HEAT PUMP APPARATUS AND METHOD

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A heat pump system and method is presented having a primary compressor, a booster compressor, an economizer, a microprocessor, an air temperature sensor, and a temperature sensor for sensing a temperature commensurate with the boiling temperature of refrigerant in the outside coil. The microprocessor effects controlled operation of the primary compressor, the booster compressor and the economizer when a thermostat calls for heat and in accordance with predetermined ranges of air temperature. The microprocessor calculates a defrost trigger temperature, and defrost operation is initiated when the sensed refrigerant boiling temperature is lower than the trigger temperature for a period of time.
MILD HEATING MODE W/O BOOSTER

Figure 1
MAX HEATING WITH BOOSTER & ECONOMIZER

Figure 2
Figure 3

COOLING MODE OPERATION
COOLING - MAX MODE OPERATION

Figure 3A
<table>
<thead>
<tr>
<th>OUTDOOR TEMPERATURE RANGE, °F</th>
<th>THERMOSTAT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STAGE 1 CALLS:</td>
</tr>
<tr>
<td>1  60 and up</td>
<td>M1</td>
</tr>
<tr>
<td>2  38 to 59</td>
<td>M1</td>
</tr>
<tr>
<td>3  31 to 37</td>
<td>M2</td>
</tr>
<tr>
<td>4  19 to 30</td>
<td>M2</td>
</tr>
<tr>
<td>5  18 &amp; down</td>
<td>M3</td>
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</tbody>
</table>

**FIGURE 4**

<table>
<thead>
<tr>
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<tr>
<td>3  31 to 37</td>
<td>M2</td>
</tr>
<tr>
<td>4  19 to 30</td>
<td>M3-C</td>
</tr>
<tr>
<td>5  18 &amp; down</td>
<td>M3</td>
</tr>
</tbody>
</table>

**FIGURE 4A**
Figure 6
HEAT PUMP APPARATUS AND METHOD

RELATIONSHIP TO OTHER APPLICATIONS

This application relates to heat pumps of the type disclosed and claimed in my previously issued U.S. Pat. Nos. 6,931,871, 6,276,148, 5,927,088, and 5,839,886 and my pending U.S. patent applications Ser. Nos. PCT/US05/34651 and 10/959,254. The entire contents of my said United States patents and patent applications are incorporated herein by reference.

BACKGROUND OF THE INVENTION

This invention relates to the field of heat pumps. More particularly, this invention relates to the field of air source heat pumps having a primary compressor and a booster compressor connected in series, the heat pumps being suitable for heating operation at temperatures down to zero degrees Fahrenheit and lower.

SUMMARY OF THE INVENTION

In accordance with the present invention, a primary compressor and a booster compressor are connected to operate in series in a heat pump system. The primary compressor is a variable capacity or partially unloadable compressor, and the booster is preferably a single speed compressor. The system also incorporates a temperature sensor for sensing the temperature of outdoor ambient air, a two stage indoor thermostat and a microprocessor. For heating operation, the system is capable of operation in any one of three modes, M1, M2, M3, depending on outdoor air temperature and the heating load on the system. M1 is partial capacity operation of the primary compressor; M2 is full capacity operation of the primary compressor; and M3 is full capacity operation of each of the primary compressor, the booster compressor, and an economizer. For outdoor temperatures in a first range between about 60°F and up (i.e., up to where heating operation is no longer allowed), only operation in M1 is allowed. For outdoor air temperatures in a second range of from about 38°F to about 59°F, operation in M1 is allowed, and, if M1 operation does not provide enough heat, operation in M2 is also allowed. For outdoor air temperatures in a third range of from about 31°F to about 37°F, operation in only M2 is allowed. For outdoor air temperatures in a fourth range of from about 19°F to about 37°F, operation in M2 is allowed, and, if M2 operation does not provide enough heat, operation in M3 is allowed. For outdoor air temperatures in a fifth range of from about 18°F and below, operation in M3 is allowed, and, if M3 operation does not provide enough heat, the system may also include an M4 mode in which the electrical resistance heat is added to the system.

The temperature sensor delivers signals to the microprocessor, and the microprocessor enables or allows operation in M1, M2 and M3 (and M4), i.e., conditions are created wherein operation in those modes will occur if the thermostat calls for heat. When the thermostat calls for heat, the microprocessor will generate signals to cause operation in M1, M2, M3 or M4 depending on the outdoor air temperature.

For cooling operation, only the primary compressor operates in either Mode 1 or 2 depending on which indoor thermostat stage is calling for cooling operation.

The heat pump system also incorporates a demand defrost cycle in modes M2, M3 and M4 (if M4 is present). Outdoor air temperature is sensed by a temperature sensor external to the outdoor (evaporator) coil, and a signal representing that temperature is delivered to a system microprocessor. Based on the sensed outdoor air temperature, the microprocessor calculates a defrost trigger temperature T1 for each of modes M2 and M3 (M4 is identical to M3 for demand defrost purposes). A temperature T2 is also sensed that is commensurate with the temperature of the refrigerant boiling in the outdoor coil.

T2 is sensed by a sensor mounted on one of the tubes feeding an evaporator circuit directly downstream of the normal pressure reduction/flashng process. Whenever T2 then drops to a value equal to or less than the calculated T1 continuously for 10 minutes, a defrost cycle is triggered to defrost the outdoor coil. The defrost cycle continues until T2 rises to a predetermined defrost terminating value.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic drawing of the heat pump system of the present invention for heating modes M1 and M2.

Fig. 2 is a schematic drawing of the heat pump system of the present invention for heating mode M3, and M4 if present.

Fig. 3 is a schematic drawing of the heat pump system of the present invention for cooling modes M1 and M2.

Fig. 3A is a schematic drawing of the heat pump system of the present invention for cooling modes M3 or M3-C.

Fig. 4 is a table showing the temperature ranges of operation for heating modes M1, M2, M3, and M4, if present.

Fig. 4A is a modified version of the table of Fig. 4.

Fig. 5 is a chart illustrating the determination of trigger temperatures for defrost operation.

Fig. 6 is a schematic showing incorporation of a refrigerant compensator for modes M3 and M4.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A closed loop heat pump system for heating operation is shown. The system includes a first or booster compressor 22, a second or high stage primary compressor 24, an indoor coil or condenser 26 that delivers heated air to a space to be heated, an outdoor coil or evaporator 28 which receives outdoor air from which heat energy is to be extracted, an economizer 30 which has a solenoid operated control valve 31, a four way flow control valve 32, and a conduit system 34 for connecting the foregoing components in a closed loop system for the flow of refrigerant. Flow control valve 32 operates to reverse the flow of refrigerant to effect cooling operation and for defrost operation. The system also has a microprocessor 36 and a two stage thermostat 38, such as is available from White Rogers. The system also has thermal expansion valves 40 and 42 in conduit 34 associated, respectively, with indoor coil 26 and outdoor coil 28, and check valves 44 and 46 for bypassing refrigerant flow around expansion valves 40 and 42, respectively, depending on the direction of refrigerant flow in the system. The check valves 44 and 46 may actually be internal parts of their respective expansion valves, but they are shown separately to facilitate the description of operation. The system also includes a first
temperature sensor 48 positioned near outdoor coil 28 for sensing the temperature of outdoor air flowing over outdoor coil 28, and a second temperature sensor 50 on or just adjacent to conduit 34 where it enters outdoor coil 28 to sense temperature commensurate with the boiling refrigerant in outdoor coil 28. Air handlers and/or fans for coils 26 and 28 are not shown, but the flow or air over these coils is indicated by arrows.

[0018] Primary compressor 22 is preferably a Bristol twin single (TS) compressor having two reciprocating pistons and cylinders. However, it can also be any multi-capacity or unloadable positive displacement or multi-speed compressor. Booster compressor 22 is any type of a positive displacement single speed compressor. The flow capacity of the primary compressor is preferably split 60%-40% is the flow capacity between both cylinders are operating, and 50% is the percentage of total flow capacity when only one piston is reciprocating. In addition, the flow capacity of booster compressor is larger than the flow capacity of primary compressor, preferably by a ratio of from about 1.3 to 1.7/1, depending on the climate where the system is to be used.

[0019] In initial operation of the system in the heating mode, a signal representing the ambient air temperature sensed by temperature sensor 48 is delivered to microprocessor 36, and the microprocessor will enable or allow partial capacity operation of primary compressor 24 upon receipt of a signal from thermostat 38 calling for heat if the outdoor ambient temperature is in a first range between about 60°F and above. A signal calling for heat is delivered to microprocessor 36 from stage 1 of thermostat 38 when the temperature of the space to be heated falls below the set point of the thermostat by, e.g., 0.6°F - 1.2°F. If the temperature sensed at sensor 48 is in the first range of at or between about 60°F and above, the microprocessor causes operation of one cylinder of primary compressor 24. That is, partial capacity operation of primary compressor 24 is effected. When that happens, compressed hot refrigerant vapor is circulated in conduit system 34 by delivery from primary compressor 24 through 4 way valve 32 and then to indoor condenser coil 26 where heat is extracted by air from an air handler passing over indoor coil 26 to be delivered to the space to be heated. On leaving the indoor condenser coil 26, the refrigerant is in the form of a warm liquid, and it flows through check valve 44, which is open, bypassing expansion valve 40. The warm refrigerant liquid then flows directly through the liquid side of economizer 30 and is delivered to thermal expansion valve 42. Since direction of flow and pressure of the refrigerant at check valve 46, the warm liquid refrigerant is delivered to and flows through thermal expansion valve 42 where part of the refrigerant is flashed or boiled to vapor. The two phase refrigerant mixture then flows to outdoor coil 28 where the remaining liquid refrigerant is vaporized due to extraction of heat from the outside air. The resulting cool vapor is then delivered through 4 way valve 32 and through check valve 52 and conduit section 54 to the inlet to primary compressor 24. The refrigerant then goes through repeat cycles of compression; subsequent vapor cooling and condensation into liquid; then liquid flashing or expansion; subsequent boiling or evaporation while it is concurrently transferring heat energy into outdoor air while cooling and condensing and extracting heat energy from the outside air while boiling or evaporating. The operating cycle described above with partial capacity operation of the primary compressor is termed Mode 1, or M1. When the set point of thermostat 38 is reached, a signal is sent from the thermostat to the microprocessor to terminate operation of primary compressor 24 in M1. If the temperature of the space to be heated again falls below the set point of the thermostat by 0.6°F - 1.2°F, the thermostat again delivers a heat calling signal to microprocessor 36, and if the temperature sensed by sensor 48 is still in the first range of between about 60°F and up, the system is again cycled through operation in M1. As long as the outdoor ambient temperature sensed at sensor 48 is in the first range between about 60°F and up, the microprocessor will only allow operation in M1, i.e., with partial capacity operation of primary compressor 24. Also, if the outside air temperature, as sensed by sensor 48 is at or below a selected upper first range temperature of, e.g., about 75°F, the microprocessor will not allow operation of primary compressor 24, and heating operation will not occur. This prevents inefficient use of the heating system.

[0020] The system continues to operate in M1 until sufficient heat has been delivered to the space being heated to satisfy the setting called for by thermostat 38. When the setting of the thermostat is satisfied, a signal is delivered from the thermostat to the microprocessor, and operation of the compressor system is terminated. However, if sufficient heat has not been delivered to the internal space to be heated within a pre-programmed period of time (typically from 5 to 10 minutes) or if the rate of increase in temperature is not fast enough, the thermostat calls for stage 2 operation by sending a second signal to microprocessor 36 to call for more heating capacity from the system. If the outdoor ambient temperature sensed at sensor 48 is in a second and lower range of temperature between about 38°F and 59°F, the microprocessor then delivers an enabling signal to primary compressor 24 to operate both pistons of the primary compressor 24 to effect operation of the primary compressor at full capacity. This full capacity operation of the primary compressor is termed Mode 2 or M2. In M2, the flow of refrigerant through the system is as in M1, but at a higher flow rate, whereby a greater volume of hot vapor is delivered to indoor condenser coil 26 to heat the indoor space to be heated. Note, again, that if the outdoor temperature sensed at sensor 48 is not at or below the upper limit of about 59°F of the second operating range of outdoor temperatures, the microprocessor will not enable M2 operation of the system. Again, this prevents inefficient operation of the heating system. The system continues to operate in M2 until sufficient heat has been delivered to the space being heated to satisfy the setting called for by thermostat 38. When the setting of the thermostat has been satisfied, a signal is delivered from the thermostat to the microprocessor to terminate operation of the compressor system. If the temperature of the space to be heated again falls below the set point of the thermostat by 0.6°F - 1.2°F, the thermostat again delivers a heat calling signal to microprocessor 36, and if the temperature sensed by sensor 48 is in the second range of between about 38°F and 59°F, the system is again cycled through operation first in M1 and then in M2. As long as the outdoor ambient temperature sensed at sensor 48 is in the second range between about 38°F and 59°F, the microprocessor will only allow operation in M1 and M2, i.e., first with partial capacity operation and then fall capacity of primary compressor 24.

[0021] At a third and lower range of outdoor ambient air temperatures, from about 31°F to 37°F the temperature signal delivered by sensor 48 to microprocessor causes the microprocessor to skip M1, and go directly to enabling or
allowing M2 operation. Accordingly, upon receipt of a heat calling signal from stage 1 of thermostat 38 being delivered to microprocessor 36 (as the result of the temperature in the space to be heated falling below the set point of the thermostat), the microprocessor delivers a signal to primary compressor 24 to operate the primary compressor at full capacity. The system continues to operate in M2 until sufficient heat has been delivered to the space being heated to satisfy the setting called for by thermostat 38. If the setting of the thermostat is satisfied, a signal is delivered from the thermostat to the microprocessor, and operation of the compressor system is terminated. However, if sufficient heat has not been delivered to the internal space to be heated within a period of time (typically from 5 to 10 minutes), or if the rate of temperature increase is not fast enough, the thermostat calls for stage 2 operation by sending a second signal (calling for more heating capacity from the system) to microprocessor 36. However, in this third range of outdoor ambient air temperatures, from about 31°F to 37°F, the microprocessor is programmed to still only allow M2 operation upon receiving the stage 2 signal from the thermostat. This prevents inefficient use of the heating system as higher capacity operation is not to be permitted by the microprocessor until it is really needed.

At a fourth and lower range of outdoor ambient air temperatures, from about 19°F to about 30°F, the temperature signal delivered by sensor 48 to the microprocessor causes the microprocessor to again skip M1, and go directly to allowing M2 operation. Accordingly, upon receipt of a heat calling signal from stage 1 of thermostat 38 being delivered to microprocessor 36 (as the result of the temperature in the space to be heated falling below the set point of the thermostat by from about 0.6°F-1.2°F), the microprocessor delivers a signal to primary compressor 24 to operate the primary compressor at full capacity. The system continues to operate in M2 until sufficient heat has been delivered to the space being heated to satisfy the setting called for by thermostat 38. If the setting of the thermostat is satisfied, a signal is delivered from the thermostat to the microprocessor, and operation of the compressor system is terminated. However, if sufficient heat has not been delivered to the internal space to be heated within a period of time (typically from 5 to 10 minutes), or if the rate of temperature increase is not fast enough, the thermostat calls for stage 2 operation by sending a second signal (calling for more heating capacity from the system) to microprocessor 36. If the outdoor ambient temperature sensed at sensor 48 is in the range of between about 19°F and 30°F, the microprocessor then generates enabling signals to operate all of the booster compressor 22, the primary compressor 24 at full capacity, and the economizer at full capacity. This operation of the booster compressor, the primary compressor at full capacity and full capacity operation of the economizer is termed Mode 3 or M3.

Referring to FIG. 2, when the system is operated in M3, the high pressure discharge from booster compressor 22 closes check valve 52, whereby the refrigerant vapor from outdoor coil 28 is delivered through 4 way valve 32 and conduit segment 55 to the inlet to booster compressor 22. After compression in booster compressor 22, the higher pressure refrigerant vapor discharge from compressor 22 is delivered via conduit segment 56 to primary compressor 24 after first mixing with the additional refrigerant saturated vapor emanating from the boiling side of economizer 30 (see description below re economizer 30). The now combined and somewhat desuperheated vapor (after mixing) is further compressed by primary compressor 24 and is then delivered to condenser indoor coil 26. The increased mass flow of the refrigerant resulting from both the high flow rate low compression booster and the heat recovering economizer enters the primary compressor resulting in significantly increased heating capacity for the system, which can be transferred to the air flowing over indoor coil 26 to be delivered to the space to be heated.

The warm liquid refrigerant discharged from indoor coil 26 is delivered to economizer 30. However, the economizer enabling signal from the microprocessor opens solenoid valve 31, whereby some of the liquid refrigerant is bled through bleed line 58 and expanded through an orifice in solenoid valve 31 thereby entering the boiling side of the economizer where it boiled (or evaporated) into saturated vapor. This boiling liquid in the boiling side of the economizer significantly subcools the warm refrigerant flowing through the liquid side of the economizer as it extracts the thermal energy originally present in the warm liquid. This results in significantly subcooled liquid refrigerant being delivered to expansion valve 42 of evaporator outdoor coil 28. This results in an increased refrigerant capacity (per unit of mass flow) which absorbs more heat energy from the ambient air passing over outdoor coil 28 thereby further increasing the heating capacity of the system.

The saturated refrigerant vapor from the boiling side of economizer 30 is delivered via conduit segment 60 to a location in conduit segment 56 between the discharge from primary compressor 22 and the inlet to primary compressor 24 where it joins and mixes with the vapor stream going form the discharge of the booster compressor to the inlet to the primary compressor.

In M3, the flow of refrigerant through the system is at a higher flow rate and pressure than in M1 or M2, whereby a greater volume of hot vapor is delivered to indoor condenser coil 26 to heat the indoor space to be heated. Note, again, that if the outdoor temperature sensed at sensor 48 is not at or below the upper limit of about 30°F of the fourth operating range of outdoor temperatures, the microprocessor will not enable M3 operation of the system. Again, this prevents inefficient operation of the heating system.

The system continues to operate in M3 until sufficient heat has been delivered to the space being heated to satisfy the setting called for by thermostat 38. When the setting of the thermostat has been satisfied, a signal is delivered from the thermostat to the microprocessor to terminate operation of the compressor system. If the temperature of the space to be heated again falls below the set point of the thermostat by about 0.6°F-1.2°F, the thermostat again delivers a heat calling signal to microprocessor 36, and if the temperature sensed by sensor 48 is in the fourth range of between about 19°F and 30°F, the system is again cycled through operation first in M2 and then in M3. As long as the outdoor ambient temperature sensed at sensor 48 is in the fourth range between about 19°F and 30°F, the microprocessor will only enable operation in M2 and M3, i.e., first with full capacity operation of primary compressor 24, and then adding in the operation of the booster compressor and the economizer.

For the sake of clarity, it should be noted that although the M3 enabling signal from the microprocessor calls for operation of both the booster compressor and the economizer, there is a slight delay in the operation of the economizer relative to operation of the booster compressor.
The booster compressor operates at full capacity almost immediately upon receipt of the enabling signal from the microprocessor. However, there is a time delay in operation of the economizer because of the time needed to bleed the fluid through the orifice of solenoid valve 31 and deliver the saturated vapor from the boiling side of the economizer through conduit segment 60 to conduit segment 56.

When ambient air temperatures in a fifth range of 18°F. and below are sensed at sensor 48, and when thermostat 32 is calling for heat, microprocessor 36 allows and effects operation of the heat pump system in M3, i.e., with full capacity operation of the primary compressor, and with operation of the booster compressor and with operation of the economizer. However, if sufficient heat has not been delivered to the internal space to be heated within a period of time (typically from 5 to 10 minutes) or if the rate of temperature rise is not fast enough, the thermostat calls for stage 2 operation by sending a second signal (calling for more heating capacity from the system) to microprocessor 36. The microprocessor then allows and effects operation of backup electrical resistance heater 62, which is positioned downstream of the air flow over indoor coil 26. This is designated as Mode 4 or M4 operation. Note, again, that if the outdoor temperature sensed at sensor 48 is not at or below about 18°F. of the fifth operating range of outdoor temperatures, the microprocessor will not allow M4 operation of the system. Again, this prevents inefficient operation of the heating system. The system continues to operate in M4 until sufficient heat has been delivered to the space being heated to satisfy the setting called for by thermostat 38. When the setting of the thermostat has been satisfied, a signal is delivered from the thermostat to the microprocessor to terminate operation of the compressor system. If the temperature of the space to be heated again falls below the set point of the thermostat by 0.6°F. to 1.2°F., the thermostat again delivers a heating signal to microprocessor 36, and if the temperature sensed by sensor 48 is in the fifth range of below about 18°F., the system is again cycled through operation first in M3 and then in M4. As long as the outdoor ambient temperature sensed at sensor 48 is in the fifth range below about 18°F., the microprocessor will only enable operation in M3 and M4, i.e., first with full capacity operation of primary compressor 24 and booster compressor 22 and the economizer 30, and then adding in operation of electrical resistance heater 62 if the thermostat is not satisfied.

It will be understood that when the booster compressor and economizer are operating, the primary compressor is also operating at full capacity. That is, operation in M3 includes operation in M2. Also, when supplemental electrical resistance heat is operation, the primary compressor is operating at full capacity and both the booster compressor and the economizer are operating. That is, operation in M4 includes operation in M3.

Referring to FIG. 4A, a table is presented showing the various modes of operation allowed and effected by the system depending on outdoor ambient temperature as sensed at sensor 48. When the outdoor ambient temperature is in the first range between about 60°F. and up, operation only in M1 is allowed and effected regardless of whether stage 1 or stage 2 of the thermostat is calling for heat. When the outdoor ambient temperature as sensed at sensor 48 is in the second temperature range between about 38°F. and about 59°F., operation first in M1 is allowed and effected when stage 1 of the thermostat is calling for heat, and operation in M2 is allowed and effected when stage 2 of the thermostat is calling for heat. When outdoor ambient temperature as sensed at sensor 48 is in the third temperature range between about 31°F. and about 37°F., operation only in M2 is allowed and effected, regardless of which stage of the thermostat is calling for heat. When outdoor ambient temperature as sensed at sensor 48 is in the fourth temperature range between about 19°F. and about 30°F., operation first in M2 is allowed and effected when stage 1 of the thermostat is calling for heat, and then operation in M3 is allowed and effected when stage 2 of the thermostat is calling for heat. When outdoor ambient temperature as sensed at sensor 48 is in the fifth temperature range below about 18°F., operation first in M3 when stage 1 of the thermostat is calling for heat, and then operation in M4 is allowed and effected when stage 2 of the thermostat is calling for heat.

In an alternative embodiment of the heat pump system, an on-off booster operation may be utilized to reduce the net capacity being delivered to the system condenser when more heat capacity than M2 is needed, but when full M3 system capacity is not absolutely necessary. As an example, instead of allowing full Mode 3 operation as the outdoor temperature falls into the fourth range of temperatures (from about 19°F. to 30°F.), the thermostat is calling for heat, microprocessor 36 is programmed to first allow and effect booster compressor 22 to start and stop for pre-determined relatively short periods of time until the outdoor temperature eventually falls to a point where it is desirable to allow continuous M3 operation. This cycling mode of operation of booster 22 is designated as Mode 3-C (M3-C) and will be incorporated approximately half way down in outdoor temperature between where M2 operation and the full M3 operation are allowed as indicated previously (e.g., for a temperature range of from about 24°F. to about 30°F.), Full M3 operation would be enabled for the lower half of the M3 operating temperature range. The booster “on” and “off” intervals can be of equal time or unequal. Alternatively, the relative “on” and “off” times for the booster compressor can be made to vary in steps as outdoor air temperature falls through the entire outdoor door temperature range for M3 operation, with booster “on” time being lowest when outdoor air temperature is lower in the M3 enabling temperature range and booster “on” time being highest when outdoor ambient temperature is lower in the M3 enabling temperature range. This variable on-off time ratio inversely proportional to the outdoor temperature may further enhance operating efficiency.

Referring to FIG. 4A, another modification is illustrated if the M3-C mode of operation is utilized. In this modification, M3-C operation is allowed and effected when the sensed outdoor ambient air temperature is in the third range of from about 31°F. to about 37°F. and stage 2 of the thermostat is calling for heat; and M3-C operation is also allowed and effected when the sensed outdoor ambient air temperature is in the fourth range of from about 19°F. to about 30°F. and the first stage of the thermostat is calling for heat.

1032 In another embodiment intended for use warmer winter climates such as in the southeastern or southwestern U.S., the heating demand on the system may be reduced. For use in such climates, economizer 30 can be eliminated from the system, and M3 or M3-C operation would then involve only full capacity operation of primary compressor 24 and operation of booster compressor 22.

It is typical to incorporate a defrost cycle or operation in heat pump systems to prevent accumulation of ice on
the outdoor evaporator coil. In the system of the present invention, temperatures are not low enough for icing of the evaporator coil to be a problem where only M1 operation is enabled. Accordingly, no provision is made for defrost operation whenever the system is enabled for operation only in M1.

However, whenever the system is enabled for operation in M2, (M3-C if that embodiment is incorporated), M3, or M4, provisions must be made for defrost cycling or operation. In the present invention, defrost cycling is accomplished on a demand basis, i.e., when defrosting is needed, as opposed to systems where defrosting operation is always initiated on a timed basis, whether needed or not.

In the present invention, microprocessor 36 uses an algorithm to calculate a defrost trigger temperature T1 based on the outdoor ambient temperature sensed by sensor 48. A second temperature sensor, sensor 50, is positioned on conduit 34 just upstream of the entrance to outdoor evaporator coil 28, whereby sensor 50 senses the temperature T2 of the boiling refrigerant entering the evaporator coil, and a signal commensurate with T2, i.e., the temperature of the boiling refrigerant entering the evaporator coil, is sent to microprocessor 36. When T2 is less than or equal to T1, i.e., T2 ≤ T1, for a predetermined period of time, e.g., ten minutes, thus indicating a possible icing condition at outdoor coil 28, then defrost operation is triggered. In the present invention, separate algorithms are used to calculate the defrost trigger temperature (DTT) depending on whether the system is operating in M2 or M3.

When the system is operating in M2, a typical algorithm is as follows:

Mode 2 $DIT(T1) = 0.85x10.4 F - 10.50$

When the system is operating in M3, a typical algorithm is:

Mode 3 $DIT(T1) = 0.707x10.4 F - 19.625$

where, in both cases, $x^0 F$ is the outdoor ambient air temperature sensed by sensor 48 and delivered to microprocessor 36. These algorithms, which are linear functions of outdoor air temperature, are illustrated in FIG. 5. Referring to FIG. 5, line 100 represents the outside air temperature; line 102 represents a temperature commensurate with the temperature of boiling refrigerant in outdoor coil 28 when the coil is free of frost or ice in M2 operation of the system; line 104 represents a temperature commensurate with the temperature of boiling refrigerant in outdoor coil 28 in M2 operation with a sufficient accumulation on the coil of frost or ice to trigger defrost operation if the temperature sensed by sensor 50 stays at or below line 104 for a predetermined time; line 106 represents a temperature commensurate with the temperature of boiling refrigerant in outdoor coil 28 when the coil is free of frost or ice in M3 operation; and line 108 represents a temperature commensurate with the temperature of boiling refrigerant in outdoor coil 28 in M3 operation with a sufficient accumulation on the coil of frost or ice to trigger defrost operation if the temperature sensed by sensor 50 stays at or below line 108 for a predetermined time.

When microprocessor 38 determines that T2 ≤ T1 for ten minutes, the microprocessor generates a signal to commence defrost operation. That defrost operation signal effectively puts the heat pump system in the cooling mode of operation (See FIG. 3). To that end, a signal is delivered from the microprocessor to 4 way valve 32 to move the valve to reverse the flow of refrigerant in conduit system 34. A signal is also delivered from the microprocessor to primary compressor 24 to operate the primary compressor at full capacity, i.e., in cooling M2. The booster compressor and the economizer are not operative in the defrost mode. During the defrost operation, airflow over outdoor coil 28 is terminated, but airflow over indoor coil 26 is maintained in order to absorb sufficient thermal energy to effect ice/frost removal on the outdoor coil.

As shown in FIG. 3, with 4 way valve 32 moved to the cooling position to effect defrost operation, refrigerant vapor discharged from primary compressor 24 is delivered to outdoor coil 28, which is now functioning as a condenser. The vapor gives up its heat of condensation as it cools while circulating through outdoor coil 28 thus melting any ice or heavy frost that has accumulated on coil 28 to effect the defrost operation. The refrigerant then flows through check valve 46 and around expansion valve 50 and is delivered as cool liquid to the liquid side of economizer 30. The liquid refrigerant flows through the liquid side of the economizer and is expanded through expansion valve 40 and is delivered as cool liquid (along with some flashed vapor) to indoor coil 26 which is now functioning as an evaporator. The resulting cool refrigerant vapor is then delivered through 4 way valve 32 and check valve 52 in conduit 54 to the inlet to primary compressor 24 to continue the defrost cycle.

The defrost cycle continues to operate until the condensed liquid refrigerant exiting the outdoor coil becomes sufficiently warm thus indicating complete removal of ice or heavy frost from the outdoor coil. At this point, responding to a now warm T1 (about 70°F) the microprocessor sends a signal effecting 4 way valve movement to the position shown in FIGS. 1 and 2, and the system resumes operation in the heating modes.

To operate the system in a cooling or air conditioning mode, thermostat 38 is moved to its air conditioning position, whereby a first stage signal is delivered from the thermostat to microprocessor 36 whereby a signal is delivered from the microprocessor to 4 way valve 32 to position the valve as shown in FIG. 3, and to enable operation of only primary compressor 24. Without regard to the outside air temperature signal from thermostat 48, when cooling is called for by the room temperature exceeding the thermostat setting, the signal from the microprocessor to primary compressor 24 operates the primary compressor first in partial capacity mode M1 to circulate refrigerant flow as described above for defrost operation. Air flowing over indoor coil 26 is then cooled to cool the space to be cooled. If partial capacity operation M1 proves insufficient to satisfy the thermostat after a predetermined time, or if the rate of the temperature of the temperature of the air being cooled is not fast enough, the thermostat delivers a stage 2 signal to the microprocessor, and the microprocessor operates the primary compressor in full capacity M2.

In the preferred embodiment of this invention, neither M3 nor M3-C operation is enabled for cooling operation. However, for very hot climates, such as the southern or southwestern U.S. in summertime, an alternative embodiment would enable M3-C and/or full M3 operation of the system in cooling operation. In this embodiment, M1 and M2 operation are effected by the microprocessor when the signal from air temperature sensor 48 indicates an outdoor air temperature in a first range of temperatures, and the first and second stages of the thermostat call for M1 and M2 operation, respectively. For an outdoor air temperature sensed by temperature sensor 48 above the first range of temperatures, microprocessor 36.
would effect full capacity operation of primary compressor 22, booster compressor 24 and economizer 30 for cooling operation (M3), or cyclical on-off (M3-C) operation of those components, if operation in M2 is not sufficient to satisfy the thermostat setting. The M3 or M3-C operation in cooling is shown in FIG. 3A.

[0045] The heat pump system may also include a refrigerant charge compensator that acts to reduce the refrigerant charge active in the system condenser during any operating mode causing booster compressor operation. Whenever the booster compressor is idle for any significant period of time, a significant amount of refrigerant vapor will condense into the booster oil in the booster sump. This occurs because the refrigerant is essentially 100% miscible in the oil. The refrigerant vapor condenses into the booster oil when agitation ceases upon shutdown of the booster compressor, and continues to condense as the booster oil temperature falls with the end result being that about 10% more refrigerant charge must be added to the system charge to ensure all operating modes without the booster will always have sufficient operating refrigerant charge. However, the refrigerant thus absorbed into the booster oil comes out of the booster oil-refrigerant solution very quickly upon booster startup and can overcharge the refrigerant system. This excess charge can cause a backup of liquid refrigerant in the condenser, thus reducing the effectiveness of condenser operation. This, in turn, can result in the primary compressor drawing more power and result in a reduction in the overall efficiency of the heat pump system. This problem can be avoided by incorporation of a refrigerant charge compensator 64 in the system (see FIG. 6).

The compensator vessel 64 can be located almost anywhere in the cold air stream leaving the system evaporator 28. Charge compensator 64 is connected via conduit 65 to conduit 60, and thus it is connected both to line 56 and to the discharge from booster compressor 22. Compensator 64 serves to condense and accumulate the excess refrigerant charge coming out of the booster oil whenever the booster is operational. This happens because the compensator is connected to the booster discharge line, and the pressure in the booster discharge line always exceeds the saturation temperature/pressure existing in the cold compensator vessel whenever the booster is operating. When the booster is not operating the refrigerant liquid charge accumulated in compensator 64 is released from the compensator and is subsequently reabsorbed by the oil in the booster sump.

[0046] While preferred embodiments have been shown and described, various modifications and substitutions may be made thereto without departing from the spirit and scope of this invention. Accordingly, it is to be understood that the present invention has been described by way of illustration and not limitation.

1. A heat pump system including:
   a. a primary compressor;
   b. a booster compressor;
   at least said primary compressor being a variable capacity compressor,
   c. a refrigerant conduit system, said primary compressor and said booster compressor being in series in said refrigerant
      conduit system, and said conduit system including a first conduit segment connected to deliver refrigerant to
      the inlet to said primary compressor when said booster compressor is inoperative, and said conduit system
      including a second conduit segment between the dis-
said controller allows operation in M3 when a first stage of said thermostat calls for heat and the outdoor ambient temperature sensed by said first temperature sensor is in a fourth range of temperatures; and said controller allows operation in M3 and allows operation of said backup heater when a second stage of said thermostat calls for heat and the outdoor ambient temperature sensed by said first temperature sensor is in a fourth range of temperatures.

6. A heat pump system as in claim 1 including:
   an outdoor coil in said conduit system;
   said controller calculating a defrost trigger temperature $T_1$ based on the outdoor ambient temperature sensed at said first temperature sensor;
   a second temperature sensor, said second temperature sensor being positioned to sense a temperature commensurate with the temperature of refrigerant in said conduit system in or adjacent to said outdoor coil;
   said second temperature sensor delivering a second temperature signal $T_2$ to said controller; and
   said controller operating to effect a defrost operation of said heat pump system when $T_2$ is equal to or less than $T_1$ for a predetermined period of time.

7. A heat pump system as in claim 6 wherein:
   said controller determines $T_1$ in accordance with a first algorithm when the heat pump system is operating in mode M2.

8. A heat pump system as in claim 7 wherein said first algorithm is:

   $$T_1 = 0.85 A^\circ F - 10.5$$

   where $A^\circ F$ is the temperature of outside air entering said outside coil.

9. A heat pump system as in claim 6 wherein:
   said controller determines $T_1$ in accordance with a second algorithm when the heat pump system is operating in mode M3.

10. A heat pump system as in claim 9 wherein said second algorithm is:

   $$T_1 = 0.7057 A^\circ F - 19.025$$

   where $A^\circ F$ is the temperature of outside air entering said outside coil.

11. A heat pump system as in claim 1 including:
   an economizer in said refrigerant conduit system; and
   a third conduit segment from said economizer to said second conduit segment; and wherein said mode M3 includes operation of said economizer.

12. A heat pump system as in claim 11 wherein:
   operation of said economizer is cyclical.

13. A heat pump system including:
   a primary compressor;
   a booster compressor;
   at least said primary compressor being a variable capacity compressor,
   a refrigerant conduit system, said primary compressor and said booster compressor being in series in said refrigerant conduit system, and said conduit system including a first conduit segment connected to deliver refrigerant to the inlet to said primary compressor when said booster compressor is inoperative, and said conduit system including a second conduit segment between the discharge from said booster compressor and the inlet to said primary compressor to deliver refrigerant between said booster compressor and said primary compressor when both of said compressors are operating;
   an economizer in said refrigerant conduit system;
   a third conduit segment from said economizer to said second conduit segment;
   a first temperature sensor for sensing the temperature of outdoor ambient air;
   a controller, said controller being connected between a two step thermostat and said primary and booster compressors, said controller receiving signals from said first temperature sensor and from the thermostat to operate said primary compressor, said booster compressor and said economizer in a predetermined sequence as follows:
   (a) effect a first mode of operation of partial capacity operation of said primary compressor (M1) when either stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor air temperature in a first range of temperatures;
   (b) effect operation in M1 when the first stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor air temperature in a first range of temperatures; and
   (c) effect operation in M2 when either stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor air temperature in a third range of temperatures; and
   (d) effect operation in M2 when the first stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor air temperature in a fourth range of temperatures; and effect a third mode of operation of full capacity operation of said primary compressor, said booster, and said economizer (M3) when the second stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor air temperature in the fourth range of temperatures.

14. A heat pump system as in claim 13 including:
   an electrical resistance backup heater in the heat pump system;
   said controller operating to effect operation in M3 when the first stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor air temperature in a fifth range of temperatures; and said controller operating to effect operation of said backup heater (M4) when the second stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor air temperature in the fifth range of temperatures.

15. A heat pump system as in claim 13 wherein:
   said first range of temperatures is from about 60° F. and above.

16. A heat pump system as in claim 13 wherein:
   said second range of temperatures is from about 38° F. to about 59° F.

17. A heat pump system as in claim 13 wherein:
   said third range of temperatures is from about 31° F. to about 37°
18. A heat pump system as in claim 13 wherein:
said fourth range of temperatures is from about 19°F. to
about 30°F.
19. A heat pump system as in claim 14 wherein:
said fifth range of temperatures is from about 18°F. and
below.
20. A heat pump system as in claim 13 including:
an outdoor coil in said conduit system;
said controller calculating a defrost trigger temperature T1
based on the outdoor ambient temperature sensed at said
first temperature sensor and in accordance with an algo-
rithm;
a second temperature sensor, said second temperature sen-
stor being positioned to sense a temperature commensu-
rate with the temperature of refrigerant in said conduit
system in or adjacent to said outdoor coil;
said second temperature sensor delivering a second tem-
perature signal T2 to said controller; and
said controller operating to effect a defrost operation of
said heat pump system when T2 is equal to or less than
T1 for a predetermined period of time.
21. A heat pump system as in claim 20 wherein:
said controller determines T1 in accordance with a first
algorithm when the heat pump system is operating in
mode M2.
22. A heat pump system as in claim 21 wherein said first
algorithm is:
\[ T1 = 0.85 \times A^oF - 10.5 \]
where A^oF. is the temperature of outside air entering said
outside coil.
23. A heat pump system as in claim 20 wherein:
said controller determines T1 in accordance with a second
algorithm when the heat pump system is operating in
mode M3.
24. A heat pump system as in claim 23 wherein said second
algorithm is:
\[ T1 = 0.7075 \times A^oF - 19.625 \]
where A^oF. is the temperature of outside air entering said
outside coil.
25. A heat pump system as in claim 13 including:
a refrigerant accumulator, said accumulator being con-
ected to the discharge from said booster compressor to
receive from the booster compressor upon operation there-
of and to store excess refrigerant absorbed in the oil
of said booster compressor when said booster compres-
sor is not operating.
26. 1. A defrost system for a heat pump system including:
at least one compressor;
an outdoor coil in said heat pump system;
a refrigerant conduit system, said compressor and said
outdoor coil being being in said refrigerant conduit sys-
tem;
a first temperature sensor for sensing the temperature of
outdoor ambient air and generating a first signal com-
mensurate with the outdoor ambient air temperature;
a second temperature sensor, said second temperature sen-
stor being positioned to sense a temperature commensu-
rate with the temperature of refrigerant in said conduit
system in or adjacent to said outdoor coil, said second
temperature sensor generating a second signal commensu-
rate with the temperature of refrigerant in or adjacent
to said outdoor coil;
a controller, said controller receiving said first signal from
said first temperature sensor and calculating a defrost
trigger temperature T1 based on the outdoor ambient
temperature sensed at said first temperature sensor, and
said controller receiving said second temperature signal
T2 from said second temperature sensor;
said controller operating to effect a defrost operation of
said heat pump system when T2 is equal to or less than
T1 for a predetermined period of time.
27. A defrost system for a heat pump system as in claim 26
wherein:
said controller determines T1 in accordance with an algo-
rithm linear with outdoor ambient air temperature.
28. A method of operating a heat pump system having a
primary compressor and a booster compressor, at least said
primary compressor being a variable capacity compressor,
and said compressors being operable in series, the method
including the steps of:
(a) sensing the temperature of outdoor ambient air;
(b) effecting a first mode of operation of partial capacity
operation of said primary compressor (M1) when heat is
called for and the outdoor air temperature is in a first
range of temperatures;
(c) effecting operation in M1 and effecting a second mode
of operation of full capacity operation of said primary
compressor (M2) when heat is called for and the outdoor
air temperature is in a second range of temperatures;
(d) effecting operation in M2 and effecting a third mode
of operation of full capacity operation of said primary
compressor, said booster, and said economizer (M3) when
heat is called for and the outdoor temperature is in a
third range of temperatures.
29. A method of operating a heat pump system as in claim
28 wherein the system includes an electrical resistance
backup heater, the method including the step of:
effecting full capacity operation of said primary compres-
sor and said booster, and effecting operation of electrical
resistance backup heat when heat is called for and the
outdoor air temperature is in a fourth range of tempera-
tures.
30. A method of operating a heat pump system as in claim
28 wherein the system includes a multi-stage thermostat, the
method including the steps of:
effecting operation in M1 when a first stage of the thermo-
stat calls for heat and the outdoor ambient temperature is
in said first range of temperatures; and,
effecting operation in M2 when a second stage of the
thermostat calls for heat and the outdoor ambient tem-
perature is in said second range of temperatures; and,
effecting operation in M2 when a second stage of said ther-
mostat calls for heat and the outdoor ambient tempera-
ture is in said third range of temperatures; and
effecting operation in M3 when a second stage of said ther-
mostat calls for heat and the outdoor ambient tempera-
ture is in said third range of temperatures.
31. A method of operating a heat pump system as in claim
28 wherein the system includes an electrical resistance
backup heater, and a multistage thermostat, the method
including the steps of:
effecting operation in M3 when a first stage of the thermo-
stat calls for heat and the outdoor ambient temperature is
in a fourth range of temperatures; and
effecting operation in M3 and effecting operation of the
backup heater when a second stage of the thermostat
calls for heat and the outdoor ambient temperature is in a fourth range of temperatures.

32. A method of operating a heat pump system as in claim 28 wherein the system includes a conduit system for the flow of refrigerant, and an outdoor coil in said conduit system for extracting heat energy from outside ambient air, the method including the steps of:
   calculating a defrost trigger temperature $T_1$ based on the outdoor ambient temperature;
   sensing the temperature $T_2$ of refrigerant in the conduit system in or adjacent to the outdoor coil; and
   effecting a defrost operation of said heat pump system when $T_2$ is equal to or less than $T_1$ for a predetermined period of time.

33. A method of operating a heat pump system as in claim 32 wherein:
   the temperature $T_1$ is determined in accordance with a first algorithm when the heat pump system is operating in mode $M_2$.

34. A method of operating a heat pump system as in claim 33 wherein said first algorithm is typically:

$$ T_1 = 0.85A^4 + F = 10.5 $$

where $A^4$ F. is the temperature of outside air entering said outside coil.

35. A method of operating a heat pump system as in claim 34 wherein:
   the temperature $T_1$ is determined in accordance with a second algorithm when the heat pump system is operating in mode $M_3$.

36. A method of operating a heat pump system as in claim 35 wherein said second algorithm is typically:

$$ T_1 = 0.7075A^4 + F = 19.625 $$

where $A^4$ F. is the temperature of outside air entering said outside coil.

37. A method of operating a heat pump system having a primary compressor, a booster compressor, and an economizer, at least said primary compressor being a variable capacity compressor, and said compressors being operable in series, the method including the steps of:
   (a) sensing the temperature of outdoor ambient air;
   (b) effecting a first mode of operation of partial capacity operation of said primary compressor ($M_1$) when heat is called for and the outdoor air temperature is in a first range of temperatures;
   (c) effecting operation in $M_1$ and effecting a second mode of operation of full capacity operation of said primary compressor ($M_2$) when heat is called for and the outdoor air temperature is in a second range of temperatures;
   (d) effecting operation in $M_2$ when heat is called for and the outdoor air temperature is in a third range of temperatures;
   (e) effecting operation in $M_2$ and effecting a third mode of operation of full capacity operation of said primary compressor, said booster, and said economizer ($M_3$) when heat is called for and the outdoor air temperature is in a fourth range of temperatures.

38. A method of operating a heat pump system as in claim 37 wherein the system includes an electrical resistance backup heater, the method including the step of:

effecting full capacity operation of said primary compressor, said booster, and said economizer when the outdoor temperature is in a fifth range of temperatures and the first stage of the thermostat is calling for heat.

39. A method of operating a heat pump system as in claim 37 wherein:
   said first range of temperatures is from about $60^\circ$ F. and above.

40. A method of operating a heat pump system as in claim 37 wherein:
   said second range of temperatures is from about $38^\circ$ F. to about $59^\circ$ F.

41. A method of operating a heat pump system as in claim 37 wherein:
   said third range of temperatures is from about $31^\circ$ F. to about $37^\circ$ F.

42. A method of operating a heat pump system as in claim 37 wherein:
   said fourth range of temperatures is from about $30^\circ$ F. and below.

43. A method of operating a heat pump system as in claim 38 wherein:
   said fifth range of temperatures is from about $18$ and below.

44. A method of operating a heat pump system having a primary compressor, a booster compressor, and an economizer, and a multi-stage thermostat, at least said primary compressor being a variable capacity compressor, and said compressors being operable in series, the method including the steps of:
   (a) sensing the temperature of outdoor ambient air;
   (b) effecting a first mode of operation of partial capacity operation of said primary compressor ($M_1$) when the outdoor air temperature is in a first range of temperatures and either the first stage or the second stage of the thermostat is calling for heat;
   (c) effecting operation in $M_1$ when the outdoor air temperature is in a second range of temperatures, and the first stage of the thermostat is calling for heat; and effecting a second mode of operation of full capacity operation of said primary compressor ($M_2$) when the outdoor air temperature is in the second range of temperatures and the second stage of the thermostat is calling for heat;
   (d) effecting operation in $M_2$ when the outdoor air temperature is in a third range of temperatures and either the first stage or the second stage of the thermostat is calling for heat;
   (e) effecting operation in $M_2$ when the outdoor air temperature is in a fourth range of temperatures and the first stage of the thermostat is calling for heat, and effecting full capacity operation of said primary compressor, said booster, and said economizer ($M_3$) when the outdoor air temperature is in a fourth range of temperatures and the second stage of the thermostat is calling for heat.

45. A method of operating a heat pump system as in claim 44 wherein the system includes an electrical resistance backup heater, the method including the step of:

effecting full capacity operation of said primary compressor, said booster, and said economizer when the outdoor temperature is in a fifth range of temperatures and the first stage of the thermostat is calling for heat, and effecting operation of electrical resistance backup heat when the outdoor air temperature is in a fifth range of temperatures and the second stage of the thermostat is calling for heat.
46. A method of operating a heat pump system as in claim 44 wherein:
said first range of temperatures is from about 60° F. and above.
47. A method of operating a heat pump system as in claim 44 wherein:
said second range of temperatures is from about 38° F. to about 59° F.
48. A method of operating a heat pump system as in claim 44 wherein:
said third range of temperatures is from about 31° F. to about 37° F.
49. A method of operating a heat pump system as in claim 44 wherein:
said fourth range of temperatures is from about 30° F. and below.
50. A method of operating a heat pump system as in claim 45 wherein:
said fifth range of temperatures is from about 18 and below.
51. A method of operating a heat pump system as in claim 44 wherein the system includes a conduit system for the flow of refrigerant, and an outdoor coil in said conduit system for extracting heat energy from outside ambient air, the method including the steps of:
calculating a defrost trigger temperature T1 based on the outdoor ambient temperature;
sensing the temperature T2 of refrigerant in the conduit system in or adjacent to the outdoor coil; and
effecting a defrost operation of said heat pump system when T2 is equal to or less than T1 for a predetermined period of time.
52. A method of operating a heat pump system as in claim 44 wherein:
the temperature T1 is determined in accordance with a first algorithm when the heat pump system is operating in mode M2.
53. A method of operating a heat pump system as in claim 44 wherein said first algorithm is typically:
\[
T_1 = 0.85 A^\circ F - 10.5
\]
where A° F. is the temperature of outside air entering said outside coil.
54. A method of operating a heat pump system as in claim 44 wherein:
the temperature T1 is determined in accordance with a second algorithm when the heat pump system is operating in mode M3.
55. A method of operating a heat pump system as in claim 44 wherein said second algorithm is typically:
\[
T_1 = 0.705 A^\circ F - 19.625
\]
where A° F. is the temperature of outside air entering said outside coil.
56. A heat pump system including:
a primary compressor;
a booster compressor;
at least said primary compressor being a variable capacity compressor,
a refrigerant conduit system, said primary compressor and said booster compressor being in series in said refrigerant conduit system, and said conduit system including a first conduit segment connected to deliver refrigerant to the inlet to said primary compressor when said booster compressor is inoperative, and said conduit system including a second conduit segment between the discharge from said booster compressor and the inlet to said primary compressor to deliver refrigerant between said booster compressor and said primary compressor when both of said compressors are operating;
a first temperature sensor for sensing the temperature of outdoor ambient air;
a controller, said controller being connected between a two step thermostat and said primary and booster compressors, said controller receiving signals from said first temperature sensor and from the thermostat to operate said primary compressor, said booster compressor and said economizer in a predetermined sequence as follows:
(a) effect a first mode of operation of partial capacity operation of said primary compressor (M1) when either stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor air temperature in a first range of temperatures;
(b) effect operation in M1 when the first stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor temperature in a second range of temperatures; and effect a second mode of operation of full capacity operation of said primary compressor (M2) when the second stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor air temperature in a second range of temperatures;
(c) effect operation in M2 when the first stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor temperature in a third range of temperatures; and effect operation in M2 and cyclical on-off operation of said booster compressor (M3-C) when the second stage of the thermostat is calling for heat and the signal from the first temperature sensor indicates an outdoor temperature in a third range of temperatures;
(d) effect operation in M3-C when the first stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor temperature in a fourth range of temperatures; and effect full capacity operation of said primary compressor and said booster (M3), when the second stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor air temperature in the fourth range of temperatures.
57. A heat pump system as in claim 56 including:
an electrical resistance backup heater in the heat pump system;
said controller operating to effect operation in M3 when the first stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor air temperature in a fifth range of temperatures; and said controller operating to effect operation of said backup heater (M4) when the second stage of the thermostat is calling for heat and the signal from said first temperature sensor indicates an outdoor air temperature in the fifth range of temperatures.
58. A heat pump system as in claim 56 including:
an economizer in said refrigerant conduit system;
a third conduit segment from said economizer to said second conduit segment; and wherein
each of modes M3-C and M3 include cyclical on-off operation of said economizer.
59. A heat pump system operating in a cooling mode, including:
   a primary compressor;
   a booster compressor;
   at least said primary compressor being a variable capacity compressor;
   a refrigerant conduit system, said primary compressor and said booster compressor being in series in said refrigerant conduit system, and said conduit system including a first conduit segment connected to deliver refrigerant to the inlet to said primary compressor when said booster compressor in inoperative, and said conduit system including a second conduit segment between the discharge from said booster compressor and the inlet to said primary compressor to deliver refrigerant between said booster compressor and said primary compressor when both of said compressors are operating;
   a first temperature sensor for sensing the temperature of outdoor ambient air;
   a controller, said controller being connected between a multi-stage thermostat and said primary and booster compressors, said controller receiving signals from said first temperature sensor and from the thermostat to operate said primary compressor and said booster compressor in a predetermined sequence as follows:
   (a) effect a first mode of operation of partial capacity operation of said primary compressor (M1) when a first stage of the thermostat calls for cooling, and without regard to the signal from said first temperature sensor;
   (b) effect a second mode of operation of full capacity operation of said primary compressor (M2) when M1 is not sufficient to meet the need for cooling and a second stage of the thermostat calls for more cooling.

60. A heat pump system operating in a cooling mode as in claim 59, including:
   an economizer in said cooling system;
   the predetermined operating sequence including to effect M1 and M2 when the signal from said first temperature sensor indicates an outdoor temperature in a first range of temperatures; and

61. A method of operating a heat pump system in cooling, the system having a primary compressor and a booster compressor, at least said primary compressor being a variable capacity compressor, and said compressors being operable in series, the method including the steps of:
   (a) effecting a first mode of operation of partial capacity operation of said primary compressor (M1) when a first stage of a thermostat calls for cooling is called for and without regard to the signal from said first temperature sensor;
   (b) effecting a second mode of operation of full capacity operation of said primary compressor (M2) when cooling is called for and the outdoor air temperature is in a second range of temperatures;
   (c) effecting operation in M2 and effecting a third mode of operation of full capacity operation of said primary compressor, said booster, and said economizer (M3) when M1 is not sufficient to meet the need for cooling and a second stage of the thermostat calls for more cooling.

62. A method of operating heat pump system in a cooling mode as in claim 61, including:
   an economizer in said cooling system; and including the steps of
   effecting operation in M1 and M2 when the signal from said first temperature sensor indicates an outdoor temperature in a first range of temperatures; and
   effecting a third mode of operation of full capacity operation of said primary compressor and operation of said booster compressor and operation of said economizer, or cyclical on-off operation thereof, when the thermostat is calling for cooling and the signal from said first temperature sensor indicates an outdoor air temperature higher than said first range of temperatures.

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