According to an embodiment, the control system 9 is configured to control the compressor 5 and the expansion device 8 so that, in a heating mode (of the second heat exchanger 6 operating as a condenser 7), when the compression ratio CR of the compressor 5 is greater than 8, both the electric expansion valves 10, 11 are open and the total opening area Aexv of the expansion device 8 is greater than the upper individual opening area limit Aexv1_max, Aexv2_max of each of the expansion valves 10, 11.

[0056] This allows enlarging the expansion device opening range with respect to the prior art, and therefore using less refrigerant fluid with (at least almost) the same performance of the heat pump 1.

[0057] Those skilled in the art know that there are several parameters available for adjusting the heat pump. In fact, the total opening area Aexv of the expansion device 8 does not depend only on the compression ratio CR but also on the frequency of the compressor 5 and on the pressure at the inlet of the compressor 5. For example, with the same compression ratio CR, if the frequency of the compressor 5 is reduced, a small total opening area Aexv is also sufficient to let through the flow of refrigerant required to obtain optimal performance. With the same compression ratio CR of the compressor 5 and the same frequency of the compressor 5, with a reduction of the pressure at the inlet of the compressor 5, the total opening area Aexv of the expansion device 8 required to let through the refrigerant flow rate required for optimal performance is also reduced. The condition described above (CR > 8, Aexv > Aexv1_max, Aexv > Aexv2_max) is thus applicable to constant frequency f_comp and pressure on the suction side of the compressor 5.

[0058] According to an embodiment, the control system 9 is configured to control the compressor 5 and the expansion device 8 so that, in a cooling mode (of the second heat exchanger 6 operating as an evaporator 4), when the compression ratio CR of the compressor 5 is less than 2, only one 10 of the electric expansion valves 10, 11 is open and the other electric expansion valves 11 are completely closed.

[0059] This allows a fine adjustment of the expansion device 8 at low compression ratios of the compressor 5.

[0060] However, also with reference to this advantageous condition, those skilled in the art will appreciate that also in this case the explanations given above apply, relating to the dependence of the total opening area of the expansion device 8 not only on the compression ratio CR of the compressor 5, but also on the frequency of the compressor 5 and the pressure on the suction side of the compressor 5.

[0061] According to a preferred embodiment, the electric expansion valves 10, 11 are exactly two in number.

[0062] Preferably, all the electric expansion valves 10, 11 of the plurality of electric expansion valves 10, 11 are the same. This simplifies the control of the valves, reduces storage and assembly costs of the parts of the heat pump 1, and prevents assembly errors due to possible confusion between two different valves.

[0063] The compressor 5 can be connected in the circuit 2 by the interposition of a switching/reversing valve 12 which allows inverting the compression and circulation direction of the refrigerant fluid and thus switching the first heat exchanger 3 from evaporator 4 to condenser 7 and of the second heat exchanger 6 from condenser 7 to evaporator 4, allowing both cooling and heating the spaces in which the first and second heat exchangers are located (i.e., the fluid in contact with the first and second heat exchangers).

[0064] The heat pump 1 further comprises, in a known manner, a refrigerant fluid storage vessel/reservoir 13, connected to the circuit 2, e.g., between the first heat exchanger 3 (e.g., external unit) and the compressor 5, or directly upstream of the compressor 5 (figure 7).

[0065] The electronic control system 9 also controls the speed of the blower associated with the first heat exchanger 3 and the speed of the water pump or the conveyor associated with the second heat exchanger 6. Advantageously, the electronic control unit 9 controls the expansion device 8 also depending on the speed of the blower of the first heat exchanger 3 and of the conveyor of the second heat exchanger 6.

Description of embodiments for controlling the expansion device 8

[0066] The control system 9 calculates the target value of the total opening area Aexv according to a predetermined operating model of the refrigerant circuit of the heat pump 1 and then determines the target values of the individual opening areas Aexv1, Aexv2 of the two expansion valves, first expansion valve 10 and second expansion valve 11, depending on the condition Aexv = Aexv1 + Aexv2 and a further criterion or set of criteria for adjusting the individual opening areas Aexv1, Aexv2. The values of the individual opening areas Aexv1, Aexv2 can be converted into step number signals for controlling electric stepper motors of the expansion valves 10 and

11.

[0067] The adjustment criterion can comprise:

If the total opening area target value Aexv is less than a first predetermined threshold value X and indicative of an upper, high-resolution adjustable opening area limit with only one of the expansion valves 10, 11, only the first expansion valve 10 is adjusted to the total opening area target value Aexv = Aexv1 and the second expansion valve 11 is completely closed. The advantage obtainable by this criterion is an improved adjustment resolution.

[0068] If the total opening area target value Aexv is greater than a second predetermined threshold value Y, greater than the first threshold value X, and indicative of the upper individual opening area limit Aexv1_max of only one of the expansion valves 10, 11, both the first 10 and second 11 expansion valves are opened. The advantage obtainable by this criterion is the extension of the total opening area to allow optimal operation of the heat pump with a small amount of refrigerant fluid.

[0069] If the total opening area target value Aexv is greater than the first threshold value X and less than the second threshold value Y, only one or both of the first 10 and second 11 expansion valves are opened, but so as to position at least one of the expansion valves 10, 11 in an opening region with high adjustment resolution. This achieves the advantage of obtaining finer and more reliable adjustment of the expansion device 8 and, therefore, greater efficiency of the heat pump 1.

[0070] According to an embodiment, the control system 9 is configured so that, starting with only one expansion valve (e.g., the first expansion valve 10) open and all the others closed, as the total opening area target value Aexv increases, the individual opening area Aexv1 = Aexv of the first open expansion valve 10 increases until reaching the upper individual opening area limit value Aexv1 = Aexv = Aexv1_max of the only one expansion valve 10 open up to now and, if the upper individual opening area limit value Aexv1 > Aexv1_max of the first open expansion valve 10 is exceeded, keeps the first expansion valve open (e.g., at the upper individual opening limit Aexv1 = Aexv1_max) and also opens the second expansion valve 11 with an individual opening area Aexv2 = Aexv - Aexv1 of the second expansion valve 11 equal to the difference between the total opening area target value Aexv and the individual opening area Aexv1 of the first expansion valve 10 (e.g., with the individual opening area Aexv2 = Aexv - Aexv1_max of the second expansion valve 11 equal to the difference between the total opening area target value Aexv and the upper individual opening area limit Aexv1_max of the first expansion valve 10).

[0071] According to an embodiment, the control system 9 is configured so that, starting with only one expansion valve (for example the first expansion valve 10) open and all the others closed, as the total opening area target value Aexv increases, the individual opening area Aexv1 = Aexv of the first open expansion valve 10 increases until the total opening area target value Aexv < Aexv1_min + Aexv2_min reaches the sum of the lower individual opening area limits Aexv1_min + Aexv2_min of both or all the expansion valves 10, 11 and, upon exceeding the sum of the individual lower opening area limits Aexv1_min + Aexv2_min of both or all the expansion valves 10, 11, opens both or all the expansion valves 10, 11 with equal individual opening area values Aexv1 = Aexv2.

Description of embodiments for determining the total opening area target value Aexv of the expansion device 8

[0072] It is noted that heat pumps of the prior art already implement algorithms for determining the opening area target value of the expansion valve.

[0073] According to an embodiment, the control system 9 determines the total opening area target value Aexv of the expansion device 8 depending on a delivery temperature target value TD_target and a detected temperature value TD of the refrigerant fluid on the delivery side of the compressor 5.

[0074] The delivery temperature target value TD_target can be calculated according to the compression ratio CR, or depending on the compression ratio and the frequency of the compressor 5 and the heating or cooling operating mode.

[0075] Alternatively, the control system 9 determines the total opening area target value Aexv of the expansion device 8 depending on a superheating target value SH_target of the refrigerant fluid vapor at the inlet of the compressor 5.

[0076] According to an embodiment, the control system 9 determines the total opening area target value Aexv depending on:

- target flow rate (in kg/s) of the refrigerant fluid,
- detected flow rate (in kg/s) of the detected refrigerant fluid,
- frequency of the compressor [1/s],
- mass of the compressor [kg],
- specific heat of the material (steel) of the compressor [J/(Kg * K)],
- mass of the hydraulic oil of the compressor [kg],
- specific heat of the hydraulic oil of the compressor [J/(Kg * K)],
- density of the refrigerant fluid [kg/m^3] on the suction side of the compressor 5,
- specific heat of the refrigerant fluid [J/(Kg * K)],
- volume of the compressor cylinder [m^3].

Description of a preferred embodiment of the heat pump 1.

[0077] Figure 8 shows a further embodiment of the heat pump 1, with an outdoor unit 14 intended to be positioned outdoors, an indoor unit 15 intended to be positioned inside a building, and with an application/usage

35, for example a heating/cooling system with a primary water circuit 16.

[0078] The outdoor unit 14 comprises (inside a housing):

- the first heat exchanger 3, possibly equipped with an air blower 17, an external air temperature sensor 18, possibly a thermal probe 19' for measuring the temperature of the refrigerant at an intermediate point in the first heat exchanger 3, and a temperature sensor 19 of the refrigerant fluid between the first heat exchanger 3 and the expansion device 8,
- the compressor 5 with a temperature sensor 20 for the refrigerant fluid on the suction side of the compressor 5, and with a temperature sensor 21 for the refrigerant fluid on the delivery side of the compressor 5
- the refrigerant fluid storage vessel 13 arranged on the suction side of the compressor 5,
- a pressure switch 22 arranged on the delivery side of the compressor 5,
- the switching/reversing valve 12,
- (connection attachments of) tubes 23 of circuit 2,
- the expansion device 8 with the first electric expansion valve 10 and the second electric expansion valve 11,
- a refrigerant temperature sensor 24 placed in the circuit 2 between the expansion device 8 and the second heat exchanger 6.

[0079] The indoor unit 15 comprises (inside a housing):

- the second heat exchanger 6 which exchanges heat between the circuit 2 of the refrigerant fluid and the primary water circuit 16,
- a water pump 25 in the primary water circuit 16 upstream of the second heat exchanger 6,
- a flow rate sensor (flowmeter) 26, e.g., on the inlet side of the water pump 25,
- a water return temperature sensor 27, e.g., on the inlet side of the water pump 25,
- an expansion vessel 28 of the water connected to the primary water circuit 16, e.g., on the inlet side of the water pump 25,
- a water filter 29 connected to the primary water circuit 16, e.g., upstream of the water pump 25 and/or upstream of the water expansion vessel 28,
- a water delivery temperature sensor 30 (LWT = Leaving Water Temperature) at the outlet of the second heat exchanger 6,
- a backup electric heater 31 connected in the primary water circuit 16, preferably downstream of the second heat exchanger 6, to an associated temperature sensor 32, for the water at the outlet of the backup electric heater 31, and
- (connection attachments of) tubes 33 of circuit 2, and
- (connection attachments of) tubes 34 of the primary water circuit.

[0080] The user/application 35 comprises a part of the primary water circuit 16 and a water vessel 36 and/or a plurality of heaters or radiators 36 for heating and cooling.

List of reference numerals in the drawings

[0081]

heat pump 1
circuit 2
first heat exchanger 3
evaporator 4
a compressor 5
second heat exchanger 6
condenser 7
expansion device 8
electronic control system 9
first electric expansion valve 10
second electric expansion valve 11
switching/reversing valve 12
storage vessel 13
outdoor unit 14
indoor unit 15
primary water circuit 16
air blower 17
outdoor air temperature sensor 18
thermal probe 19' for the refrigerant fluid in the first heat exchanger
temperature sensor 19 for the refrigerant fluid at the first heat exchanger,
temperature sensor 20 for the refrigerant fluid on the suction side of the compressor 5
temperature sensor 21 for the refrigerant fluid on the delivery side of the compressor 5
high pressure switch (pressure switch) 22
(connection attachments of) tubes 23 of the refrigerant circuit 2
refrigerant temperature sensor 24
water pump 25
water flow rate sensor 26
water temperature sensor 27
water expansion vessel 28
water filter 29
water delivery temperature sensor 30
backup electric heater 31
temperature sensor 32 for the water at the outlet of the electric heater
(connection attachments of) tubes 33 of the refrigerant circuit 2
(connection attachments of the) tubes 34 of the primary water circuit
User/application 35
water vessels/radiators 36

Claims

1. A heat pump (1) comprising:

- a circuit (2) for circulating a refrigerant fluid,
- a first heat exchanger (3) placed in the circuit (2) and forming an evaporator (4),
- a compressor (5) placed in the circuit (2) downstream of the first heat exchanger (3),
- a second heat exchanger (6) placed in the circuit (2) downstream of the compressor (5) and forming a condenser (7),
- an expansion device (8) placed in the circuit (2) downstream of the second heat exchanger (6),
- an electronic control system (9) which controls the compressor (5) and the expansion device (8),

wherein, during operation of the heat pump (1) with the expansion device (8) open, the electronic control system (9) controls an upper total opening area limit (Aexv_max) of the expansion device (8) and a lower total opening area limit (Aexv_min) of the expansion device (8),
characterized in that the electronic control system (9) and the expansion device (8) are configured so as to create a ratio (Aexv_max / Aexv_min) between the upper total opening area limit (Aexv_max) and the lower total opening area limit (Aexv_min) of the expansion device (8) greater than 15, or in the range from 22 to 70, or greater than 70.

2. A heat pump (1) according to claim 1, wherein said ratio (Aexv_max / Aexv_min) between the upper total opening area limit (Aexv_max) and the lower total opening area limit (Aexv_min) of the expansion device (8) is in the range from 22 to 26, or in the range from 23 to 25, or 24.

3. A heat pump (1) according to any one of the preceding claims, wherein:

- the upper total opening area limit (Aexv_max) of the expansion device (8) is greater than 2.5 mm^2, or from 3.14 mm^2 to 11.45 mm^2, or **5.09 mm^2,** whereas
- the lower total opening area limit (Aexv_min) is less than 4% of the upper opening area limit (Aexv_min < 0.04*Aexv_max), or **0.21mm^2.**

4. A heat pump (1) according to claim 3, wherein the upper total opening area limit (Aexv_max) of the expansion device (8) is in the range from 4.9 mm^2 to 5.2 mm^2, or from 5.04 mm^2 to 5.13 mm^2, or **5.09 mm^2.**

5. A heat pump (1) according to claim 3 or 4, wherein the lower total opening area limit (Aexv_min) is in the range from 0.20 mm^2 to 0.22 mm^2, or from 0.205 mm^2 to 0.215 mm^2, or **0.21 mm^2.**

6. A heat pump (1) according to any one of the preceding claims, wherein the total opening area range (Aexv_max - Aexv_min) expressed as the difference between the upper total opening area limit (Aexv_max) and the lower total opening area limit (Aexv_min) of the expansion device (8) when it is open and controlled by the electronic control system (9), is greater than 2.5 mm^2, or in the range between 4.83 mm^2 and 11 mm^2, or **4.88 mm^2.**

7. A heat pump (1) according to any one of the preceding claims, wherein the total opening area range (Aexv_max - Aexv_min) expressed as the difference between the upper total opening area limit (Aexv_max) and the lower total opening area limit (Aexv_min) of the expansion device (8) open and controlled by the electronic control system (9), is comprised between 4.6 mm^2 e 5.18 mm^2, or between 4.83 mm^2 and 4.93 mm^2, or **4.88 mm^2.**

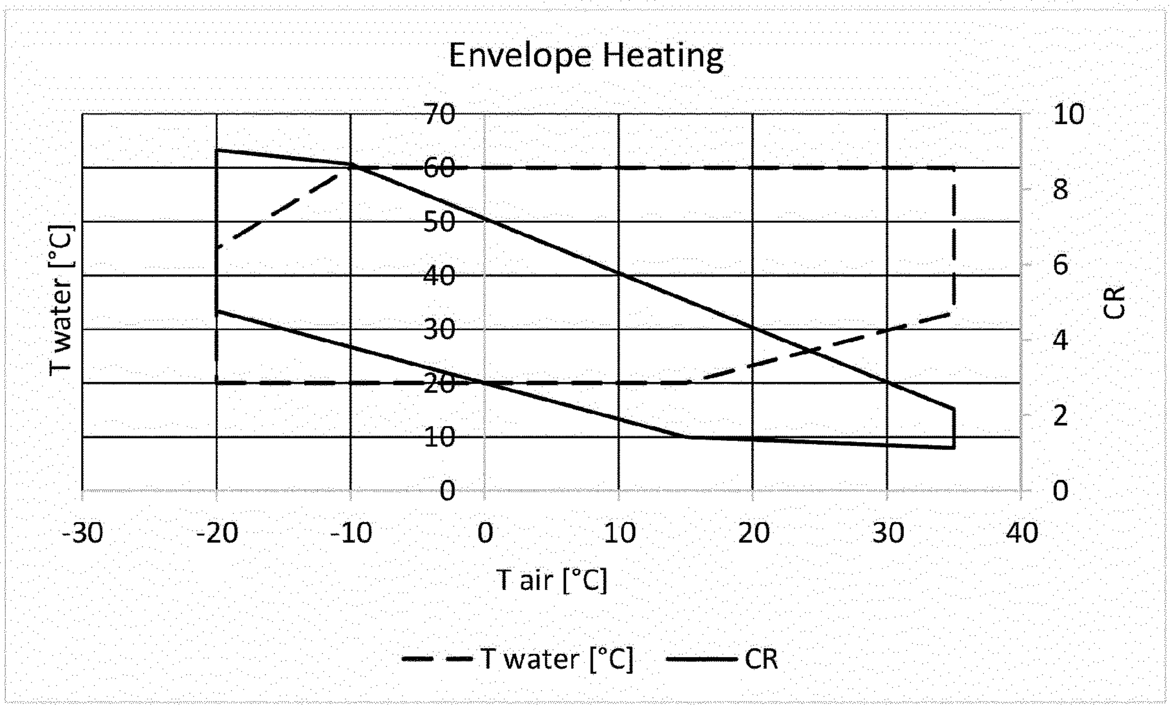
8. A heat pump (1) according to any one of the preceding claims, wherein:

- the expansion device (8) comprises a plurality of electric expansion valves (10, 11) placed in parallel in the circuit (2),
- the electric expansion valves (10, 11) each have an adjustable individual opening area (Aexv1, Aexv2) which together define a total opening area (Aexv) of the expansion device (8),
- the control system (9) is configured to control the plurality of electric expansion valves (10, 11) in a total opening area range delimited by a lower total opening area limit (Aexv_min) and an upper total opening area limit (Aexv_max),
- the upper total opening area limit (Aexv_max) is greater than an upper individual opening area limit (Aexv1_max, Aexv2_max) of each of the electric expansion valves (10,11).

9. A heat pump (1) according to any one of the preceding claims, wherein a ratio (Aexv1_max / Aexv1_min, Aexv2_max / Aexv2_min) between the upper individual opening area limit (Aexv1_max, Aexv2_max) and the lower individual opening area limit (Aexv1_min, Aexv2_min) of one or each of the electric expansion valves (10, 11) is in the range from 10.5 to 13.5, or from 11.5 to 12.5, or is **12.**

10. A heat pump (1) according to any one of the preceding claims, wherein the upper individual opening area limit (Aexv1_max, Aexv2_max) of one or each of the electric expansion valves (10, 11) is greater than 2.13 mm^2 , or from 2.54 mm^2 to 4.52 mm^2, or **2.54 mm^2,** whereas the lower individual opening area limit (Aexv1_min, Aexv2_min) of one or each of the electric expansion valves (10, 11) is less than 0.25 mm^2, or from 0.106 mm^2 to 0.25 mm^2, or **0.21 mm^2.**

11. A heat pump (1) according to any one of the preceding claims, wherein the individual opening area range (Aexv1_max - Aexv1_min, Aexv2_max - Aexv2_min) expressed as the difference between the upper individual opening area limit (Aexv1_max, Aexv2_max) and the lower individual opening area limit (Aexv1_min, Aexv2_min) of one or each of the electric expansion valves (10, 11) is less than 5.27 mm^2, or between 1.22 mm^2 and 2.9 mm^2, or **2.33 mm^2.**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60
50
40
30
20
10
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10
8
6
4
2
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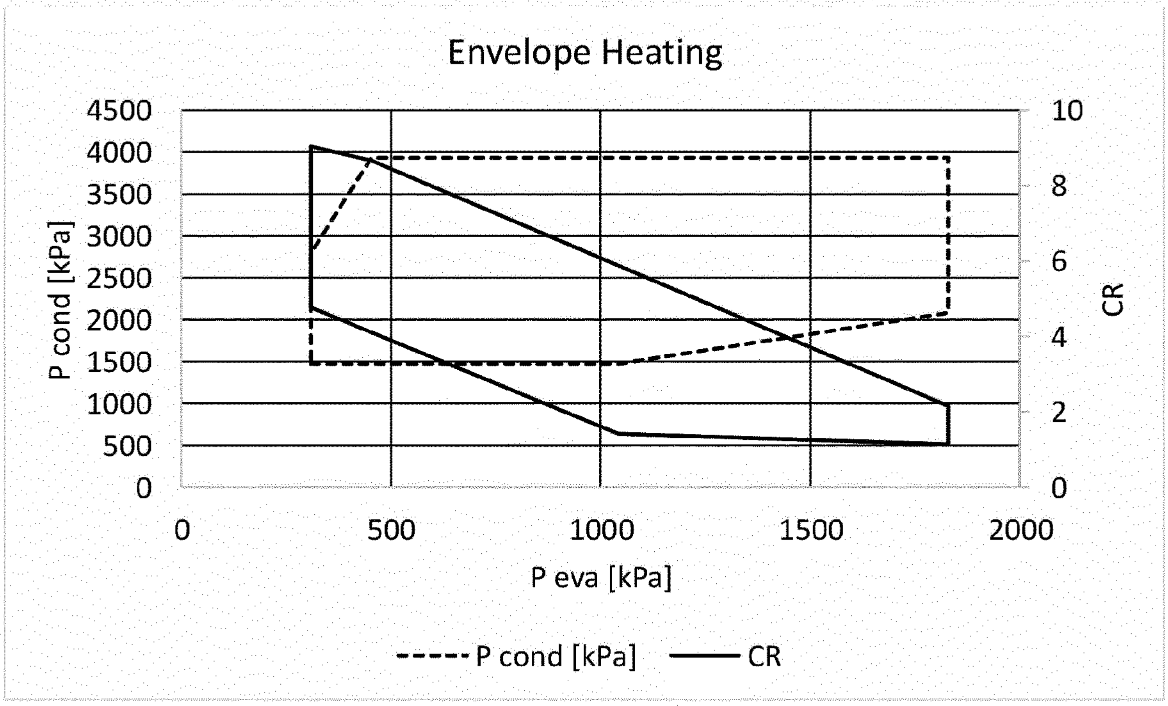
-30
-20
-10
0
10
20
30
40
T air [°C]
T water [°C]
CR

FIG. 1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3500
3000
2500
2000
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500
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10
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4
2
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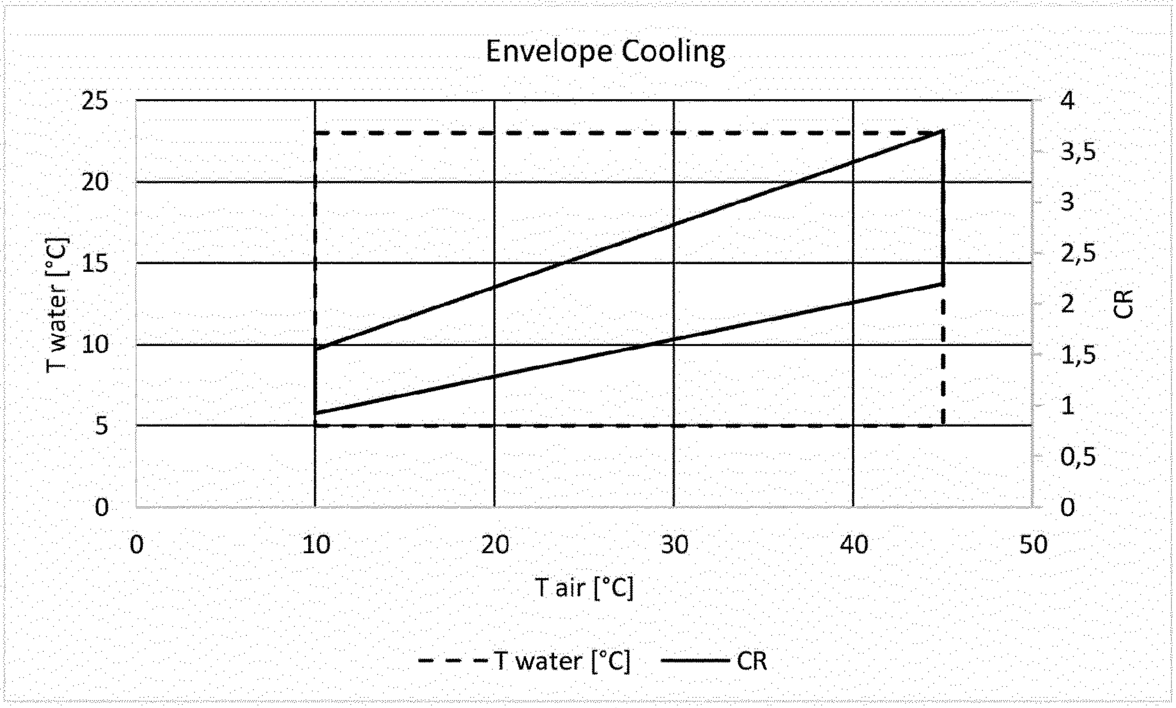
CR
0
500
1000
1500
2000
P eva [kPa]
P cond [kPa]
CR

FIG. 2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15
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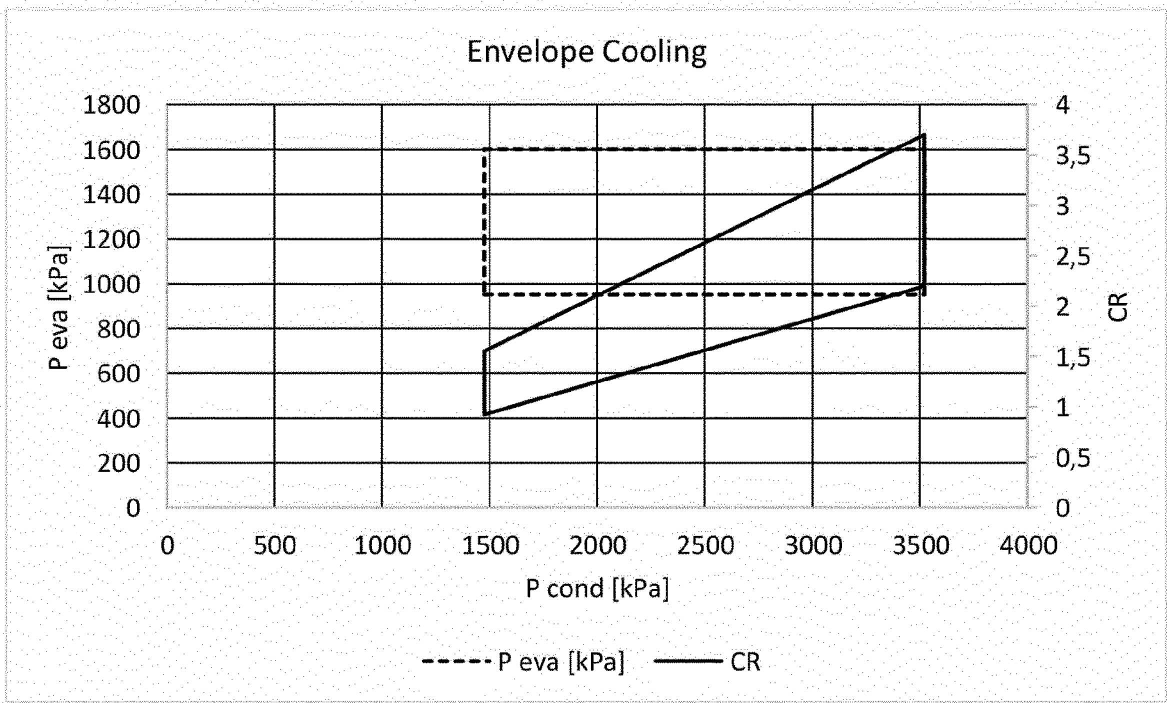
CR
0
10
20
30
40
50
T air [°C]
T water [°C]
CR

FIG. 3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1400
1200
1000
800
600
400
200
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2
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1
0,5
0
CR
0
500
1000
1500
2000
2500
3000
3500
4000
P cond [kPa]
P eva [kPa]
CR

FIG. 4

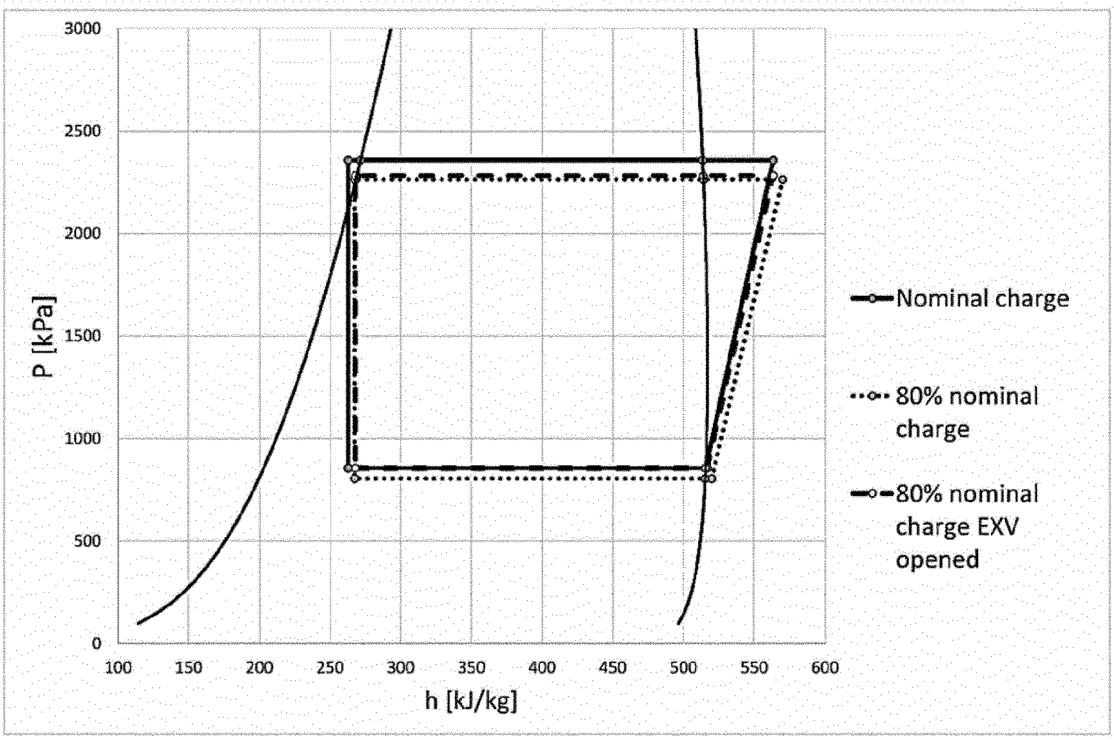
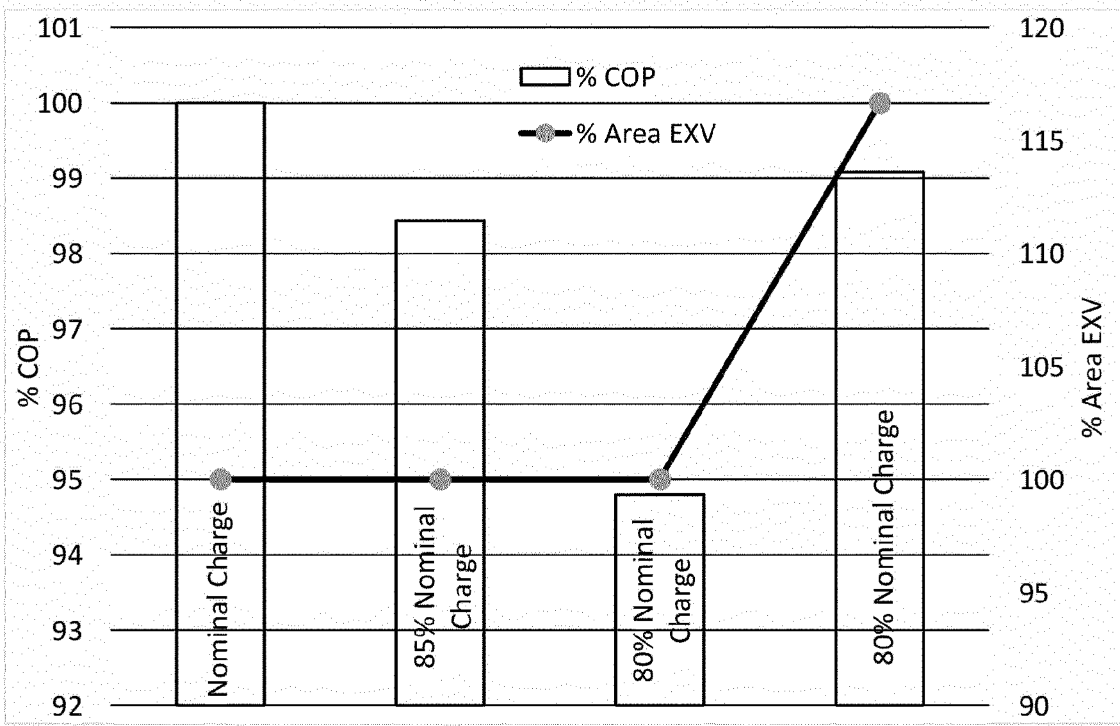

3000
2500
2000
1500
1000
500
0
P [kPa]
100
150
200
250
300
350
400
450
500
550
600
h [kJ/kg]
Nominal charge
80% nominal charge
80% nominal charge EXV opened

FIG. 5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100
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% COP
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% COP
% Area EXV
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80% Nominal Charge
80% Nominal Charge

FIG. 6

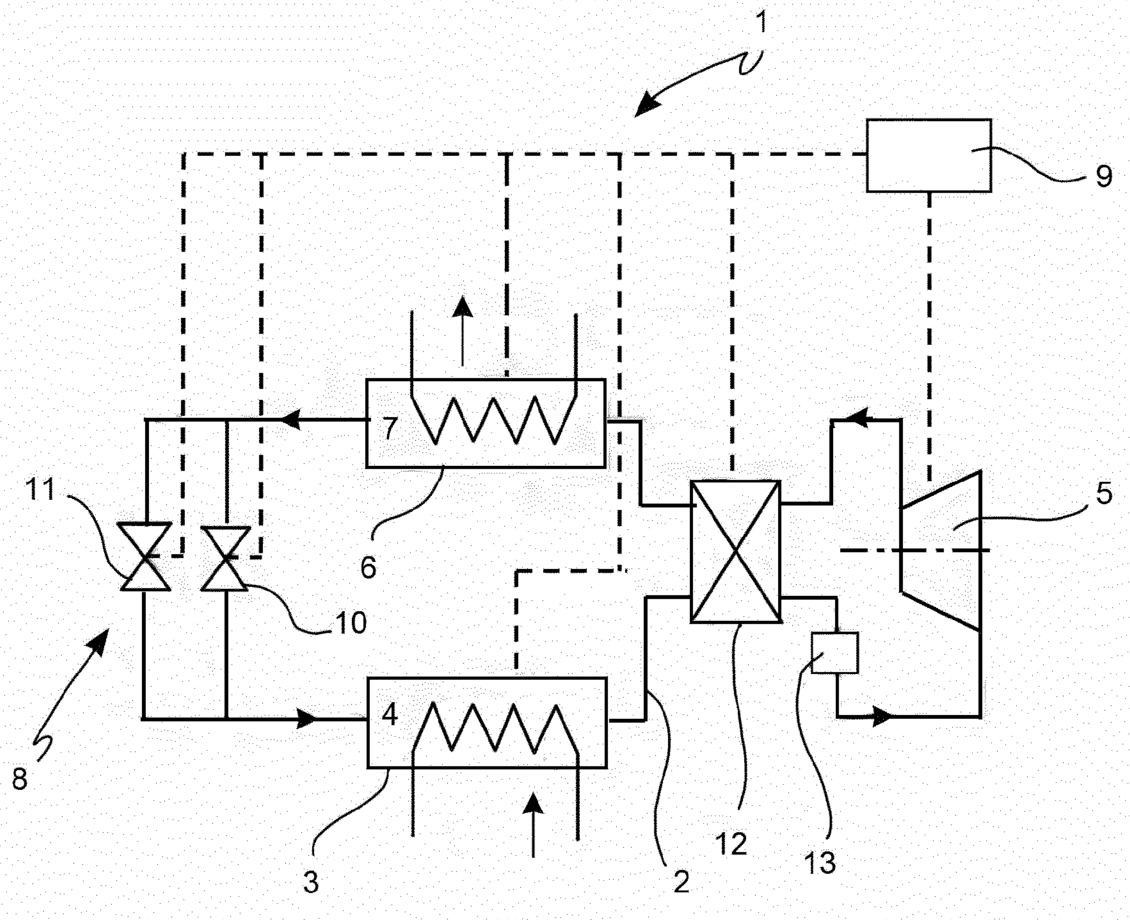
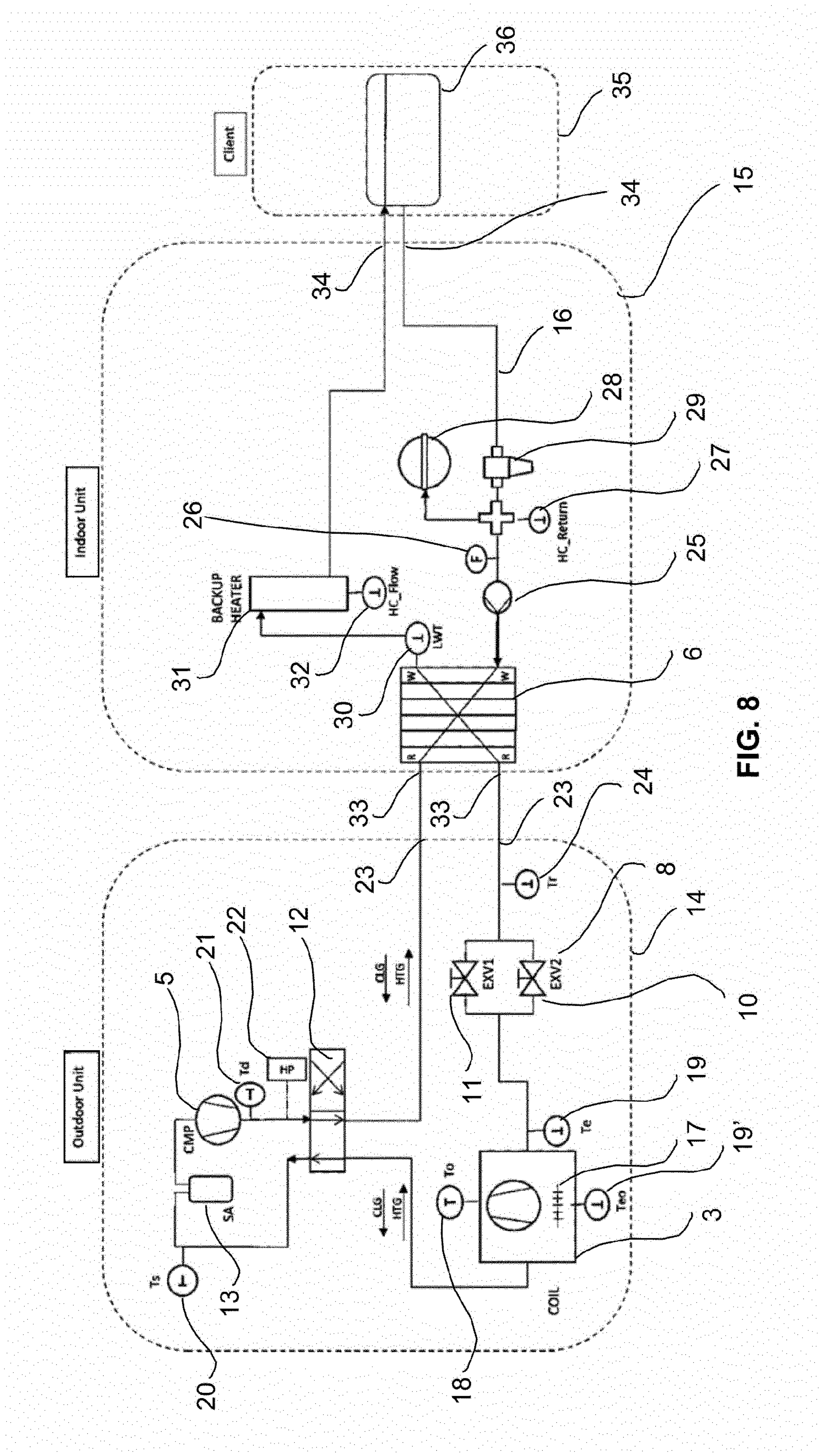


FIG. 7


Client
Indoor Unit
Outdoor Unit
BACKUP HEATER
HC_Flow
HC_Return
LWT
CMP
SA
HP
Td
Ts
To
Te
Teo
Tr
EXV1
EXV2
CLG
HTG
COIL
3
5
6
8
10
11
12
13
14
15
16
17
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19'
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FIG. 8

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EUROPEAN SEARCH REPORT

Application Number
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The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	30 October 2023	Gasper, Ralf

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