



## (51) International Patent Classification:

*F25B 11/00* (2006.01) *F25D 11/00* (2006.01)  
*F25B 1/00* (2006.01)

## (21) International Application Number:

PCT/IL2013/051019

## (22) International Filing Date:

10 December 2013 (10.12.2013)

## (25) Filing Language:

English

## (26) Publication Language:

English

## (30) Priority Data:

61/735,066 10 December 2012 (10.12.2012) US

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## (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

## Published:

— with international search report (Art. 21(3))

[Continued on next page]

## (54) Title: HEAT PUMP ENERGY SUPPLY OPTIMIZATION METHOD AND SYSTEM

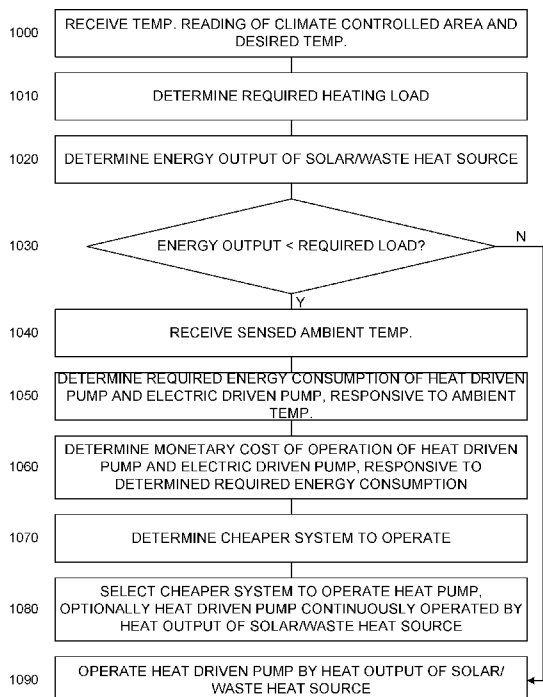


FIG. 2

(57) Abstract: A method of optimizing a heat pump energy supply, comprising: sensing the ambient temperature; and responsive to the sensed ambient temperature, selecting one of a first energy source and a second energy source to provide energy for processing a working fluid of the heat pump, the second energy source different than the first energy source.



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## HEAT PUMP ENERGY SUPPLY OPTIMIZATION METHOD AND SYSTEM

### TECHNICAL FIELD

**[0001]** The present disclosure relates generally to the field of air conditioning and in particular to a system and method for optimizing the energy usage of a heat pump utilizing a combination of waste heat, electric powered heat and combustible material powered heat.

### BACKGROUND

**[0002]** Heat pumps operate by extracting heat from outdoor ambient air, and transferring that heat to a climate controlled area, such as a home or business. In a cooling mode, heat pumps operate by extracting heat from the air of the climate controlled area into the ambient air. In a heating mode, heat pumps operate by extracting heat from the outside ambient air and passing the heat into the climate controlled area. Heat pumps are generally more economical to operate than conventional furnaces that burn fossil fuels. However, the coefficient of performance (COP) of the heat pump is a function of the ambient air temperature. During a heating cycle, as the ambient temperature decreases the COP of the heat pump will decrease, since more work is necessary to extract the heat from the ambient air. During the heating cycle, at a certain point the COP becomes too small to be considered economically efficient in comparison to a furnace or other fossil fuel heating source.

**[0003]** One typical solution is to provide a backup heater to the heat pump, such that when the ambient temperature becomes too low, the heat pump will cease operation and a heater, such as a gas or electric radiator, will provide heat to the climate controlled environment. Unfortunately, this adds cost and complexity since two separate systems are needed, a heat pump and a heater. Additionally, the additional heater does not necessarily provide the most energy efficient form of heating. Moreover, typically such double systems are not able to switch between the heat pump and additional heater within an appropriate time frame to allow for an economical control of the desired target temperature of the climate controlled area. Furthermore, such a system provides no method for optimizing the energy consumption of the heat pump during a cooling cycle.

**[0004]** Additionally, many industrial processes produce waste heat of low temperature, typically less than 150° C, which is typically too low to be used to accomplish useful work. Certain thermodynamic cycles, such as absorption refrigeration, can provide environmental cooling and heating from low grade heat sources. Similarly, solar thermal energy received in a solar collector such as a concentrating type or an evacuated tube type is typically of the order of waste heat, and has been employed in absorption chillers to provide environmental cooling. Unfortunately, the absorption refrigeration cycles typically used suffer from inefficiency, and are typically unable to achieve a COP greater than about 0.7, where the term COP is defined as  $\Delta Q / \Delta W$ , where  $\Delta Q$  is defined as the heating/cooling load change and  $\Delta W$  is defined as the work consumed by the cooling system. Other types of heat pumps achieve a greater COP, however the energy output of the waste/solar heat source is not always sufficient to power such a heat pump.

**[0005]** What is desired is a method and system for optimizing the energy supply of a heat pump, so that the cost of operation of the heat pump will be continuously maintained at a minimum for a wide range of ambient air temperatures.

#### SUMMARY OF INVENTION

**[0006]** In view of the discussion provided above and other considerations, the present disclosure provides methods and apparatus to overcome some or all of the disadvantages of prior and present methods of energy supply optimization of heat pumps. Other new and useful advantages of the present methods and apparatus will also be described herein and can be appreciated by those skilled in the art.

**[0007]** In an exemplary embodiment, a heat pump apparatus is provided, the heat pump apparatus comprising: a control circuitry; a first energy source input port arranged to receive energy from a first energy source; a second energy source input port arranged to receive energy from a second energy source, the second energy source different than the first energy source, each of the first and second energy source input ports arranged to provide energy for processing a working fluid contained within the heat pump apparatus, responsive to the control circuitry; and an ambient temperature sensor in communication with the control circuitry, the ambient temperature sensor arranged to sense the temperature of the ambient air, wherein the control circuitry is arranged to alternately select one of the first energy source input port and the second energy source

input port to provide energy for processing the working fluid, the selection responsive to the sensed ambient air temperature.

**[0008]** In one embodiment, the control circuitry is arranged to determine the required energy output from each of the first energy source and the second energy source to provide energy for processing the single working fluid, responsive to the sensed ambient temperature, and wherein the control circuitry is arranged to determine the cost of operation of the heat pump apparatus by each of the first energy source and the second energy source responsive to the determined required energy output, the selection performed responsive to the determined cost of operation. In another embodiment, the first energy source comprises a source of electricity and the second energy source comprises a combustible material powered water heater. In one further embodiment, the heat pump apparatus further comprises: a compressor in electrical communication with the first energy source input port, the compressor arranged to compress the working fluid; and a heat exchanger in thermal communication with the second energy source input port, the heat exchanger arranged to transfer heat from the combustible material powered water heater to the working fluid.

**[0009]** In one embodiment, the heat pump apparatus further comprises a third energy source input port arranged to receive energy from a third energy source, different than the first and second energy sources, the third energy source input port arranged to provide energy for processing the working fluid, wherein the control circuitry is further arranged to determine the energy output of the third energy source, the selection performed only in the event that the determined energy output of the third energy source is less than the energy requirements of the heat pump apparatus. In one further embodiment, the third energy source comprises one of a waste heat source and a solar water heater.

**[00010]** In one yet further embodiment, the heat pump apparatus further comprises a heat exchanger in thermal communication with: the second energy source input port; and the third energy source input port. In another further embodiment, the arrangement of the third energy source input to provide energy for processing the working fluid is responsive to the control circuitry, wherein in the event that the determined energy output of the third energy source is less than the energy requirements of the heat pump apparatus, the control circuitry is further arranged to control the third energy source input port to provide energy for processing the working fluid.

**[00011]** In one independent embodiment, a method of optimizing a heat pump energy supply is provided, the method comprising: sensing the ambient temperature; responsive to the sensed ambient temperature, selecting one of a first energy source and a second energy source to provide energy for processing a working fluid of the heat pump, the second energy source different than the first energy source.

**[00012]** In one embodiment, the method further comprises: determining the required energy output from each of the first energy source and the second energy source to provide energy for processing the working fluid, responsive to the sensed ambient temperature; and determining the cost of operation of the heat pump by each of the first energy source and the second energy source responsive to the determined required energy output, the selecting performed responsive to the determined cost of operation. In another embodiment, the first energy source comprises a source of electricity and the second energy source comprises a combustible material powered water heater. In one further embodiment, the selecting the first energy source comprises providing electric power from the source of electricity to a compressor, wherein the selecting the second energy source comprises providing heat from the combustible material powered water heater to a heat exchanger.

**[00013]** In one embodiment, the method further comprises determining the energy output of a third energy source, the third energy source different than the first and second energy sources, the selecting performed only in the event that the determined energy output of the third energy source is less than the energy requirements of the heat pump. In one further embodiment, the third energy source comprises one of a waste heat source and a solar water heater.

**[00014]** In one yet further embodiment, the method further comprises providing heat from the output of the second and third energy sources to a heat exchanger. In another embodiment, the method further comprises in the event that the determined energy output of the third energy source is less than the energy requirements of the heat pump, providing energy output from the third energy source for processing the working fluid.

**[00015]** In another independent embodiment, a non-transitory computer readable medium having instructions stored thereon is provided, which, when executed by one or more processors, causes the one or more processors to perform operations, the operations comprising: sensing the ambient temperature; and responsive to the sensed ambient temperature, selecting one of a first energy source and a second energy source

to provide energy for processing a working fluid of the heat pump, the second energy source different than the first energy source.

**[00016]** In one embodiment, the operations further comprise: determining the required energy output from each of the first energy source and the second energy source to provide energy for processing the working fluid, responsive to the sensed ambient temperature; and determining the cost of operation of the heat pump by each of the first energy source and the second energy source responsive to the determined required energy output, the selecting performed responsive to the determined cost of operation. In another embodiment, the first energy source comprises a source of electricity and the second energy source comprises a combustible material powered water heater. In one further embodiment, the selecting the first energy source comprises providing electric power from the source of electricity to a compressor, and wherein the selecting the second energy source comprises providing heat from the combustible material powered water heater to a heat exchanger.

**[00017]** In one embodiment, the operations further comprise determining the energy output of a third energy source, the third energy source different than the first and second energy sources, the selecting performed only in the event that the determined energy output of the third energy source is less than the energy requirements of the heat pump. In one further embodiment, the third energy source comprises one of a waste heat source and a solar water heater.

**[00018]** In one yet further embodiment, the operations further comprise providing heat from the output of the second and third energy sources to a heat exchanger. In another further embodiment, the operations further comprise, in the event that the determined energy output of the third energy source is less than the energy requirements of the heat pump, providing energy output from the third energy source for processing the working fluid.

**[00019]** Additional features and advantages of the invention will become apparent from the following drawings and description.

#### BRIEF DESCRIPTION OF DRAWINGS

**[00020]** For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made, purely by way of example, to the accompanying drawings in which like numerals designate corresponding elements or sections throughout.

**[00021]** With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice. In the accompanying drawings:

**[00022]** FIG. 1A illustrates a high level schematic diagram of a heat pump apparatus, according to certain embodiments;

**[00023]** FIG. 1B illustrates a high level schematic diagram of a heat pump apparatus, comprising a compressor and a heat exchanger, according to certain embodiments;

**[00024]** FIG. 1C illustrates a high level schematic diagram of a control circuitry of the heat pump apparatuses of FIGs. 1A – 1B;

**[00025]** FIG. 2 illustrates a high level flow chart of a method of operation of the heat pump apparatus of FIG. 1B in a heating cycle, according to certain embodiments; and

**[00026]** FIG. 3 illustrates a high level flow chart of a method of operation of the heat pump apparatus of FIG. 1B in a cooling cycle, according to certain embodiments.

## DESCRIPTION OF EMBODIMENTS

**[00027]** Before explaining at least one embodiment in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is applicable to other embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting. In particular, the term connected as used herein is not meant to be limited to a direct connection, and allows for intermediary devices or components without limitation.

**[00028]** FIG. 1A illustrates a high level schematic diagram of a heat pump apparatus 10, according to certain embodiments. Heat pump apparatus 10 comprises: an external unit 20; an internal unit 30; a combustible material driven heat energy source 40; and an electric energy source 50. External unit 20 comprises: a combustible material driven energy source input port 60; an electric energy source input port 70; a control circuitry 80; a heat driven heat pump sub-system 90; an electric driven heat pump sub-system 100; and an ambient temperature sensor 110.

**[00029]** External unit 20 is positioned outside a climate controlled area 120 and internal unit 30 is positioned within climate controlled area 120. External unit 20 is in fluidic communication with internal unit 30 such that working fluid of heat pump apparatus 10, such as refrigerant, is transferred bi-directionally between external unit 20 and internal unit 30. In one embodiment, power is supplied from external unit 20 to internal unit 30 and internal unit 30 is further in communication with control circuitry 80 of external unit 20. Heat pump apparatus 10 is illustrated and described as comprising an internal unit 30 and an external unit 20, however this is not meant to be limiting in any way and a heat pump apparatus comprising only an internal unit is contemplated without exceeding the scope.

**[00030]** In one embodiment, combustible material driven energy source 40 comprises a water heater, optionally heated by burning any of natural gas, liquid petroleum gas, diesel combustible material and heating oil, without limitation. The output of combustible material driven energy source 40 is coupled to heat driven heat pump sub-system 90, via combustible material driven energy source input port 60 of external unit 20, and is arranged to provide heat thereto. Electric energy source 50 is coupled to electric driven heat pump sub-system 100, via electric energy source input port 70, and is arranged to provide electricity thereto. In one embodiment, electric energy source 50 comprises an electric mains power supply. Ambient temperature sensor 110 is arranged to sense the temperature of the ambient air surrounding external unit 20. Heat driven heat pump sub-system 90 and electric driven heat pump sub-system 100 are illustrated as separate units, however this is not meant to be limiting in any way and heat pump apparatus 10 is particularly contemplated with heat driven heat pump sub-system 90 and electric driven heat pump sub-system 100 being integrated within a single system, each arranged to process a common working fluid to provide heating/cooling.

**[00031]** Heat driven heat pump sub-system 90 and electric driven heat pump sub-system 100 are arranged to provide heating/cooling via internal unit 30 to adjust the temperature in climate controlled area 120. A working liquid, such as a refrigerant, is provided within external unit 20. In one further embodiment, heat driven heat pump sub-system 90 and electric driven heat pump sub-system 100 are each arranged to provide compression and expansion of the working fluid in order to provide heating/cooling, as known to those skilled in the art. In another further embodiment, heat driven heat pump sub-system 90 and electric driven air conditioning sub-system 100 are each arranged to provide an absorption cycle utilizing a water-ammonia mixture in order to provide heating/cooling, as known to those skilled in the art. In another embodiment, heat driven heat pump sub-system 90 and electric driven air conditioning sub-system 100 are arranged to provide heating/cooling as described in U.S. Patent Application Publication S/N 2012/0023982 to Berson et al., of publication date Feb. 2, 2012, the entire contents of which are incorporated herein by reference. As described therein, heat driven heat pump sub-system 90 and electric driven air conditioning sub-system 100 comprise an integrated single unit.

**[00032]** Control circuitry 80 is in communication with heat driven heat pump sub-system 90, electric driven heat pump sub system 100 and ambient temperature sensor 110. In one embodiment, control circuitry 80 is further in communication with combustible material driven energy source input port 60 and electric energy source input port 70. In another, optionally alternate, embodiment, control circuitry 80 is in communication with combustible material driven energy source 40 and electric energy source 50.

**[00033]** In operation, as will be described further below, control circuitry 80 is arranged to receive from ambient temperature sensor 110 the sensed temperature of the ambient air. Responsive to the received temperature, control circuitry 80 is arranged to determine the energy requirements of each of heat driven heat pump sub-system 90 and electric driven heat pump sub-system 100 to adjust the temperature of the air within climate controlled area 120 to a desired target temperature. Control circuitry 80 is further arranged to determine the monetary cost of the above determined energy requirements. Control circuitry 80 is further arranged to select and operate a particular one of heat driven heat pump sub-system 90 and electric driven heat pump sub system 100, the selection performed responsive to the determination of

the energy requirements exhibiting the least monetary cost. Advantageously, a single heat pump 10, optionally with a single working fluid, and with a single internal unit 30, is alternately operated by two different energy sources, responsive to the monetary cost thereof.

**[00034]** FIG. 1B illustrates a high level schematic diagram of a heat pump apparatus 200, according to certain embodiments. Heat pump apparatus 200 comprises: an external unit 220; an internal unit 30; a combustible material driven energy source 40; an electric energy source 50; and a solar/waste heat source 230. External unit 220 comprises: a combined combustible material driven energy source and solar /waste heat source input port 170; an electric energy source input port 70; a control circuitry 80; a heat driven heat pump sub-system 250, comprising a heat exchanger 260; an electric driven heat pump sub-system 270, comprising a compressor 280; and an ambient temperature sensor 110. Solar/waste heat source 230 in one embodiment comprises one or more solar panels. In another embodiment, solar/waste heat source 230 comprises a waste heat source.

**[00035]** External unit 220 is positioned outside climate controlled area 120 and internal unit 30 is positioned within climate controlled area 120, as described above in relation to heat pump apparatus 10 of FIG. 1A. External unit 220 is in fluidic communication with internal unit 30 such that working fluid of heat pump apparatus 200, such as refrigerant, is transferred bi-directionally between external unit 220 and internal unit 30. In one embodiment, power is supplied from external unit 220 to internal unit 30 and internal unit 30 is further in communication with control circuitry 80 of external unit 220. Heat pump apparatus 200 is illustrated and described as comprising an internal unit 30 and an external unit 220, however this is not meant to be limiting in any way and a heat pump apparatus comprising only an internal unit is contemplated without exceeding the scope.

**[00036]** The output of combustible material driven heat energy source 40 is coupled to heat driven heat pump sub-system 250, via combustible material driven energy source input port 60 of external unit 220, and is arranged to provide heat thereto. Electric energy source 50 is coupled to electric driven heat pump sub-system 270, via electric energy source input port 70, and is arranged to provide electricity thereto.

**[00037]** Solar/waste heat source 230 is coupled to heat driven heat pump sub-system 250, via combustible material driven energy source input port 60, and is

arranged to provide heat thereto. Solar/waste heat source is in thermal communication with heat driven heat pump sub-system 250, and in particular to heat exchanger 260 thereof. In another embodiment, combustible material driven energy source 40 and solar/waste heat source 230 are both arranged to provide hot water to heat exchanger 260 of heat driven heat pump sub-system 250. Heat pump apparatus 200 is illustrated where combustible material driven energy source 40 and solar/waste heat source 230 are arranged in a serial formation, however this is not meant to be limiting in any way. In another embodiment, combustible material driven energy source 40 and solar/waste heat source 230 can be thermally coupled to heat driven heat pump sub-system 250 in a parallel configuration, without exceeding the scope. In one embodiment, heat exchanger 260 is arranged to transfer heat from the received hot water to the working fluid of heat pump apparatus 200, such as a refrigerant. Compressor 280 of electric driven heat pump sub-system 270 is arranged to provide a vapor compression cycle for the operation liquid of heat pump apparatus 200.

**[00038]** Heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270 are illustrated as separate units, however this is not meant to be limiting in any way and heat pump apparatus 200 is particularly contemplated with heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270 being integrated within a single system, each arranged to process a common working fluid to provide heating/cooling.

**[00039]** Control circuitry 80 is in communication with heat driven heat pump sub-system 250, electric driven heat pump sub-system 270 and ambient temperature sensor 110. In one embodiment, control circuitry 80 is further in communication with combustible material driven energy source input port 60 and electric energy source input port 70. In another, optionally alternate, embodiment, control circuitry 80 is in communication with combustible material driven energy source 40 and electric energy source 50.

**[00040]** In operation, control circuitry 80 is arranged to determine the energy output of solar/waste heat source 230. In one embodiment, the energy output is determined by sensing the temperature output of solar/waste heat source 230. In the event that control circuitry 80 determines that the energy output of solar/waste heat source 230 is less than the energy needed for heat pump apparatus 200 to adjust the temperature of climate controlled area 120 to the desired temperature, control circuitry 80 is arranged to select one of heat driven heat pump sub-system 250 and

electric driven heat pump sub-system 270, as described above in relation to heat pump apparatus 10 of FIG. 1A. In one embodiment, as will be described below, in the event that control circuitry 80 selects heat driven heat pump sub-system 250, both combustible material driven energy source 40 and solar/waste heat source 230 provide power thereto. In the event that control circuitry 80 selects electric driven heat pump sub-system 270, control circuitry 80 is further arranged, in parallel, to control heat driven heat pump sub-system 250 to provide heating/cooling with power being provided by solar/waste heat source 230. Thus, both heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270 provide heating to climate controlled area 120.

**[00041]** FIG. 1C illustrates a high level block diagram of control circuitry 80 of heat pump apparatus 10 of FIG. 1A and heat pump apparatus 200 of FIG. 1B. Control circuitry 80 comprises: a solar/waste heat energy output determination functionality 290; an energy consumption determination functionality 300, arranged to determine the energy consumption of each of combustible material driven energy source 40 and electric energy source 50, as will be described below; a monetary cost determination functionality 310, arranged to determine the monetary cost of operating heat driven heat pump sub-systems 90 and 250, and electric driven heat pump sub-systems 100 and 270, as will be described below; a selection functionality 320, arranged to select one or more of heat driven heat pump sub-systems 90 and 250, and electric driven heat pump sub-systems 100 and 270 to operate the respective one of heat pumps 10 and 200, as will be described below. Solar/waste heat energy output determination functionality 290, energy consumption determination functionality 300, monetary cost determination functionality 310 and selection functionality 320 can each be implemented by any of: a dedicated functionality; computer readable instructions for a general purpose computing device or processor, the readable instructions stored on a memory 330 and arranged to be run by a processor 340; dedicated hardware; and a dedicated control circuitry, without limitation.

**[00042]** FIG. 2 illustrates a high level flow chart of a method of operation of heat pump apparatus 200 of FIG. 1B in a heating cycle, according to certain embodiments. In stage 1000, control circuitry 80 is arranged to receive a temperature reading of the temperature within climate controlled area 120 and the desired temperature, from internal unit 30. In stage 1010, control circuitry 80 is arranged to determine the required heating load to bring the temperature of climate controlled area

120 to the desired temperature. The term 'determine' is not meant to be limited to an exact determination and is particularly meant to include an approximation. In stage 1020, solar/waste heat energy output determination functionality 290 of control circuitry 80 is arranged to determine the energy output of solar/waste heat source 230. Optionally, the energy output is determined by sensing the output temperature of the heat of solar/waste heat source 230, optionally by sensing the temperature of the heat supply fluid of the combined combustible material driven energy source 40 and solar/waste heat source input port 170 and flow.

**[00043]** In stage 1030, selection functionality 320 is arranged to compare the determined energy output of solar/waste heat source 230 of stage 1020 with the determined required heating load of stage 1010. In the event that the determined energy output of solar/waste heat source 230 is less than required heating load, in stage 1040 energy consumption determination functionality 300 is arranged to receive the sensed ambient temperature from ambient temperature sensor 110.

**[00044]** In stage 1050, energy consumption determination functionality 300 is arranged to determine the required energy consumption of each of heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270 to provide the determined heating load of stage 1010, the required energy consumption determined responsive to the sensed ambient temperature of stage 1040. In particular, energy consumption determination functionality 300 is arranged to determine how much energy would need to be produced from each of combustible material driven energy source 40 and electric energy source 50 to power heat pump apparatus 200, optionally after subtracting the provided energy from solar/waste heat source 230, as will be described below. In one embodiment, the required energy consumption is determined responsive to a pre-measured function of the operation of each of heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270 for one or more measured ambient temperatures. In another embodiment, the required energy consumption is determined responsive to a lookup table comprising measured energy requirements of each of heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270 for a plurality of ambient temperature ranges. In another embodiment, the required energy consumption is determined responsive to known thermodynamic properties of heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270. Optionally, the required energy consumption is

determined only for the portion of the heating load which cannot sufficiently be supplied by solar/waste heat source 230.

**[00045]** In stage 1060, monetary cost determination functionality 310 of control circuitry 80 is arranged to determine the monetary cost of operation for each of heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270. In particular, the determined required energy consumption of stage 1050 is multiplied by the monetary cost per unit of the combustible material of combustible material driven energy source 40 and of electricity. Optionally, the monetary cost per unit is periodically updated.

**[00046]** In stage 1070, selection functionality 320 is arranged to determine which of heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270 is cheaper to operate. In stage 1080, selection functionality 320 is arranged to select the one of heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270 which is cheaper to operate, and control the selected sub-system to provide the desired heating cycle. Thus, the most economically efficient energy source is utilized to provide energy to process the working fluid of heat pump apparatus 200. Optionally, heat driven heat pump sub-system 250 is continuously operated by the energy output of solar/waste heat source 230 and is supplemented by either: electric driven heat pump sub-system 270; or the addition of the heat energy output of combustible material driven energy source 40 to heat driven heat pump sub-system 250.

**[00047]** In the event that in stage 1030 selection functionality 320 determines that the energy output of solar/waste heat source 230 is sufficient for the required heating load, in stage 1090 heat driven heat pump sub-system 250 is operated by the energy output of solar/waste heat source 230, thereby operating heat pump apparatus 200.

**[00048]** FIG. 3 illustrates a high level flow chart of a method of operation of heat pump apparatus 200 of FIG. 1B in a cooling cycle, according to certain embodiments. In stage 2000, control circuitry 80 is arranged to receive a temperature reading of the temperature within climate controlled area 120 and the desired temperature, from internal unit 30. In stage 2010, control circuitry 80 is arranged to determine the required cooling load to bring the temperature of climate controlled area 120 to the desired temperature. In stage 2020, solar/waste heat energy output determination functionality 290 of control circuitry 80 is arranged to determine the

energy output of solar/waste heat source 230. Optionally, the energy output is determined by sensing the output temperature of the heat of solar/waste heat source 230.

**[00049]** In stage 2030, selection functionality 320 is arranged to compare the determined energy output of solar/waste heat source 230 of stage 2020 with the determined required cooling load of stage 2010. In the event that the determined energy output of solar/waste heat source 230 is less than required cooling load, in stage 2040, energy consumption determination functionality 300 is arranged to determine the required energy consumption of each of heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270 to provide the determined cooling load of stage 2010. In particular, energy consumption determination functionality 300 is arranged to determine how much energy would need to be produced from each of combustible material driven energy source 40 and electric energy source 50 to power heat pump apparatus 200. Optionally, the required energy consumption is determined only for the portion of the cooling load which cannot sufficiently be supplied by solar/waste heat source 230.

**[00050]** In stage 2050, monetary cost determination functionality 310 of control circuitry 80 is arranged to determine the monetary cost of operation for each of heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270. In particular, the determined required energy consumption of stage 1050 is multiplied by the monetary cost per unit of the combustible material of combustible material driven energy source 40 and of electricity. Optionally, the monetary cost per unit is periodically updated.

**[00051]** In stage 2060, selection functionality 320 is arranged to determine which of heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270 is cheaper to operate. In stage 2070, selection functionality 320 is arranged to select the one of heat driven heat pump sub-system 250 and electric driven heat pump sub-system 270 which is cheaper to operate, and control the selected sub-system to provide the desired cooling cycle. Thus, the most economically efficient energy source is utilized to provide energy to process the working fluid of heat pump apparatus 200. Optionally, heat driven heat pump sub-system 250 is continuously operated by the energy output of solar/waste heat source 230 and is supplemented by either: electric driven heat pump sub-system 270; or the

addition of the heat energy output of combustible material driven energy source 40 to heat driven heat pump sub-system 250.

**[00052]** In the event that in stage 2030 selection functionality 320 determines that the energy output of solar/waste heat source 230 is sufficient for the required cooling load, in stage 2070 heat driven heat pump sub-system 250 is operated by the energy output of solar/waste heat source 230, thereby operating heat pump apparatus 200.

**[00053]** The method of operation of heat pump apparatus 10 of FIG. 1A is in all respects similar to the method of operation of heat pump apparatus 200 of FIG. 1B described above, with the exception that solar/waste heat source 230 is not provided. Thus, in the interest of brevity, the method of operation thereof will not be further described.

**[00054]** It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable sub-combination.

**[00055]** Unless otherwise defined, all technical and scientific terms used herein have the same meanings as are commonly understood by one of ordinary skill in the art to which this invention belongs. Although methods similar or equivalent to those described herein can be used in the practice or testing of the present invention, suitable methods are described herein.

**[00056]** All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the patent specification, including definitions, will prevail. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

**[00057]** The terms “include”, “comprise” and “have” and their conjugates as used herein mean “including but not necessarily limited to”. The term “connected” is not limited to a direct connection, and connection via intermediary devices is specifically included.

**[00058]** It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather the scope of the present invention is defined by the appended claims and includes both combinations and sub-combinations of the various features

described hereinabove as well as variations and modifications thereof, which would occur to persons skilled in the art upon reading the foregoing description.

We claim:

1. A heat pump apparatus comprising:

a control circuitry;

a first energy source input port arranged to receive energy from a first energy source;

a second energy source input port arranged to receive energy from a second energy source, the second energy source different than the first energy source, each of the first and second energy source input ports arranged to provide energy for processing a working fluid contained within the heat pump apparatus, responsive to the control circuitry; and

an ambient temperature sensor in communication with the control circuitry, the ambient temperature sensor arranged to sense the temperature of the ambient air,

wherein the control circuitry is arranged to alternately select one of the first energy source input port and the second energy source input port to provide energy for processing the working fluid, the selection responsive to the sensed ambient air temperature.

2. The heat pump apparatus of claim 1, wherein the control circuitry is arranged to determine the required energy output from each of the first energy source and the second energy source to provide energy for processing the single working fluid, responsive to the sensed ambient temperature, and

wherein the control circuitry is arranged to determine the cost of operation of the heat pump apparatus by each of the first energy source and the second energy source responsive to the determined required energy output, the selection performed responsive to the determined cost of operation.

3. The heat pump apparatus of claim 1, wherein the first energy source comprises a source of electricity and the second energy source comprises a combustible material powered water heater.

4. The heat pump apparatus of claim 3, further comprising:

a compressor in electrical communication with the first energy source input port, the compressor arranged to compress the working fluid; and

a heat exchanger in thermal communication with the second energy source input port, the heat exchanger arranged to transfer heat from the combustible material powered water heater to the working fluid.

5. The heat pump apparatus of claim 1, further comprising a third energy source input port arranged to receive energy from a third energy source, different than the first and second energy sources, the third energy source input port arranged to provide energy for processing the working fluid,

wherein the control circuitry is further arranged to determine the energy output of the third energy source, the selection performed only in the event that the determined energy output of the third energy source is less than the energy requirements of the heat pump apparatus.

6. The heat pump apparatus of claim 5, wherein the third energy source comprises one of a waste heat source and a solar water heater.

7. The heat pump apparatus of claim 6, further comprising a heat exchanger in thermal communication with:

the second energy source input port; and

the third energy source input port.

8. The heat pump apparatus of claim 5, wherein the arrangement of the third energy source input to provide energy for processing the working fluid is responsive to the control circuitry, and

wherein in the event that the determined energy output of the third energy source is less than the energy requirements of the heat pump apparatus, the control circuitry is further arranged to control the third energy source input port to provide energy for processing the working fluid.

9. A method of optimizing a heat pump energy supply, the method comprising:

sensing the ambient temperature; and

responsive to the sensed ambient temperature, selecting one of a first energy source and a second energy source to provide energy for processing a working fluid of the heat pump, the second energy source different than the first energy source.

10. The method of claim 9, further comprising:

determining the required energy output from each of the first energy source and the second energy source to provide energy for processing the working fluid, responsive to the sensed ambient temperature; and

determining the cost of operation of the heat pump by each of the first energy source and the second energy source responsive to the determined required energy output, the selecting performed responsive to the determined cost of operation.

11. The method of claim 9, wherein the first energy source comprises a source of electricity and the second energy source comprises a combustible material powered water heater.

12. The method of claim 11, wherein the selecting the first energy source comprises providing electric power from the source of electricity to a compressor, and

wherein the selecting the second energy source comprises providing heat from the combustible material powered water heater to a heat exchanger.

13. The method of claim 9, further comprising determining the energy output of a third energy source, the third energy source different that the first and second energy sources, the selecting performed only in the event that the determined energy output of the third energy source is less than the energy requirements of the heat pump.

14. The method of claim 13, wherein the third energy source comprises one of a waste heat source and a solar water heater.

15. The method of claim 14, further comprising providing heat from the output of the second and third energy sources to a heat exchanger.

16. The method of claim 13, further comprising, in the event that the determined energy output of the third energy source is less than the energy requirements of the heat pump, providing energy output from the third energy source for processing the working fluid.

17. A non-transitory computer readable medium having instructions stored thereon, which, when executed by one or more processors, causes the one or more processors to perform operations, the operations comprising:

sensing the ambient temperature; and

responsive to the sensed ambient temperature, selecting one of a first energy source and a second energy source to provide energy for processing a working fluid of the heat pump, the second energy source different than the first energy source.

18. The non-transitory computer readable medium of claim 17, wherein the operations further comprise:

determining the required energy output from each of the first energy source and the second energy source to provide energy for processing the working fluid, responsive to the sensed ambient temperature; and

determining the cost of operation of the heat pump by each of the first energy source and the second energy source responsive to the determined required energy output, the selecting performed responsive to the determined cost of operation.

19. The non-transitory computer readable medium of claim 17, wherein the first energy source comprises a source of electricity and the second energy source comprises a combustible material powered water heater.

20. The non-transitory computer readable medium of claim 19, wherein the selecting the first energy source comprises providing electric power from the source of electricity to a compressor, and

wherein the selecting the second energy source comprises providing heat from the combustible material powered water heater to a heat exchanger.

21. The non-transitory computer readable medium of claim 17, wherein the operations further comprise determining the energy output of a third energy source, the third energy source different than the first and second energy sources, the selecting performed only in the event that the determined energy output of the third energy source is less than the energy requirements of the heat pump.

22. The non-transitory computer readable medium of claim 21, wherein the third energy source comprises one of a waste heat source and a solar water heater.

23. The non-transitory computer readable medium of claim 22, wherein the operations further comprise providing heat from the output of the second and third energy sources to a heat exchanger.

24. The non-transitory computer readable medium of claim 21, wherein the operations further comprise, in the event that the determined energy output of the third energy source is less than the energy requirements of the heat pump, providing energy output from the third energy source for processing the working fluid.

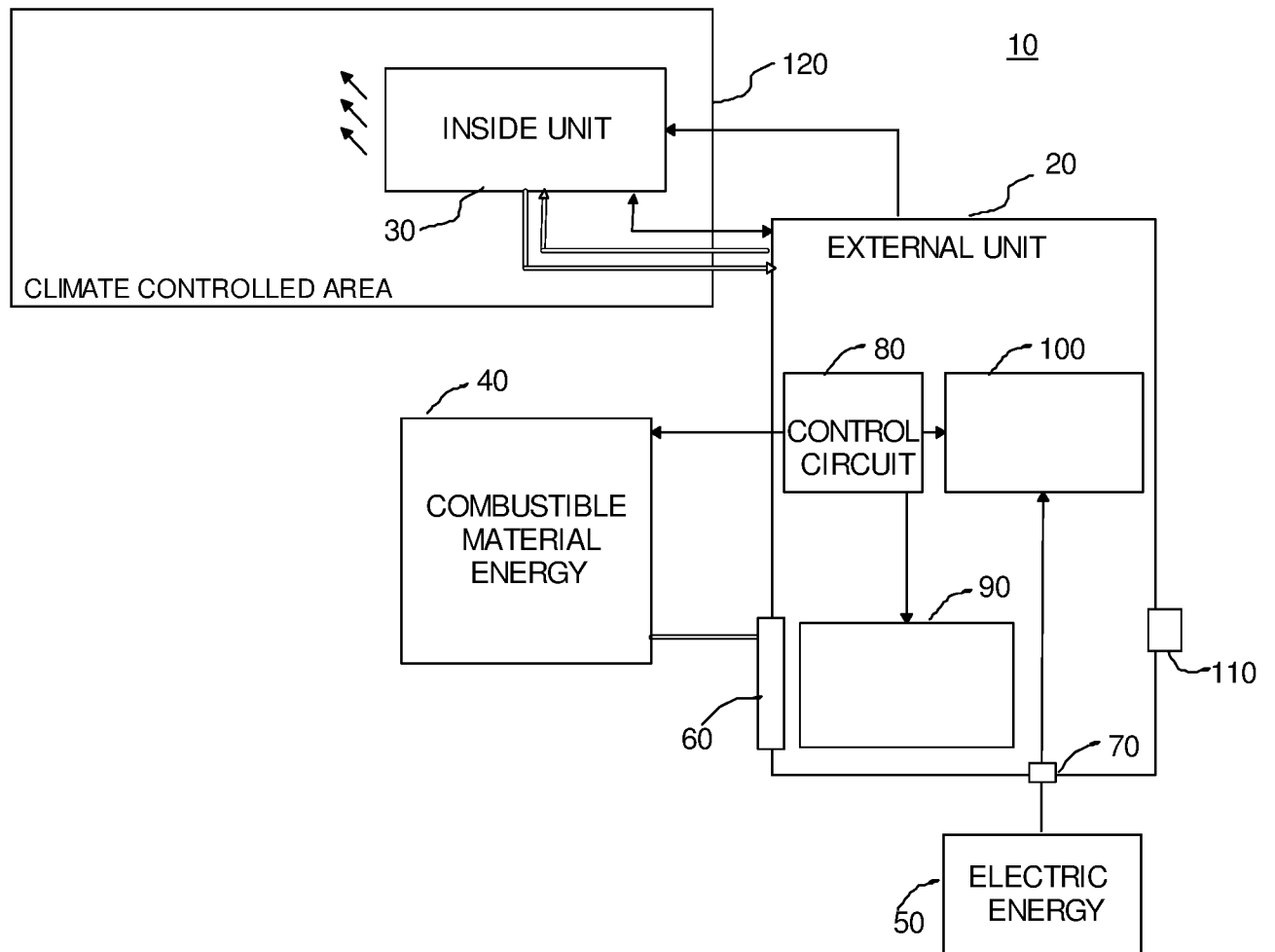


FIG. 1A

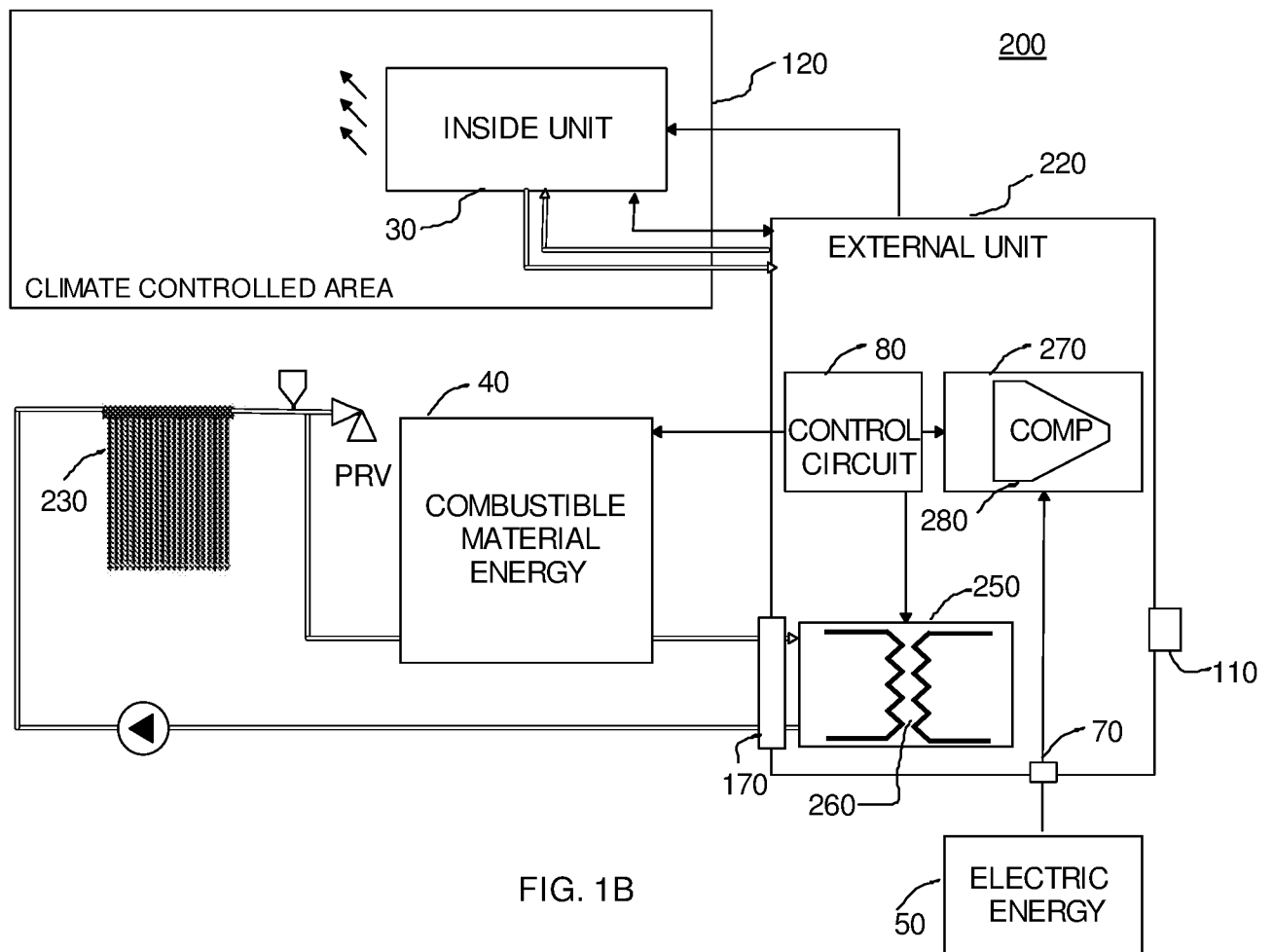


FIG. 1B

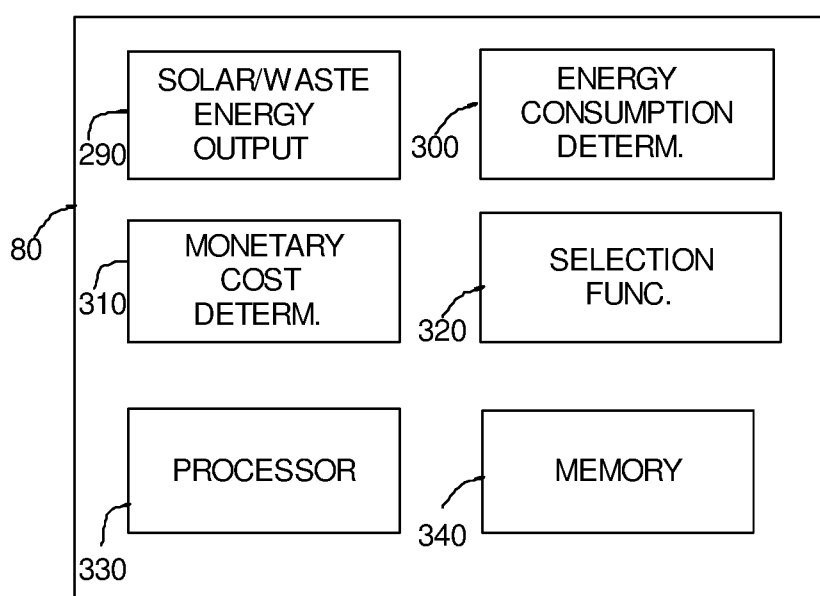


FIG. 1C

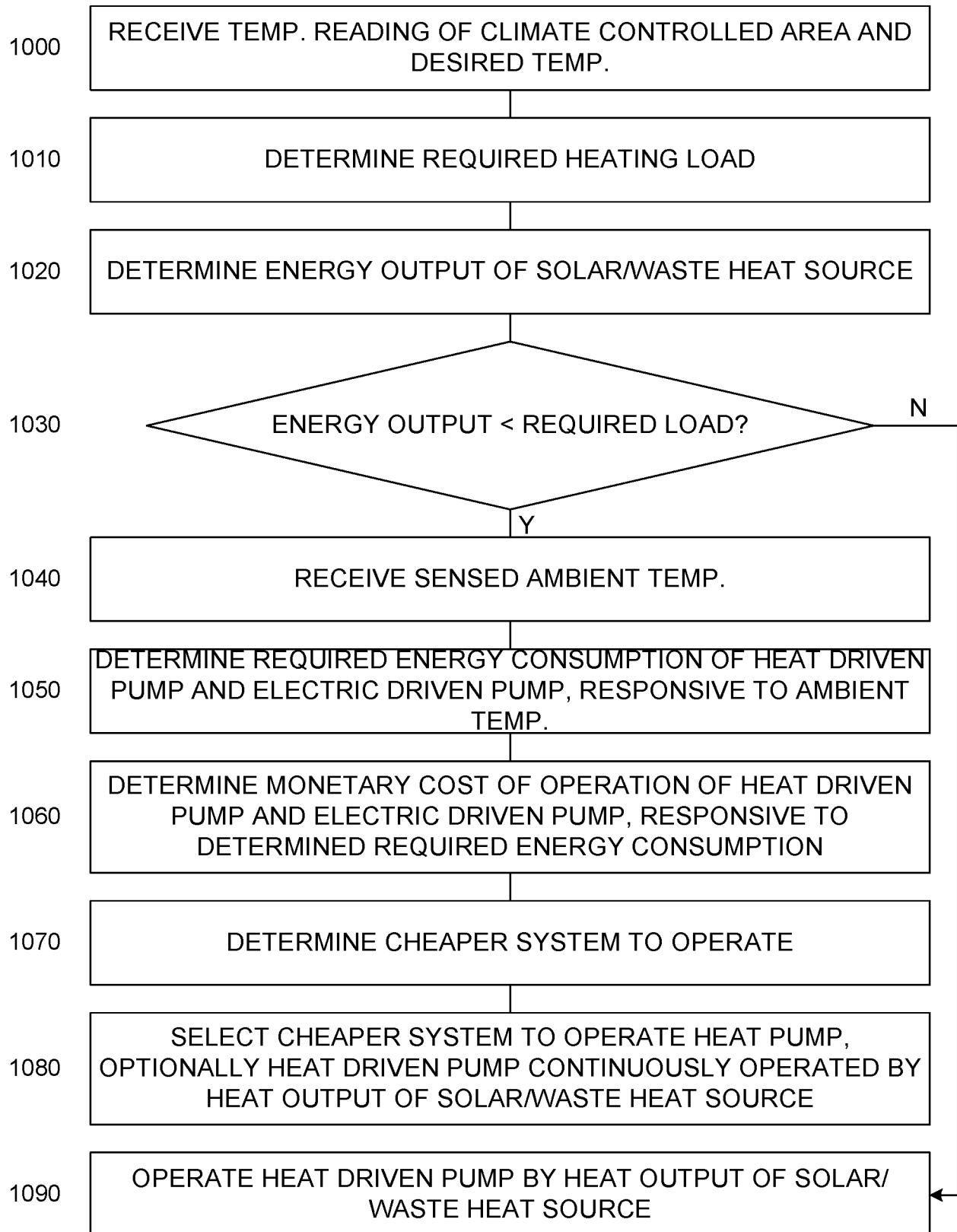


FIG. 2

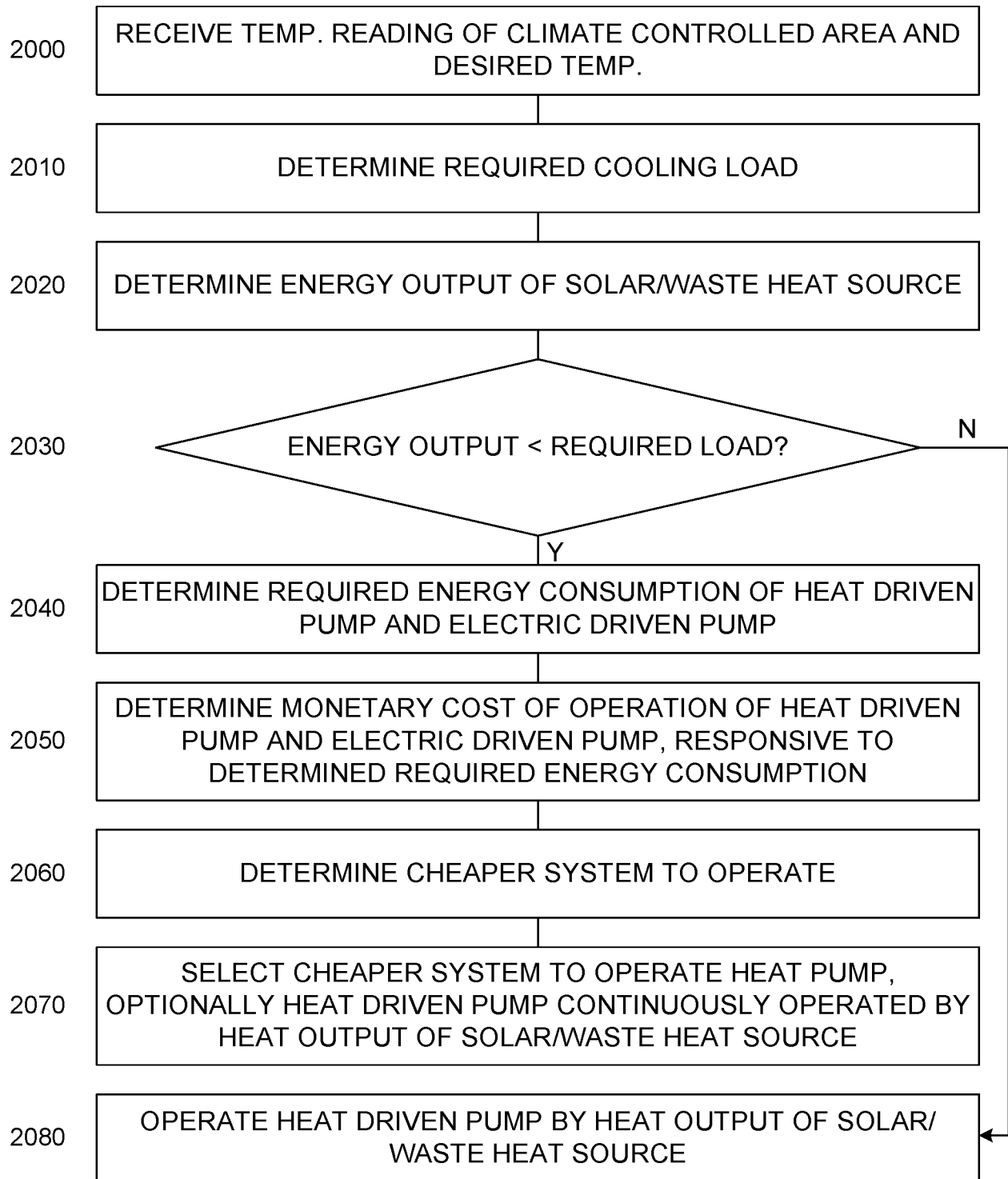


FIG. 3

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/IL2013/051019

| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br>IPC (2014.01) F25B 11/00, F25D 1/00, F25D 11/00<br><br>According to International Patent Classification (IPC) or to both national classification and IPC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                        |                                                                           |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| <b>B. FIELDS SEARCHED</b><br><br>Minimum documentation searched (classification system followed by classification symbols)<br>IPC (2014.01) F25B 11/00, F25D 1/00, F25D 11/00<br><br>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched<br><br>Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)<br>Databases consulted: Esp@cenet, Google Patents, FamPat database                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                        |                                                                           |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                        |                                                                           |
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| * Special categories of cited documents:<br>"A" document defining the general state of the art which is not considered to be of particular relevance<br>"E" earlier application or patent but published on or after the international filing date<br>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)<br>"O" document referring to an oral disclosure, use, exhibition or other means<br>"P" document published prior to the international filing date but later than the priority date claimed<br>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention<br>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone<br>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art<br>"&" document member of the same patent family |                                                                                        |                                                                           |
| Date of the actual completion of the international search<br>24 Apr 2014                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                        | Date of mailing of the international search report<br>27 Apr 2014         |
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PCT/IL2013/051019

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