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(54) **VARIABLE SPEED OUTDOOR FAN CONTROL**

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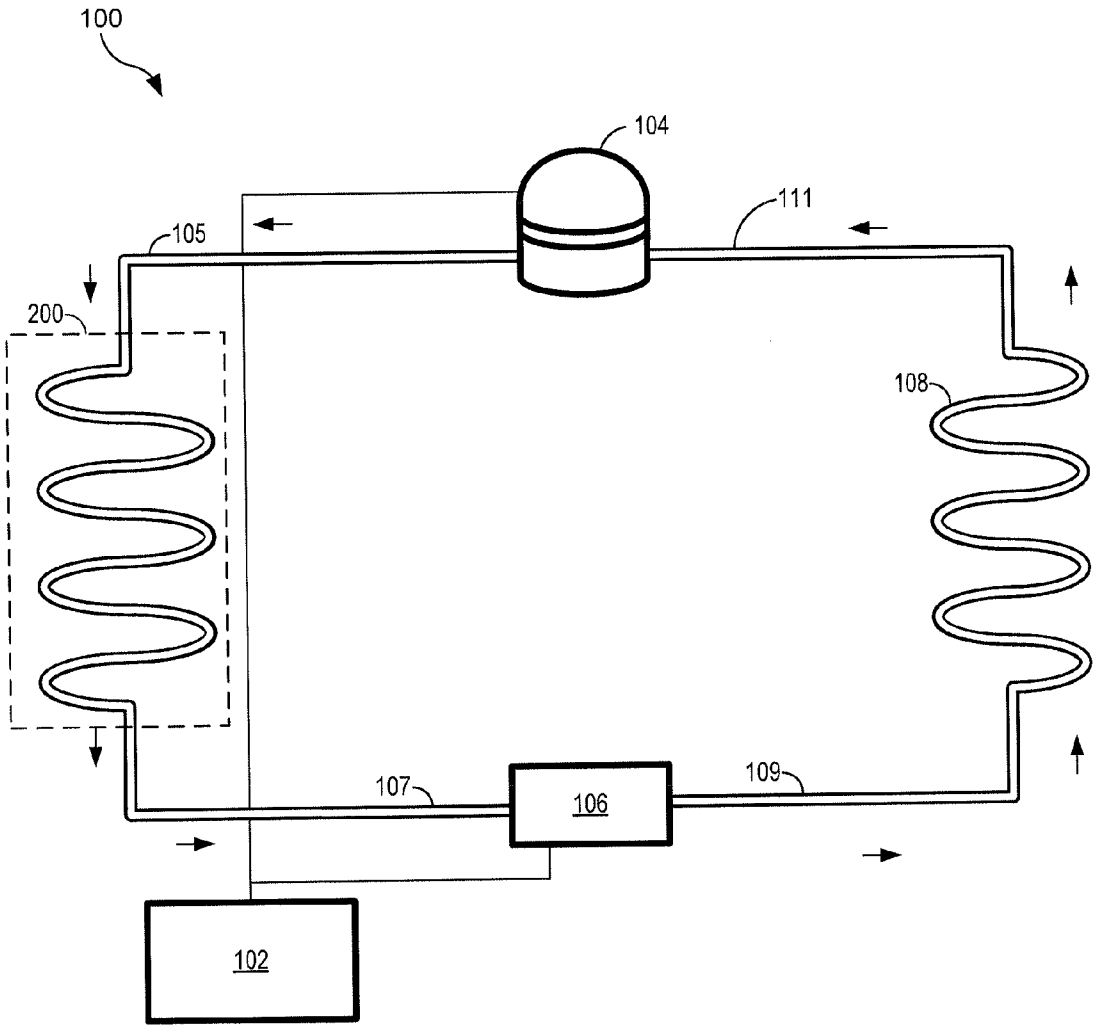
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(57) **ABSTRACT**

A method and apparatus for setting the speed of a fan during operation of an HVAC system are provided. The HVAC system may comprise a heat exchanger, a fan, and a sensor disposed within an outdoor unit of the HVAC system. A controller coupled to the fan and sensor may receive a first signal from the sensor indicating one or more ambient air temperature values and determine a desired speed setting of the fan using at least the one or more ambient air temperatures indicated by the first signal. The controller may further generate a control signal based on the desired speed setting and transmit the control signal to the first fan.



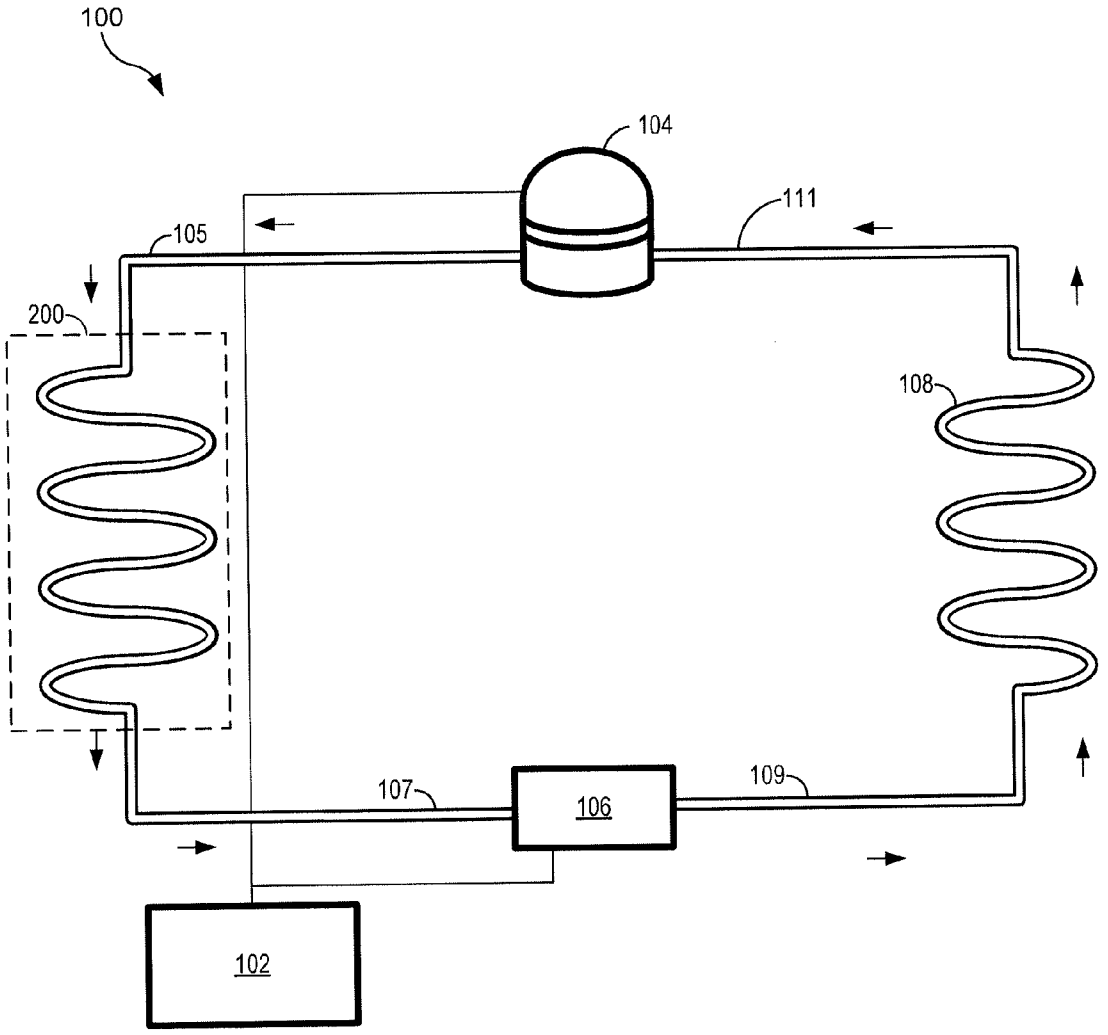


FIG. 1

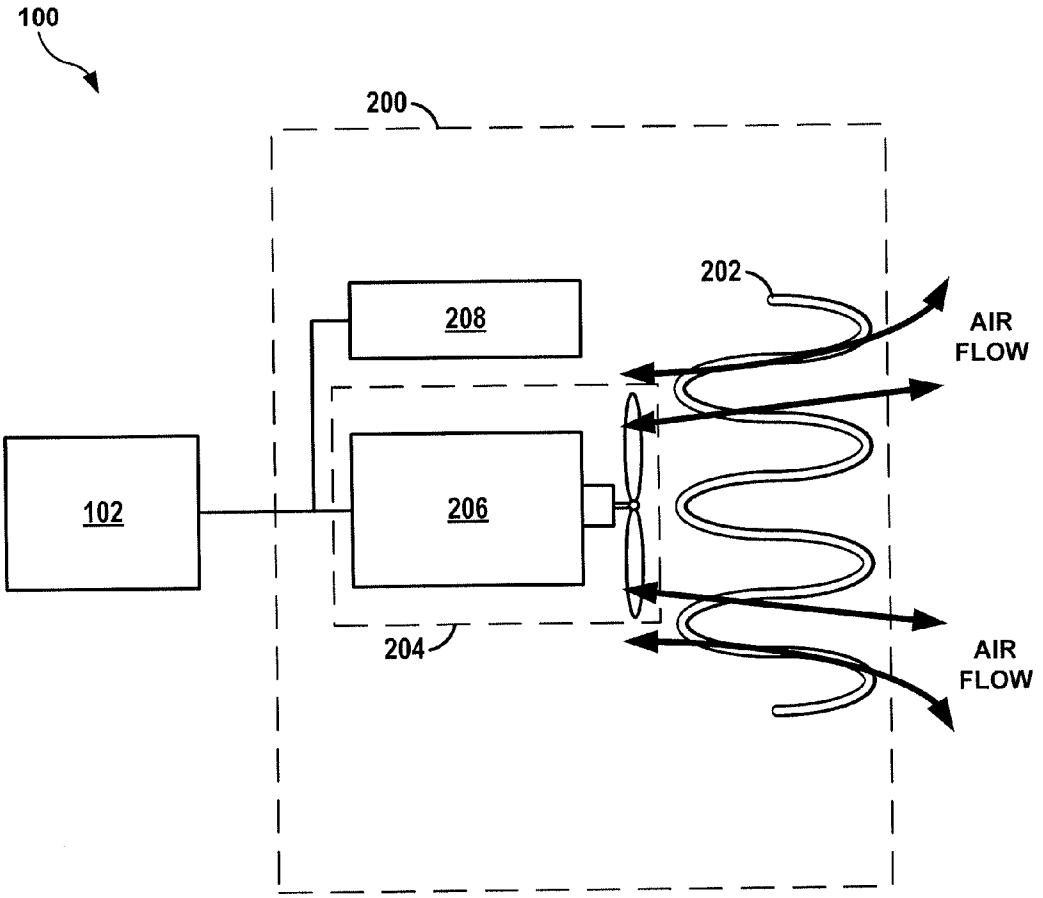


FIG. 2

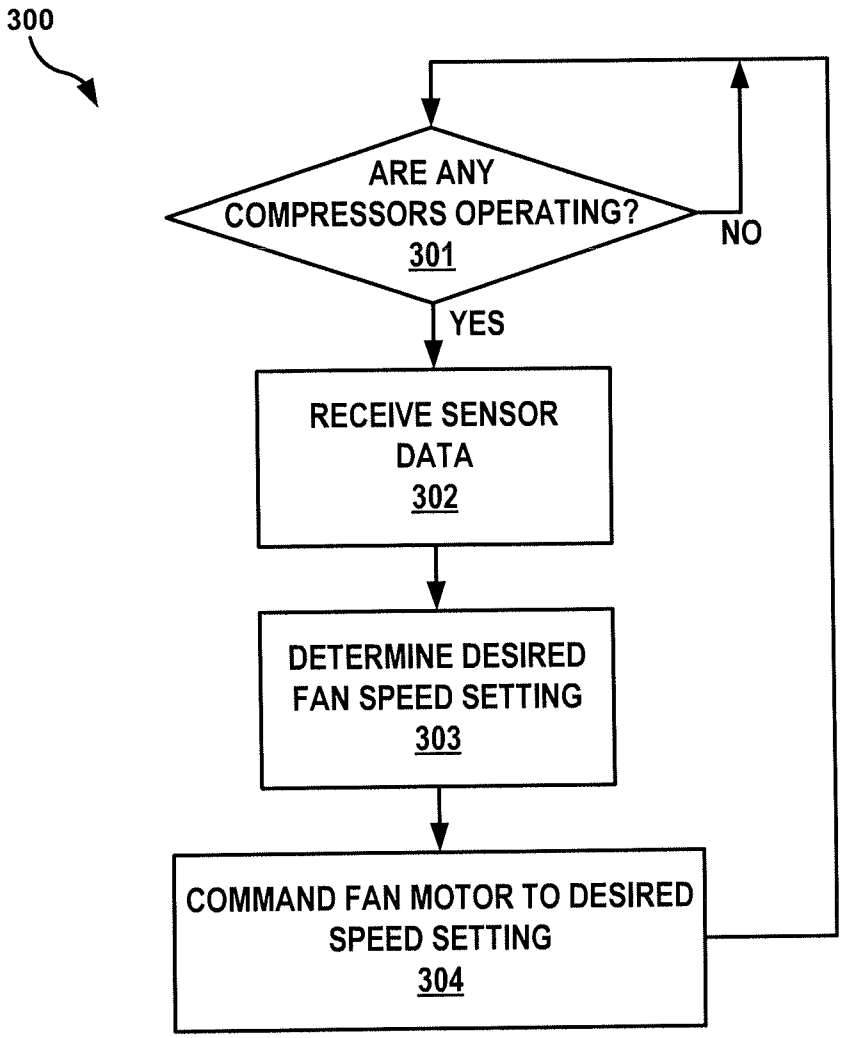

300
ARE ANY COMPRESSORS OPERATING?
301
NO
YES
RECEIVE SENSOR DATA
302
DETERMINE DESIRED FAN SPEED SETTING
303
COMMAND FAN MOTOR TO DESIRED SPEED SETTING
304

FIG. 3

VARIABLE SPEED OUTDOOR FAN CONTROL

RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application Ser. No. 62/002,576, filed on May 23, 2014, entitled "Method for Variable Speed Outdoor Fan Control," which is commonly assigned with this application and incorporated herein by reference.

TECHNICAL FIELD

[0002] This application is directed, in general, to heating, ventilation, and air conditioning systems (HVAC) and, more specifically, to systems and methods for outdoor fan speed control.

BACKGROUND

[0003] Heating, ventilation, and air conditioning (HVAC) systems operate in heating and cooling modes throughout the year and in varying ambient conditions. Commonly, outdoor ambient air is used by HVAC systems as a heat sink, or heat source, for HVAC system refrigerant as part of vapor compression cycle operation. Changing ambient conditions, such as increases or decreases in the ambient air temperature, may affect the amount of heat transfer between the HVAC system refrigerant and the ambient air. HVAC system performance and operation may be negatively affected. Variations in ambient temperatures, for example, may cause an HVAC system to operate inefficiently. Large variations in outdoor ambient temperatures may cause unsafe conditions which may harm HVAC system components.

[0004] HVAC systems commonly use Permanent Split Capacitor (PSC) condenser fan motors. PSC motors operate at only a single speed setting, regardless of changes in the operating conditions within which the HVAC system is operating. As operating conditions vary, such as the ambient air temperature, for example, temperatures and pressures of the HVAC system refrigerant may fluctuate. These fluctuations may cause instability within the HVAC system, potentially causing the HVAC system to operate inefficiently or unsafely. HVAC systems utilizing PSC motors may not be capable of responding to variations in ambient conditions, leaving the HVAC system to operate either inefficiently, or unsafely.

SUMMARY

[0005] According to one embodiment, an apparatus comprises a heat exchanger disposed within an outdoor unit of an HVAC system, a fan disposed within the outdoor unit and configured to cause movement of ambient air within the outdoor unit when operating, a sensor configured to sense ambient air temperatures; and a controller operably coupled to the fan and the sensor. The controller comprises a memory having instructions configured to receive a first signal from the sensor, the first signal indicating one or more ambient air temperature values, determine a desired speed setting of the fan using at least the one or more ambient air temperatures indicated by the first signal, generate a control signal based on the desired speed setting, the control signal configured to drive the fan at the desired speed, and transmit the control signal to the first fan.

[0006] According to another embodiment, a method comprises receiving, at a controller of an HVAC system, a first signal from a first sensor indicating one or more ambient air temperature values, determining, using the controller, a desired speed setting of a fan coupled to an outdoor unit of the HVAC system using at least the one or more ambient air temperatures indicated by the first signal, generating, using the controller, a control signal for at least setting a speed of the fan to the desired speed setting, and transmitting, using the controller, the control signal to the fan.

[0007] According to yet another embodiment, a computer-readable medium comprises instructions configured, when executed by a processor to receive a first signal from a sensor, the first signal indicating one or more ambient air temperature values, determine, using at least the one or more ambient air temperatures indicated by the first signal, a desired speed setting of a fan using at least the one or more ambient air temperatures indicated by the first signal, generate a control signal based on the desired speed setting, the control signal configured to drive the fan at the desired speed, and transmit the control signal to the first fan.

[0008] Advantageously, aspects of the present disclosure may allow for the HVAC system to operate in changing ambient conditions while maintaining operating conditions within safe ranges. Further, aspects of the present disclosure may maintain the HVAC system operation at optimal conditions while the HVAC system operates in changing ambient conditions. The speed settings of the outdoor fans may be commanded to any speed within the operating range of the motor. Aspects of the present disclosure may be utilized, therefore, to set and maintain the fan speeds of the outdoor fans at desired speed settings for maintaining the HVAC system refrigerant pressures substantially at optimal values for improved HVAC system performance even as ambient conditions vary.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] For a more complete understanding of the present disclosure and the advantages thereof, reference is now made to the following Detailed Description taken in conjunction with the accompanying drawings, in which:

[0010] FIG. **1** illustrates an example HVAC system in accordance with embodiments of the present disclosure;

[0011] FIG. **2** illustrates an example outdoor unit of an HVAC system in accordance with embodiments of the present disclosure; and

[0012] FIG. **3** illustrates an example method for setting the speed of an outdoor fan of an HVAC system in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION OF THE DRAWINGS

[0013] Referring to FIG. **1**, an example embodiment of an HVAC system **100** which may supply conditioned air to a space is shown. According to the embodiment shown, the HVAC system **100** may include a controller **102**, a compressor **104**, a metering device **106**, an indoor heat exchanger **108**, and an outdoor section **200**, as well as the refrigerant piping shown.

[0014] The HVAC system **100** components, as described herein and below, may comprise a single stage of vapor compression cycle components within a larger multi-stage HVAC system. The compressor **104**, the metering device **106**, the indoor heat exchanger **108**, the outdoor heat exchanger **202**, and the refrigerant piping shown in FIGS. **1** and **2** may comprise a single "stage" of a multi-stage HVAC system. Each additional stage within a multi-stage HVAC system may com-

prise a component configuration having substantially similar features, functions, and characteristics as those of the single stage of components of the HVAC system **100**, described herein.

[0015] The controller **102** may operate to control operation of one, some, or all stages of components within the multi-stage HVAC system to meet a demand. Each stage within such a multi-stage HVAC system may be operated in concert with, or independently of, each other stage to meet a demand. The controller **102** may be implemented with logic defining one or more control methods which may use, at least, the operational status of one or more stages of components as input. For example, the controller **102** may be configured to operate one or more system components within a multi-stage HVAC system differently at times in which only a single stage is operating than the controller **102** may operate those system components when multiple stages are operating concurrently. In an embodiment, a stage within a multi-stage HVAC system may be operating at times when a compressor within that stage is operating.

[0016] Referring to the embodiment of FIG. **1**, the HVAC system **100** components may be configured for a single stage of cooling operation as part of the vapor compression cycle with the refrigerant of HVAC system **100** flowing in the directions indicated by the arrows of FIG. **1**. The HVAC system **100** may be any type of HVAC system, including heat pump, variable refrigerant flow (VRF), split, packaged, or other system type. The HVAC system **100** may, in an embodiment, be provided with a component configuration capable of cooling only, heating only, or both heating and cooling operation. The HVAC system **100** may be used in residential and commercial buildings, and in refrigeration.

[0017] In alternative embodiments, the HVAC system **100** may be provided with component configuration differing from that shown in the embodiment of FIG. **1**. For example, the HVAC system **100** may include: additional compressors **104**, such as in a tandem compressor group; additional, or fewer, indoor heat exchangers **108** and/or outdoor sections **200**, such as in VRF systems; additional metering devices **106**; and the like. Further, in alternative embodiments, the HVAC system **100** may be provided with a different component configuration than is shown in the embodiment of FIG. **1**. For example, the HVAC system **100** may include, additionally, one or more sensing devices for sensing parameter values indicating refrigerant and/or ambient air characteristics of HVAC system **100**, such as pressures, temperatures, rates of flow, and the like. In further alternative embodiments, the HVAC system **100** may additionally, or alternatively, include one or more valves for controlling the direction and/or rate of refrigerant flow within the HVAC system **100**. For example, in an embodiment of the HVAC system **100** configured for heat pump operation, the HVAC system **100** may be additionally provided with a reversing valve as well as additional piping sections to accommodate bi-directional refrigerant flow capability within the HVAC system **100**. Those of ordinary skill in the art will appreciate that corresponding variations to the refrigerant piping configuration may be provided to accommodate the particular component configuration of the HVAC system **100** embodiment provided.

[0018] The HVAC system **100** may include the controller **102** for operating the HVAC system **100** components. The controller **102** may selectively energize, de-energize, or configure the HVAC system **100** components. For example, the controller **102** may selectively energize, de-energize, or set the operating speed of a compressor, motor, or the like. The controller **102** may operably couple to the HVAC system **100** components via wired or wireless connections.

[0019] The controller **102** may receive data, which may comprise signals, from one or more remote sensing devices. The data received by the controller **102** may be received directly from one or more remote sensing devices, or, may be received indirectly through one or more intermediate devices such as a signal converter, a processor, an input/output interface, an amplifier, a conditioning circuit, a connector, and the like. The controller **102** may operate the HVAC system **100** components in response to received data from remote sensing devices. Additionally, the controller **102** may operate the HVAC system **100** components in response to user input, demands of the conditioned space, refrigerant and/or ambient air conditions, control logic, and the like.

[0020] In an embodiment, the controller **102** may comprise or be coupled to a computer-readable medium with a memory for storing control logic or instructions for operating the HVAC system **100** components. The controller **102** memory may be a volatile or non-volatile memory of any known type commonly used in HVAC systems. The controller **102** may store computer executable instructions within the memory. The computer executable instructions may be included in computer code. The controller **102** may be implemented with hardware, software, firmware, or any combination thereof.

[0021] The controller **102** may, additionally, be implemented with a processor for executing stored instructions. The controller **102** may be responsive to or operable to execute instructions stored as part of software, hardware, integrated circuits, firmware, micro-code or the like. The functions, acts, methods or tasks performed by the controller **102**, as described herein, may be performed by a processor executing instructions stored in a memory. The instructions are for implementing the processes, techniques, methods, or acts described herein. The controller **102** processor may be any known type of processor commonly used in HVAC systems. The processor may be a single device or a combination of devices, such as associated with a network or distributed processing.

[0022] Referring to FIG. **1**, in an embodiment, the HVAC system **100** may include the compressor **104** for compressing refrigerant as part of a vapor compression cycle. According to the embodiment shown in FIG. **1**, the compressor **104** may receive refrigerant via a suction pipe **111** and may discharge compressed refrigerant into a discharge pipe **105**. The suction pipe **111** may couple to a suction port of the compressor **104**. The discharge pipe **105** may couple to a discharge port of the compressor **104**. The discharge pipe **208** may direct the compressed refrigerant to the outdoor section **200** of the HVAC system **100**.

[0023] The compressor **104** may be of any suitable type, such as a reciprocating compressor, a scroll compressor, or any other type of compressor suitable for use in HVAC system applications. The compressor **104** may be configured for single speed or variable speed operation. The compressor **104** may operably couple to the controller **102** via a wired or wireless connection and may be selectively energized, de-energized, or set to a desired operating speed by the controller **102** to meet a demand on the HVAC system **100**.

[0024] As shown, a single compressor **104** may be included in the HVAC system **100**. In alternative embodiments, the HVAC system **100** may include more than one compressor **104**. In such embodiments, the compressors **104** provided

may be configured to operate as a tandem compressor group. The tandem compressors may each be incorporated within a single circuit of HVAC components configured for vapor compression cycle operation, with each tandem compressor operatively coupling to the discharge pipe **105** and the suction pipe **111**.

[0025] Referring to FIGS. **1** and **2**, in an embodiment, the HVAC system **100** may include the outdoor section **200**. The outdoor section **200** may include an outdoor heat exchanger **202** which may provide for heat transfer between the refrigerant of HVAC system **100** and airflow passing over the outdoor heat exchanger **202** as part of the vapor compression cycle. The outdoor section **200** may be disposed at an outdoor location, such as on the roof of a building, for example. Airflow passing over the outdoor heat exchanger **202** may comprise outdoor ambient air. The outdoor heat exchanger **202** may be a coil-type heat exchanger of any known type commonly used in HVAC systems, such as a fin-and-tube heat exchanger coil, a microchannel heat exchanger coil, or the like. In an embodiment, the outdoor section **200** may be provided with more than one outdoor heat exchanger **202**, such as in a VRF or multi-stage system.

[0026] According to the embodiment shown in FIGS. **1** and **2**, the HVAC system **100** may be configured for cooling operation, with the outdoor heat exchanger **202** receiving refrigerant via the discharge pipe **105**. In this configuration, the outdoor heat exchanger **202** may be a condenser within a circuit of vapor compression cycle components. The refrigerant received by the outdoor heat exchanger **202** may be at a relatively high pressure and temperature gas phase refrigerant. The received refrigerant may reject heat and condense while flowing within the outdoor heat exchanger **202**. High pressure liquid refrigerant may exit the outdoor heat exchanger **202** and flow into a high pressure liquid pipe **107**, as shown in FIGS. **1** and **2**. In alternative embodiments, the HVAC system **100** may be configured to operate in heating mode. In such embodiments, the outdoor heat exchanger **202** within the outdoor section **200** may be configured to operate as an evaporator as part of the vapor compression cycle.

[0027] As shown in FIG. **1**, in an embodiment, the HVAC system **100** may include the metering device **106**. The metering device **106** may throttle the refrigerant flow of the HVAC system **100**. The metering device **106** may be disposed between the outdoor section **200** and the indoor heat exchanger **108** of the HVAC system **100**, as part of a vapor compression cycle. According to the HVAC system **100** embodiment shown, a single metering device **106** is provided. In alternative embodiments of the HVAC system **100**, additional metering devices **106** may be provided. For example, additional metering devices may be provided in an HVAC system configured to operate as a dual flow, heat pump, VRF, and/or other HVAC system type.

[0028] Refrigerant flow within the HVAC system **100** may be directed through the metering device **106** to the indoor heat exchanger **108**. The metering device **106** may couple with, and receive high temperature and pressure liquid refrigerant from, the high pressure liquid pipe **107**. The metering device **106** may also couple with, and deliver low pressure liquid refrigerant to, the low pressure liquid pipe **109**. In an embodiment, the metering device **106** may be operably coupled to the controller **102** via a wired or wireless connection. In an embodiment, the metering device **106** may be any suitable type of metering device, including thermal expansion valves (TXVs), short orifices, electronic expansion valves (EXVs), and the like. The operation of such metering devices is well known to those of ordinary skill in the art and is omitted from this description.

[0029] As shown in FIG. **1**, in an embodiment, the HVAC system **100** may include the indoor heat exchanger **108**. The indoor heat exchanger **108** may provide for heat transfer between the refrigerant of HVAC system **100** and airflow passing over the indoor heat exchanger **108**, as part of the vapor compression cycle. In an embodiment, the indoor heat exchanger **108** may be a heat exchanger coil assembly of any known type commonly used in HVAC systems, such as a fin-and-tube heat exchanger coil, a microchannel heat exchanger coil, and the like. In an embodiment, the HVAC system **100** may be provided with one or more indoor heat exchangers **108**. In an embodiment, the indoor heat exchanger **108** may be located in an indoor section of the HVAC system **100**. In such an embodiment, the air flow over the indoor heat exchanger **108** may comprise a mixture of return air from within the conditioned space and outdoor ventilation air.

[0030] The indoor heat exchanger **108** may couple with, and receive refrigerant via the low pressure liquid pipe **109**. According to the component configuration and refrigerant flow directions shown in FIG. **1**, the indoor heat exchanger **108** may be an evaporator and the HVAC system **100** may be configured for operating in cooling mode. During cooling operation, refrigerant flowing through the indoor heat exchanger **108** may boil, changing from the liquid state to the gaseous state, as part of the vapor compression cycle. Gaseous refrigerant may be routed to the compressor **104** via the common suction pipe **111** to complete the refrigerant flow cycle within the HVAC system **100** when operating in cooling mode.

[0031] The HVAC system **100**, as shown, may be a cooling-only unit or, alternatively, may be a heat pump unit operating in cooling mode. In alternative embodiments, the HVAC system **100** may be configured to operate in heating mode as part of a heating only, or a heat pump unit, for example. In such embodiments, the indoor heat exchanger **108** may be configured to operate as a condenser as part of the vapor compression cycle, with the refrigerant flow directed in the opposite direction than that shown.

[0032] Referring now to FIG. **2**, an embodiment of the outdoor section **200** of the HVAC system **100** is shown. As shown, the outdoor section **200** may include an outdoor heat exchanger **202**, an outdoor fan **204**, and a sensor **208**. The outdoor fan **204** may include a motor **206**. In alternative embodiments, the outdoor section **200** may include additional, fewer, or different components than those shown in the embodiment of FIG. **2**. For example, the outdoor section **200** may include additional outdoor fans **204** along with corresponding additional motors **206**. Further, the outdoor section **200** may include additional, or fewer, of the sensors **208** which may be disposed at a location, or locations, differing from that shown.

[0033] The outdoor section **200** may include the outdoor fan **204** for inducing flow of ambient air over the outdoor heat exchanger **202**. According to the embodiment shown, the outdoor fan **204** may comprise of a plurality of blades (not labeled) which may couple to, and be rotated about, a hub or shaft through actuation of the motor **206**. Energizing of the motor **206** may cause rotation of the outdoor fan **204** blades about the hub. Rotation of the outdoor fan **204** blades may cause ambient air movement to induce a flow of ambient air

over the outdoor heat exchanger **202**. The ambient air flowing over the outdoor heat exchanger **202** may be at an ambient temperature.

[0034] The motor **206** may be an electric motor which may rotate in response to a received signal, or signals. The motor **206** may be configured to operate as a variable speed motor, whereby the motor **206** may operate at a plurality of speeds, as measured in revolutions per minute (RPM). The speed of motor **206** may vary in response to changes to the signal, or signals, received. In such embodiments, the motor **206** may be provided with a range of speed values within which the motor **206** may be operated. The range may have a lower bound indicated a speed setting below which the motor **206** may not operate. If commanded to operate at a speed outside of the operating range of the motor **206**, the motor **206** may de-energize or may, alternatively, operate at a lowest speed setting.

[0035] In an embodiment, the motor **206** may be an electric commutation (EC) type motor. The electrical input to the motor **206** may be a direct current (DC) input or an alternating current (AC) input. In one embodiment, the electrical input may be a 4-wire pulse width modulated (PWM) signal that may include a power signal, a ground signal, a control signal, and a sense signal. The control signal may be a PWM signal in which the relative width of pulses determines the level of power applied to the motor **206**. The speed of the motor **206** may have a direct relationship to the width of PWM pulses. While the control signal may control the power supplied to the motor **206**, the actual power may be applied by the power signal. Alternatively, the function of the power signal and the control signal may be combined in a 3-wire configuration, where the controller **102** may directly set the amplitude of the power signal to control the speed of the motor **206**. In further alternative embodiments, the speed of the motor **206** may be controlled using any known method of motor speed control.

[0036] The motor **206** may operably connect to the controller **102**. The controller **102** may transmit control and/or power signals to the motor **206** for varying the speed of motor **206** and direction settings. For example, in an embodiment, the controller **102** may vary the control and/or power signal voltage to adjust the speed of motor **206**. Alternatively, the controller **102** may vary the pulse widths of a power and/or control signal transmitted to the motor **206** to vary the speed of motor **206**. The controller **102** may accordingly set the speed of motor **206** in response to conditions within the HVAC system **100** in accordance with control logic executed by the controller **102**.

[0037] Importantly, the rate of ambient air flow over the outdoor heat exchanger **202**, in combination with the ambient temperature, may affect the amount of heat transfer to, or from, the refrigerant of HVAC system **100** as it flows through the outdoor heat exchanger **202**. The amount of heat transfer between the refrigerant of HVAC system **100** and the ambient air flow may vary depending, in part, on the cubic feet per minute (CFM) of ambient air passing over the outdoor heat exchanger **202**. Additionally, or alternatively, the amount of heat transfer may vary in response the ambient air temperature, the refrigerant temperature, and the refrigerant flow rate, among other refrigerant and/or ambient air characteristics within the outdoor heat exchanger **202**.

[0038] Generally, an increase in the speed of motor **206** may cause a corresponding increase in the CFM of ambient air passing over the outdoor heat exchanger **202**. Such an increase in airflow may cause an increase in the amount of heat transfer between the ambient air and the refrigerant of HVAC system **100** within the outdoor heat exchanger **202** of HVAC system **100**. Similarly, a decrease in the speed of motor **206** may cause a corresponding decrease in the CFM of ambient air passing over the outdoor heat exchanger **202** of HVAC system **100**. Such a decrease in airflow may cause a decrease in the amount of heat transfer between the ambient air and the refrigerant of HVAC system **100** within the outdoor heat exchanger **202**. Further, holding the ambient air flow rate constant, an ambient temperature that differs from the refrigerant of HVAC system **100** temperature by larger extent will induce a greater rate of heat transfer between the ambient air and the refrigerant of HVAC system **100** within the outdoor heat exchanger **202**. Similarly, holding the ambient air flow rate constant, an ambient temperature that differs from the refrigerant of HVAC system **100** temperature by lesser extent will induce a lesser rate of heat transfer between the ambient air and the refrigerant within the outdoor heat exchanger **202** or HVAC system **100**.

[0039] In an embodiment in which the outdoor heat exchanger **202** is a condenser, an increase in the amount of heat transfer occurring within the outdoor section **200** may result in lower refrigerant temperatures and lower refrigerant pressures within the HVAC system **100**. Conversely, a decrease in the amount of heat transfer occurring within the outdoor section **200** may result in higher refrigerant temperatures and higher refrigerant pressures within the HVAC system **100**. Importantly, therefore, the speed of motor **206** may be used to vary the ambient air flow CFM to manipulate refrigerant pressures within the HVAC system **100** in response to changing ambient conditions as well as changing conditions within the HVAC system **100** during operation.

[0040] As shown in FIG. **2**, in an embodiment, the outdoor section **200** may include the sensor **208** for sensing, or measuring, one or more parameter values of characteristics of the HVAC system **100**. The parameter value may indicate a condition of the refrigerant of HVAC system **100** and/or a condition of the outdoor ambient air within the outdoor section **200**. For example, the sensor **208** may be configured to sense the ambient temperature, the refrigerant temperature, the refrigerant pressure, ambient air or refrigerant flow rates, and the like.

[0041] The sensor **208** may be a remote sensing device which may connect with the controller **102** via a wired or wireless connection for transmitting sensed, or measured, data to the controller **102**. The sensor **208** may transmit analog or pneumatic signals either directly, or indirectly, to the controller **102**. In such an embodiment, the signals transmitted by the sensor **208** may be converted to digital signals prior to use by the controller **102**. Alternatively, in an embodiment, the sensor **208** may transmit digital signals to the controller **102**. In such an embodiment, the digital signals transmitted by the sensors **208** may be processed prior to use by the controller **102** to convert the signals to a different voltage, to remove interference from the circuits, to amplify the signals, or other similar forms of digital signal processing. For each alternative described, herein, the signals of the sensor **208** may be transmitted to the controller **102** directly or indirectly, such as through one or more intermediary devices.

[0042] In an embodiment, the sensor **208** may be disposed within the outdoor section **200** and may be configured to sense the outdoor ambient air temperature within the outdoor section **200**. In such an embodiment, the sensor **208** may be a thermistor. Alternatively, in such an embodiment, the sensor

208 may be a thermocouple, a resistance temperature detection sensor, pyrometric sensor, an infrared thermographic sensor, or some other sensor type for sensing temperature values of outdoor ambient air. The sensor may transmit the sensed ambient temperature to the controller **102** for use by the controller **102** as input to one or more control methods. For example, the controller **102** may use ambient temperature data received from the sensor **208** as an input to a control method for setting the speed of motor **206** during the operation of HVAC system **100** to control the rate of heat transfer to, or from, refrigerant within the outdoor section **200**.

[0043] In alternative embodiments, the sensor **208** may be disposed within the HVAC system **100** at a position different from that shown in the particular embodiment of FIG. **2**. For example, the sensor **208** may be disposed within an indoor section of the HVAC system **100** or may be coupled to a section of refrigerant piping within the HVAC system **100**. Further, in alternative embodiments, the HVAC system **100** may be provided with additional sensing devices similar to the sensor **208** for sensing parameter values indicating conditions of the refrigerant of HVAC system **100**, ambient air, indoor return air, and the like. The sensing devices may be configured to sense temperature, pressure, flow rate, relative humidity, and other like parameter values. Additional sensing devices may be disposed within the HVAC system **100** at the outdoor heat exchanger **202**, at the indoor heat exchanger **108**, at the metering device **106**, within the conditioned space, and/or coupled to refrigerant piping. The additional sensing devices provided may connect to, and communicate with, the controller **102** or, alternatively, may operate independently of the controller **102**, as described above. It will also be appreciated that some of the control methods described herein may require that the HVAC system **100** be provided with one or more of the sensors **208** as shown or described, herein.

[0044] The controller **102** may be implemented with logic for setting the speed of motor **206** to a speed setting which may correspond to a desired rate of outdoor ambient air flow. In an embodiment, for example, the controller **102** may store one or more predefined functions that may be used by the controller **102** to operate the motor **206** at different speed and direction settings. Input to the predefined function may comprise sensed, or measured, parameter values indicating a refrigerant and/or ambient air characteristic. The refrigerant and/or ambient air characteristic, or characteristics, may be temperatures, pressures, flow rates, and the like. The parameter values may be sensed by sensor devices, such as the sensor **208**, and communicated to the controller **102**. Additionally, or alternatively, the input to a predefined function may additionally comprise of the capacity at which the HVAC system **100** is operating, which may be indicated by the current operation setting of the compressor **104**.

[0045] An output of the predefined function may be a speed and direction setting of the motor **206** or, alternatively, a control and/or power signal configuration corresponding to a desired speed setting of the motor **206**. The speed setting of the motor **206** may have a direct relationship with the rate of ambient air flow passing over the outdoor heat exchanger **202**. An increase in the speed of motor **206** may correspond to an increase in the rate of ambient air flow passing over the outdoor heat exchanger **202** while a decrease in the speed of motor **206** may correspond to a decrease in the rate of ambient air flow passing over the outdoor heat exchanger **202**.

[0046] Importantly, the refrigerant pressures and temperatures of HVAC system **100** may vary in response to changes in the flow rate of ambient air over the outdoor heat exchanger **202**. A decrease in the flow rate of ambient air may cause a corresponding increase in the pressures and temperatures of the refrigerant of HVAC system **100** within the outdoor section **200**. An increase in the flow rate of ambient air may cause a decrease in the pressures and temperatures of the refrigerant of HVAC system **100** within the outdoor section **200**. As such, control of the speed setting of the motor **206** of the outdoor fan **204** may be used to manipulate the operating pressures and temperatures of the refrigerant of HVAC system **100**. Advantageously, speed control of the motor **206** may be implemented to maintain the HVAC system **100** within safe operating conditions as ambient conditions change. Further, speed control of the motor **206** may be implemented to maintain the HVAC system **100** substantially at optimal operating conditions even as ambient conditions change during operation of the HVAC system **100**.

[0047] Referring to FIG. **3**, a flowchart of an example method **300** for controlling the speed of an outdoor fan **204** is shown. The method **300** may be implemented in the order shown or, alternatively, may be implemented in an order different than that shown. In alternative embodiments, additional, fewer, or different steps of the method **300** may be provided in accordance with the alternative inputs, functions, and/or actions taken included in the discussion, below.

[0048] The method **300** may be implemented by the controller **102** to control the motor **206** of the outdoor fan **204** of the HVAC system **100**. Additionally, or alternatively, the method **300** may be implemented by the controller **102** to control a multi-stage HVAC system comprising of a plurality of stages of vapor compression cycle components.

[0049] At step **301**, the controller **102** may determine whether the compressor **104** is operating. The controller **102** may determine compressor operational status by any suitable means. Compressor operation may include operation at any compressor power or speed setting, including full and part load operation. In a multi-stage HVAC system, the controller **102** may determine whether any compressor within the multi-stage system is operating and, further, may determine the number and identity of stages of the multi-stage HVAC system operating.

[0050] If the controller **102** determines that a compressor, or compressors, **104** are operating, the controller **102** may receive a first signal from the sensor **208** at step **302** for use at step **303**. In an embodiment, for example, the first signal may indicate the ambient air temperature for the ambient airflow within the outdoor section **200**. The sensor **208** may be any sensor coupled to the HVAC system **100**, and may be disposed within the outdoor section **200**. In certain embodiments, for example, the sensor **208** may be a thermistor.

[0051] At step **303**, the controller **102** may use the received first signal information (e.g., ambient temperature data) from the sensor **208** to determine a desired speed setting for the motor, or motors, **206**. The desired speed setting may correspond to a control signal configuration that may be generated by the controller **102** and applied to the motor, or motors, **206** at step **304**.

[0052] In an embodiment, the desired speed setting may be derived from a function, or functions, stored within the controller **102**. The function, or functions, may be derived, for example, through implementation of a test plan and may comprise of one or more correlation equations. Alternatively, the function, or functions, may comprise one or more lookup tables. The input to the function, or functions, may be the first

signal (e.g., the ambient temperature) received from the sensor **208** at step **302**. The output may be a control signal configuration for commanding the motor, or motors, **206** to the desired speed setting, or settings.

[0053] In an embodiment, for example, the function may comprise one or more equations for relating an ambient temperature input to a voltage value output to be applied to one or more motors **206** via one or more control signals. Additionally, or alternatively, the controller **102** may use the compressor operational statuses determined at step **301** as an input to the function, or functions. For example, the desired ambient airflow rate may be determined using different correlation equations depending on the number of stages in operation within a multi-stage HVAC system.

[0054] The desired speed setting may correspond to a desired ambient airflow rate within the outdoor section **200**. The desired ambient airflow rate may correspond to optimal performance of the HVAC system **100**, as may be determined through testing of HVAC system **100**. In an embodiment, for example, a linear function relating ambient temperature to a desired speed setting for motor, or motors, **206** may be developed using a test plan, such as the example test plan described below. The test plan may be implemented to generate a unique correlation equation for use with each unique operational configuration of the HVAC system. For example, unique correlation equations may be developed for each stage of operation of a multi-stage HVAC system.

[0055] According to one example test plan, a first set point may be determined by operating the HVAC system **100** at full load at an indoor airflow temperature, a first ambient temperature, a first indoor static pressure and first indoor airflow rate. The speed setting, or settings, of the motor, or motors, **206** may be gradually reduced from a maximum speed setting. The ambient temperature and the speed setting, or settings, of the motor, or motors, **206** found to achieve optimal performance of the HVAC system for the unique operational configuration tested may be set as a first point. In an embodiment, optimal performance may be defined as greatest efficiency performance, as measured in integrated energy efficiency ratio (IEER), energy efficiency ratio (EER), or some other similar metric. Alternatively, optimal performance may be defined in terms of operating pressures of the refrigerant of HVAC system **100**, with the optimal settings being those that yield operation at desired refrigerant pressure, or pressures, within the HVAC system **100**.

[0056] A second point may be determined by operating the HVAC system **100** at partial load and with the same indoor airflow temperature as for the first point. The ambient temperature, indoor static pressure, and indoor airflow rate may each be reduced to lower set points. The speed setting, or settings, of the motor, or motors, **206** may be decreased during operation from the speed setting, or settings, of the first point until the operation of HVAC system **100** approaches performance substantially equal to that of the first point. The ambient temperature and the speed setting, or settings, of the motor, or motors, **206** at which substantially equal performance to the first point performance is achieved may be the second point. The first and second points may be used to generate a linear function relating ambient temperature to the desired speed setting, or settings, of the motor, or motors, **206**. Advantageously, such a correlation equation may allow for continuous control of the motor, or motors, **206** throughout the operating range, or ranges, of the motor, or motors, **206** of the HVAC system **100**. Continuous control may allow for continuous setting of the motor, or motors, **206** to optimal speed settings in response to changes in ambient temperatures to enhance the performance of HVAC system **100**.

[0057] At step **304**, the controller **102** may generate a control signal configured to correspond to the desired speed setting, or settings, of the motor, or motors **206**. The controller **102** may transmit the control signal to command the motor, or motors, **206** to the desired speed setting, or settings. In an embodiment, the voltage of the control signal may be configured to set the speed of the motor, or motors **206**. For example, the motor, or motors, **206** speed may increase as the control signal voltage is increased within an operating range. The specific control signal voltages corresponding to various speed settings for fans **102** may be provided by the manufacturer or developed through testing, as described above.

[0058] In an embodiment, the controller **102** may be configured to return to step **301** following the execution of step **304** to continuously repeat the method **300** during times when the HVAC system **100** is operating. Alternatively, the controller **102** may be configured to execute the method **300** at regular intervals during HVAC system operation, waiting a defined period of time following step **304** before returning to step **301**.

[0059] In an embodiment, using the methods described above, an HVAC system **100** may be operating to condition a space. The HVAC system **100** may be provided with a controller **102** implementing the method **300**, described above. During operation of the HVAC system **100**, the ambient temperature may decrease and may cause the refrigerant pressures of the HVAC system **100** to decrease. Decreases in the refrigerant pressures may cause operation of the HVAC system **100** at non-optimal conditions and, further, may create dangerous operating conditions for the compressor, or compressors of the HVAC system **100**.

[0060] The controller **102** may respond to the decrease in the ambient temperature in accordance with the method **300** by determining a new control signal to apply to the motors **206** of the outdoor fans **204** of the HVAC system **100** (e.g., decreasing the amplitude of the control signal). The motors **206** may accordingly rotate at a lower speed, resulting in a reduction of ambient airflow over the outdoor heat exchanger **202**. The operating pressures of the HVAC system **100** may increase in response to the decrease in airflow over the outdoor heat exchanger **202**. The controller **102** may configure the speed settings of the motors **206** of the outdoor fans **204** to rotate at a speed corresponding to an optimal airflow rate over the outdoor heat exchanger **202**. In this embodiment, the controller **102** may also increase the control signal amplitude to increase condenser fan speeds in response to a subsequent increase in the outdoor ambient temperature to prevent the refrigerant pressures of HVAC system **100** from rising to unsafe levels.

[0061] Alternatively, in an embodiment, an HVAC system **100** may use one or more sensors **208** configured to sense the refrigerant temperatures and/or pressures of HVAC system **100** in a manner similar to that described above to control the motor, or motors, **206** in response to changing ambient conditions. In such an embodiment, the controller **102** may use the refrigerant temperatures and/or pressures of HVAC system **100** as input to an embodiment of the method **300**, rather than ambient temperature. The controller **102** may detect a drop in the refrigerant pressure of HVAC system **100** and respond by adjusting the speed setting, or settings, of the motor, or motors **206**. In such an embodiment, a sensed

decrease in refrigerant pressure and/or temperature may indicate a decrease in the ambient temperature.

[0062] In the preceding discussion, numerous specific details are set forth to provide a thorough understanding of the present disclosure. However, it will be understood that the present disclosure may be practiced without such specific details. In other instances, well-known elements have been illustrated in schematic or block diagram form in order not to obscure the present disclosure in unnecessary detail. Additionally, for the most part, details concerning well-known features and elements have been omitted inasmuch as such details are not considered necessary to obtain a complete understanding of the present disclosure, and are considered to be within the understanding of persons of ordinary skill in the relevant art.

[0063] Having thus described the present disclosure by reference to certain of its preferred embodiments, it is noted that the embodiments disclosed are illustrative rather than limiting in nature and that a wide range of variations, modifications, changes, and substitutions are contemplated in the foregoing disclosure and, in some instances, some features of the present disclosure may be employed without a corresponding use of other features. Many such variations and modifications may be recognized based upon a review of the foregoing description of preferred embodiments.

1. An apparatus, comprising:
- a heat exchanger disposed within an outdoor unit of an HVAC system;
- a fan disposed within the outdoor unit and configured to cause movement of ambient air within the outdoor unit when operating;
- a sensor configured to sense ambient air temperatures; and
- a controller operably coupled to the fan and the sensor, the controller comprising a memory having instructions configured to:
  - receive a first signal from the sensor, the first signal indicating one or more ambient air temperature values;
  - determine a desired speed setting of the fan using at least the one or more ambient air temperatures indicated by the first signal;
  - generate a control signal based on the desired speed setting, the control signal configured to drive the fan at the desired speed; and
  - transmit the control signal to the first fan.

2. The apparatus of claim **1**, wherein the desired speed setting corresponds to a desired rate of ambient air movement within the outdoor unit.

3. The apparatus of claim **1**, wherein the desired speed setting is determined using at least a first correlation equation relating the one or more ambient air temperature values indicated by the first signal to a corresponding speed setting of the fan.

4. The apparatus of claim **3**, wherein the first correlation equation comprises a linear equation relating ambient air temperatures to speed settings of the fan.

5. The apparatus of claim **1**, wherein the desired speed setting is determined using a lookup table relating ambient air temperatures to speed settings of the fan.

6. The apparatus of claim **1**, wherein the fan comprises an electronic commutation motor.

7. The apparatus of claim **1**, wherein the first sensor is a thermistor.

8. The apparatus of claim **1**, further comprising:
- a first compressor and a second compressor, the first and second compressors operable independently from one another;
- wherein the controller is operably coupled to each of the first and second compressors and the instructions are further configured to:
  - determine an operating status for each of the first compressor and the second compressor; and
  - if the first compressor is operating while the second compressor is not operating, determine the desired speed setting of the fan using at least a first correlation equation relating the one or more ambient air temperature values indicated by the first signal to a corresponding speed setting of the fan; and
  - if both the first and second compressors are operating, determine the desired speed setting of the fan using at least a second correlation relating the one or more ambient air temperature values indicated by the first signal to a corresponding speed setting of the fan.

9. A method, comprising:
- receiving, at a controller of an HVAC system, a first signal from a first sensor indicating one or more ambient air temperature values;
- determining, using the controller, a desired speed setting of a fan coupled to an outdoor unit of the HVAC system using at least the one or more ambient air temperatures indicated by the first signal;
- generating, using the controller, a control signal for at least setting a speed of the fan to the desired speed setting; and
- transmitting, using the controller, the control signal to the fan.

10. The method of claim **9**, wherein the desired speed setting is the speed setting of the fan corresponding to a desired rate of ambient air movement within the outdoor unit.

11. The method of claim **9**, wherein the desired speed setting of the fan is determined using at least a first correlation equation relating at least the ambient air temperatures indicated by the first signal to a corresponding speed setting of the fan.

12. The method of claim **11**, wherein the first correlation equation comprises a linear equation relating ambient air temperatures to speed settings of the fan.

13. The method of claim **9**, wherein the desired speed setting of the fan is determined using first a lookup table relating ambient air temperatures to speed settings of the fan.

14. The method of claim **9**, wherein the fan comprises an electronic commutation motor.

15. The method of claim **9**:
- wherein the HVAC system further comprises a first compressor and a second compressor, the first and second compressors operable independently from one another and the controller is operably coupled to each of the first compressor and the second compressor; and
- wherein the method further comprises:
  - determining the operating status for each of the first compressor and the second compressor; and
  - if the first compressor is operating while the second compressor is not operating, determining the desired speed setting of the fan using at least a first correlation equation relating the one or more ambient air temperature values indicated by the first signal to a corresponding speed setting of the fan; and

if both the first and second compressors are operating, determining the desired speed setting of the fan using at least a second correlation relating the one or more ambient air temperature values indicated by the first signal to a corresponding speed setting of the fan.

16. A computer-readable medium comprising instructions configured, when executed by a processor to:

receive a first signal from a sensor, the first signal indicating one or more ambient air temperature values;

determine, using at least the one or more ambient air temperatures indicated by the first signal, a desired speed setting of a fan using at least the one or more ambient air temperatures indicated by the first signal;

generate a control signal based on the desired speed setting, the control signal configured to drive the fan at the desired speed; and

transmit the control signal to the first fan.

17. The computer-readable medium of claim **16**, wherein the desired speed setting corresponds to a desired rate of ambient air movement within the outdoor unit.

18. The computer-readable medium of claim **16**, wherein the desired speed setting is determined using at least a first correlation equation relating the one or more ambient air temperature values indicated by the first signal to a corresponding speed setting of the fan.

19. The computer-readable medium of claim **18**, wherein the first correlation equation comprises a linear equation relating ambient air temperatures to speed settings of the fan.

20. The computer-readable medium of claim **16**, wherein the desired speed setting is determined using a lookup table relating ambient air temperatures to speed settings of the fan.

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