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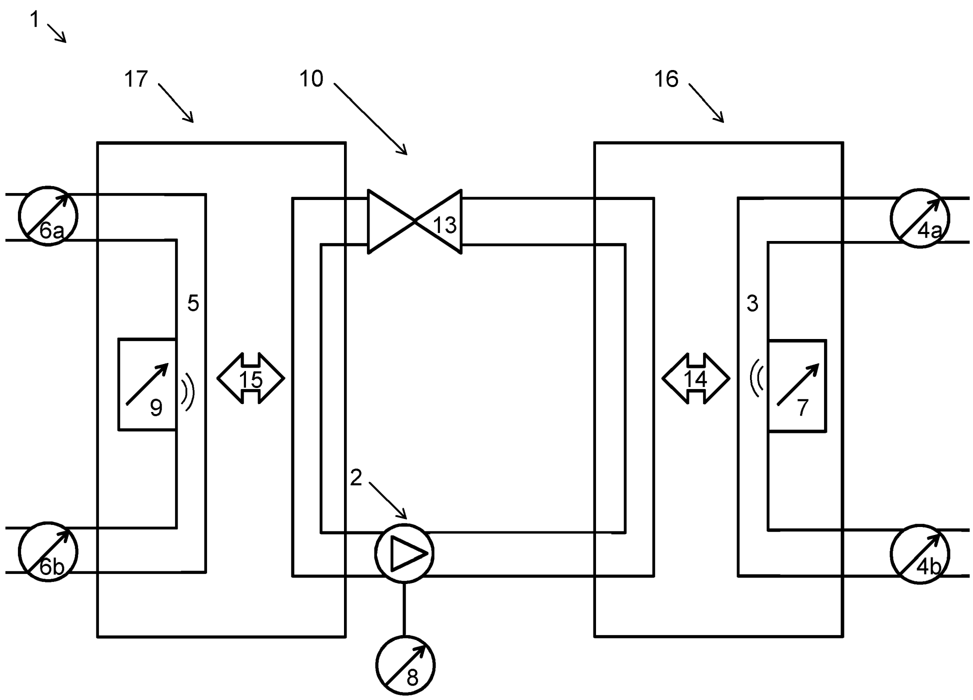
(54) OPTIMUM OPERATION OF A HEAT EXCHANGER

(57) Optimum operation of a heat exchanger. A method of operating a heat exchange assembly (1) having a compressor (2), a first circuit (3; 5) having first (4a; 6a) and second temperature sensors (4b; 6b), a first flow meter (7; 9), a second circuit (5; 3) having a third temperature sensor (6a; 4a), the heat exchange assembly (1) having a power meter selected from a compressor meter (8) or from a second circuit meter comprising the third temperature sensor (6a; 4a), a fourth temperature sensor (6b; 4b), and a second flow meter (9; 7), the method comprising: reading a first temperature signal from a sensor selected from the first temperature sensor (4a; 6a) or the second temperature sensor (4b; 6b), reading a second temperature signal from the third temperature sensor (6a; 4a); determining a first expected coefficient of performance from the first and second temperature signals; starting the compressor (2).

FIG 1



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Description

Background

[0001] The present disclosure relates to a heat exchanger such as a heat pump, a refrigerator, or an air conditioning system. More specifically, the instant disclosure focuses on operation of a heat exchanger at or above a minimum coefficient of performance.

[0002] Systems for **h**eating, **v**entilation and/or **a**ir-**c**onditioning (HVAC) comprise one or several heat exchangers such as heat pumps, refrigerators, or fan coil units. A **c**oefficient **o**f **p**erformance *COP* describes an efficiency of such heat pumps. The coefficient of performance relates an electrical or mechanical amount of received power *W* to an amount of heat *Q* transferred by the device:

$$COP = \frac{Q}{W}$$

[0003] A coefficient of performance typically exceeds one (*COP*>1). That is, an amount of heat *Q* transferred between a source and a sink typically exceeds the amount of received power *W* of the heat exchanger. For cooling purposes, heat is transferred from a cold reservoir to a hot reservoir. For heating purposes, heat is transferred from a hot reservoir to a cold reservoir.

[0004] Any cost of cooling and/or of heating generally is a function of the coefficient of performance of a heat exchanger. An operator can require a minimum coefficient of performance during operation of a heat exchanger. Operation at a minimum coefficient of performance can, however, not be technically feasible in some circumstances. That is, operation of a heat exchanger can become uneconomical for certain supply temperatures and/or for certain return temperatures. The operator can then switch over from one heat exchanger to an alternate source of cooling and/or to an alternate source of heating. The operator thereby tries to minimize cost at a system level.

[0005] The issue can be addressed by providing heat exchangers with lookup tables. These lookup tables provide coefficients of performance as a function of supply and return temperatures. *COP* values in between tabulated pairs of supply and return temperatures are then determined via (linear) interpolation. In other words, a compressor of a heat exchanger will be enabled if the *COP* at given supply and return temperatures exceeds a predetermined minimum.

[0006] Due to adverse factors such as ageing equipment, moisture, and/or icing, a coefficient of performance as determined from a lookup table is not always achieved. A heat exchanger operating below a predetermined coefficient of performance is then disabled. To that end, a compressor of the heat exchanger typically stops. A restart of the heat exchanger will under such circumstances be carried out only if a demand for heat is significantly lower than before.

[0007] The present disclosure teaches use of a learning algorithm to improve on control of heating, ventilation and/or air-conditioning. The present disclosure yields accurate predictions of coefficients of performance.

Summary

[0008] The instant disclosure provides a learning algorithm to update a lookup table with coefficients of performance. To that end, a coefficient of performance is measured with a heat exchanger in operation. Also, supply side and return temperatures are measured. An entry is read from the lookup table that corresponds to the measured supply side and return temperatures. The measured coefficient of performance is compared to the entry read from the lookup table. If the measured coefficient of performance deviates from the entry read from the lookup table by more than a threshold value, corrective action will be taken. That is, the entry read from the lookup table will be replaced by the measured coefficient of performance. The modified lookup table will be stored. The system will rely on the modified lookup table for future operation.

[0009] It is also an object of the present disclosure to readily apply results of the learning algorithm to a heat exchanger in operation. To that end, the modified lookup table is loaded from a memory prior to operation of the heat exchanger. The heat exchanger will be started on the condition that the coefficient of performance according to the modified lookup table exceeds a threshold value.

[0010] It is also an object of the present disclosure to apply the learning algorithm not only to a single entry of the lookup table. The learning algorithm rather modifies entries adjacent the entry that corresponds to the measured supply side and return temperatures. It is envisaged that the learning algorithm modifies nearest neighbors only.

[0011] In a related embodiment, the learning algorithm is applied to a subset of the entries of the lookup table. The learning algorithm can, be way of non-limiting example, be applied to also to second nearest neighbors or also to third nearest neighbors.

[0012] It is another object of the present disclosure to apply the learning algorithm not all entries of the lookup table. To that end, the learning algorithm modifies each entry of the lookup table as a function of a distance measure. The distance measure describes a distance between the supply side and return temperatures of an individual entry from the measured supply side and return temperatures.

[0013] It is a further object of the present disclosure to leverage characteristics of power systems. Most power systems operate at or near alternating voltages of 110 Volts phase-to-ground, 190 Volts phase-to-phase, 240 Volts phase-to-ground, or 415 Volts phase-to-phase. The electric amount of power received by a heat pump is then proportional to an amount of electric current feeding the heat exchanger. The coefficient of performance can thus be determined as a function of the inverse of that electric current.

[0014] It is a further object of the present disclosure to leverage sensors of a heat exchanger. A heat exchanger can, by way of non-limiting example, have supply side and return temperature sensors and supply side and return side flow sensors. An amount of heat transferred by the heat exchanger can then be determined from the readings of such sensors.

[0015] In a special embodiment, flow sensors having a wide dynamic range are employed either on the supply side or on the return side of the heat exchanger. These sensors afford determinations of amounts of transferred heat in an equally wide range.

Brief description of the drawings

[0016] Various features will become apparent to those skilled in the art from the following detailed description of the disclosed non-limiting embodiments. The drawings that accompany the detailed description can be briefly described as follows:

FIG 1 shows a heat exchange assembly according to the instant disclosure.

FIG 2 schematically depicts a heat exchange assembly in operative communication with an appliance controller.

FIG 3 shows an appliance controller in operative communication with the heat exchange assembly and with a remote controller.

Detailed decription

[0017] A heat exchange assembly (1) having a source circuit (5) and a sink circuit (3) is depicted in FIG 1. Each circuit (3, 5) is provided with one or several temperatures sensors (4a, 4b, 6a, 6b). In addition to the temperature sensors, the circuits (3, 5) also have flow meters (7, 9).

[0018] A heat pump (10) couples the source circuit (5) to the sink circuit (3). Heat is exchanged (15) between the source circuit (3) and the heat pump (10). Heat is also exchanged (14) between the heat pump (10) and the sink circuit (3).

[0019] The heat pump (10) comprises an expansion valve (13). The heat pump (10) further comprises a compressor (2). A compressor meter (8) connects to the compressor (2). The compressor meter (8) records signals indicative of electric amounts of power received by the compressor (2). It is envisaged that the compressor meter (8) is an integral part of the compressor (2).

[0020] Determination of a coefficient of performance requires signals indicative of an amount of power absorbed by a first circuit (3; 5). The first circuit (3; 5) is selected from the sink circuit (3) or from the source circuit (5). The first circuit (3; 5) has a first temperature sensor (4a; 6a) and a second temperature sensor (4b; 6b). The first (4a; 6a) and the second temperature sensors (4b; 6b) allow for a determination of a temperature drop in the first circuit (3; 5). An additional signal from a first flow meter (7; 9) is then retrieved. The signal from the first flow meter (7; 9) is multiplied with the temperature drop in the first circuit (3; 5). This product indicates an amount of power absorbed by or dissipated by the first circuit (3; 5).

[0021] Determination of a coefficient of performance also requires a signal indicative of a received amount of power. The received amount of power is received by the heat exchange assembly (1). In a first embodiment, this signal is obtained from a compressor meter (8) connected to the compressor (2). A coefficient of performance is then determined by relating the amount of power associated to the first circuit (3; 5) by the power received by the compressor (2).

[0022] In a second embodiment, a signal is obtained from a second circuit (5; 3). The second circuit (5; 3) is selected from the source circuit (5) or from the sink circuit (3). The second circuit (5; 3) is different from the first circuit (3; 5). The second circuit (5; 3) has a third temperature sensor (6a; 4a) and a fourth temperature sensor (6b; 4b). The third (6a; 4a) and the fourth temperature sensors (6b; 4b) allow for a determination of a temperature drop in the second circuit (5; 3). An additional signal from a second flow meter (9; 7) is then retrieved. The signal from the second flow meter (9; 7) is multiplied with the temperature drop in the second circuit (5; 3). This product indicates an amount of power absorbed by or dissipated by the second circuit (5; 3).

[0023] A received amount of power is then determined as a difference between amounts of power associated with the first (3; 5) and the second circuits (5; 3). By relating the amount of power associated with the first circuit (3; 5) to the received amount of power, a coefficient of performance is obtained.

[0024] The components (2, 4a, 4b, 6a, 6b, 7 - 9) of the heat exchange assembly (1) are in operative communication with an appliance controller (11). It is envisaged that the appliance controller (11) as shown on FIG 2 comprises a microcontroller and/or comprises a microcomputer.

[0025] In a special embodiment, the appliance controller (11) comprises an analog-to-digital converter. The analog-to-digital converter provides conversion of analog signals from the components (2, 4a, 4b, 6a, 6b, 7 - 9) into (digital) measures. The analog-to-digital converter can be an integral part of the appliance controller (11). That is, the analog-to-digital converter and the appliance controller (11) are arranged on the same system-on-a-chip.

[0026] In another special embodiment, the appliance controller (11) comprises a sigma-delta converter. The sigma-delta converter provides conversion of analog signals from the components (2, 4a, 4b, 6a, 6b, 7 - 9) into (digital) measures. The sigma-delta converter can be an integral part of the appliance controller (11). That is, the sigma-delta converter and the appliance controller (11) are arranged on the same system-on-a-chip.

[0027] FIG 3 illustrates that the appliance controller (11) can be in operative communication with a remote controller (12). The remote controller (12) can be a system controller and can control several appliance controllers (11). The remote controller (12) can also be part of an energy management system of a site.

[0028] The connection between the appliance controller (11) and the remote controller (12) can be bidirectional. A bidirectional connection affords flexibility. The connection between the appliance controller (11) and the remote controller (12) can also be unidirectional. Communication from the remote controller (12) to the appliance controller (11) is facilitated by such a unidirectional connection. A unidirectional connection reduces complexity.

[0029] As described in detail herein, the instant disclosure teaches a method of operating a heat exchange assembly (1), the heat exchange assembly (1) comprising a compressor (2), a first circuit (3; 5) having a first (4a; 6a) and a second temperature sensor (4b; 6b), and a first flow meter (7; 9), a second circuit (5; 3) having a third temperature sensor (6a; 4a), the heat exchange assembly (1) further comprising a power meter selected from a compressor meter (8) connected to the compressor (2) or from a second circuit meter comprising the third temperature sensor (6a; 4a), a fourth temperature sensor (6b; 4b) mounted to the second circuit (5; 3), and a second flow meter (9; 7) mounted to the second circuit (5; 3), the method comprising:

reading a first temperature signal from a sensor selected from the first temperature sensor (4a; 6a) or the second temperature sensor (4b; 6b), and reading a second temperature signal from the third temperature sensor (6a; 4a);
determining a first expected coefficient of performance from the first and second temperature signals;
starting the compressor (2);
after starting the compressor (2), reading a third signal from the first temperature sensor (4a; 6a), a fourth signal from the second temperature sensor (4b; 6b), a fifth signal from the first flow meter (7; 9), and a sixth signal from the power meter;
determining an actual coefficient of performance as a function of the third to sixth signals;
comparing the actual coefficient of performance to the first expected coefficient of performance; and
if the actual coefficient of performance is less than the first expected coefficient of performance:
modifying the first expected coefficient of performance as a function of the actual coefficient of performance.

[0030] The first temperature sensor (4a; 6a) is different from the second temperature sensor (4b; 6b) and is different from the third temperature sensor (6a; 4a) and is different from the fourth temperature sensor (6b; 4b). The second temperature sensor (4b; 6b) is different from the third temperature sensor (6a; 4a) and is different from the fourth temperature sensor (6b; 4b). The third temperature sensor (6a; 4a) and is different from the fourth temperature sensor (6b; 4b).

[0031] The first flow meter (7; 9) is different from the second flow meter (9; 7).

[0032] In an embodiment, the first temperature sensor (4a; 6a) is or comprises a flow temperature sensor. The second temperature sensor (4b; 6b) preferably is or comprises a return temperature sensor. The circuit (5) advantageously is or comprises a source circuit. The circuit (3) ideally is or comprises a sink circuit.

[0033] It is envisaged that the heat exchange assembly (1) comprises a heat pump (10) having the compressor (2). In an embodiment, the compressor (2) is or comprises a scroll compressor. The heat pump (10) advantageously also comprises the compressor meter (8). The heat pump (10) can also comprise an expansion valve (13) such as a thermostatic expansion valve. The expansion valve (13) is preferably arranged in series with the compressor (2).

[0034] In an embodiment, the sixth signal is or comprises an aggregate signal having a plurality of signals. In a preferred embodiment, the sixth signal is or comprises an aggregate signal having a plurality of sensor signals. This plurality of sensor signals can, by way of non-limiting example, comprise signals read from the third temperature sensor (6a; 4a), from the fourth temperature sensor (6b; 4b), and from the second flow meter (9; 7).

[0035] According to an aspect, the determination of the first expected coefficient of performance comprises the steps of:

reading a first temperature signal from a sensor selected from the first temperature sensor (4a; 6a) or the second temperature sensor (4b; 6b) and reading a second temperature signal from the third temperature sensor (6a; 4a);
producing a first measure of temperature from the first temperature signal and a second measure of temperature from the second temperature signal; and
determining a first expected coefficient of performance from the first and second measures of temperature.

[0036] It is envisaged that determination of the actual coefficient of performance comprises the steps of:

after starting the compressor (2), reading a third signal from the first temperature sensor (4a; 6a), a fourth signal from the second temperature sensor (4b; 6b), a fifth signal from the first flow meter (7; 9), and a sixth signal from the second circuit meter;

producing a third measure from the third signal, a fourth measure from the fourth signal, a fifth measure from the fifth signal, and a sixth measure from the sixth signal; and

determining an actual coefficient of performance as a function of the third to sixth measures.

[0037] The instant disclosure also teaches a method of operating a heat exchange assembly (1), the heat exchange assembly (1) comprising a source circuit (5) and a sink circuit (3), a heat pump (10) having an expansion valve (13) and coupling the source circuit (5) to the sink circuit (3) for heat exchange (15) between the source circuit (5) and the sink circuit (3), the heat exchange assembly (1) further comprising a first heat exchanger (16; 17) and a second heat exchanger (17; 16), a compressor (2), a first circuit (3; 5) having a first (4a; 6a) and a second temperature sensor (4b; 6b), and a first flow meter (7; 9), a second circuit (5; 3) having a third temperature sensor (6a; 4a), the heat exchange assembly (1) further comprising a power meter selected from a compressor meter (8) connected to the compressor (2) or from a second circuit meter comprising the third temperature sensor (6a; 4a), a fourth temperature sensor (6b; 4b) mounted to the second circuit (5; 3), and a second flow meter (9; 7) mounted to the second circuit (5; 3), the method comprising:

reading a first temperature signal from a sensor selected from the first temperature sensor (4a; 6a) or the second temperature sensor (4b; 6b), and reading a second temperature signal from the third temperature sensor (6a; 4a);

determining a first expected coefficient of performance from the first and second temperature signals;

starting the compressor (2);

after starting the compressor (2), reading a third signal from the first temperature sensor (4a; 6a), a fourth signal from the second temperature sensor (4b; 6b), a fifth signal from the first flow meter (7; 9), and a sixth signal from the power meter;

determining an actual coefficient of performance as a function of the third to sixth signals;

comparing the actual coefficient of performance to the first expected coefficient of performance; and

if the actual coefficient of performance is less than the first expected coefficient of performance:

modifying the first expected coefficient of performance as a function of the actual coefficient of performance.

[0038] The present disclosure also teaches any method of the aforementioned methods, the method comprising the steps of:

reading a lookup table from a memory; and

employing the lookup table to determine the first expected coefficient of performance as a function of the first temperature signal and of the second temperature signal.

[0039] The method ideally comprises the steps of:

reading a lookup table from a memory; and

employing the lookup table to determine the first expected coefficient of performance as a direct function of the first temperature signal and of the second temperature signal. Direct functions accept no arguments other than those specified. The lookup table advantageously comprises a plurality of rows, the plurality of rows mapping pairs of temperature signals each to an expected coefficient of performance. The expected coefficient of performance can, by way of non-limiting example, be a first expected coefficient of performance or a second expected coefficient of performance or a modified first coefficient of performance.

[0040] The present disclosure also teaches any method of the aforementioned methods, the method comprising the steps of:

reading a mathematical relationship from a memory; and

employing the mathematical relationship to calculate the first expected coefficient of performance as a function of the first temperature signal and as a function of the second temperature signal.

[0041] The method ideally comprises the steps of:

reading a mathematical relationship from a memory; and

employing the mathematical relationship to calculate the first expected coefficient of performance as a direct function of the first temperature signal and of the second temperature signal. Direct functions accept no arguments other than those specified. A direct function can, nonetheless, accept a parameter. The mathematical relationship advantageously maps pairs of temperature signals each to an expected coefficient of performance. The expected coefficient of performance can, by way of non-limiting example, be a first expected coefficient of performance or a second expected coefficient of performance or a modified first coefficient of performance.

[0042] It is envisaged that the memory is a non-volatile memory. In a first embodiment, the heat exchange assembly (1) comprises the memory. In a related embodiment, the heat exchange assembly (1) comprises a controller (11) such as a microcontroller and/or a microprocessor, the controller (11) comprising the memory such as the non-volatile memory. In a second embodiment, the heat pump (10) comprises the memory. In an embodiment related to the second embodiment, the heat pump (10) comprises a controller such as a microcontroller and/or a microprocessor, the controller comprising the memory such as the non-volatile memory. In a third embodiment, the compressor (2) comprises the memory. In an embodiment related to the third embodiment, the compressor (2) comprises a controller such as a microcontroller and/or a microprocessor, the controller comprising the memory such as the non-volatile memory.

[0043] The instant disclosure also teaches any method of the aforementioned methods, the method comprising the step of:
modifying the first expected coefficient of performance by setting the first expected coefficient of performance equal to the actual expected coefficient of performance.

[0044] The present disclosure also teaches any method of the aforementioned methods, the method comprising the steps of:

after starting the compressor (2), reading a sixth signal from the power meter
by reading a seventh signal from the third temperature sensor (6a; 4a) and
by reading an eighth signal from the fourth temperature sensor (6b; 4b) and
by reading a ninth signal from the second flow meter (9; 7).

[0045] The method advantageously comprises the steps of:

after starting the compressor (2), reading a sixth signal from the second circuit meter

by reading a seventh signal from the third temperature sensor (6a; 4a) and

by reading an eighth signal from the fourth temperature sensor (6b; 4b) and

by reading a ninth signal from the second flow meter (9; 7) and

by determining a second circuit difference signal as a function of a difference between the seventh signal and the eighth signal and

by producing the sixth signal as a function of a product between the second circuit difference signal and the ninth signal. In this embodiment, the power meter is the second circuit meter.

[0046] The present disclosure also teaches any method of the aforementioned methods, wherein the power meter is the second circuit meter, the method comprising the steps of:

producing a sourced energy measure from the sixth signal;
producing a third measure from the third signal, a fourth measure from the fourth signal, and a fifth measure from the fifth signal;
determining a temperature difference measure between the third measure and the fourth measure;
determining a delivered energy measure as a function of a product of the temperature difference measure and of the fifth measure;
determining an energy difference measure as a difference between the delivered energy measure and the sourced energy measure; and
determining the actual coefficient of performance by relating the delivered energy measure to the energy difference measure.

[0047] In a preferred embodiment, determination of the actual coefficient of performance comprises the steps of:

producing a sourced energy measure from the sixth signal;
producing a third measure from the third signal, a fourth measure from the fourth signal, and a fifth measure from the fifth signal;
calculating a temperature difference measure between the third measure and the fourth measure;
calculating a delivered energy measure as a function of a product of the temperature difference measure and of the fifth measure;
calculating an energy difference measure as a difference between the delivered energy measure and the sourced energy measure; and
calculating the actual coefficient of performance by dividing the delivered energy measure by the energy difference measure.

[0048] In this embodiment, the power meter is the second circuit meter.

[0049] The instant disclosure also teaches any method of the aforementioned methods, wherein the power meter is the compressor meter (8), the method comprising the step of:

after starting the compressor (2), reading a sixth signal from the power meter by
reading a sixth signal from the compressor meter (8), the sixth signal being indicative of an amount of power received by the compressor (2).

[0050] The present disclosure also teaches the aforementioned method, the method comprising the steps of:

producing a third measure from the third signal, a fourth measure from the fourth signal, and a fifth measure from the fifth signal;
determining a temperature difference measure between the third measure and the fourth measure;
determining a delivered energy measure as a func-

tion of a product of the temperature difference measure and of the fifth measure;
producing a compressor power measure from the sixth signal; and
determining the actual coefficient of performance by relating the delivered energy measure to the compressor power measure.

[0051] In a preferred embodiment, determination of the actual coefficient of performance comprises the steps of:

producing a third measure from the third signal, a fourth measure from the fourth signal, and a fifth measure from the fifth signal;
calculating a temperature difference measure between the third measure and the fourth measure;
calculating a delivered energy measure as a function of a product of the temperature difference measure and of the fifth measure;
producing a compressor power measure from the sixth signal; and
calculating the actual coefficient of performance by dividing the delivered energy measure by the compressor power measure.

[0052] In this embodiment, the power meter is the compressor meter (8).
[0053] The instant disclosure also teaches any method of the aforementioned methods, the method comprising the step of:
storing the modified first expected coefficient of performance in a memory.
[0054] It is envisaged that a lookup table is modified as a function of the modified first expected coefficient of performance. The modified lookup table is then stored in a memory. The modified lookup table is preferably stored in a non-volatile memory such as a non-volatile memory of the heat exchange assembly (1) and/or a non-volatile memory of the heat pump (10) and/or a non-volatile memory of the compressor (2).
[0055] It is envisaged that a mathematical relationship is modified as a function of the modified first expected coefficient of performance. In an embodiment, the mathematical relationship is or comprises a polynomial equation. A polynomial coefficient of the polynomial equation can in this case be modified as a function of the modified first coefficient of performance. The modified mathematical relationship is then stored in a memory. The modified mathematical relationship is preferably stored in a non-volatile memory such as a non-volatile memory of the heat exchange assembly (1) and/or a non-volatile memory of the heat pump (10) and/or a non-volatile memory of the compressor (2).
[0056] It is envisaged that a neural network such as a convolutional neural network is modified as a function of the modified first expected coefficient of performance. The neural network advantageously has an input layer with input neurons each for the first temperature signal and for the second temperature signal. The neural network also has an output layer with a neuron representing the first expected coefficient of performance. The neural network can further comprise one or several hidden layers in between the input layer and the output layer. Weighed connections provide connections between the layers. In an exemplary embodiment, the neural network is modified by changing at least one weight of at least one connection between two neurons. The weight of the at least one connection thus changes as a function of the modified first expected coefficient of performance.
[0057] The present disclosure also teaches any method of the aforementioned methods, the method comprising the steps of:

receiving a minimum coefficient, the minimum coefficient indicating a minimum coefficient of performance;
stopping the compressor (2);
with the compressor (2) stopped, reading a tenth signal from a sensor selected from the first temperature sensor (4a; 6a) or the second temperature sensor (4b; 6b) and reading an eleventh signal from the third temperature sensor (6a; 4a);
producing a tenth measure from the tenth signal and an eleventh measure from the eleventh signal;
determining a second expected coefficient of performance as a function of the tenth measure, of the eleventh measure, and of the modified first coefficient of performance;
comparing the second expected coefficient of performance to the minimum coefficient; and
if the second expected coefficient of performance exceeds the minimum coefficient:
starting the compressor (2).

[0058] It is envisaged that a start signal will be sent to the compressor (2) if the second expected coefficient of performance exceeds the minimum coefficient. The start signal causes the compressor (2) to start. The start signal advantageously causes the compressor (2) to start in response to the compressor (2) receiving the start signal.
[0059] The instant disclosure also teaches any of the aforementioned methods involving a modified first expected coefficient stored in a memory and determination of a second expected coefficient of performance, the method comprising the steps of:

reading the modified first expected coefficient of performance from the memory; and
after reading the modified first expected coefficient of performance from the memory, determining a second expected coefficient of performance as a function of the tenth measure, of the eleventh measure, and of the modified first coefficient of performance.

[0060] Determination of the second expected coefficient of performance preferably comprises the steps of:

reading the modified first expected coefficient of performance from the memory; and

after reading the modified first expected coefficient of performance from the memory, determining a second expected coefficient of performance as a direct function of the tenth measure, of the eleventh measure, and of the modified first coefficient of performance. Direct functions accept no arguments other than those specified.

[0061] The instant disclosure also teaches any of the aforementioned methods involving a comparison between a minimum signal and a predetermined threshold, the method comprising the step of:

if and only if the second expected coefficient of performance exceeds the minimum signal by a predetermined threshold:

starting the compressor (2).

[0062] It is envisaged that a start signal will be sent to the compressor (2) if and only if the second expected coefficient of performance exceeds the minimum signal by a predetermined threshold. The start signal causes the compressor (2) to start. The start signal advantageously causes the compressor (2) to start in response to the compressor (2) receiving the start signal.

[0063] According to an aspect of the present disclosure, the compressor (2) is started and/or is enabled if and only if the second expected coefficient of performance exceeds the minimum coefficient at least by 0.1. According to a special aspect of the instant disclosure, the compressor (2) is started and/or is enabled if and only if the second expected coefficient of performance exceeds the minimum coefficient at least by 0.2. According to a further aspect of the instant disclosure, the compressor (2) is started and/or is enabled if and only if the second expected coefficient of performance exceeds the minimum coefficient at least by 0.5.

[0064] In an embodiment, the minimum coefficient is received from a remote controller (12) such as a system controller. The minimum coefficient of performance can also be received from and/or be manually entered by an operator. In another embodiment, the minimum coefficient is received by reading the minimum coefficient from a memory of the heat exchange assembly (1) such as a non-volatile memory of the heat exchange assembly (1). In yet another embodiment, the minimum coefficient is received by reading the minimum coefficient from a memory of the heat pump (10) such as a non-volatile memory of the heat pump (10). In still another embodiment, the minimum coefficient is received by reading the minimum coefficient from a memory of the compressor (2) such as a non-volatile memory of the compressor (2).

[0065] The instant disclosure further teaches a non-transitory, computer-readable medium containing a program which executes the steps of any of the methods of the instant disclosure.

[0066] The present disclosure still teaches a non-transitory computer-readable medium having stored thereon instructions that, in response to execution, cause a system comprising a processor to perform the operations according to any method of this disclosure.

[0067] The computer-readable medium advantageously contains instructions that when executed perform a method according to the present disclosure. It is also envisaged that the computer-readable medium is tangible.

[0068] The present disclosure also teaches a heat exchange assembly (1) comprising a compressor (2), a first circuit (3; 5) having a first temperature sensor (4a; 6a) and a second temperature sensor (4b; 6b), and a first flow meter (7; 9), a second circuit (5; 3) having a third temperature sensor (6a; 4a), the heat exchange assembly (1) further comprising a power meter selected from a compressor meter (8) connected to the compressor (2) or from a second circuit meter comprising the third temperature sensor (6a; 4a), a fourth temperature sensor (6b; 4b) mounted to the second circuit (5; 3), and a second flow meter (9; 7) mounted to the second circuit (5; 3), the heat exchange assembly (1) further comprising an appliance controller (11) in operative communication with the first temperature sensor (4a; 6a), with the second temperature sensor (4b; 6b), with the first flow meter (7; 9), with the compressor (2), and with the power meter, the appliance controller (11) being configured to:

read a first signal from a sensor selected from the first temperature sensor (4a; 6a) or the second temperature sensor (4b; 6b), and read a second signal from the third temperature sensor (6a; 4a);

produce a first measure from the first signal and a second measure from the second signal;

determine a first expected coefficient of performance from the first and second measures;

send a start signal to the compressor (2), the start signal causing the compressor (2) to start operation;

after sending the start signal, read a third signal from the first temperature sensor (4a; 6a), a fourth signal from the second temperature sensor (4b; 6b), a fifth signal from the first flow meter (7; 9), and a sixth signal from the power meter;

produce a third measure from the third signal, a fourth measure from the fourth signal, a fifth measure from the fifth signal, and a sixth measure from the sixth signal;

determine an actual coefficient of performance from the third measure, from the fourth measure, from the fifth measure, and from the sixth measure;

compare the actual coefficient of performance to the first expected coefficient of performance; and

if the actual coefficient of performance is less than the first expected coefficient of performance:

modify the first expected coefficient of performance as a function of the actual coefficient of performance.

[0069] The controller (11) is advantageously configured to:

read a first temperature signal from a sensor selected from the first temperature sensor (4a; 6a) or the second temperature sensor (4b; 6b), and read a second temperature signal from the third temperature sensor (6a; 4a) ;
produce a first measure of temperature from the first temperature signal and a second measure of temperature from the second temperature signal; and
determine a first expected coefficient of performance from the first and second temperature measures.

[0070] In an embodiment, the heat exchange assembly (1) comprises one or more heat exchangers (16, 17). A first heat exchanger (16; 17) couples the first circuit (3; 5) to the heat pump (10). A second heat exchanger (17; 16) couples the second circuit (5; 3) to the heat pump (10).

[0071] It is envisaged that the appliance controller (11) is configured to:

send a start signal to the compressor (2), the start signal causing the compressor (2) to start operating; and
with the compressor (2) operating, read a third signal from the first temperature sensor (4a; 6a), a fourth signal from the second temperature sensor (4b; 6b), a fifth signal from the first flow meter (7; 9), and a sixth signal from the power meter.

[0072] The appliance controller (11) is advantageously configured to:

determine an actual coefficient of performance from the third measure, from the fourth measure, from the fifth measure, and from the sixth measure
by determining a temperature difference measure between the third measure and the fourth measure and
by determining a delivered energy measure as a function of a product of the temperature difference measure and of the fifth measure and
by determining the actual coefficient of performance as a function of the delivered energy measure and of the sixth measure.

[0073] It is envisaged that the heat exchange assembly (1) comprises a heat pump (10) having the compressor (2). In an embodiment, the compressor (2) is or comprises a scroll compressor. The heat pump (10) advantageously also comprises the compressor meter (8). The heat pump (10) can also comprise an expansion valve (13) such as a thermostatic expansion valve. The expansion valve (13) is preferably arranged in series with the compressor (2).

[0074] The compressor (2) is ideally configured to be started and/or to be stopped. A start of the compressor (2) starts and/or enables operation of the compressor (2). A start of the compressor (2) also starts and/or enables operation of the heat pump (10). A stop of the compressor (2) stops and/or disables and/or halts operation of the compressor (2). A stop of the compressor (2) also stops and/or disables and/or halts operation of the heat pump (10).

[0075] The first flow meter (7; 9) is advantageously secured relative to the first circuit (3; 5). The second flow meter (9; 7) is advantageously secured relative to the second circuit (5; 3). The first flow meter (7; 9) is ideally mounted to the first circuit (3; 5). The second flow meter (9; 7) is ideally mounted to the second circuit (5; 3). The first flow meter (7; 9) is preferably associated with the first circuit (3; 5). The second flow meter (9; 7) is preferably associated with the second circuit (5; 3).

[0076] In an embodiment, the heat exchange assembly (1) comprises a first conduit, the first conduit having the first circuit (3; 5). It is also envisaged that the heat exchange assembly (1) comprises a second conduit, the second conduit having the second circuit (5; 3).

[0077] The compressor meter (8) is advantageously configured to produce a compressor power signal, the compressor power signal being indicative of an amount of power received by the compressor (2). The compressor meter (8) is ideally configured to produce a compressor power signal, the compressor power signal being indicative of an electric amount of power received by the compressor (2).

[0078] The heat exchange assembly (1) advantageously comprises a first circuit meter having the first temperature sensor (4a; 6a), the second temperature sensor (4b; 6b), and the first flow meter (7; 9). The first circuit meter is advantageously configured to produce a first circuit power signal, the first circuit power signal being indicative of an amount of thermal power dissipated by or absorbed by the first circuit (3; 5). Production of the first circuit power signal typically comprises the steps of:

recording first circuit temperature signals from each of the first temperature sensor (4a; 6a) and the second temperature sensor (4b; 6b);
producing first circuit measures of temperature from the first circuit temperature signals;
determining a first circuit difference measure between the first circuit measures of temperature;
recording a first circuit flow signal from the first flow meter (7; 9);
producing a first circuit flow measure from the first circuit flow signal; and
producing the first circuit power signal as a function of a product of the first circuit difference measure and the first circuit flow measure.

[0079] The second circuit meter is advantageously configured to produce a second circuit power signal, the second circuit power signal being indicative of an amount of thermal power dissipated by or absorbed by the second circuit (5; 3). Production of the second circuit power signal typically comprises the steps of:

recording second circuit temperature signals from each of the third temperature sensor (6a; 4a) and the fourth temperature sensor (6b; 4b);
producing second circuit measures of temperature from the second circuit temperature signals;
determining a second circuit difference measure between the second circuit measures of temperature;
recording a second circuit flow signal from the second flow meter (9; 7);
producing a second circuit flow measure from the second circuit flow signal; and
producing the second circuit power signal as a function of a product of the second circuit difference measure and the second circuit flow measure.

[0080] In an embodiment, the first flow meter (7; 9) is or comprises a volume flow sensor. In an alternate embodiment, the first flow meter (7; 9) is or comprises a mass flow sensor. In an ultrasonic embodiment, the first flow meter (7; 9) is or comprises an ultrasonic flow sensor. In a special ultrasonic embodiment, the first flow meter (7; 9) is or comprises an ultrasonic flow sensor assembly.

[0081] In an embodiment, the second flow meter (9; 7) is or comprises a volume flow sensor. In an alternate embodiment, the second flow meter (9; 7) is or comprises a mass flow sensor. In an ultrasonic embodiment, the second flow meter (9; 7) is or comprises an ultrasonic flow sensor. In a special ultrasonic embodiment, the second flow meter (9; 7) is or comprises an ultrasonic flow sensor assembly.

[0082] The instant disclosure further teaches a heat exchange assembly (1) comprising a source circuit (5) and a sink circuit (3), a heat pump (10) having an expansion valve (13) and coupling the source circuit (5) to the sink circuit (3) for heat exchange (15) between the source circuit (5) and the sink circuit (3), the heat exchange assembly (1) further comprising a first heat exchanger (16; 17) and a second heat exchanger (17; 16), a compressor (2), a first circuit (3; 5) having a first temperature sensor (4a; 6a) and a second temperature sensor (4b; 6b), and a first flow meter (7; 9), a second circuit (5; 3) having a third temperature sensor (6a; 4a), the heat exchange assembly (1) further comprising a power meter selected from a compressor meter (8) connected to the compressor (2) or from a second circuit meter comprising the third temperature sensor (6a; 4a), a fourth temperature sensor (6b; 4b) mounted to the second circuit (5; 3), and a second flow meter (9; 7) mounted to the second circuit (5; 3), the heat exchange assembly (1) further comprising an appliance controller (11) in operative communication with the first temperature sensor (4a; 6a), with the second temperature sensor (4b; 6b), with the first flow meter (7; 9), with the compressor (2), and with the power meter, the appliance controller (11) being configured to:

read a first signal from a sensor selected from the first temperature sensor (4a; 6a) or the second temperature sensor (4b; 6b), and read a second signal from the third temperature sensor (6a; 4a);
produce a first measure from the first signal and a second measure from the second signal;
determine a first expected coefficient of performance from the first and second measures;
send a start signal to the compressor (2), the start signal causing the compressor (2) to start operation;
after sending the start signal, read a third signal from the first temperature sensor (4a; 6a), a fourth signal from the second temperature sensor (4b; 6b), a fifth signal from the first flow meter (7; 9), and a sixth signal from the power meter;
produce a third measure from the third signal, a fourth measure from the fourth signal, a fifth measure from the fifth signal, and a sixth measure from the sixth signal;
determine an actual coefficient of performance from the third measure, from the fourth measure, from the fifth measure, and from the sixth measure;
compare the actual coefficient of performance to the first expected coefficient of performance; and
if the actual coefficient of performance is less than the first expected coefficient of performance:
modify the first expected coefficient of performance as a function of the actual coefficient of performance.

[0083] It is envisaged that the first heat exchanger (16; 17) comprises the first circuit (3; 5). It is still envisaged that the second heat exchanger (17; 16) comprises the second circuit (5; 3).

[0084] The instant disclosure also teaches any of the aforementioned heat exchangers and/or heat exchange assemblies (1), wherein the appliance controller (11) is in operative communication with a remote controller (12), the appliance controller (11) being configured to:

receive a minimum coefficient from the remote controller (12), the minimum coefficient indicating a minimum coefficient of performance;
send a stop signal to the compressor (2), the stop signal causing the compressor (2) to stop operation;
after sending the stop signal, read a tenth signal from a sensor selected from the first temperature sensor (4a; 6a) or the second temperature sensor (4b; 6b), and read an eleventh signal from the third temperature sensor (6a; 4a);
produce a tenth measure from the tenth signal and an eleventh measure from the eleventh signal;
determine a second expected coefficient of performance as a function of the tenth measure, of the eleventh measure, and of the modified first coefficient of performance;
compare the second expected coefficient of performance to the minimum coefficient; and
if the second expected coefficient of performance exceeds the minimum coefficient:
send a further start signal to the compressor (2), the further start signal causing the compressor (2) to

start operation.

[0085] The remote controller (12) is advantageously installed in a location that is remote from the heat exchange assembly (1). The appliance controller (11) advantageously is in operative communication with the remote controller (12) via a communication bus such as a digital communication bus. The appliance controller (11) ideally is in operative communication with the remote controller (12) using a communication bus protocol such as a digital communication bus protocol.

[0086] It is envisaged that the remote controller (12) is or comprises a system controller. It is also envisaged that the second circuit meter is or comprises a second circuit power meter. It is further envisaged that the compressor meter (8) is or comprises a compressor power meter.

[0087] Any steps of a method according to the present disclosure can be embodied in hardware, in a software module executed by a processor, in a software module being executed using operating-system-level virtualization, in a cloud computing arrangement, or in a combination thereof. The software can include a firmware, a hardware driver run in the operating system, or an application program. Thus, the disclosure also relates to a computer program product for performing the operations presented herein. If implemented in software, the functions described can be stored as one or more instructions on a computer-readable medium. Some examples of storage media that can be used include random access memory (RAM), read only memory (ROM), flash memory, EPROM memory, EEPROM memory, registers, a hard disk, a removable disk, other optical disks, or any available media that can be accessed by a computer or any other IT equipment and appliance.

[0088] It should be understood that the foregoing relates only to certain embodiments of the disclosure and that numerous changes can be made therein without departing from the scope of the disclosure as defined by the following claims. It should also be understood that the disclosure is not restricted to the illustrated embodiments. Various modifications can be made within the scope of the following claims.

Reference numerals

[0089]

1	heat exchange assembly
2	compressor
3	conduit
4a, 4b	temperature sensors
5	conduit
6a, 6b	temperature sensors
7	flow meter
8	compressor meter
9	flow meter
10	heat pump
11	appliance controller
12	remote controller
13	expansion valve
14	heat exchange
15	heat exchange
16	heat exchanger
17	heat exchanger

Claims

1. A method of operating a heat exchange assembly (1), the heat exchange assembly (1) comprising a source circuit (5) and a sink circuit (3), a heat pump (10) having an expansion valve (13) and coupling the source circuit (5) to the sink circuit (3) for heat exchange (15) between the source circuit (5) and the sink circuit (3), the heat exchange assembly (1) further comprising a first heat exchanger (16; 17) and a second heat exchanger (17; 16), a compressor (2), a first circuit (3; 5) having a first (4a; 6a) and a second temperature sensor (4b; 6b), and a first flow meter (7; 9), a second circuit (5; 3) having a third temperature sensor (6a; 4a), the heat exchange assembly (1) further comprising a power meter selected from a compressor meter (8) connected to the compressor (2) or from a second circuit meter comprising the third temperature sensor (6a; 4a), a fourth temperature sensor (6b; 4b) mounted to the second circuit (5; 3), and a second flow meter (9; 7) mounted to the second circuit (5; 3), the method comprising:

reading a first temperature signal from a sensor selected from the first temperature sensor (4a; 6a) or the second temperature sensor (4b; 6b), and reading a second temperature signal from the third temperature sensor (6a; 4a);
determining a first expected coefficient of performance from the first and second temperature signals;
starting the compressor (2);
characterised in that the method comprises the steps of:

after starting the compressor (2), reading a third signal from the first temperature sensor (4a; 6a), a fourth signal from the second temperature sensor (4b; 6b), a fifth signal from the first flow meter (7; 9), and a sixth signal from the power meter;
determining an actual coefficient of performance as a function of the third to sixth signals;
comparing the actual coefficient of performance to the first expected coefficient of performance; and
if the actual coefficient of performance is less than the first expected coefficient of performance:

modifying the first expected coefficient of performance as a function of the actual coefficient of performance.

2. The method according to claim 1, the method comprising the steps of:

reading a lookup table from a memory;
employing the lookup table to determine the first expected coefficient of performance as a function of the first temperature signal and of the second temperature signal.

3. The method according to any of the claims 1 to 2, the method comprising the steps of:

reading a mathematical relationship from a memory; and
employing the mathematical relationship to calculate the first expected coefficient of performance as a function of the first temperature signal and as a function of the second temperature signal.

4. The method according to any of the claims 1 to 3, the method comprising the step of:
modifying the first expected coefficient of performance by setting the first expected coefficient of performance equal to the actual expected coefficient of performance.

5. The method according to any of the claims 1 to 4, the method comprising the steps of:

after starting the compressor (2), reading a sixth signal from the power meter
by reading a seventh signal from the third temperature sensor (6a; 4a) and
by reading an eighth signal from the fourth temperature sensor (6b; 4b) and
by reading a ninth signal from the second flow meter (9; 7).

6. The method according to claim 5, the method comprising the steps of:

producing a sourced energy measure from the sixth signal;
producing a third measure from the third signal, a fourth measure from the fourth signal, and a fifth measure from the fifth signal;
determining a temperature difference measure between the third measure and the fourth measure;
determining a delivered energy measure as a function of a product of the temperature difference measure and of the fifth measure;
determining an energy difference measure as a difference between the delivered energy measure and the sourced energy measure; and
determining the actual coefficient of performance by relating the delivered energy measure to the energy difference measure.

7. The method according to any of the claims 1 to 4, the method comprising the step of:

after starting the compressor (2), reading a sixth signal from the power meter by
reading a sixth signal from the compressor meter (8), the sixth signal being indicative of an amount of power received by the compressor (2).

8. The method according to claim 7, the method comprising the steps of:

producing a third measure from the third signal, a fourth measure from the fourth signal, and a fifth measure from the fifth signal;
determining a temperature difference measure between the third measure and the fourth measure;
determining a delivered energy measure as a function of a product of the temperature difference measure and of the fifth measure;
producing a compressor power measure from the sixth signal; and
determining the actual coefficient of performance by relating the delivered energy measure to the compressor power measure.

9. The method according to any of the claims 1 to 8, the method comprising the step of:
storing the modified first expected coefficient of performance in a memory.

10. The method according to any of the claims 1 to 9, the method comprising the steps of:

receiving a minimum coefficient, the minimum coefficient indicating a minimum coefficient of performance;
stopping the compressor (2);
with the compressor (2) stopped, reading a tenth signal from a sensor selected from the first temperature sensor (4a; 6a) or the second temperature sensor (4b; 6b) and reading an eleventh signal from the third temperature sensor (6a; 4a);
producing a tenth measure from the tenth signal and an eleventh measure from the eleventh signal;
determining a second expected coefficient of performance as a function of the tenth measure, of the eleventh measure, and of the modified

first coefficient of performance;
comparing the second expected coefficient of performance to the minimum coefficient; and
if the second expected coefficient of performance exceeds the minimum coefficient:
starting the compressor (2).

11. The method according to the claims 9 and 10, the method comprising the steps of:

reading the modified first expected coefficient of performance from the memory; and
after reading the modified first expected coefficient of performance from the memory, determining a second expected coefficient of performance as a function of the tenth measure, of the eleventh measure, and of the modified first coefficient of performance.

12. The method according to any of the claims 10 to 11, the method comprising the step of:
if and only if the second expected coefficient of performance exceeds the minimum signal by a predetermined threshold:
starting the compressor (2).

13. A non-transitory, computer-readable medium containing a program which executes the steps of any of the claims 1 to 12.

14. A heat exchange assembly (1) comprising a source circuit (5) and a sink circuit (3), a heat pump (10) having an expansion valve (13) and coupling the source circuit (5) to the sink circuit (3) for heat exchange (15) between the source circuit (5) and the sink circuit (3), the heat exchange assembly (1) further comprising a first heat exchanger (16; 17) and a second heat exchanger (17; 16), a compressor (2), a first circuit (3; 5) having a first temperature sensor (4a; 6a) and a second temperature sensor (4b; 6b), and a first flow meter (7; 9), a second circuit (5; 3) having a third temperature sensor (6a; 4a), the heat exchange assembly (1) further comprising a power meter selected from a compressor meter (8) connected to the compressor (2) or from a second circuit meter comprising the third temperature sensor (6a; 4a), a fourth temperature sensor (6b; 4b) mounted to the second circuit (5; 3), and a second flow meter (9; 7) mounted to the second circuit (5; 3), the heat exchange assembly (1) further comprising an appliance controller (11) in operative communication with the first temperature sensor (4a; 6a), with the second temperature sensor (4b; 6b), with the first flow meter (7; 9), with the compressor (2), and with the power meter, the appliance controller (11) being configured to:

read a first signal from a sensor selected from the first temperature sensor (4a; 6a) or the second temperature sensor (4b; 6b), and read a second signal from the third temperature sensor (6a; 4a);
produce a first measure from the first signal and a second measure from the second signal;
determine a first expected coefficient of performance from the first and second measures;
send a start signal to the compressor (2), the start signal causing the compressor (2) to start operation;
characterised in that the controller (11) is configured to:

after sending the start signal, read a third signal from the first temperature sensor (4a; 6a), a fourth signal from the second temperature sensor (4b; 6b), a fifth signal from the first flow meter (7; 9), and a sixth signal from the power meter;
produce a third measure from the third signal, a fourth measure from the fourth signal, a fifth measure from the fifth signal, and a sixth measure from the sixth signal;
determine an actual coefficient of performance from the third measure, from the fourth measure, from the fifth measure, and from the sixth measure;
compare the actual coefficient of performance to the first expected coefficient of performance; and
if the actual coefficient of performance is less than the first expected coefficient of performance:
modify the first expected coefficient of performance as a function of the actual coefficient of performance.

15. The heat exchange assembly (1) according to claim 14, wherein the appliance controller (11) is in operative communication with a remote controller (12), the appliance controller (11) being configured to:

receive a minimum coefficient from the remote controller (12), the minimum coefficient indicating a minimum coefficient of performance;
send a stop signal to the compressor (2), the stop signal causing the compressor (2) to stop operation;
after sending the stop signal, read a tenth signal from a sensor selected from the first temperature sensor (4a; 6a) or the second temperature sensor (4b; 6b), and read an eleventh signal from the third temperature sensor (6a; 4a);
produce a tenth measure from the tenth signal and an eleventh measure from the eleventh signal;
determine a second expected coefficient of per-

formance as a function of the tenth measure, of the eleventh measure, and of the modified first coefficient of performance;

compare the second expected coefficient of performance to the minimum coefficient; and

if the second expected coefficient of performance exceeds the minimum coefficient:

send a further start signal to the compressor (2), the further start signal causing the compressor (2) to start operation.

FIG 1

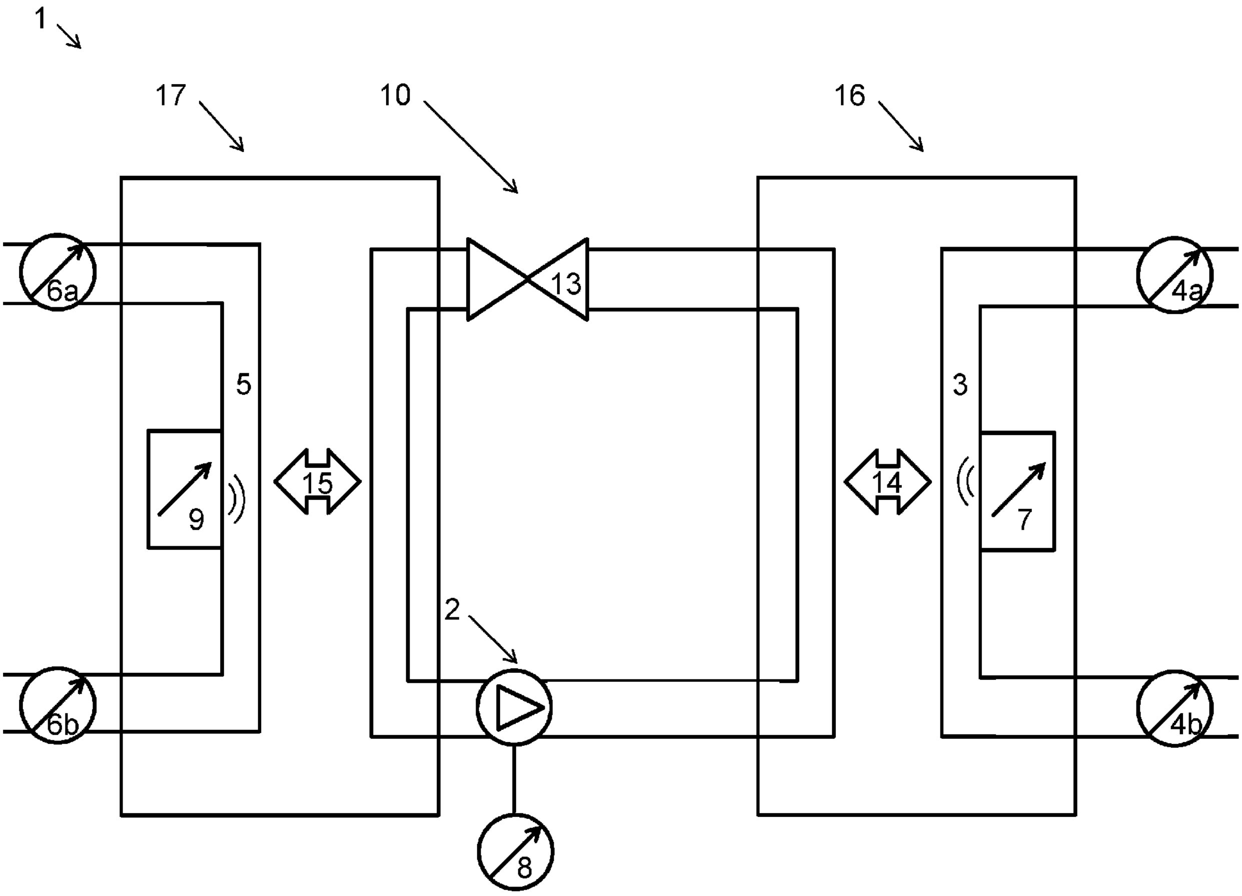


FIG 2

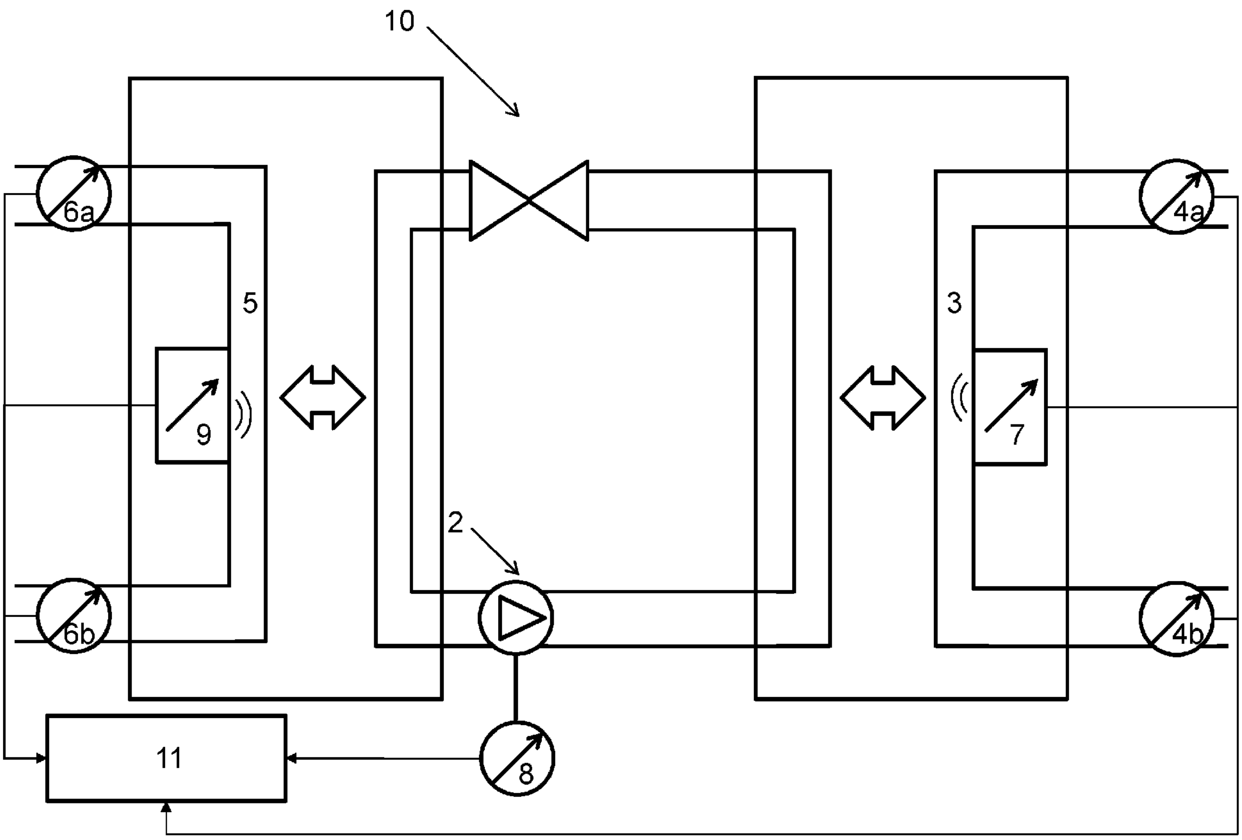
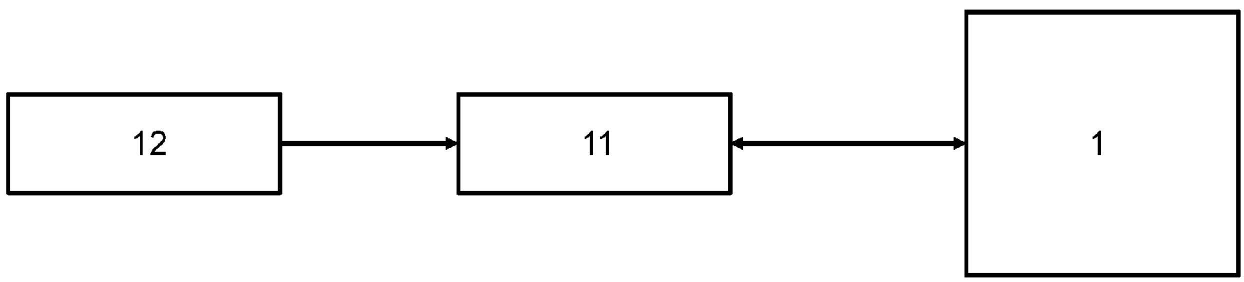


FIG 3



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EUROPEAN SEARCH REPORT

Application Number
EP 20 15 6890

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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A	US 8 745 999 B2 (HAMADA MAMORU [JP]; UNEZAKI FUMITAKE [JP] ET AL.) 10 June 2014 (2014-06-10) * & associated description; figures 17-19 * -----	1-15	
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A	US 8 812 263 B2 (TOGANO YOSHIE [JP]; UEDA KENJI [JP] ET AL.) 19 August 2014 (2014-08-19) * the whole document * -----	1-15	
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			F25B

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	17 September 2020	Gasper, Ralf

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