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(54) **HVAC SYSTEM WITH WIRELESS WAVEGUIDE SYSTEM**

(71) Applicant: **Johnson Controls Technology Company**, Auburn Hills, MI (US)

(72) Inventors: **Tri V. Ky**, Waukesha, WI (US); **Allison M. Ahern**, New Berlin, WI (US); **David C. Ullenberg**, Brown Deer, WI (US)

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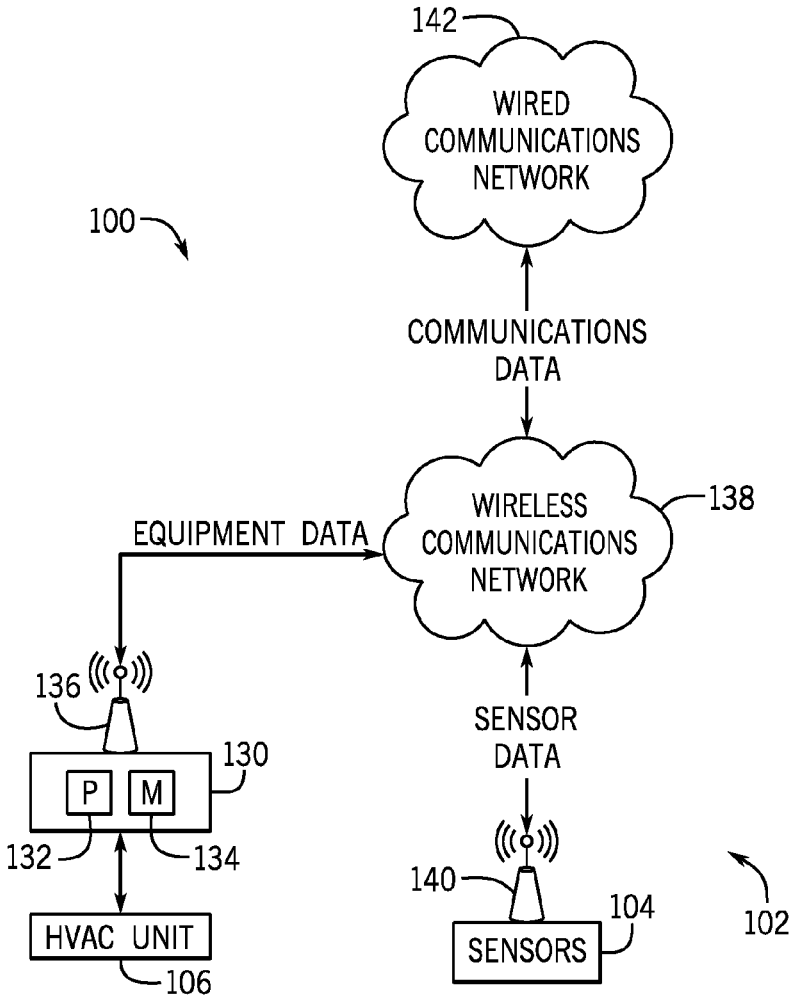
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(52) **U.S. Cl.**

CPC ***F24F 11/30*** (2018.01); *H01P 3/127* (2013.01); ***H01Q 1/2291*** (2013.01); ***F24F 11/58*** (2018.01)

(57) **ABSTRACT**

A wireless waveguide system for a heating, ventilation, and air conditioning (HVAC) system. The wireless waveguide system includes a sensor that detects an environmental condition and directs a signal indicative of the environmental condition along an interior of a ductwork. A signal sensor detects a strength of the signal within the interior of the ductwork. A repeater that operates based on the strength of the signal detected by the signal sensor and repeats the signal along a communication path at least partially within the interior of the ductwork to a controller of an HVAC unit.



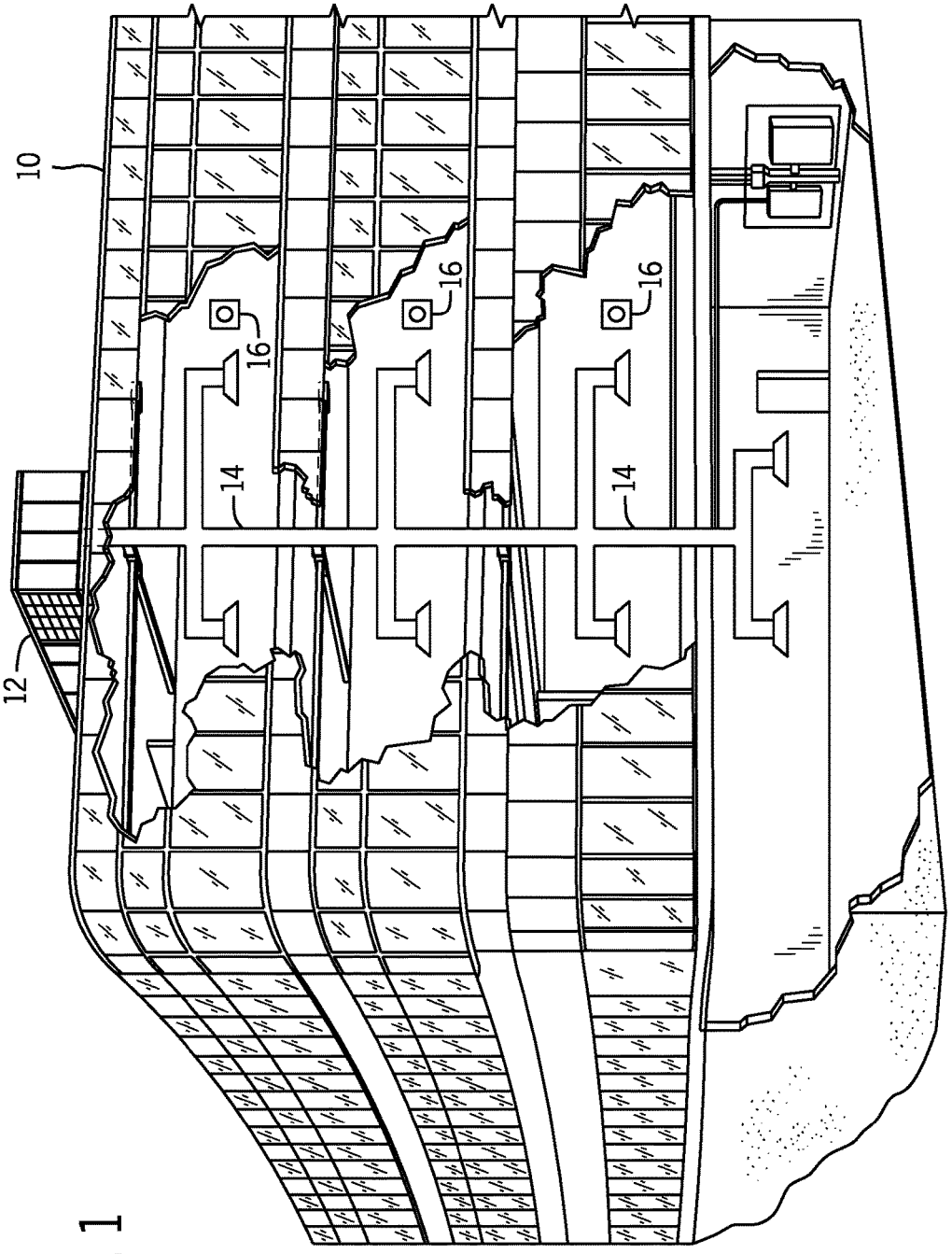


FIG. 1

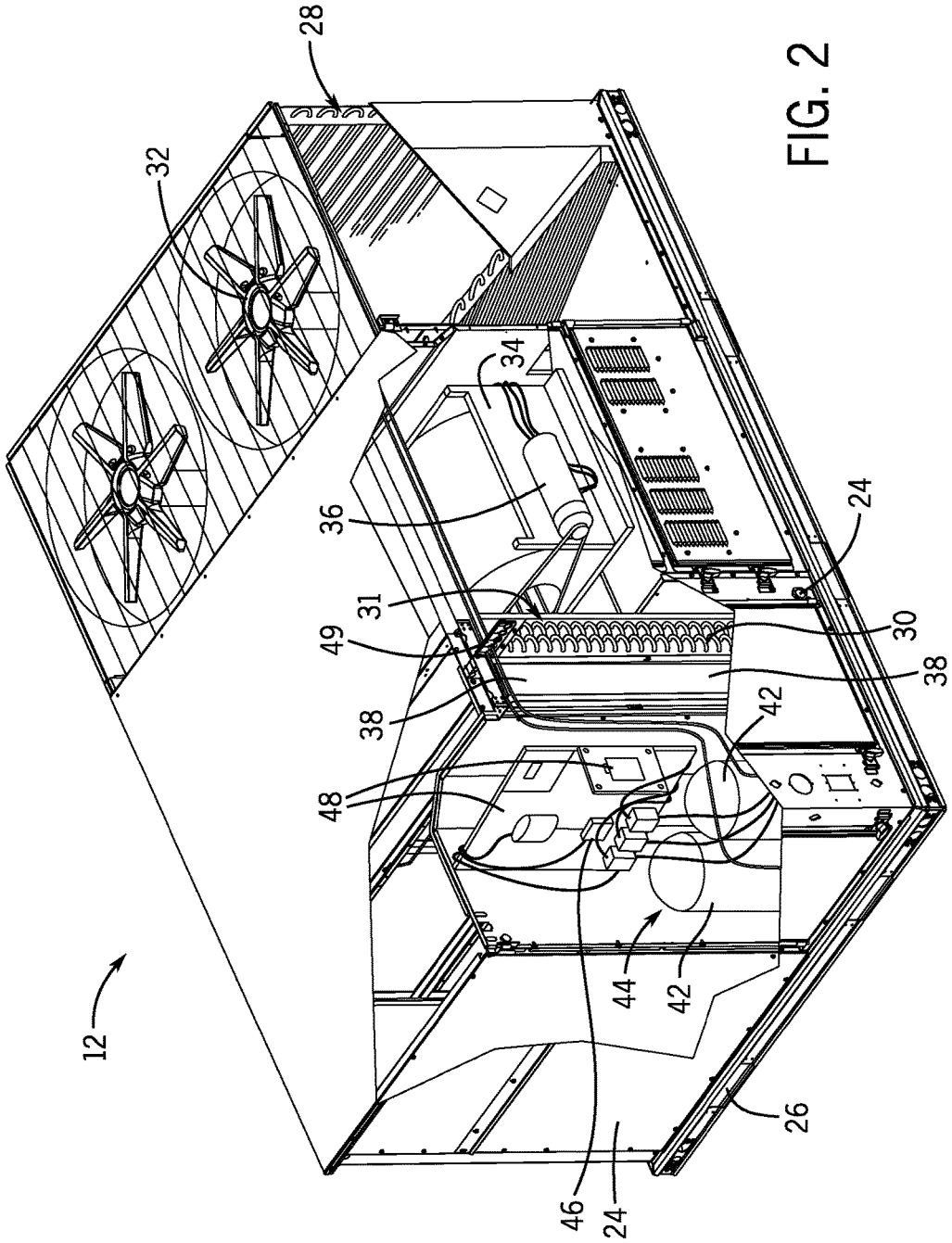


FIG. 2

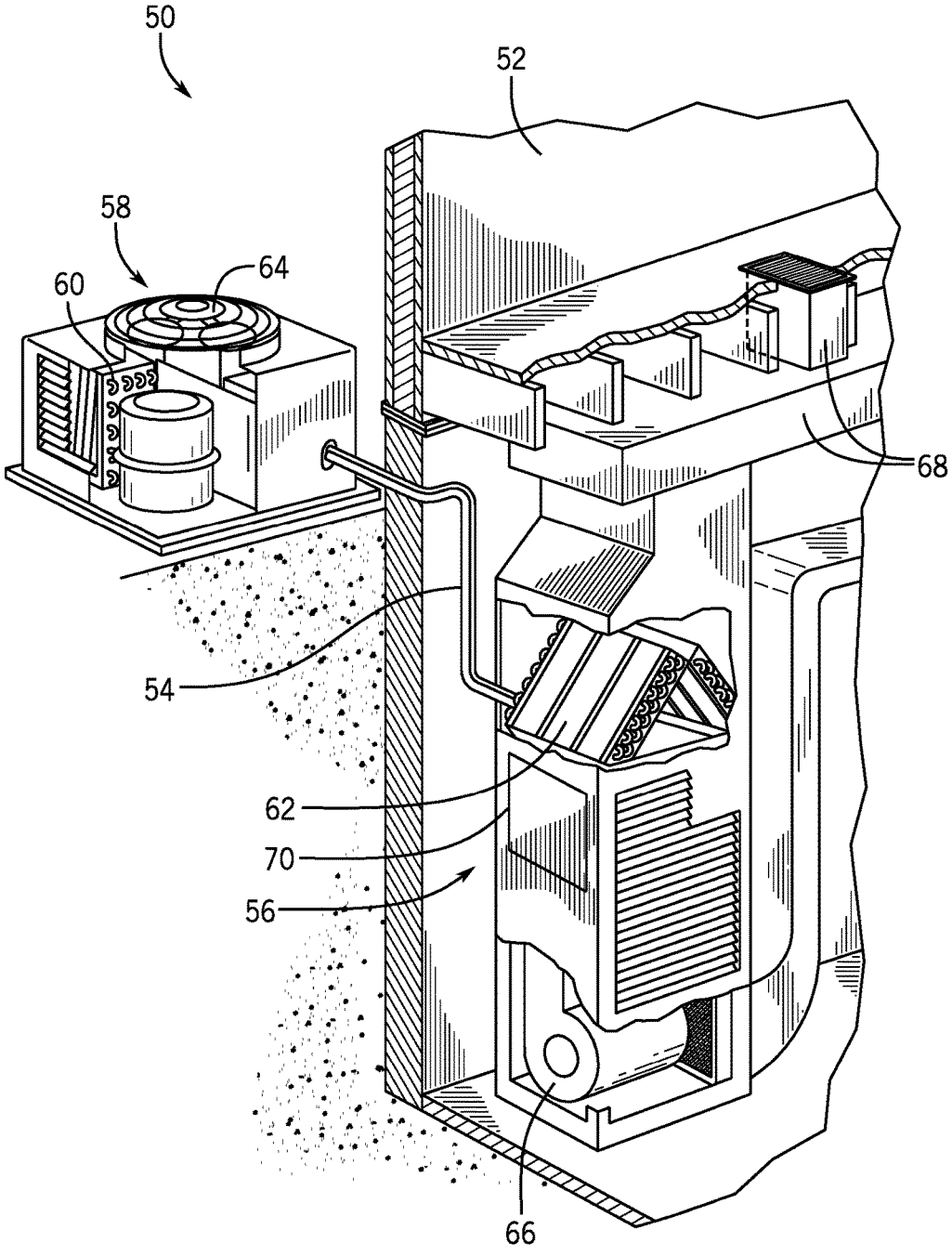


FIG. 3

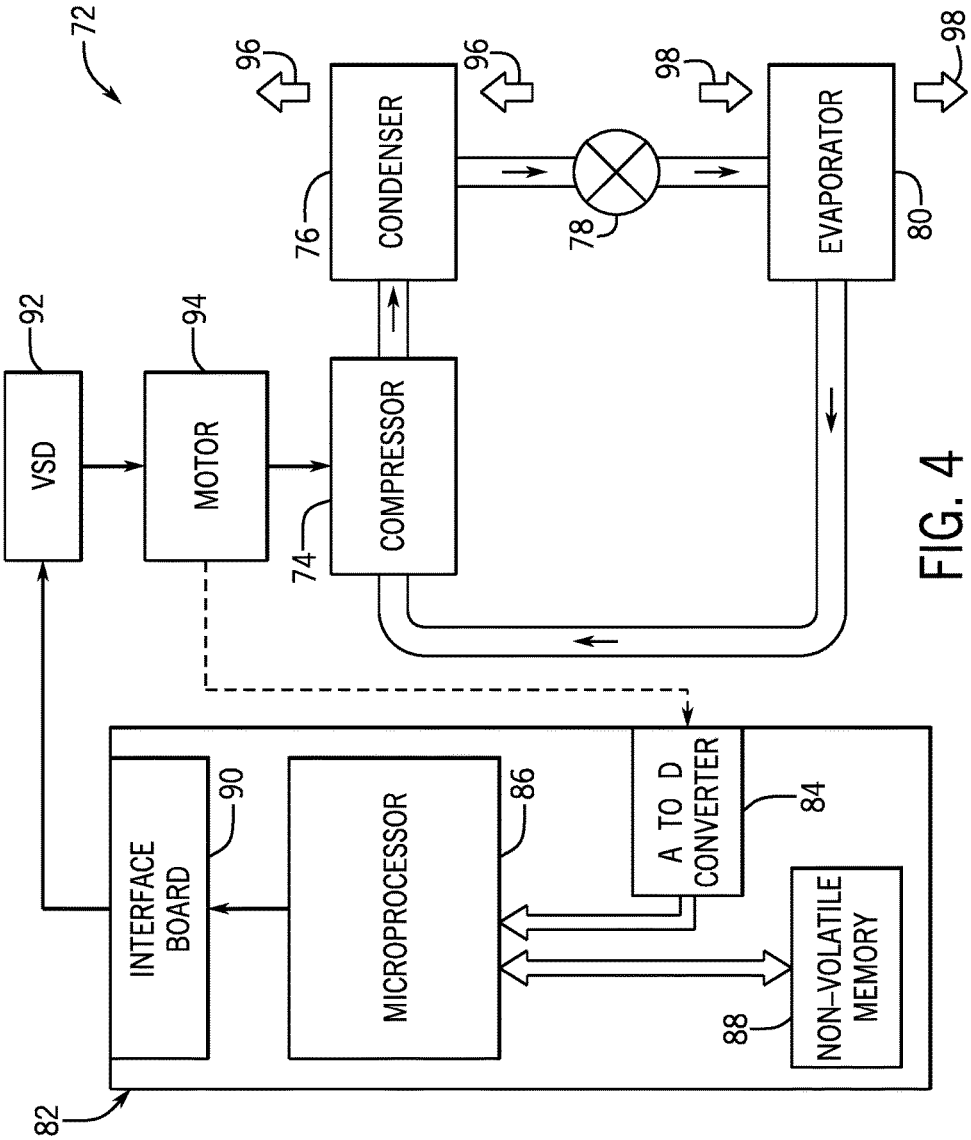

72
96
96
98
98
CONDENSER
EVAPORATOR
76
78
80
92
94
VSD
MOTOR
COMPRESSOR
74
INTERFACE BOARD
90
MICROPROCESSOR
86
A TO D CONVERTER
84
NON-VOLATILE MEMORY
88
82

FIG. 4

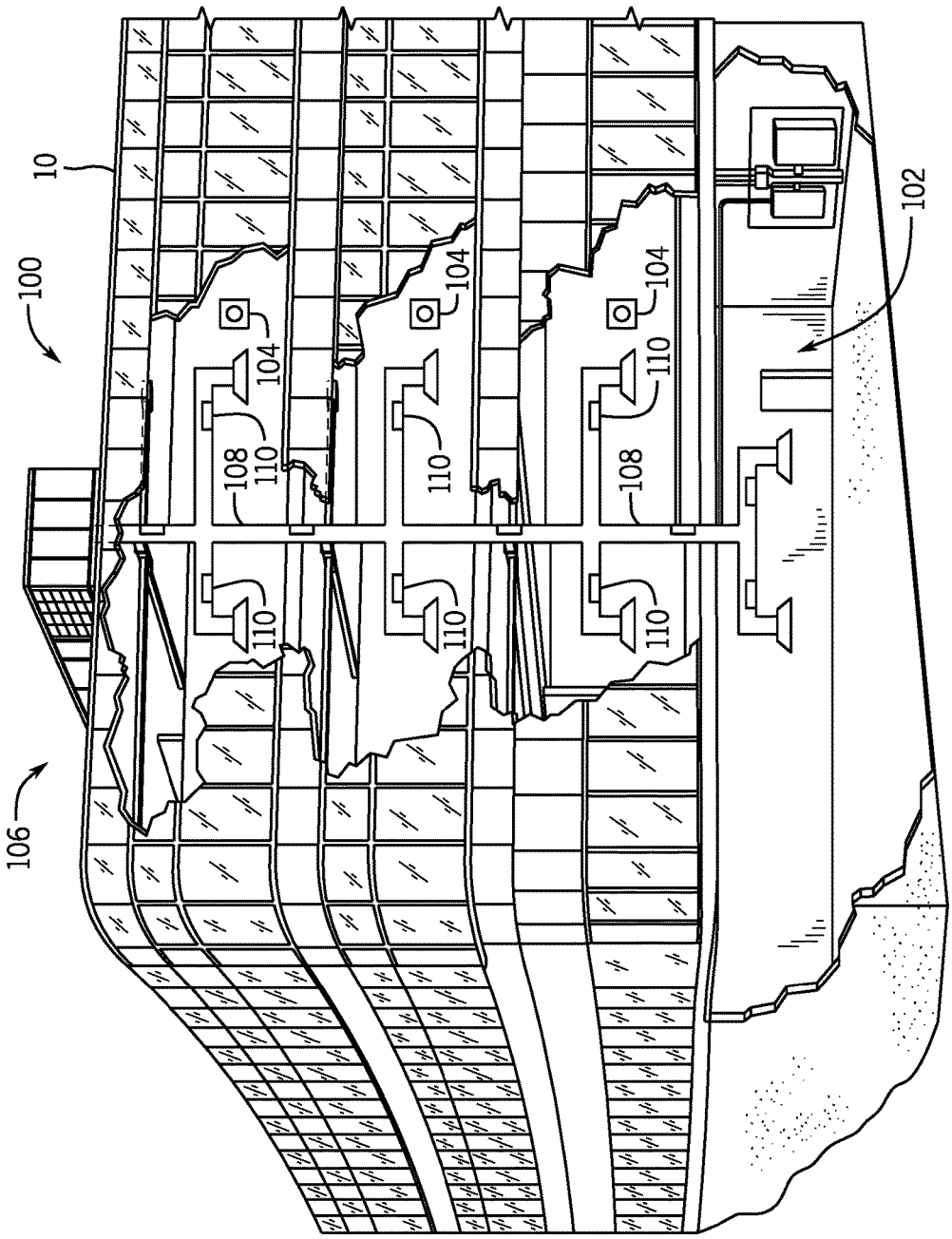


FIG. 5

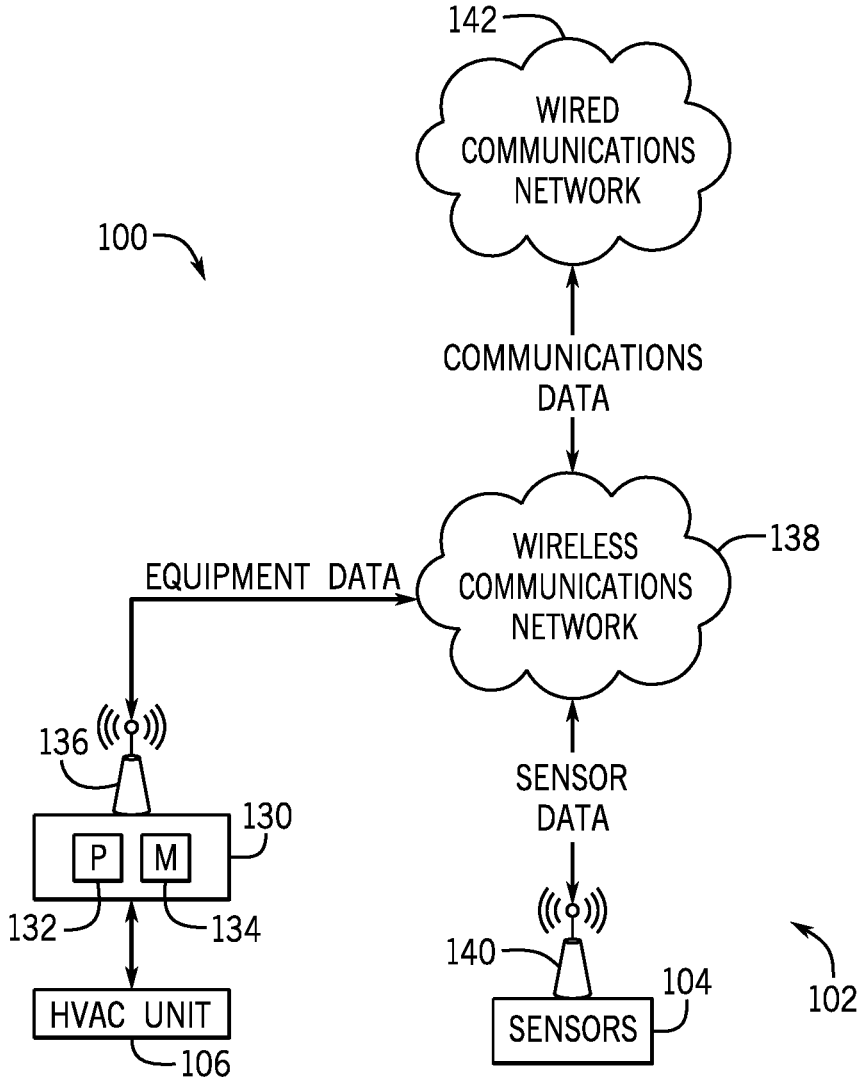

142
WIRED COMMUNICATIONS NETWORK
100
COMMUNICATIONS DATA
WIRELESS COMMUNICATIONS NETWORK
138
EQUIPMENT DATA
136
130
P
M
132
134
HVAC UNIT
106
SENSOR DATA
140
104
SENSORS
102

FIG. 6

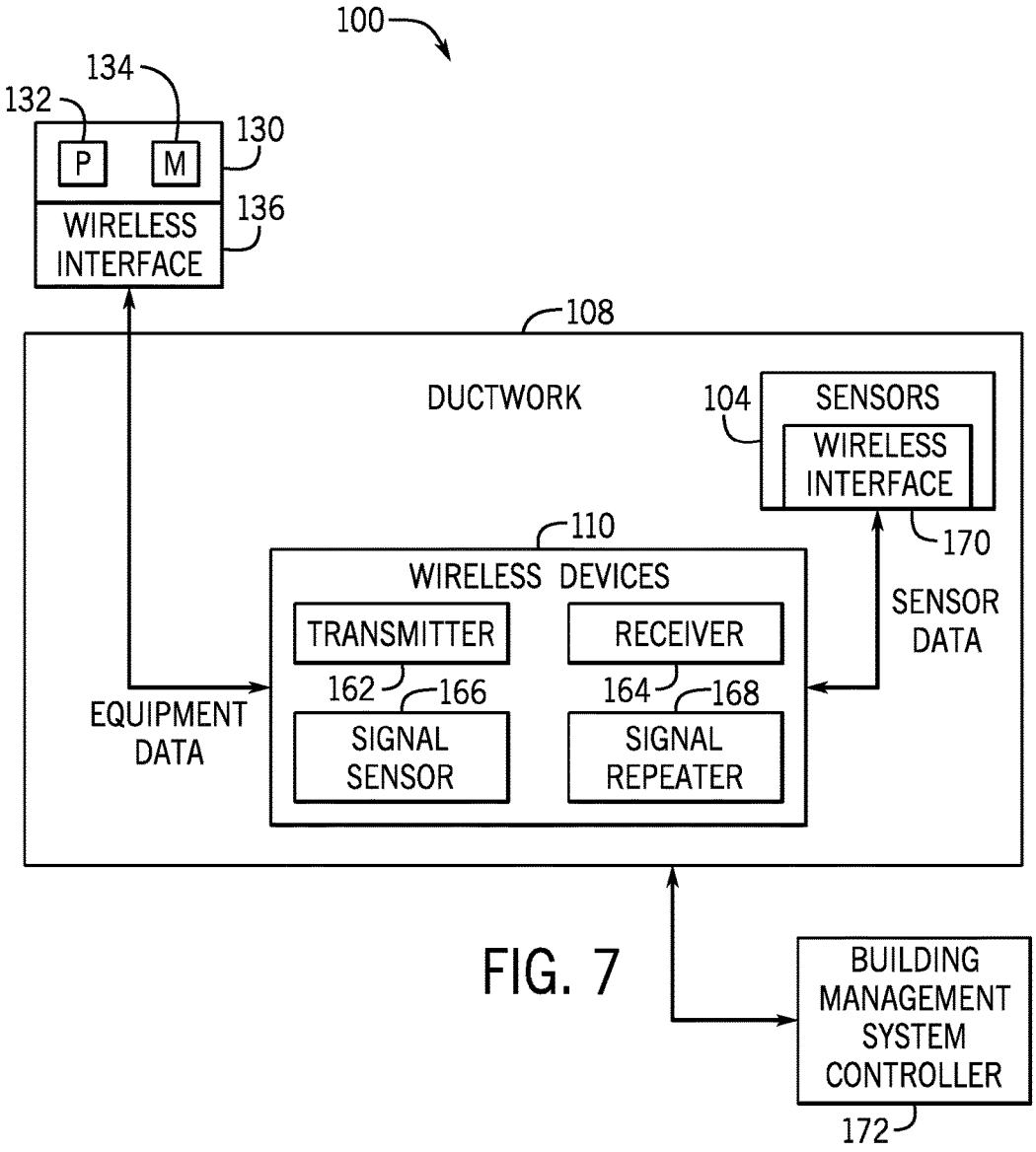

100
134
132
130
P
M
136
WIRELESS INTERFACE
108
DUCTWORK
104
SENSORS
WIRELESS INTERFACE
170
110
WIRELESS DEVICES
TRANSMITTER
RECEIVER
162
166
164
168
SIGNAL SENSOR
SIGNAL REPEATER
SENSOR DATA
EQUIPMENT DATA
BUILDING MANAGEMENT SYSTEM CONTROLLER
172

FIG. 7

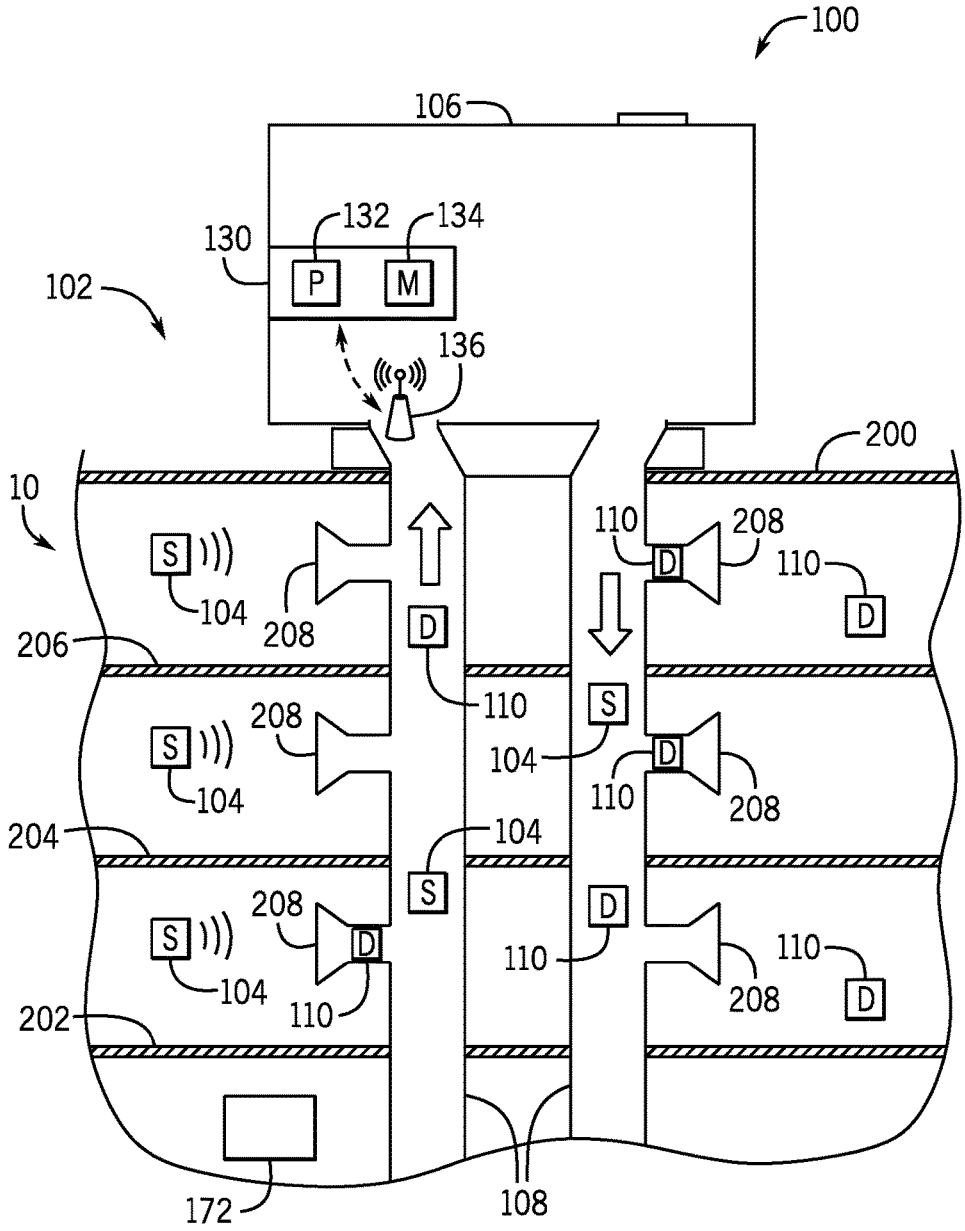

100
106
130
132
134
P
M
102
136
200
10
S
104
208
D
110
206
204
202
172
108

FIG. 8

HVAC SYSTEM WITH WIRELESS WAVEGUIDE SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a Non-Provisional application claiming priority to U.S. Provisional Application No. 62/460,434, entitled "HVAC DUCTWORK SYSTEM WITH INTEGRATED WIRELESS WAVEGUIDE," filed Feb. 17, 2017, which is hereby incorporated by reference in its entirety for all purposes.

BACKGROUND

[0002] The present disclosure relates generally to communication in a heating, ventilation, and air conditioning (HVAC) system.

[0003] Heat exchangers are used in (HVAC) systems to exchange energy between fluids. Typical HVAC systems have two heat exchangers commonly referred to as an evaporator coil and a condenser coil. The evaporator coil and the condenser coil facilitate heat transfer between air surrounding the coils and a refrigerant that flows through the coils. For example, as air passes over the evaporator coil, the air cools as it loses energy to the refrigerant passing through the evaporator coil. In contrast, the condenser facilitates the discharge of heat from the refrigerant to the surrounding air. In some HVAC systems, air is supplied to the condenser and evaporator coils using air-handling units (AHU) located on a rooftop of a building. In order to communicate with the AHU, additional perforations may be formed in the building envelope to run cables between sensors in the building and the controller of the AHU. These perforations may enable water, air, and pests to enter the building as well as increases the costs of setting up and operating the HVAC system.

SUMMARY

[0004] The present disclosure relates to a wireless waveguide system for a heating, ventilation, and air conditioning (HVAC) system. The wireless waveguide system includes a sensor that detects an environmental condition and directs a signal indicative of the environmental condition along an interior of a ductwork. A signal sensor detects a strength of the signal within the interior of the ductwork. A repeater that operates based on the strength of the signal detected by the signal sensor and repeats the signal along a communication path at least partially within the interior of the ductwork to a controller of an HVAC unit.

[0005] The present disclosure also relates to a wireless waveguide system for a heating, ventilation, and air conditioning (HVAC) system. The wireless waveguide system includes a sensor that detects a characteristic of air in an enclosed space and emits a signal indicative of the characteristic along a communication path through an interior of a ductwork to a controller of an HVAC unit. A repeater is placed within the ductwork along the communication path and is positioned proximate a bend in the ductwork. The repeater repeats the signal indicative of the characteristic along the communication path toward the controller.

[0006] The present disclosure also relates to a wireless waveguide system for a heating, ventilation, and air conditioning (HVAC) system. The wireless waveguide system includes ductwork that defines an airflow path therethrough and a controller of an HVAC unit. A sensor detects an environmental condition and directs a signal indicative of the environmental condition along the airflow path. A repeater is disposed within the ductwork along the airflow path. The repeater repeats the signal indicative of the environmental condition further along the airflow path and toward the controller.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Some embodiments will become more fully understood from the following detailed description, taken in conjunction with the accompanying drawings, wherein like reference numerals refer to like elements, in which:

[0008] FIG. **1** is a perspective view of an embodiment of a building that may utilize a heating, ventilation, and air conditioning (HVAC) system in a commercial setting, in accordance with an aspect of the present disclosure;

[0009] FIG. **2** is a perspective view of an embodiment of an HVAC unit of the HVAC system of FIG. **1**, in accordance with an aspect of the present disclosure;

[0010] FIG. **3** is a perspective view of an embodiment of a residential, split HVAC system that includes an indoor HVAC unit and an outdoor HVAC unit, in accordance with an aspect of the present disclosure;

[0011] FIG. **4** is a schematic of an embodiment of an HVAC system, in accordance with an aspect of the present disclosure;

[0012] FIG. **5** is a perspective view of an embodiment of a building with an HVAC system that includes a wireless waveguide system, in accordance with an aspect of the present disclosure;

[0013] FIG. **6** is a schematic view of an embodiment of an HVAC system with a wireless waveguide system, in accordance with an aspect of the present disclosure;

[0014] FIG. **7** is a schematic view of an embodiment of a wireless waveguide system, in accordance with an aspect of the present disclosure; and

[0015] FIG. **8** is a partial cross-sectional view of an embodiment of a building with an HVAC system and wireless waveguide system, in accordance with an aspect of the present disclosure.

DETAILED DESCRIPTION

[0016] HVAC systems include various pieces of equipment in order to control the climate within a building. Some of this equipment includes HVAC units, such as air handling units (AHU), that rest on the rooftops of buildings. Operation of these HVAC units is controlled using feedback from one or more sensors inside of the building. These sensors may include dynamic pressure sensors, temperature sensors, flow rate sensors, carbon dioxide sensors, humidity level sensors, air quality sensors, motion sensors, among others. For example, motion sensors may detect the presence of one or more people. This information is communicated to a controller which then controls the HVAC system to control the climate in an enclosed space.

[0017] To facilitate communication between the sensors and a controller controlling the HVAC unit, the HVAC system may include a wireless waveguide system. The wireless waveguide system includes one or more wireless devices that facilitate communication between the sensors and the HVAC unit controller using the building's ductwork. For example, these wireless devices may be placed within the ductwork to facilitate transmission of the signals from

the sensors to the HVAC unit controller. Examples of wireless devices used in the wireless waveguide system may include transmitters, receivers, signal sensors, signal repeaters, among others. Use of the wireless waveguide system therefore reduces the number of perforations in the building envelope in order to communicate with an HVAC unit controller. As explained above, perforations in the building envelope may enable water, air, and pests to enter the building as well as increases the costs of setting up and operating an HVAC system.

[0018] Turning now to the drawings, FIG. **1** illustrates a heating, ventilating, and air conditioning (HVAC) system for building environmental management that may employ one or more HVAC units. In the illustrated embodiment, a building **10** is air conditioned by a system that includes an HVAC unit **12**. The building **10** may be a commercial structure or a residential structure. As shown, the HVAC unit **12** is disposed on the roof of the building **10**; however, the HVAC unit **12** may be located in other equipment rooms or areas adjacent the building **10**. The HVAC unit **12** may be a single package unit containing other equipment, such as a blower, integrated air handler, and/or auxiliary heating unit. In other embodiments, the HVAC unit **12** may be part of a split HVAC system, such as the system shown in FIG. **3**, which includes an outdoor HVAC unit **58** and an indoor HVAC unit **56**.

[0019] The HVAC unit **12** is an air-cooled device that implements a refrigeration cycle to provide conditioned air to the building **10**. Specifically, the HVAC unit **12** may include one or more heat exchangers across which an airflow is passed to condition the airflow before the airflow is supplied to the building. In the illustrated embodiment, the HVAC unit **12** is a rooftop unit (RTU) that conditions a supply air stream, such as environmental air and/or a return airflow from the building **10**. After the HVAC unit **12** conditions the air, the air is supplied to the building **10** via ductwork **14** extending throughout the building **10** from the HVAC unit **12**. For example, the ductwork **14** may extend to various individual floors or other sections of the building **10**. In certain embodiments, the HVAC unit **12** may be a heat pump that provides both heating and cooling to the building with one refrigeration circuit configured to operate in different modes. In other embodiments, the HVAC unit **12** may include one or more refrigeration circuits for cooling an air stream and a furnace for heating the air stream.

[0020] A control device **16**, one type of which may be a thermostat, may be used to designate the temperature of the conditioned air. The control device **16** also may be used to control the flow of air through the ductwork **14**. For example, the control device **16** may be used to regulate operation of one or more components of the HVAC unit **12** or other components, such as dampers and fans, within the building **10** that may control flow of air through and/or from the ductwork **14**. In some embodiments, other devices may be included in the system, such as pressure and/or temperature transducers or switches that sense the temperatures and pressures of the supply air, return air, and so forth. Moreover, the control device **16** may include computer systems that are integrated with or separate from other building control or monitoring systems, and even systems that are remote from the building **10**.

[0021] FIG. **2** is a perspective view of an embodiment of the HVAC unit **12**. In the illustrated embodiment, the HVAC unit **12** is a single package unit that may include one or more independent refrigeration circuits and components that are tested, charged, wired, piped, and ready for installation. The HVAC unit **12** may provide a variety of heating and/or cooling functions, such as cooling only, heating only, cooling with electric heat, cooling with dehumidification, cooling with gas heat, or cooling with a heat pump. As described above, the HVAC unit **12** may directly cool and/or heat an air stream provided to the building **10** to condition a space in the building **10**.

[0022] As shown in the illustrated embodiment of FIG. **2**, a cabinet **24** encloses the HVAC unit **12** and provides structural support and protection to the internal components from environmental and other contaminants. In some embodiments, the cabinet **24** may be constructed of galvanized steel and insulated with aluminum foil faced insulation. Rails **26** may be joined to the bottom perimeter of the cabinet **24** and provide a foundation for the HVAC unit **12**. In certain embodiments, the rails **26** may provide access for a forklift and/or overhead rigging to facilitate installation and/or removal of the HVAC unit **12**. In some embodiments, the rails **26** may fit into "curbs" on the roof to enable the HVAC unit **12** to provide air to the ductwork **14** from the bottom of the HVAC unit **12** while blocking elements such as rain from leaking into the building **10**.

[0023] The HVAC unit **12** includes heat exchangers **28** and **30** in fluid communication with one or more refrigeration circuits. Tubes within the heat exchangers **28** and **30** may circulate refrigerant (for example, R-**410**A, steam, or water) through the heat exchangers **28** and **30**. The tubes may be of various types, such as multichannel tubes, conventional copper or aluminum tubing, and so forth. Together, the heat exchangers **28** and **30** may implement a thermal cycle in which the refrigerant undergoes phase changes and/or temperature changes as it flows through the heat exchangers **28** and **30** to produce heated and/or cooled air. For example, the heat exchanger **28** may function as a condenser where heat is released from the refrigerant to ambient air, and the heat exchanger **30** may function as an evaporator where the refrigerant absorbs heat to cool an air stream. In other embodiments, the HVAC unit **12** may operate in a heat pump mode where the roles of the heat exchangers **28** and **30** may be reversed. That is, the heat exchanger **28** may function as an evaporator and the heat exchanger **30** may function as a condenser. In further embodiments, the HVAC unit **12** may include a furnace for heating the air stream that is supplied to the building **10**. While the illustrated embodiment of FIG. **2** shows the HVAC unit **12** having two of the heat exchangers **28** and **30**, in other embodiments, the HVAC unit **12** may include one heat exchanger or more than two heat exchangers.

[0024] The heat exchanger **30** is located within a compartment **31** that separates the heat exchanger **30** from the heat exchanger **28**. Fans **32** draw air from the environment through the heat exchanger **28**. Air may be heated and/or cooled as the air flows through the heat exchanger **28** before being released back to the environment surrounding the rooftop unit **12**. A blower assembly **34**, powered by a motor **36**, draws air through the heat exchanger **30** to heat or cool the air. The heated or cooled air may be directed to the building **10** by the ductwork **14**, which may be connected to the HVAC unit **12**. Before flowing through the heat exchanger **30**, the conditioned airflows through one or more filters **38** that may remove particulates and contaminants from the air. In certain embodiments, the filters **38** may be

disposed on the air intake side of the heat exchanger **30** to prevent contaminants from contacting the heat exchanger **30**.

[0025] The HVAC unit **12** also may include other equipment for implementing the thermal cycle. Compressors **42** increase the pressure and temperature of the refrigerant before the refrigerant enters the heat exchanger **28**. The compressors **42** may be any suitable type of compressors, such as scroll compressors, rotary compressors, screw compressors, or reciprocating compressors. In some embodiments, the compressors **42** may include a pair of hermetic direct drive compressors arranged in a dual stage configuration **44**. However, in other embodiments, any number of the compressors **42** may be provided to achieve various stages of heating and/or cooling. As may be appreciated, additional equipment and devices may be included in the HVAC unit **12**, such as a solid-core filter drier, a drain pan, a disconnect switch, an economizer, pressure switches, phase monitors, and humidity sensors, among other things.

[0026] The HVAC unit **12** may receive power through a terminal block **46**. For example, a high voltage power source may be connected to the terminal block **46** to power the equipment. The operation of the HVAC unit **12** may be governed or regulated by a control board **48**. The control board **48** may include control circuitry connected to a thermostat, sensors, and alarms, one or more which may be referred to separately or collectively as the control device **16**. The control circuitry may be configured to control operation of the equipment, provide alarms, and monitor safety switches. Wiring **49** may connect the control board **48** and the terminal block **46** to the equipment of the HVAC unit **12**.

[0027] FIG. **3** illustrates a residential heating and cooling system **50**, also in accordance with present techniques. The residential heating and cooling system **50** may provide heated and cooled air to a residential structure, as well as provide outside air for ventilation and provide improved indoor air quality (IAQ) through devices such as ultraviolet lights and air filters. In the illustrated embodiment, the residential heating and cooling system **50** is a split HVAC system. In general, a residence **52** conditioned by a split HVAC system may include refrigerant conduits **54** that operatively couple the indoor unit **56** to the outdoor unit **58**. The indoor unit **56** may be positioned in a utility room, an attic, a basement, and so forth. The outdoor unit **58** is typically situated adjacent to a side of residence **52** and is covered by a shroud to protect the system components and to prevent leaves and other debris or contaminants from entering the unit. The refrigerant conduits **54** transfer refrigerant between the indoor unit **56** and the outdoor unit **58**, typically transferring primarily liquid refrigerant in one direction and primarily vaporized refrigerant in an opposite direction.

[0028] When the system shown in FIG. **3** is operating as an air conditioner, a heat exchanger **60** in the outdoor unit **58** serves as a condenser for re-condensing vaporized refrigerant flowing from the indoor unit **56** to the outdoor unit **58** via one of the refrigerant conduits **54**. In these applications, a heat exchanger **62** of the indoor unit functions as an evaporator. Specifically, the heat exchanger **62** receives liquid refrigerant, which may be expanded by an expansion device, and evaporates the refrigerant before returning it to the outdoor unit **58**.

[0029] The outdoor unit **58** draws environmental air through the heat exchanger **60** using a fan **64** and expels the air above the outdoor unit **58**. When operating as an air conditioner, the air is heated by the heat exchanger **60** within the outdoor unit **58** and exits the unit at a temperature higher than it entered. The indoor unit **56** includes a blower or fan **66** that directs air through or across the indoor heat exchanger **62**, where the air is cooled when the system is operating in air conditioning mode. Thereafter, the air is passed through ductwork **68** that directs the air to the residence **52**. The overall system operates to maintain a desired temperature as set by a system controller. When the temperature sensed inside the residence **52** is higher than the set point on the thermostat, or a set point plus a small amount, the residential heating and cooling system **50** may become operative to refrigerate additional air for circulation through the residence **52**. When the temperature reaches the set point, or the set point minus a small amount, the residential heating and cooling system **50** may stop the refrigeration cycle temporarily.

[0030] The residential heating and cooling system **50** may also operate as a heat pump. When operating as a heat pump, the roles of heat exchangers **60** and **62** are reversed. That is, the heat exchanger **60** of the outdoor unit **58** will serve as an evaporator to evaporate refrigerant and thereby cool air entering the outdoor unit **58** as the air passes over outdoor the heat exchanger **60**. The indoor heat exchanger **62** will receive a stream of air blown over it and will heat the air by condensing the refrigerant.

[0031] In some embodiments, the indoor unit **56** may include a furnace system **70**. For example, the indoor unit **56** may include the furnace system **70** when the residential heating and cooling system **50** is not configured to operate as a heat pump. The furnace system **70** may include a burner assembly and heat exchanger, among other components, inside the indoor unit **56**. Fuel is provided to the burner assembly of the furnace **70** where it is mixed with air and combusted to form combustion products. The combustion products may pass through tubes or piping in a heat exchanger, separate from heat exchanger **62**, such that air directed by the blower **66** passes over the tubes or pipes and extracts heat from the combustion products. The heated air may then be routed from the furnace system **70** to the ductwork **68** for heating the residence **52**.

[0032] FIG. **4** is an embodiment of a vapor compression system **72** that can be used in any of the systems described above. The vapor compression system **72** may circulate a refrigerant through a circuit starting with a compressor **74**. The circuit may also include a condenser **76**, an expansion valve(s) or device(s) **78**, and an evaporator **80**. The vapor compression system **72** may further include a control panel **82** that has an analog to digital (A/D) converter **84**, a microprocessor **86**, a non-volatile memory **88**, and/or an interface board **90**. The control panel **82** and its components may function to regulate operation of the vapor compression system **72** based on feedback from an operator, from sensors of the vapor compression system **72** that detect operating conditions, and so forth.

[0033] In some embodiments, the vapor compression system **72** may use one or more of a variable speed drive (VSDs) **92**, a motor **94**, the compressor **74**, the condenser **76**, the expansion valve or device **78**, and/or the evaporator **80**. The motor **94** may drive the compressor **74** and may be powered by the variable speed drive (VSD) **92**. The VSD **92**

receives alternating current (AC) power having a particular fixed line voltage and fixed line frequency from an AC power source, and provides power having a variable voltage and frequency to the motor **94**. In other embodiments, the motor **94** may be powered directly from an AC or direct current (DC) power source. The motor **94** may include any type of electric motor that can be powered by a VSD or directly from an AC or DC power source, such as a switched reluctance motor, an induction motor, an electronically commutated permanent magnet motor, or another suitable motor.

[0034] The compressor **74** compresses a refrigerant vapor and delivers the vapor to the condenser **76** through a discharge passage. In some embodiments, the compressor **74** may be a centrifugal compressor. The refrigerant vapor delivered by the compressor **74** to the condenser **76** may transfer heat to a fluid passing across the condenser **76**, such as ambient or environmental air **96**. The refrigerant vapor may condense to a refrigerant liquid in the condenser **76** as a result of thermal heat transfer with the environmental air **96**. The liquid refrigerant from the condenser **76** may flow through the expansion device **78** to the evaporator **80**.

[0035] The liquid refrigerant delivered to the evaporator **80** may absorb heat from another air stream, such as a supply air stream **98** provided to the building **10** or the residence **52**. For example, the supply air stream **98** may include ambient or environmental air, return air from a building, or a combination of the two. The liquid refrigerant in the evaporator **80** may undergo a phase change from the liquid refrigerant to a refrigerant vapor. In this manner, the evaporator **80** may reduce the temperature of the supply air stream **98** via thermal heat transfer with the refrigerant. Thereafter, the vapor refrigerant exits the evaporator **80** and returns to the compressor **74** by a suction line to complete the cycle.

[0036] In some embodiments, the vapor compression system **72** may further include a reheat coil in addition to the evaporator **80**. For example, the reheat coil may be positioned downstream of the evaporator relative to the supply air stream **98** and may reheat the supply air stream **98** when the supply air stream **98** is overcooled to remove humidity from the supply air stream **98** before the supply air stream **98** is directed to the building **10** or the residence **52**.

[0037] It should be appreciated that any of the features described herein may be incorporated with the HVAC unit **12**, the residential heating and cooling system **50**, or other HVAC systems. Additionally, while the features disclosed herein are described in the context of embodiments that directly heat and cool a supply air stream provided to a building or other load, embodiments of the present disclosure may be applicable to other HVAC systems as well. For example, the features described herein may be applied to mechanical cooling systems, free cooling systems, chiller systems, or other heat pump or refrigeration applications.

[0038] FIG. **5** is a perspective view of an HVAC system **100** with a wireless waveguide system **102** that facilitates communication from one or more sensors **104** to an HVAC unit **106**. As illustrated, the HVAC unit **106** is disposed on the roof of the building **10**. This may place the roof, one or more ceilings, and one or more walls between the controller of the HVAC unit **106** and the sensors **104**. These structures may interfere with wireless communication, and thus control, of the HVAC system **100**. However, the wireless waveguide system **102** facilitates communication between the HVAC unit **106** and the sensors **104** by transmitting the wireless signal through the interior of the ductwork **108** in the building **10**. By using the ductwork **108**, the wireless waveguide system **102** enables communication while simultaneously reducing perforations of the walls, ceilings, and/or the roof in order to install communication cables and/or wireless antennas. As will explained in detail below, the wireless waveguide system **102** may include one or more wireless devices **110** placed within the ductwork **108** that facilitate signal transmission from one or more sensors **104** to the controller of the HVAC unit **106**.

[0039] In some embodiments, the HVAC unit **106** may be located in other equipment rooms or areas adjacent the building **10**. The HVAC unit **106** may include a single packaged unit containing other equipment, such as a blower, integrated air handler, and/or auxiliary heating unit. In other embodiments, the HVAC unit **106** may be a split HVAC system, such as the system shown in FIG. **3**, which includes the outdoor HVAC unit **58** and the indoor HVAC unit **56**. However, regardless of the HVAC system setup, the wireless waveguide system **102** facilitates communication between the sensors **104** and the HVAC unit **106**.

[0040] The HVAC system **100** uses a refrigeration cycle to provide conditioned air to the building **10**. Specifically, the HVAC system **100** may include one or more heat exchangers across which an air flow is passed, which conditions the airflow before the airflow is supplied to the building. In the illustrated embodiment, the HVAC unit **106** is a rooftop unit (RTU) that conditions a supply air stream, such as environmental air and/or a return airflow from the building **10**. After the HVAC system **100** conditions the air, the air is supplied to the building **10** via ductwork **108** extending throughout the building **10** from the HVAC system **100**. For example, the ductwork **108** may extend to various floors or other sections of the building **10**. In some embodiments, the HVAC system **100** may include one or more refrigeration circuits for cooling an air stream and a furnace for heating the air stream.

[0041] Controllers and/or sensors **104**, one type of which may be a thermostat, may be used to designate the temperature of the conditioned air. These devices may also be used to control the flow of air through the ductwork **108**. For example, the controllers and/or sensors **104** may be used to regulate operation of one or more components of the HVAC system **100**, such as dampers and fans, within the building **10** that may control flow of air through and/or from the ductwork **108**.

[0042] FIG. **6** is a schematic view of the HVAC system **100** with the wireless waveguide system **102**. As explained above, the HVAC system **100** includes one or more HVAC units **106**, such as a roof top unit. The HVAC unit **106** includes a controller **130** configured to monitor and/or control the HVAC unit **106**. The controller **130** includes a processor **132** and a memory **134**. For example, the processor **132** may be a microprocessor that executes software to control the HVAC unit **106**. The processor **132** may include multiple microprocessors, one or more "general-purpose" microprocessors, one or more special-purpose microprocessors, and/or one or more application specific integrated circuits (ASICS), or some combination thereof. For example, the processor **132** may include one or more reduced instruction set (RISC) processors.

[0043] The memory **134** may include a volatile memory, such as random access memory (RAM), and/or a nonvolatile memory, such as read-only memory (ROM). The memory

134 may store a variety of information and may be used for various purposes. For example, the memory 134 may store processor executable instructions, such as firmware or software, for the processor 132 to execute. The memory may include ROM, flash memory, a hard drive, or any other suitable optical, magnetic, or solid-state storage medium, or a combination thereof. The memory may store data, instructions, and any other suitable data.

[0044] Coupled to the controller 130 is a wireless interface 136. The wireless interface 136 may be any device configured for wireless communications with wireless communications network 138, and/or configured for wired and/or wireless communication with controller 130. Although FIG. 6 shows one controller 130, one HVAC unit 106, and one wireless interface 136, it should be understood that other embodiments may include additional HVAC equipment controllers 130, HVAC units 106, and wireless interfaces 136.

[0045] In operation, the controller 130 may receive equipment data from the HVAC unit 106 and subsequently transmit that data to the wireless communications network 138 via wireless interface 136. Likewise, the controller 130 may receive equipment data from the wireless communications network 138 via the wireless interface 136, which then transmits the data to the HVAC unit 106. Data communication via the wireless communications network 138 may be implemented using any suitable wireless communication protocol such as 802.11a/b/g/n/ac, Bluetooth, RFID, and at any suitable frequency band, such as 2.4 GHz, 5 GHz, or 5.8 GHz.

[0046] As explained above, the HVAC unit 106 may be controlled in response to feedback from sensors 104. These sensors 104 may be any type of sensor used in HVAC systems, such as dynamic pressure sensors, temperature sensors, flow rate sensors, carbon dioxide sensors, humidity level sensors, air quality sensors, motion sensors, among others. These sensors may couple to wireless transmitters 140 that transmit data indicative of the measured property. The wireless transmitters 140 transmit this information to the wireless communications network 138. The wireless communications network carries this data to the controller 130, which then controls operation of the HVAC unit 106 in response to the data.

[0047] In some embodiments, the wireless communications network 138 may communicate with a wired communications network 142. The wired communications network 142 may include network devices that facilitate wireless transmission throughout the building 10 or another enclosed space. For example, the wired communications network 142 may include wireless gateways, routers, hubs, switches, signal sensors, signal repeaters, interconnecting cables and wiring.

[0048] In some embodiments, the wireless communications network 138 includes one or more network devices configured to send and receive data to one or more network devices in wired communications network 142. For example, the wireless communications networks 138 may include a Wi-Fi router or similar device with an interface configured to communicate with a compatible interface in the wired communications network 142. In this regard, components that directly communicate with the wireless communications network 138, such as the HVAC unit 106 and sensors 104, may communicate with other components that are configured to directly communicate with wired communications network 142. Accordingly, FIG. 6 is not intended to limit possible configurations of the wireless communications network 138, possible configurations of wired communications network 142, and the interconnection of various components, such as the HVAC unit 106 and sensors 104, in the HVAC system 100.

[0049] FIG. 7 is a schematic view of an embodiment of the HVAC system 100 with the wireless waveguide system 102. In operation, the wireless waveguide system 102 uses the electrical and mechanical properties of the ductwork 108 to efficiently contain and propagate wireless signals through portions of or all of the ductwork 108.

[0050] As explained above, the HVAC system 100 includes the HVAC unit 106, such as a rooftop unit, for cooling the building 10. The HVAC unit 106 is controlled with the controller 130. As illustrated, the controller 130 may couple to and/or include the wireless interface 136 that enables the controller 130 to receive wireless signals used in controlling the HVAC unit 106. The wireless interface 136 enables data communications with wireless devices 110 and/or other devices capable of wireless communication. In this regard, wireless interface 136 may include a Wi-Fi transceiver, cellular or mobile phone transceiver, antennas, among others. In some embodiments, the controller 130 uses an external device for sending and receiving wireless communications, and wireless interface 136 may interface with the external device via wired connection, such as Ethernet and coaxial cable. For example, in some embodiments, the controller 130 is provided outside building 10 on a rooftop, whereas a transmitter 162 is an independent device capable of wireless communications and is located inside the building 10. More specifically, the transmitter 162 is located inside ductwork 108 of the building 10. In this regard, wireless interface 136 is communicatively connected via wired connection to the transmitter 162 located inside building 10.

[0051] The wireless interface 136 can generally be configured to facilitate communication of equipment data between controller 130 and wireless devices 110. For example, the wireless interface 136 may communicate with transmitters 162, receivers 164, signal sensors 166, and/or signal repeaters 168. These wireless devices in turn communicate with one or more sensors 104. Types of sensors 104 include dynamic pressure sensors, temperature sensors, flow rate sensors, carbon dioxide sensors, humidity level sensors, air quality sensors, motion sensors, among others. The sensors 104 each include a wireless interface 170 that facilitates communication of sensor data to and/or from one or more wireless devices 110. For example, static pressure sensors can be dispersed throughout building 10 to facilitate control of static pressure level in the ductwork 108. Any number and/or type of static pressure sensors may be provided. The number and type of static pressure sensors may vary based on the size of building 10 and requirements of the HVAC system 100. For example, a network of static pressure sensors in ductwork 108 may be vertically implemented across various floors of building 10 and also horizontally implemented throughout each of the various floors.

[0052] The wireless interface 170 can generally be configured to facilitate communication of sensor data between the static pressure sensors and one or more wireless devices 110. In this regard, static pressure sensors can provide sensor data to wireless devices 110, and wireless devices 110 can subsequently transmit the sensor data to the controller 130. In response to the sensor data, the controller 130 may send

control commands to various components, such as fans and actuators, in the HVAC unit **106** or in the building **10**, thereby adjusting the supply of conditioned air to meet changing demands.

[0053] In FIG. **7**, the ductwork **108** is shown to include wireless devices **110**. In some embodiments, wireless devices **110** are provided to enable wireless communication for other systems, such as a building management system (BMS). For example, wireless devices **110** can be configured to send and receive equipment data between the controller **130** and a BMS controller **172**. Wireless devices **110** may also be configured to send and receive sensor data between the sensors **104** and the BMS controller **172**. Furthermore, wireless devices **110** may be configured to send and receive communication data between the BMS controller **172** and various building components in a building management system. In some embodiments, a set of wireless devices **110** is provided for wireless communication among the set of wireless devices **110**, for example, to extend the range of wireless signals sent and received by the wireless devices **110** or other wireless communication components.

[0054] Wireless devices **110** can be configured for communication with devices both internal to the ductwork **108** and/or external to the ductwork **108**. For example, wireless devices **110** can be configured within one end of a duct in ductwork **108** in a manner that uses the ductwork **108** as a waveguide. In particular, the electrical and mechanical properties of ductwork **108** may be advantageously used such that wireless signals are efficiently contained and propagated through portions of the ductwork **108**. In this regard, using the interior space defined by the ductwork **108** as a waveguide may extend the range of a wireless signal both vertically across floors of building **10** and horizontally across each floor of building **10**.

[0055] As mentioned above, the wireless devices **110** may include transmitters **162**, receivers **164**, signal sensors **166**, and/or signal repeaters **168**. The type, number, and configuration of wireless devices **110** may vary. In this regard, embodiments may vary based on size and other characteristics of the building **10**, the HVAC system **100**, among others. For example, a set of transmitters **162**, receivers **164**, signal sensors **166**, and signal repeaters **168**, may be vertically implemented across various floors of the building **10** in the ductwork **108**, and another set of wireless devices **110** can be horizontally implemented throughout each of the various floors through the ductwork **108**.

[0056] In FIG. **7**, the wireless devices **110** are shown to include the transmitter **162**. The transmitter **162** may be any device capable of receiving data input, such as equipment data and sensor data, and transmitting the received data to a device capable of receiving the transmitted data, such as receiver **164**. For example, the transmitter **162** can be configured to receive equipment data from the controller **130** via the wireless interface **136** and subsequently send the received equipment data to one of the wireless devices **110**. The transmitter **162** can also be configured to receive data from wireless devices **110**. In some embodiments, the transmitter **162** is mounted within a predetermined proximity in relation to the controller **130**, such as on a rooftop of building **10**. In some embodiments, the transmitter **162** is mounted below the controller **130** and within ductwork **108**. For example, the transmitter **162** may be mounted in the return side of ductwork **108** leading up to the controller **130**.

[0057] In some embodiments, mounting the transmitter **162** in the ductwork **108** may optimize transmission of wireless signals. For example, the interior reflective surfaces of the ductwork **108** may cause transmitted signals to reflect and cause cancellation of transmitted waves, thereby reducing throughput of wireless communications. In this regard, transmitters **162** may be mounted in relation to reflective surfaces of the ductwork **108** to minimize undesirable transmission properties.

[0058] In some embodiments, the transmitter **162** may be mounted at a predetermined distance in relation to internal surfaces of the ductwork **108**, such that reflected waves are in phase with incoming waves. For example, the transmitter **162** may be mounted at a calculated distance (d) from internal surfaces of ductwork **108** according to the following equation:

$$d=\lambda+¼\lambda$$

where λ is the wavelength of a wireless signal sent by the transmitter **162**. For example, in some embodiments, the transmitter **162** sends a wireless signal at a frequency of 2.4 GHz. In this regard, wavelength (A) may be approximately 12.5 cm, and the calculated distance (d) is approximately 15.625 cm. Thus, the transmitter **162** may be mounted at a distance (d) of 15.625 cm from an internal surface of the ductwork **108**.

[0059] As mentioned above, the wireless devices **110** may include the receiver **164**. The receiver **164** can be any device capable of receiving wireless communication signals via an antenna communicably connected to the receiver **164**. In some embodiments, the receiver **164** provides the received data to other wireless devices **110**, the BMS controller **172**, the controller **130**, the sensors **104**, and/or any device in the HVAC system **100**. To this end, the receiver **164** may provide received data via a wired or wireless connection to wireless devices **110**, the BMS controller **172**, the controller **130**, the sensors **104**, and/or any device in the HVAC system **100**.

[0060] In some embodiments, the receiver **164** can be configured to address transmission consequences arising from multipath propagation. Multipath propagation may occur when reflective surfaces internal to the ductwork **108** cause transmitted signals to reflect, and in turn cause signal paths to vary as they reaches their destination. This may cause wireless signals to be received at different times and may reduce throughput of wireless communication.

[0061] In some embodiments, the receiver **164** may be configured to employ a diversity system generally configured to include two or more antennae spaced at a predetermined distance apart from each other. For example, the receiver **164** may be configured to employ a diversity system with two integral antennae. The receiver **164** may choose a preferred antenna by sampling throughput at each of the two antennae and may compare the sampling results to determine a maximum throughput. In some embodiments, when the receiver **164** detects a suboptimal wireless signal at a first antenna, the receiver **164** may switch to a second antenna and begin receiving data from the second antenna.

[0062] The wireless devices **110** may also include the signal sensor **166** and signal repeater **168**. The signal sensor **166** is generally configured to receive a wireless signal and determine various performance characteristics of the wireless signal. For example, the signal sensor **166** may be configured to determine an amplitude and/or throughput

capability of received wireless signals. In some embodiments, the signal sensor **166** may be mounted at various locations internal to the ductwork **108** to sense transmission characteristics of wireless signals. The signal sensor **166** may be mounted in a hollow cavity of the ductwork **108**, or the signal sensor **166** may be mounted external to the ductwork **108**.

[0063] In some embodiments, the signal repeater **168** is generally configured to receive a wireless signal, amplify the signal, and subsequently transmit the amplified signal via an integral antenna or transmitter device. In this regard, the signal repeater **168** is configured to increase the range of a wireless signal and/or increase throughput. Moreover, the signal repeater **168** may be any device capable of boosting, repeating, extending wireless signal range, or otherwise improving wireless performance. For example, in some embodiments, the signal repeater **168** employs an integral processor configured to reduce signal noise in received wireless signals. The signal repeater **168** can then amplify the processed wireless signal and subsequently transmit the amplified signal via an integral antenna.

[0064] Signal sensors **166** and signal repeaters **168** may be placed at various locations in the building **10** and/or within the HVAC system **100** to facilitate transmission of the wireless signal. For example, the signal sensor **166** and signal repeater **168** may be mounted around a 90° bend in the ductwork **108**, such that wireless signals at one end of a 90° bend can be received at transmitted around the 90° bend. It should be understood that the ductwork **108** may include multiple bends with different angles ranging from approximately 20°-180°, and that some or all of these bends may include signal sensors **166** and signal repeaters **168** that facilitate transmission of the wireless signal.

[0065] In some embodiments, the signal sensor **166** may take various actions in response to input received from other wireless devices **110** and/or the BMS controller **172**. For example, in some embodiments, when the signal sensor **166** detects a low signal strength, such as low signal amplitude, it can cause the signal repeater **168** to operate. In some embodiments, the signal sensor **166** sends communication data relating to received wireless signals to the BMS controller **172**.

[0066] FIG. **8** is a partial cross-sectional view a portion of the building **10** with the wireless waveguide system **102**. As illustrated, the HVAC system **100** includes the HVAC unit **106**, such as a rooftop unit. The HVAC unit **106** may be spaced any suitable distance from rooftop **200** and/or affixed to a rooftop curb. The controller **130** of the HVAC unit **106** is communicatively connected to the wireless interface **136** located on the return side of the ductwork **108** leading up to HVAC unit **106**. The controller **130** may communicate with wireless interface **136** using a wired or wireless connection. Sensors **104** are shown to be vertically distributed throughout the building **10** across floors **202**, **204**, **206**. The sensors **104** may be dynamic pressure sensors, temperature sensors, flow rate sensors, carbon dioxide sensors, humidity level sensors, air quality sensors, among others, that communicate with the controller **130** via the wireless interface **136**. As explained above, the controller **130** controls operation of the HVAC unit **106** in response to feedback from the sensors **104**. For example, the HVAC unit **106** may operate to heat, cool, or blow air into the building **10** in response to feedback received from the sensors **104**.

[0067] In order to transmit the signals from the sensors **104**, the wireless waveguide system **102** uses the ductwork **108** of the building **10**. For example, placement of the sensors **104** within a threshold distance of openings **208**, such as registers or vents, enables the ductwork **108** to propagate the signal from the sensor **104** to the wireless interface **136**. In some embodiments, the threshold distance between the sensors **104** and the openings **208** may be less than 15 ft, 10 ft, or 5 ft. In other embodiments, additional wireless devices **110** may facilitate transmission of the signal to the controller **130**. These wireless devices **110** may include one or more of the transmitters **162**, receivers **164**, signal sensors **166**, and signal repeaters **168** described above. These wireless devices **110** may be placed within the ductwork **108**, at the openings **208**, and/or in other locations in with building **10**, such as in rooms outside of the ductwork **108**. In operation, the wireless waveguide system **102** facilitates wireless communication from one or more sensors **104** to the controller **130** of the HVAC unit **106** and/or another controller, such as the BMS controller **172**. In this way, the wireless waveguide system **102** may enable and improve wireless communication while simultaneously reducing the use of cables and associated perforations of the building **10** to run communication cables.

[0068] The construction and arrangement of the systems and methods as shown in the various exemplary embodiments are illustrative only. Although only a few embodiments have been described in detail in this disclosure, many modifications are possible including variations in sizes, dimensions, structures, shapes and proportions of the various elements, values of parameters, mounting arrangements, use of materials, colors, orientations, among others. For example, the position of elements can be reversed or otherwise varied and the nature or number of discrete elements or positions can be altered or varied. Accordingly, all such modifications are intended to be included within the scope of the present disclosure. The order or sequence of any process or method steps can be varied or re-sequenced according to alternative embodiments. Other substitutions, modifications, changes, and omissions can be made in the design, operating conditions and arrangement of the exemplary embodiments without departing from the scope of the present disclosure.

[0069] The present disclosure contemplates methods, systems, and program products on any machine-readable media for accomplishing various operations. The embodiments of the present disclosure can be implemented using existing computer processors, or by a special purpose computer processor for an appropriate system, incorporated for this or another purpose, or by a hardwired system. Embodiments within the scope of the present disclosure include program products comprising machine-readable media for carrying or having machine-executable instructions or data structures stored thereon. Such machine-readable media can be any available media that can be accessed by a general purpose or special purpose computer or other machine with a processor. By way of example, such machine-readable media can comprise RAM, ROM, EPROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to carry or store desired program code in the form of machine-executable instructions or data structures and which can be accessed by a general purpose or special purpose computer or other machine with a processor. Combinations of the above are also included within the scope of

machine-readable media. Machine-executable instructions include, for example, instructions and data that cause a general purpose computer, special purpose computer, or special purpose processing machines to perform a certain function or group of functions.

1. A wireless waveguide system for a heating, ventilation, and air conditioning (HVAC) system, comprising:

a sensor configured to detect an environmental condition and to direct a signal indicative of the environmental condition along an interior of a ductwork;

a signal sensor configured to detect a strength of the signal within the interior of the ductwork; and

a repeater configured to operate based on the strength of the signal detected by the signal sensor and configured to repeat the signal along a communication path at least partially within the interior of the ductwork to a controller of an HVAC unit.

2. The wireless waveguide system of claim **1**, wherein the sensor comprises a dynamic pressure sensor, a temperature sensor, a flow rate sensor, a motion sensor, a carbon dioxide sensor, a humidity level sensor, an air quality sensor, or a combination thereof.

3. The wireless waveguide system of claim **1**, comprising the ductwork including a bend of the ductwork, wherein the repeater is positioned inside the ductwork substantially at the bend.

4. The wireless waveguide system of claim **1**, wherein the sensor is positioned within the ductwork.

5. The wireless waveguide system of claim **1**, wherein the sensor is positioned outside of the ductwork.

6. The wireless waveguide system of claim **1**, wherein the HVAC unit is a rooftop unit.

7. The wireless waveguide system of claim **1**, wherein the sensor comprises a wireless transmitter configured to emit the signal indicative of the environmental condition.

8. The wireless waveguide system of claim **1**, wherein the sensor comprises a wireless receiver, wherein the wireless receiver is configured to receive feedback from the controller.

9. The wireless waveguide system of claim **1**, wherein the signal sensor is configured to activate the repeater if the strength of the signal is less than a threshold strength.

10. The wireless waveguide system of claim **1**, wherein the controller is configured to couple to a transmitter, wherein the transmitter is configured to transmit a second signal through the interior of the ductwork.

11. The wireless waveguide system of claim **10**, comprising a building management system controller configured to receive the second signal.

12. The wireless waveguide system of claim **10**, wherein the repeater is configured to receive and repeat the second signal.

13. The wireless waveguide system of claim **12**, wherein the signal sensor is configured to detect the second signal and to control the repeater in response to a second signal strength of the second signal.

14. A wireless waveguide system for a heating, ventilation, and air conditioning (HVAC) system, comprising:

a sensor configured to detect a characteristic of air in an enclosed space and to emit a signal indicative of the characteristic along a communication path through an interior of a ductwork to a controller of an HVAC unit; and

a repeater configured to be placed within the ductwork along the communication path and positioned proximate a bend in the ductwork, wherein the repeater is configured to repeat the signal indicative of the characteristic further along the communication path and toward the controller.

15. The wireless waveguide system of claim **14**, comprising a signal sensor configured to be positioned within the ductwork, configured to detect a strength of the signal indicative of the characteristic, and configured to activate the repeater in response to the strength of the signal indicative of the characteristic being less than a threshold strength value.

16. The wireless waveguide system of claim **14**, wherein the sensor comprises a dynamic pressure sensor, a temperature sensor, a motion sensor, a flow rate sensor, a carbon dioxide sensor, a humidity level sensor, an air quality sensor, or a combination thereof.

17. The wireless waveguide system of claim **14**, wherein the HVAC unit is a rooftop unit.

18. The wireless waveguide system of claim **14**, wherein the sensor comprises a wireless transmitter configured to emit the signal indicative of the characteristic.

19. The wireless waveguide system of claim **14**, wherein the repeater is positioned proximate an opening in the ductwork.

20. A wireless waveguide system for a heating, ventilation, and air conditioning (HVAC) system, comprising:

ductwork defining an airflow path therethrough;

a controller of an HVAC unit;

a sensor configured to detect an environmental condition and to direct a signal indicative of the environmental condition along the airflow path; and

a repeater disposed within the ductwork along the airflow path, wherein the repeater is configured to repeat the signal indicative of the environmental condition further along the airflow path and toward the controller.

21. The wireless waveguide system of claim **20**, wherein the ductwork comprises a bend and wherein the repeater is disposed approximately at the bend.

22. The wireless waveguide system of claim **20**, wherein the ductwork defines an opening, and wherein the sensor is placed within a threshold distance of the opening.

23. The wireless waveguide system of claim **20**, comprising a signal sensor, wherein the signal sensor is configured to activate the repeater if a strength of the signal indicative of the environmental condition is less than a threshold strength.

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