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SUPPLEMENTAL ELECTRIC HEATER ASSEMBLY FOR A HEAT PUMP

Abstract

Described herein is a supplemental electric heater assembly for a heat pump. The assembly comprises a plurality of electric heaters, each having a different heating capacity value, wherein the heating capacity values of the plurality of electric heaters are in a geometric progression.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] This patent application claims the benefit of U.S. Provisional Patent Application No. 63/551,515, filed on Feb. 8, 2024, which is incorporated by reference herein in its entirety.

BACKGROUND

[0002] The subject disclosure relates to the field of heat pumps, and more particularly, to a supplemental electric heater assembly for a heat pump.

SUMMARY

[0003] Described herein is a supplemental electric heater assembly (hereafter referred to as assembly) for a heat pump. The assembly comprises a plurality of electric heaters, each having a different heating capacity value, wherein the heating capacity values of the plurality of electric heaters are in a geometric progression.

[0004] In one or more embodiments, the heating capacity values of the plurality of electric heaters are in the geometric progression by a multiple of two or having a common ratio of 2.

[0005] In one or more embodiments, the assembly is configured downstream or upstream of an indoor coil associated with the heat pump.

[0006] In one or more embodiments, the heat pump is associated with a heating, ventilation, and air conditioning (HVAC) system that is configured to supply air to an area of interest (AOI), wherein the assembly comprises a controller operatively connected to each of the electric heaters and the heat pump, wherein the controller is configured to receive data pertaining to a predefined temperature for the air to be supplied to the AOI, monitor real-time temperature of the air downstream of the indoor coil of the heat pump, and operate, based on the real-time temperature and the predefined temperature, the heat pump and/or at least one of the electric heaters to adjust the temperature of the air being supplied to the AOI to the predefined temperature.

[0007] In one or more embodiments, the controller is a digital control circuitry that comprises one or more processors coupled to a memory storing instructions executable by the processors, which causes the controller to operate the heat pump and/or individually control the switching of each of the electric heaters.

[0008] In one or more embodiments, the assembly or controller comprises a plurality of control switches, each electrically configured between an electrical power source and one of the electric heaters, wherein each of the control switches comprises a triode for alternative current (TRIAC) electrically connected in series with a heating element associated with the corresponding electric heater, and a gate triggering circuit connected to a gate terminal associated with the TRIAC, wherein the gate triggering circuit is configured to control one or more of a firing angle, switching frequency, and switching duration of the TRIAC per cycle of the electrical power to adjust root means square (RMS) value of current supplied by the power source to the corresponding heating element via the TRIAC.

[0009] In one or more embodiments, the gate triggering circuit comprises a voltage sensor electrically connected to the power source to monitor voltage of the electrical power being supplied by the power source, a zero-crossing detector connected to the voltage sensor to monitor zero-crossing points of a sine waveform associated with the monitored voltage by tracking a change in the waveform from positive to negative or vice versa while the waveform crosses Zero voltage, a flip-flop connected to an output of the zero-crossing detector, and a delay circuit configured between a Q-output of the flip-flop and the gate terminal associated with the TRIAC, wherein the flip-flop is configured to actuate the delay circuit upon detection of the zero-crossing points in the voltage waveform, which causes the delay circuit to trigger the gate of the TRIAC after a predefined time from the zero-crossing points in the voltage waveform to adjust the firing angle of the TRIAC to a predefined value, thereby adjusting the RMS value of the current supplied by the power source to the corresponding heating element.

[0010] In one or more embodiments, the TRIAC and one or more components associated with the gate triggering circuit are configured on a printed circuit board.

[0011] In one or more embodiments, the controller is configured to stop the operation of the plurality of electric heaters when occupants are detected to be absent within the AOI and/or when temperature outside of the AOI is above the predefined temperature.

[0012] Also described herein is a supplemental electric heater assembly for a heat pump. The assembly comprises a first set of electric heaters, each having a fixed electric heating capacity value, and a second set of electric heaters having a variable heating capacity value, the second set of electric heat heaters configured parallelly to the first set of electric heaters, wherein the second set of electric heaters has a maximum heating capacity value equal to the electric heating capacity value associated with an electric heater having a minimum heating capacity value among the first set of electric heaters.

[0013] In one or more embodiments, the heating capacity values of at least two electric heaters among the first set of electric heaters are the same.

[0014] In one or more embodiments, the heating capacity values of at least two electric heaters among the first set of electric heaters are different.

[0015] In one or more embodiments, each electric heater in the first set of electric heaters has a different heating capacity value, wherein the heating capacity values of the first set of electric heaters are in a geometric progression by a multiple of two.

[0016] The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, features, and techniques of the subject disclosure will become more apparent from the following description taken in conjunction with the drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The accompanying drawings are included to provide a further understanding of the subject disclosure and are incorporated in and constitute a part of this specification. The drawings illustrate exemplary embodiments of the subject disclosure and, together with the description, serve to explain the principles of the subject disclosure.

[0018] In the drawings, similar components and/or features may have the same reference label. Further, various components of the same type may be distinguished by following the reference label with a second label that distinguishes among the similar components. If only the first reference label is used in the specification, the description is applicable to any one of the similar components having the same first reference label irrespective of the second reference label.

[0019] FIG. **1** illustrates an exemplary representation of a system comprising a heat pump configured with a supplemental electric heater assembly, which is installed at an area of interest (AOI) or environment, in accordance with one or more embodiments of the subject disclosure.

[0020] FIGS. **2**A and **2**B illustrate an exemplary representation and an exemplary circuit diagram respectively of a first embodiment of the supplemental electric heater assembly of FIG. **1**, in accordance with one or more embodiments of the subject disclosure.

[0021] FIGS. **3**A and **3**B illustrate an exemplary representation and an exemplary circuit diagram respectively of a second embodiment of the supplemental electric heater assembly of FIG. **1**, in accordance with one or more embodiments of the subject disclosure.

[0022] FIG. **4** illustrates an exemplary plot depicting the heating capacity options available with the electric heater assemblies of FIGS. **2**A to **3**B, when compared with an existing discrete-stage electric heater assembly, in accordance with one or more embodiments of the subject disclosure.

[0023] FIG. **5**A illustrates an exemplary plot depicting the heating cycle of the system using the heat pump with a 10 KW supplemental electric heater in a preset environment.

[0024] FIG. **5**B illustrates an exemplary plot depicting the heating cycle of the system using the heat pump with a 2KW supplemental electric heater in the preset environment.
[0025] FIG. **5**C illustrates an exemplary plot depicting the heating cycle of the system using the heat pump with an assembly of 1 KW and 2 KW supplemental electric heaters in the preset environment.
[0026] FIG. **6**A illustrates an exemplary circuit diagram of a first embodiment of the switching circuit associated with the electric heaters of the electric heater assembly, in accordance with one or more embodiments of the subject disclosure.
[0027] FIG. **6**B illustrates an exemplary plot depicting the resultant current control strategy implemented by the first embodiment of the switching circuit, in accordance with one or more embodiments of the subject disclosure.
[0028] FIG. **7**A illustrates an exemplary circuit diagram of a second embodiment of the switching circuit associated with the electric heaters of the electric heater assembly, in accordance with one or more embodiments of the subject disclosure.
[0029] FIG. **7**B illustrates an exemplary plot depicting the resultant control strategy implemented by the second embodiment of the switching circuit, in accordance with one or more embodiments of the subject disclosure.

DETAILED DESCRIPTION

[0030] The following is a detailed description of embodiments of the subject disclosure depicted in the accompanying drawings. The embodiments are in such detail as to clearly communicate the subject disclosure. However, the amount of detail offered is not intended to limit the anticipated variations of embodiments; on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the subject disclosure as defined by the appended claims.
[0031] Various terms are used herein. To the extent a term used in a claim is not defined below, it should be given the broadest definition persons in the pertinent art have given that term as reflected in printed publications and issued patents at the time of filing.
[0032] In the specification, reference may be made to the spatial relationships between various components and to the spatial orientation of various aspects of components as the devices are depicted in the attached drawings. However, as will be recognized by those skilled in the art after a complete reading of the subject disclosure, the components described herein may be positioned in any desired orientation. Thus, the use of terms such as “above,” “below,” “upper,” “lower,” “first”, “second” or other like terms to describe a spatial relationship between various components or to describe the spatial orientation of aspects of such components should be understood to describe a relative relationship between the components or a spatial orientation of aspects of such components, respectively, described herein may be oriented in any desired direction. Further, the term ‘set’ in reference to a component means and includes a collection having one or more of the component.
[0033] A heat pump may be installed at a given space to provide warm or conditioned air within the environment based on occupants' comfort. However, the heat pump operating in heating mode may not be capable of supplying air temperature as per occupants' comfort. The occupants may find the temperature of the air leaving the indoor coil of the heat pump to be cooler than their comfortable range. To overcome this, the temperature of the air leaving the indoor coil of the heat pump (for the environment) may be increased to a comfortable level by using a supplemental electric heater. The heating capacity of the electric heater may be varied to different levels as per the air temperature values being set by the occupants based on their comfort and the actual temperature of the air leaving the indoor coil of the heat pump. Accordingly, the electric heater may increase the temperature of the air leaving the indoor coil of the heat pump to a (first) predefined air temperature being set by the occupants.
[0034] However, traditional electric heating systems commonly employ fixed-stage heating

elements, providing only a few discrete options for adjusting the heating capacity. This approach often leads to suboptimal energy usage, as the heating system is unable to precisely match the heating load requirements of a given space. Consequently, these systems frequently operate at capacities well in excess of what is necessary, resulting in energy wastage and reduced overall system efficiency. There exists a need for an improved electric heating system that overcomes the drawbacks of existing supplemental electric heaters, by providing a flexible and efficient solution to dynamically adjust the heating capacity of the supplemental electric heaters, allowing for optimization of energy consumption and enhancing overall performance.
[0035] Referring to FIG. **1**, the supplemental electric heater assembly **106** (referred to as assembly **106**, hereinafter) associated with a heat pump is disclosed. The heat pump and the assembly **106** may be associated with a heating, ventilation, and air conditioning (HVAC) system or a heating system **100** (referred to as system **100**, hereinafter) that can be configured to supply user-selected conditioned air to an area of interest (AOI) **102** where the HVAC system **100** is installed.
[0036] The heat pump can include an indoor coil **104** (also referred to as heat pump coil, herein), where the indoor coil **104** of the heat pump and the assembly **106** may be in fluidic communication with the AOI **102**, with the assembly **106** configured downstream or upstream of the indoor coil **104** of the heat pump, such that air flowing into the AOI **102** may flow through the indoor coil **104** as well as the assembly **106** and then into the AOI **102**. The AOI **102** may be a space or room associated with a building. The AOI **102** may also be a storage space associated with a container or a cargo truck, but is not limited to the like.
[0037] Referring to FIG. **2**A and **2**B, an embodiment of the supplemental electric heater assembly **106** implemented in FIG. **1** is disclosed. The assembly **106** can include a plurality of electric heaters **202-1** to **202-**N (also referred to as heaters **202**, herein) arranged in parallel in any sequence, where each heater **202** may have a different heating capacity value. In one or more embodiments, the heating capacity values of the plurality of heaters **202-1** to **202-**N may be in a geometric progression by a multiple of two or having a common ratio of 2, but are not limited to the like. Further, the heating elements associated with each of the plurality of electric heaters **202** may be electrically connected to an electrical power source P.
[0038] In one or more embodiments, a first heater (**202-1**) (having the minimum heating capacity value) among the plurality of heaters **202** may have a heating capacity of X KW, the second heater (**202-2**) may have a heating capacity of 2X KW, the third heater (**202-2**) may have a heating capacity of 4X KW, and so on with the Nth heater (**202-**N) among the plurality of heaters **202** having a heating capacity of 2.sup.N−1X KW, based on the number (N) of heaters being implemented. Accordingly, any one or a combination of the heaters **202-1** to **202-**N may be operated at a time in the assembly **106**, which may allow the assembly **106** to provide an overall heating capacity ranging from a minimum of X (or 0) KW to a maximum of X(2.sup.N−1) KW with evenly spaced small incremental variations of X KW as shown in FIG. **4**. For instance, in a non-limiting example, when four heaters are employed in the assembly **106**, with the first heater of 1 KW (minimum heating capacity), the remaining heaters may be of 2 KW, 4 KW, and 8 KW. This enables the assembly **106** to provide heating capacity ranging from 1 KW to 15 KW with evenly spaced small incremental variations of 1 KW. Similarly, in another non-limiting example, if the first heater is 1.25 KW (minimum heating capacity), the remaining heaters may be 2.5 KW, 5 KW, and 10 KW.
[0039] While various figures and embodiments described herein illustrate the assembly **106** of FIG. **2**A and **2**B as have a specific (4) number of electric heaters with specific heating capacities (selected from 1 KW, 2 KW, 4 KW, and 8 KW) for the sake of brevity, the number of electric heaters employed in the assembly **106** and their heating capacities are not limited to the same and may be different, and all such embodiments are well within the scope of the disclosure.
[0040] Referring to FIG. **3**A and **3**B, another embodiment of the supplemental electric heater assembly **106** implemented in FIG. **1** is disclosed. The assembly **106** can include a first set of

electric heaters **302-1** to **302**-N (also referred to as first heaters **302**, herein) arranged in parallel, where each heater **302** may have a fixed heating capacity, which may or may not be of the same value. The assembly **106** can further include a second set of electric heaters, such as electric heater **304** (also referred to as a second heater **304**, herein) having a variable heating capacity value, where the second heater **304** may also be configured parallel to the first set of heaters **302** in any sequence. In one or more embodiments, the second heater **304** may have a maximum heating capacity value equal to the electric heating capacity value associated with an electric heater having a minimum heating capacity value among the first set of heaters **302-1** to **302**-N. However, in other embodiments, the maximum heating capacity value of the second heater **304** may also be different from the minimum heating capacity value among the first set of heaters **302**. Accordingly, the overall assembly **106** can provide a continuously variable heating capacity covering the entire range of all the heating capacity values combined. Further, the heating elements associated with each of the plurality of electric heaters may be electrically connected to an electrical power source (represented as ‘P’ in FIGS. **2**B and **3**B).

[0041] In one or more embodiments, the first set of electric heaters **302** may include N number of heaters having the same but fixed heating capacity value of X KW. Accordingly, the second heater **304** may have a variable heating capacity ranging from 0 KW to X KW. Thus, the assembly **106** can provide a continuously variable heating capacity ranging from any of 0 KW to X.sup.N+1 KW as shown in FIG. **4**. For instance, in a non-limiting example, the first set of electric heaters **302** may include two heaters having the same but fixed heating capacity value of 5 KW each. Accordingly, the second heater **304** may have a variable heating capacity ranging from 0 KW to 5 KW. Thus, the overall assembly **106** may provide a continuously variable heating capacity ranging from 0 KW to 15 KW.

[0042] In one or more embodiments, the first set of electric heaters **302** may include N number of heaters having fixed heating capacity values selected from X KW (minimum) to Y KW (maximum). Accordingly, the second heater **304** may have a variable heating capacity ranging from 0 KW to X KW. For instance, in a non-limiting example, the first set of electric heaters may include two electric heaters having different but fixed heating capacity values of 5 KW and 10 KW respectively. Thus, the second heater **304** may have a variable heating capacity ranging from 0 KW to 5 KW. This enables the assembly **106** to provide a continuously variable heating capacity ranging from 0 KW to 20 KW.

[0043] While various figures and embodiments described herein illustrate the assembly **106** of FIG. **3**A and **3**B having a specific number (2) of first heaters having the fixed heating capacity (of 5 KW and/or 10 KW) and one second heater (having variable heating capacity ranging from 0 to 5 KW) for the sake of brevity, the number of heaters employed in the assembly **106** and their heating capacities are not limited to the same and may be different, and all such embodiments are well within the scope of the disclosure.

[0044] In one or more embodiments, the heating capacity values of the first set of electric heaters **302** of FIG. **3**A to **3**B can also be in the geometric progression by a multiple of two or having a common ratio of 2, wherein the first set of heaters **302** can have fixed heating capacity values ranging from X KW to 2.sup.N−1X KW, and the second heater **304** having the variable heating capacity ranging from 0 to X KW.

[0045] Referring to FIG. **5**A, an exemplary plot depicting the heating cycle of the system (such as system **100**) using the heat pump with a 10 KW supplemental electric heater (implemented similarly to the assembly **106**) is disclosed. The heating cycle was observed in a preset environment, where the outdoor temperature was 30° F. and the indoor temperature within the AOI was set at 70° F. The heat pump selected had a capacity of 36 kbtu with a coefficient of performance (COP) of 2.5. Further, the heating ON/OFF trigger threshold for the heat pump was measured to be −0.5° F. and for the supplemental heater to be −1° F. for switch ON and +1° F. for switch OFF.

[0046] As illustrated, in an example, when initially only the heat pump was running and the heater assembly (e.g., **106**) was switched OFF, the COP of the system (e.g., **100**) using the heat pump alone was 2.5 where the heating load provided by the heat pump was maximum, however, the heating load requirement of the AOI was not met by the heat pump and the indoor air temperature continued to decrease because the required heating load was higher. Further, when the 10 KW supplemental heater was also switched ON, the COP of the system using the heat pump and the 10 KW supplemental heater dropped from 2.5 to 1.45 because of the added electric heat by the 10 KW electric heater. However, the indoor temperature of the AOI rose rapidly up to a cut-off point of 71° F. Later, when both the heat pump and the 10 KW electric heater were switched OFF, the indoor temperature then dropped from 71° F. back down to a turn-ON threshold of 69.5° F. where the heat pump was started up again. During the overall cycle, the average COP was measured to be 1.86. This cycle was then continued over time as the indoor temperature was to be maintained at the same 70° F. temperature.
[0047] Referring to FIG. **5**B, an exemplary plot depicting the heating cycle with a 2KW supplemental electric heater (implemented similarly to the assembly **106**) is disclosed. The heating cycle was observed in the same preset environment. As illustrated, in an example, when only the heat pump was running and the heater assembly (e.g., **106**) was switched OFF, the COP of the system (e.g., **100**) using the heat pump alone was 2.5 where the heating load provided by the heat pump was maximum, however, the heating load requirement of the AOI was again not met by the heat pump and the indoor air temperature continued to drop to 69° F. because the required heating load was higher. Further, when the 2 KW supplemental heater (which is smaller compared to the heater of FIG. **5**A) was also switched ON, the COP of the system using the heat pump and the 2 KW supplemental heater dropped down from 2.5 to 2.25 as the added electric heat by the 2 KW electric heater was little more than the set indoor temperature. However, the indoor temperature of the AOI rose to the cut-off point of 71° F. but at a much slower pace compared to that of the 10 KW heater of FIG. **5**A. Later, when both the heat pump and the 2 KW electric heater were switched OFF, the indoor temperature then dropped from 71° F. back down to a turn ON threshold of 69.5° F. where the heat pump was started up again. During the overall cycle, the average COP was measured to be 2.07 which was higher than the COP of 1.86 achieved in the heating cycle of FIG. **5**A. This cycle was then continued over time as the indoor temperature was to be maintained at the same 70° F. temperature.
[0048] Referring to FIG. **5**C, an exemplary plot depicting the heating cycle with the assembly **106** comprising 1 KW and 2 KW supplemental electric heaters is disclosed. The heating cycle was observed in the same preset environment. As illustrated, in an example, the heat pump was continuously operated while switching between the 1 KW and 2KW electric heaters. Initially, when the 1 KW heater was switched ON along with the heat pump, the COP of the system (e.g., **100**) using the heat pump and the 1 KW heater was observed to be 2.21 where the heating load provided by the heat pump and the 1 KW heater was maximum, however, the heating load requirement of the AOI was not met by the heat pump and the 1 KW electric heater collectively. As a result, the indoor air temperature continued to drop to 69.5° F. at a slower pace and the COP of the heat pump dropped from 2.21 to 2.02 because of the added electric heat by the 1 KW electric heater. Later, when the 2 KW electric heater was operated/switched ON along with the heat pump, the indoor temperature rose from 69.5° F. to 70.5° F. During the overall cycle, the average COP was measured to be 2.18 which was higher than the COP achieved in the heating cycles of FIGS. **5**A and **5**B, thereby improving the performance of the system.
[0049] In one or more embodiments, a controller **116** (as shown in FIGS. **1** to **3**B) can be operatively coupled to the (indoor coil **104** of the) heat pump, and the assembly **106** to control the operation of the heat pump, and further control individual actuation and operation of the respective heaters associated with the assemblies of FIGS. **2**A to **3**B.
[0050] In one or more embodiments (not shown), the controller **116** can be a digital control

circuitry, such as, but not limited to, a microcontroller that comprises one or more processors coupled to a memory storing instructions executable by the processors, which causes the controller **116** to operate the heat pump and/or individually control switching/actuation of each of the electric heaters associated with the assemblies **106** of FIGS. **2**A to **3**B to adjust root means square (RMS) value of current supplied by the power source to the heating element of the corresponding heaters, and correspondingly adjust the heating capacities of the heaters based on the overall heating capacity to be attained using the assembly. However, in other embodiments, the controller **116** can also be an analog control circuitry comprising one or more of electrical devices, solid-state electronic devices, and/or power electronic devices available in the art, which can cause the controller **116** to operate the heat pump and/or individually control switching/actuation of each of the electric heaters associated with the assemblies **106** of FIGS. **2**A to **3**B.

[0051] In one or more embodiments, the digital control circuitry can function as a zero-crossing detector that can monitor zero-crossing points of a sine waveform associated with the monitored voltage by tracking, using a voltage sensor, a change in the waveform from positive to negative or vice versa while the waveform crosses Zero voltage. The digital control circuitry can further function as a flip-flop connected to an output of the zero-crossing detector and a delay circuit configured between a Q-output of the flip-flop and the gate terminal associated with a triode for alternating current (TRIAC). The digital control circuitry can accordingly trigger the gate of the TRIAC after a predefined time from the zero-crossing points in the voltage waveform to adjust the firing angle of the TRIAC to a predefined value, thereby adjusting the RMS value of the current supplied by the power source to the corresponding heating element.

[0052] In one or more embodiments, the controller **116** can include a plurality of control switches S**1** to Sn (as shown in FIGS. **2**B and **3**B), each electrically configured between the electrical power source P and one of the electric heaters associated with the assemblies of FIGS. **2**A to **3**B. In one or more embodiments, referring to FIGS. **6**A and **7**A, each of the control switches S**1** to Sn can include a TRIAC (T) electrically connected in series with the heating element (H) associated with the corresponding electric heater of the assemblies (e.g., those embodiments of the assembly **106**), and a gate triggering circuit (GTC) connected to a gate terminal (G) associated with the TRIAC (T) via a diode. The gate triggering circuit can be configured to control the firing angle, switching frequency, and/or switching duration of the TRIAC (T) per cycle of the electrical power to adjust the root means square (RMS) value of current supplied by the power source P to the corresponding heating element (H), thereby actuating the respective electric heaters and further adjusting the heating capacities of the heaters based on the overall heating capacity to be attained using the assembly **106**. In one or more embodiments, the TRIAC (T) and the components of the gate triggering circuit (GTC) can be configured on a printed circuit board.

[0053] Referring to FIG. **6**A, in one or more embodiments, the gate triggering circuit for the TRIAC (T) can include a voltage sensor electrically connected to the power source P to monitor the voltage of the electrical power being supplied by the power source P. In addition, a zero-crossing detector can be connected to the voltage sensor to monitor zero-crossing points of a sine waveform associated with the monitored voltage by tracking a change in the waveform from positive to negative or vice versa while the waveform crosses Zero voltage. Further, a flip-flop (FF) can be connected to an output of the zero-crossing detector and a delay circuit (DC) can be configured between a Q-output of the flip-flop (FF) and the gate terminal (G) associated with the TRIAC (T). Accordingly, the flip-flop (FF) can actuate the delay circuit (DC) upon detection of the zero-crossing points in the voltage waveform, which can cause the delay circuit (DC) to trigger the gate (G) of the TRIAC (T) after a predefined time from the zero-crossing points in the voltage waveform to adjust the firing angle of the TRIAC (T) to a predefined value. This adjustment of the firing angle of the TRIAC (T) can control the current flow via the TRIAC per cycle of the voltage waveform as shown in FIG. **6**B to adjust the RMS value of the current supplied by the power source P to the corresponding heating element (H), thereby adjusting the heating capacity of the corresponding heaters.

[0054] Referring to FIG. **7**A, in one or more embodiments, the gate triggering circuit for the TRIAC (T) may or may not involve the voltage sensor to monitor the voltage of the electrical power being supplied by the power source. In the sensor-less approach, the controller **116** can provide a command to the TRIAC (T) to control the switching duration of the TRIAC (T) to either enable a continuous flow of current through the TRIAC (T) for the entire duration or enable the current to flow for 25% or 50% of the entire duration. As illustrated, the gate triggering circuit (GTC) can include the zero-crossing detector to monitor zero-crossing points of the sine waveform associated with the monitored voltage. Further, a flip-flop (FF) can be configured between the zero-crossing detector and the gate terminal (G) of the TRIAC (T) without the involvement of the delay circuit as in FIG. **6**A. Accordingly, the flip-flop (FF) can trigger the gate (G) of the TRIAC (T) to control the switching frequency, and/or switching duration of the TRIAC (T) for an entire duration of the electrical power. This adjustment can control the current flow via the TRIAC (T) as shown in FIG. **7**B to adjust the RMS value of the current supplied by the power source P to the corresponding heating element (H) while eliminating current harmonics associated with the TRIAC (T) (compared to FIG. **6**B), thereby efficiently adjusting the heating capacity of the corresponding heaters.

[0055] While various embodiments and drawings have been elaborated for the assembly involving a TRIAC as the switch, the switch can also be implemented using other electronic or power-electronic devices available in the art, and all such embodiments are well within the scope of the disclosure without any limitation.

[0056] Referring back to FIG. **1**, in one or more embodiments, the indoor coil **104** of the heat pump and the assembly **106** may be configured in a duct system that may fluidically connect the indoor coil **104** and the assembly to the AOI **102**. The duct system may include a supply air duct extending between the ambient and the AOI **102** to allow the flow of ambient air from the ambient into the AOI **102** while flowing the received air through the indoor coil **104** of the heat pump and the assembly **106**. The duct system may further include a return air duct (not shown) that may be configured to receive return air from the AOI **102** and further supply the received return air into the AOI **102** while flowing the received return air through the indoor coil **104** of the heat pump and the assembly **106**. Accordingly, the duct system may enable the flow of supply air (ambient air and/or return air) through the indoor coil **104** of the heat pump and the assembly **106** and then into the AOI **102**

[0057] In one or more embodiments, the assembly **106** may be in thermal contact with the refrigerant coils associated with the heat pump to increase the temperature of the air being supplied through the refrigerant coils of the heat pump, thereby increasing the heating capacity of the overall heating system **100**.

[0058] In one or more embodiments, the system **100** may include a variable speed fan **108** configured with the duct system to enable circulation of the air between the ambient and the AOI **102** and further enable the flow of the air through the indoor coil **104** of the heat pump and the assembly **106** before being supplied to the AOI **102**. However, in one or more embodiments, the system **100** may also include a single speed fan **108**, instead of a variable speed fan, to enable circulation of the air between the ambient and the AOI **102** and further enable the flow of the air through the indoor coil **104** of the heat pump and the assembly **106** before being supplied to the AOI **102**. In one or more embodiments, the fan **108** may be positioned before (upstream of) both the indoor coil **104** (of the heat pump) and the assembly **106**, or between the indoor coil **104** and the assembly **106** or after (downstream of) both the indoor coil **104** and the assembly **106**.

[0059] The system **100** may include an occupancy sensor **110** positioned in the AOI **102**. The occupancy sensor **110** may detect the presence or absence of one or more occupants within the AOI **102**. The system **100** may further include a first temperature sensor **114** that may be positioned downstream of the indoor coil **104** of the heat pump to monitor the temperature of the air leaving the indoor coil **104**. Further, the system **100** may include a second temperature sensor **112** that may be positioned downstream of the assembly **106** within the duct system or at an outlet of the duct system, or within the AOI **102** in the proximity of the assembly **106** to monitor the temperature of the air flowing within the AOI **102** after being heated by the indoor coil **104** of the heat pump and/or the assembly **106**. In one or more embodiments, the first temperature sensor **114** and the second temperature sensor **112** may be replaced with a single temperature sensor that may be positioned after both the indoor coil **104** of the heat pump and the assembly **106** (regardless of the order of indoor coil **104** and the assembly **106** in the airflow) to monitor the temperature of the air being supplied to the AOI. In an example, when the heat pump and the assembly **106** are operating, the temperature of the air (sensed by the first temperature sensor **114**) downstream of (or leaving) the indoor coil **104** of the heat pump may be greater than the temperature of the air upstream of the indoor coil **104**. Further, the temperature of the air (sensed by the second temperature sensor **112**) downstream of the assembly **106** may be greater than the temperature of the air upstream of the electric heater (or downstream of the indoor coil **104** of the heat pump **104**).

[0060] The system **100** may further include a thermostat **118** positioned within the AOI **102**. The thermostat **118** may be configured to enable the occupants to set one or more of a first predefined temperature of the air to be supplied into the AOI **102** based on the occupant's comfort and further set a second predefined temperature to be maintained within the AOI **102**. The first predefined temperature of the air may facilitate adjusting or controlling or maintaining the second predefined temperature within the AOI **102**, however, the first predefined temperature of the air may provide comfort to the occupants. In one or more embodiments, the second temperature sensor **112** may be associated with the thermostat **118**, however, the second temperature sensor **112** may also be a standalone sensor.

[0061] In one or more embodiments, the controller **116** may be configured to receive, from the thermostat **118**, data pertaining to the first predefined temperature for the air to be supplied to the AOI **102**. However, in other embodiments, the controller **116** may be configured to receive, from a control unit associated with the air handling unit, data pertaining to the first temperature for the air to be supplied to the AOI **102**. The controller **116** may further monitor the real-time temperature of the air being supplied to the AOI **102** using the second temperature sensor **112**. Further, the controller **116** may detect, using the occupancy sensor **110**, the presence or absence of the occupants within the AOI **102**. Accordingly, in one or more embodiments, upon detecting the presence of the occupants within the AOI **102**, the controller **116** may operate the heat pump and/or the assembly **106** to adjust the temperature of the air being supplied to the AOI **102** to the first predefined temperature.

[0062] Further, in one or more embodiments, the controller **116** may be configured to stop the operation of the assembly **106** when the occupants are detected to be absent from the AOI **102** and/or when temperature outside of the AOI **102** is above the first predefined temperature.

[0063] In one or more embodiments, when the real-time temperature of the air (monitored by the second temperature sensor **112**) being supplied to the AOI **102** is detected to be less than the first predefined temperature set by the occupants and the occupants are also detected within the AOI **102**, the controller **116** may be configured to operate both of the heat pump and the assembly **106** to adjust the temperature of the air being supplied to the AOI **102** to the first predefined temperature.

[0064] In one or more embodiments, when the real-time temperature of the air (monitored by the second temperature sensor **112**) being supplied to the AOI **102** is detected to be less than the first predefined temperature set by the occupants but the occupants are detected to be absent from the AOI **102**, the controller **116** may be configured to stop the operation of the assembly **106** while continuing to operate the heat pump to increase the temperature of the air being supplied to the AOI **102**.

[0065] In one or more embodiments, when the monitored real-time temperature of the air being

supplied to the AOI **102** is detected to be greater than the first predefined temperature set by the occupants, the controller **116** may be configured to reduce or stop the operation of the assembly **106** while operating the heat pump and allowing the supply of air into the AOI **102** to increase or maintain a second predefined temperature within the AOI **102**. In one or more embodiments, when the monitored real-time temperature within the AOI **102** is detected to be greater than a second predefined temperature set by the occupants, the controller **116** may be configured to stop the operation of the heat pump as well as the assembly **106**.
[0066] In some embodiments, the controller **116** may also be configured to adjust speed of the fan **108**, based on the temperature of the air to be supplied to the AOI **102**. This may facilitate in increasing or decreasing the temperature of the air supplied to the AOI **102**. Further, in one or more embodiments, the controller **116** may be configured to adjust the heating capacity of the heat pump and/or the assembly **106** (by actuating the heating elements of the electric heaters) based on the real-time temperature of the air being supplied to the AOI **102** and the first predefined temperature for the air to be supplied to the AOI **102** and/or based on the real-time temperature within the AOI **102** and the second predefined temperature to be maintained within the AOI **102**.
[0067] Thus, the subject disclosure provides an improved solution that overcomes the drawbacks of existing heat pumps supplemental electric heaters, by providing a flexible and efficient supplemental electric heater assembly that dynamically adjusts the heating capacity of the electric heaters, allowing for optimization of energy consumption and enhancing overall performance.
[0068] While the subject disclosure has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the subject disclosure as defined by the appended claims. Modifications may be made to adopt a particular situation or material to the teachings of the subject disclosure without departing from the scope thereof. Therefore, it is intended that the subject disclosure not be limited to the particular embodiment disclosed, but that the subject disclosure includes all embodiments falling within the scope of the subject disclosure as defined by the appended claims.
[0069] In interpreting the specification, all terms should be interpreted in the broadest possible manner consistent with the context. In particular, the terms “comprises” and “comprising” should be interpreted as referring to elements, components, or steps in a non-exclusive manner, indicating that the referenced elements, components, or steps may be present, or utilized, or combined with other elements, components, or steps that are not expressly referenced. Where the specification claims refer to at least one of something selected from the group consisting of A, B, C . . . and N, the text should be interpreted as requiring only one element from the group, not A plus N, or B plus N, etc.

Claims

1. A supplemental electric heater assembly for a heat pump, the supplemental electric heater assembly comprising: a plurality of electric heaters, each having a different heating capacity value, wherein the heating capacity values of the plurality of electric heaters are in a geometric progression.
2. The supplemental electric heater assembly of claim 1, wherein the heating capacity values of the plurality of electric heaters are in the geometric progression by a multiple of two or having a common ratio of 2.
3. The supplemental electric heater assembly of claim 1, wherein the assembly is configured downstream or upstream of an indoor coil associated with the heat pump.
4. The supplemental electric heater assembly of claim 1, wherein the heat pump is associated with a heating, ventilation, and air conditioning (HVAC) system that is configured to supply air to an area of interest (AOI), wherein the supplemental electric heater assembly comprises a controller

operatively connected to each of the plurality of electric heaters and the heat pump, and wherein the controller is configured to: receive data pertaining to a predefined temperature for the air to be supplied to the AOI; monitor real-time temperature of the air downstream of an indoor coil of the heat pump; and operate, based on the real-time temperature and the predefined temperature, the heat pump and/or at least one of the plurality of electric heaters to adjust the temperature of the air being supplied to the AOI to the predefined temperature.

5. The supplemental electric heater assembly of claim 4, wherein the controller is a digital control circuitry that comprises one or more processors coupled to a memory storing instructions executable by the one or more processors, which causes the controller to operate the heat pump and/or individually control switching of each of the electric heaters.

6. The supplemental electric heater assembly of claim 4, wherein the assembly or the controller comprises a plurality of control switches, each electrically configured between an electrical power source and one of the plurality of electric heaters, and wherein each of the plurality of control switches comprises: a triode for alternating current (TRIAC) electrically connected in series with a heating element associated with a corresponding electric heater from the plurality of electric heaters; and a gate triggering circuit connected to a gate terminal associated with the TRIAC, wherein the gate triggering circuit is configured to control one or more of a firing angle, a switching frequency, and a switching duration of the TRIAC per cycle of the electrical power to adjust root means square (RMS) value of current supplied by the electric power source to the corresponding heating element via the TRIAC.

7. The supplemental electric heater assembly of claim 6, wherein the gate triggering circuit comprises: a voltage sensor electrically connected to the power source to monitor voltage of the electrical power being supplied by the power source; a zero-crossing detector connected to the voltage sensor to monitor zero-crossing points of a sine waveform associated with the monitored voltage by tracking a change in the waveform from positive to negative or vice versa while the waveform crosses Zero voltage; a flip-flop connected to an output of the zero-crossing detector; and a delay circuit configured between a Q-output of the flip-flop and the gate terminal associated with the TRIAC, wherein the flip-flop is configured to actuate the delay circuit upon detection of the zero-crossing points in the voltage waveform, which causes the delay circuit to trigger the gate of the TRIAC after a predefined time from the zero-crossing points in the voltage waveform to adjust the firing angle of the TRIAC to a predefined value, thereby adjusting the RMS value of the current supplied by the power source to the corresponding heating element.

8. The supplemental electric heater assembly of claim 7, wherein the TRIAC and one or more components associated with the gate triggering circuit are configured on a printed circuit board.

9. The supplemental electric heater assembly of claim 4, wherein the controller is configured to stop the operation of the plurality of electric heaters when occupants are detected to be absent within the AOI and/or when temperature outside of the AOI is above the predefined temperature.

10. A supplemental electric heater assembly for a heat pump, the supplemental electric heater assembly comprising: a first set of electric heaters, each having a fixed electric heating capacity value; and a second set of electric heaters having a variable heating capacity value, the second set of electric heaters are configured parallelly to the first set of electric heaters, wherein the second set of electric heaters has a maximum heating capacity value equal to the electric heating capacity value associated with an electric heater having a minimum heating capacity value among the first set of electric heaters.

11. The supplemental electric heater assembly of claim 10, wherein the heating capacity values of at least two electric heaters among the first set of electric heaters are the same.

12. The supplemental electric heater assembly of claim 10, wherein the heating capacity values of at least two electric heaters among the first set of electric heaters are different.

13. The supplemental electric heater assembly of claim 10, wherein each electric heater in the first set of electric heaters has a different heating capacity value, and wherein the heating capacity

values of the first set of electric heaters are in a geometric progression by a multiple of two.
14. The supplemental electric heater assembly of claim 10, wherein the supplemental electric heater assembly is configured downstream or upstream of an indoor coil associated with the heat pump.
15. The supplemental electric heater assembly of claim 10, wherein the heat pump is associated with a heating, ventilation, and air conditioning (HVAC) system that is configured to supply conditioned air to an area of interest (AOI), wherein the supplemental electric heater assembly comprises a controller operatively connected to each of the first set of electric heaters, the second set of electric heaters, and the heat pump, and wherein the controller is configured to: receive data pertaining to a predefined temperature for the air to be supplied to the AOI; monitor real-time temperature of the air downstream of an indoor coil of the heat pump; and operate, based on the real-time temperature and the predefined temperature, any or a combination of the heat pump, at least one of the first set of electric heaters, and the second set of electric heaters to adjust the temperature of the air being supplied to the AOI to the predefined temperature.
16. The supplemental electric heater assembly of claim 15, wherein the controller is a digital control circuitry that comprises one or more processors coupled to a memory storing instructions executable by the one or more processors, which causes the controller to operate the heat pump and/or individually control switching of each of the first set or second set of electric heaters.
17. The supplemental electric heater assembly of claim 15, wherein the supplemental electric heater assembly or the controller comprises a plurality of control switches, each electrically configured between an electrical power source and one of the electric heaters, and wherein each of the plurality of control switches comprises: a triode for alternating current (TRIAC) electrically connected in series with a heating element associated with a corresponding electric heater from the first set of electric heaters or the second set of electric heaters; and a gate triggering circuit connected to a gate terminal associated with the TRIAC, wherein the gate triggering circuit is configured to control one or more of a firing angle, a switching frequency, and a switching duration of the TRIAC per cycle of the electrical power to adjust root means square (RMS) value of current supplied by the power source to the corresponding heating element via the TRIAC.
18. The supplemental electric heater assembly of claim 17, wherein the gate triggering circuit comprises: a voltage sensor electrically connected to the power source to monitor voltage of the electrical power being supplied by the power source; a zero-crossing detector connected to the voltage sensor to monitor zero-crossing points of a sine waveform associated with the monitored voltage by tracking a change in the waveform from positive to negative or vice versa while the waveform crosses Zero voltage; a flip-flop connected to an output of the zero-crossing detector; and a delay circuit configured between a Q-output of the flip-flop and the gate terminal associated with the TRIAC, wherein the flip-flop is configured to actuate the delay circuit upon detection of the zero-crossing points in the voltage waveform, which causes the delay circuit to trigger the gate of the TRIAC after a predefined time from the zero-crossing points in the voltage waveform to adjust the firing angle of the TRIAC to a predefined value, thereby adjusting the RMS value of the current supplied by the power source to the corresponding heating element.
19. The supplemental electric heater assembly of claim 17, wherein the TRIAC and one or more components associated with the gate triggering circuit are configured on a printed circuit board.
20. The supplemental electric heater assembly of claim 15, wherein the controller is configured to stop the operation of the first set of electric heaters or the second set of electric heaters when occupants are detected to be absent within the AOI and/or when temperature outside of the AOI is above the predefined temperature.