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(71) Applicant: **Carrier Corporation**
Palm Beach Gardens, FL 33418 (US)

(72) Inventor: **CLUFF, Charles**
Indianapolis 46231 (US)

(74) Representative: **Dehns**
10 Old Bailey
London EC4M 7NG (GB)

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(54) **AN OPTIMIZED SETBACK CONTROL SYSTEM AND A METHOD THEREOF**

(57) There is provided a method 400 for controlling setback of a heating, ventilation, and air conditioning (HVAC) system comprising a first HVAC unit and a second HVAC unit. The method is performed by a setback control system. The method comprises monitoring 402 an interior temperature of a target area associated with the HVAC system and monitoring 404 an exterior temperature of the target area associated with the HVAC system. The method comprises determining 406 one or more operating parameters associated with the first HVAC unit of the HVAC system, wherein the one or more operating parameters include at least one of an excess capacity of the first HVAC unit or a relative cost of operation of the first HVAC unit with respect to the second HVAC unit. The method comprises determining 408 a recovery time based on the determined one or more operating parameters, the recovery time being indicative of a time required to recover an internal temperature value of the target area from a setback temperature setpoint value to a normal temperature setpoint value by the first HVAC unit. The method comprises triggering 410 a setback recovery based on the determined recovery time and a remaining time in a setback period associated with the setback of the HVAC system.

HVAC unit of the HVAC system and determining 408 a recovery time based on the operating parameters, wherein the recovery time is a time required to recover interior temperature value from a setback temperature setpoint value to a normal temperature setpoint value by the first HVAC unit. The method comprises triggering 410 a setback recovery based on the determined recovery time and a remaining time in a setback period associated with the setback of the HVAC system.

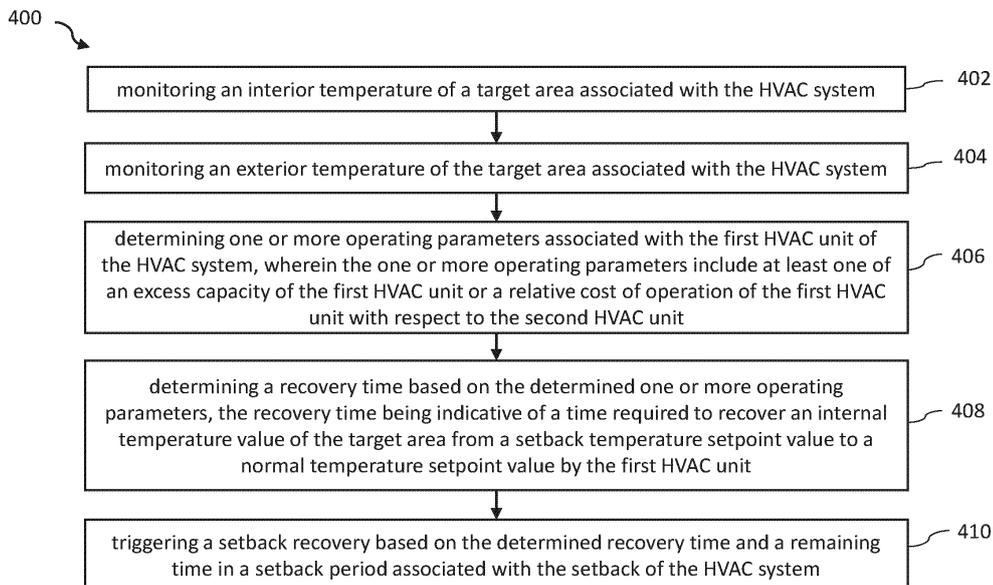


Figure 4

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Description

[0001] The present invention generally relates to a heating, ventilation, and air conditioning (HVAC) control system, and more particularly relates to an optimized setback control system that optimizes the performance of a HVAC system and reduces an operating cost of the HVAC system.

[0002] Typically, HVAC systems operate by transferring heat from one location to another to either heat or cool indoor spaces. The HVAC systems may include one or more HVAC units for heating or cooling of the indoor spaces. A thermal capacity of the one or more HVAC units is an ability of the one or more HVAC units to deliver heat at a particular time. Usually, the thermal capacity of the one or more HVAC units is dependent on various factors, such as an outdoor temperature with respect to the indoor space, a temperature difference between a current indoor temperature and a current outdoor temperature, an area of a barrier separating the indoor space and an outdoor space, and a thermal conductivity of the barrier separating the indoor space and an outdoor space.

[0003] Generally, for heating purposes, when the outdoor temperature is below the indoor temperature and the outdoor temperature decreases, a thermal capacity required to maintain a temperature of the indoor space increases. However, a maximum thermal capacity of the heat pump decreases with a decrease in the outdoor temperature. At one threshold temperature, the thermal capacity required to maintain interior temperature will be the same as a maximum thermal capacity of the heat pump. If the outside temperature goes further below the threshold temperature, an additional heating source will be required to maintain interior temperature.

[0004] Furthermore, the HVAC system may operate in a setback mode. During setback mode, a temperature setting of a heating or a cooling system for an indoor space is adjusted, i.e., changed from a normal setpoint to a setback setpoint, to save energy during periods when the indoor space is not in active use. As the time for the setback mode approaches the end, a setback recovery mode may be employed to recover temperature to the normal setpoint from the setback setpoint when the setback mode ends. During a setback recovery mode, additional heating or cooling source is required to reach back to a pre-set temperature value.

[0005] Operation in setback mode reduces heating costs and/or cooling costs. Such a setback mode is generally beneficial for HVAC systems having a single heating and/or cooling technology. Nowadays, the HVAC systems may include multiple heating and/or cooling technologies, however, for HVAC systems using multiple heating and/or cooling technologies, the setback performance may not be efficient. This is because it is significantly challenging to optimize the setback performance taking into consideration varying costs of operation of the multiple heating and/or cooling technologies. For example, a system that reduces the use of a lower cost heating

technology during setback, but then requires the use of a higher cost heating technology to accomplish the setback recovery may ultimately experience a higher overall heating cost as a result of the setback compared to not having used a setback during the same period. In this case the benefit of the setback is lost and may become disadvantageous overall. Hence, there is a requirement of an improved control system and method that can overcome the above-mentioned problems.

[0006] Disclosed herein is a setback control system for controlling setback of a heating, ventilation, and air conditioning (HVAC) system comprising a first HVAC unit and a second HVAC unit. The setback control system comprises a memory and one or more processors communicatively coupled to the memory. The one or more processors are configured to monitor an interior temperature of a target area associated with the HVAC system. The one or more processors are further configured to monitor an exterior temperature of the target area associated with the HVAC system. The one or more processors are further configured to determine one or more operating parameters associated with the first HVAC unit of the HVAC system, wherein the one or more operating parameters include at least one of an excess capacity of the first HVAC unit or a relative cost of operation of the first HVAC unit with respect to the second HVAC unit. The one or more processors are further configured to determine a recovery time based on the determined one or more operating parameters. The recovery time is indicative of a time required to recover an interior temperature value of the target area from a setpoint temperature setpoint value to a normal temperature setpoint value by the first HVAC unit. The one or more processors are further configured to trigger a setback recovery based on the determined recovery time and a remaining time in a setback period associated with the setback of the HVAC system.

[0007] In one or more embodiments, the one or more processors are configured to, prior to triggering the setback recovery, continuously monitor the remaining time in the setback period. The setback period is indicative of a time period when the HVAC system operates in a setback mode. The remaining time is indicative of a time left in completion of the setback period.

[0008] In one or more embodiments, to trigger the setback recovery, the one or more processors are configured to compare the determined recovery time with the determined remaining time. The one or more processors are further configured to, upon a determination that the determined recovery time is equal to the determined remaining time, trigger the setback recovery.

[0009] In one or more embodiments, the normal temperature setpoint value is indicative of a temperature value maintained when the HVAC system operates in a normal mode. The setback temperature setpoint value is indicative of a temperature value maintained during the setback period when the HVAC system operates in a setback mode.

[0010] In one or more embodiments, the one or more processors are configured to trigger the setback recovery prior to the interior temperature value of the target area reaching the setback temperature setpoint value.

[0011] In one or more embodiments, to determine the recovery time, the one or more processors are further configured to determine the recovery time based on one or more of a current interior temperature value, a maximum capacity of the first HVAC unit, an operating cost of the first HVAC unit, a temperature difference between the interior temperature and the exterior temperature, a thermal conductivity of a barrier separating the target area and an area exterior to the target area.

[0012] Also disclosed herein is a method for controlling setback of a heating, ventilation, and air conditioning (HVAC) system comprising a first HVAC unit and a second HVAC unit. The method is performed by a setback control system. The method comprises monitoring an interior temperature of a target area associated with the HVAC system. Further, the method comprises monitoring an exterior temperature of the target area associated with the HVAC system. Further, the method comprises determining one or more operating parameters associated with the first HVAC unit of the HVAC system, wherein the one or more operating parameters include at least one of an excess capacity of the first HVAC unit or a relative cost of operation of the first HVAC unit with respect to the second HVAC unit. Further, the method comprises determining a recovery time based on the determined one or more operating parameters. The recovery time is indicative of a time required to recover an interior temperature value of the target area from a setpoint temperature setpoint value to a normal temperature setpoint value by the first HVAC unit. Further, the method comprises triggering a setback recovery based on the determined recovery time and a remaining time in a setback period associated with the setback of the HVAC system.

[0013] In one or more embodiments, the method comprises, prior to triggering the setback recovery, continuously monitoring the remaining time in the setback period. The setback period is indicative of a time period when the HVAC system operates in a setback mode. The remaining time is indicative of a time left in completion of the setback period.

[0014] In one or more embodiments, triggering the setback recovery comprises comparing the determined recovery time with the determined remaining time. Further, the method comprises, upon a determination that the determined recovery time is equal to the determined remaining time, triggering the setback recovery.

[0015] In one or more embodiments, the normal temperature setpoint value is indicative of a temperature value maintained when the HVAC system operates in a normal mode. The setback temperature setpoint value is indicative of a temperature value maintained during the setback period when the HVAC system operates in a setback mode.

[0016] In one or more embodiments, the method comprises triggering the setback recovery prior to the interior temperature value of the target area reaching the setback temperature setpoint value.

5 **[0017]** In one or more embodiments, determining the recovery time comprises determining the recovery time based on one or more of a current interior temperature value, a maximum capacity of the first HVAC unit, an operating cost of the first HVAC unit, a temperature difference between the interior temperature and the exterior temperature, a thermal conductivity of a barrier separating the target area and an area exterior to the target area.

10 **[0018]** To further clarify the advantages and features of the methods, systems, and apparatuses, a more particular description of the methods, systems, and apparatuses will be rendered by reference to specific embodiments thereof, which are illustrated in the appended drawings.

15 **[0019]** These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

Figure 1 illustrates an environment comprising a Heating, Ventilation, and Air Conditioning (HVAC) system and a setback control system;

30 Figures 2a-2b illustrate characteristic graphs depicting relation of interior temperature value of the target area with the capacity of the first HVAC unit of the HVAC system and the exterior temperature;

35 **Fig. 2c** illustrates a characteristic graph depicting the relation of thermal capacity of a first HVAC unit of the HVAC system and the capacity required to maintain interior temperature with respect to the exterior temperature;

40 Figures 3a-3e illustrate graphical representations of operation of the setback control system; and

45 **Figure 4** illustrates a process flow depicting a method for controlling setback of the HVAC system.

50 **[0020]** Further, skilled artisans will appreciate that elements in the drawings are illustrated for simplicity and may not have necessarily been drawn to scale. For example, the flow charts illustrate the method in terms of the most prominent steps involved to help to improve understanding of aspects of the present invention. Furthermore, in terms of the construction of the device, one or more components of the device may have been represented in the drawings by conventional symbols, and the drawings may show only those specific details that are pertinent to understanding the present invention

so as not to obscure the drawings with details that will be readily apparent to those of ordinary skill in the art having the benefit of the description herein.

[0021] It will be understood by those skilled in the art that the foregoing general description and the following detailed description are explanatory of the present invention and are not intended to be restrictive thereof.

[0022] Reference throughout this specification to "an aspect", "another aspect" or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrase "in an embodiment", "in another embodiment", "some embodiments", "one or more embodiments" and similar language throughout this specification may but do not necessarily, all refer to the same embodiment.

[0023] The terms "comprises", "comprising", or any other variations thereof, are intended to cover a non-exclusive inclusion, such that a process or method that comprises a list of steps does not include only those steps but may include other steps not expressly listed or inherent to such process or method. Similarly, one or more devices or sub-systems or elements or structures or components preceded by "comprises... a" does not, without more constraints, preclude the existence of other devices or other sub-systems or other elements or other structures or other components or additional devices or additional sub-systems or additional elements or additional structures or additional components.

[0024] In addition to overcoming the challenges related to an operating cost of a HVAC system, the present invention provides for a system and method of operating the smart setback HVAC control system that results in energy and cost savings. Embodiments of the invention will be described below in detail with reference to the accompanying drawings.

[0025] **Figure 1** illustrates an environment 100 comprising a Heating, Ventilation, and Air Conditioning (HVAC) system and a setback control system. The environment 100 may include a target area 102. The target area 102 may be a room in, but is not limited to, a residential building, a commercial building, an industrial facility, a hospital facility, an educational institute, hotels, entertainment venues, etc. The target area 102 may have at least one temperature sensor 106 mounted inside the target area 102. Further, a HVAC system 104 may be installed within or in proximity to the target area 102 to maintain the interior temperature value of the target area 102. The HVAC system 104 may be configured to provide at least one of heated air and cooled air to the target area 102.

[0026] A setback control system 108 may be communicatively connected to the at least one temperature sensor 106 and the HVAC system 104. The setback control system 108 may include one or more processors 112, a memory 110, an Input/ Output (I/O) interface unit 114, one or more modules 116, and database 118. In an

embodiment, the memory 110, the Input/ Output (I/O) interface unit 114, the database 118, and one or more modules 116 may be external to the one or more processors 112. The one or more processors 112 may be a single controlling unit or a number of units, all of which could include multiple computing units. The one or more processors 112 may be implemented as one or more microprocessors, microcomputers, microcontrollers, digital signal processors, central processing units, state machines, logic circuitries, and/or any devices that manipulate signals based on operational instructions. Among other capabilities, the one or more processors 112 may be configured to fetch and execute computer-readable instructions and data stored in the memory 110.

[0027] The memory 110 may include any non-transitory computer-readable medium known in the art including, for example, volatile memory, such as static random-access memory (SRAM) and dynamic random access memory (DRAM), and/or non-volatile memory, such as read-only memory (ROM), erasable programmable ROM, flash memories, hard disks, optical disks, and magnetic tapes.

[0028] The module(s) 116, amongst other things, include routines, programs, objects, components, data structures, etc., which perform particular tasks or implement data types. The module(s) 116 may also be implemented as, signal processor(s), state machine(s), logic circuitries, and/or any other device or component that manipulate signals based on operational instructions.

[0029] Further, the module(s) 116 may be implemented in hardware, instructions executed by the one or more processors 112, or by a combination thereof. The one or more processors 112 may comprise a computer, a processor, a state machine, a logic array and/or any other suitable devices capable of processing instructions. The one or more processors 112 may be a general-purpose controller which executes instructions to cause a general-purpose processor to perform operations, or a processing unit may be dedicated to performing the required functions. In some example embodiments, the module(s) 116 may be machine-readable instructions (software, such as webapplication, mobile application, program, etc.) which when executed by the one or more processors 112, perform any of the described functionalities.

[0030] The database 118 serves, amongst other things, as a repository for storing data processed, received, and generated by one or more of the module(s) 116. The programs or routines stored in the database 118 may include HVAC control programs and/or scheduling software that may be capable of automatically controlling a HVAC system.

[0031] In an embodiment, the module(s) 116 may be implemented as part of the one or more processors 112. In another embodiment, the module(s) 116 may be external to the one or more processors 112. In yet another embodiment, the module(s) 116 may be part of the memory 110. In another embodiment, the module(s) 116 may be part of hardware, separate from the one or

more processors 112.

[0032] The one or more processors 112 may be included in a computing system installed in a cloud-based network, a mobile computing device, or a local control system such as, for example, the HVAC control system. The one or more processors 112 may electronically communicate with the memory 110 in response to receiving commands from one or more input/output (I/O) devices. In some embodiments, the I/O device(s) may include one or more of a keyboard or keypad, a touchscreen or touch panel, a display screen, a microphone, a speaker, a mouse, a button, a remote control, a joystick, a printer, a telephone or mobile device (e.g., a smartphone), etc. The I/O device(s) may be configured to provide an interface such as a thermostat interface, for example, to allow a user to interact with the system.

[0033] The one or more processors 112 may be configured to communicate with the memory 110 to execute programmable instructions stored in the memory 110. The programmable instructions, when executed by the one or more processors 112, cause the one or more processors 112 to provide the functionalities of the setback control system 108 as discussed. In one or more embodiments, the one or more processors 112 may be one or more microprocessor(s) or microcontroller(s). The one or more processors 112 may include one or a plurality of processors, which may further include one or more general-purpose processors, such as a central processing unit (CPU), an application processor (AP), or the like, a graphics-only processing unit such as a graphics processing unit (GPU), a visual processing unit (VPU), and/or an Artificial intelligence (AI) dedicated processor such as a neural processing unit (NPU).

[0034] In some embodiments, the memory 110 may store data and instructions executable by the one or more processors 112 to perform the method steps for optimizing setback of the HVAC system 104, as discussed herein throughout. The memory 110 may further include, but is not limited to, a non-transitory computer-readable storage media such as various types of volatile and non-volatile storage media, including but not limited to, random access memory, read-only memory, programmable read-only memory, electrically programmable read-only memory, electrically erasable read-only memory, flash memory, magnetic tape or disk, optical media and the like. Further, the non-transitory computer-readable storage media of memory 110 may include executable instructions in the form of modules and the database 118 to store data. The modules may include a set of instructions that may be executed to cause the one or more processors 112 to perform any one or more of the methods as disclosed herein throughout. In one or more embodiments, the modules may be configured to perform the steps as disclosed herein using the data stored in the database 118 of the memory 110 for optimizing the setback of the HVAC system.

[0035] In some embodiments, the HVAC system 104 may comprise a first HVAC unit and a second HVAC unit.

The first HVAC unit may be associated with a lower cost of operation as compared to the second HVAC unit. In an embodiment, the first HVAC unit may be a heat pump. In some embodiments, the second HVAC unit may be an electric resistance heater or a furnace that produces heat through the combustion of a fossil fuel or similar fuel source. In other embodiments, the first and second HVAC units may be integrated into a single piece of equipment where the first and second HVAC units operate independently or together to provide heating.

[0036] In some embodiments, the HVAC system 104 may be adapted to operate in a normal mode and a setback mode. In the normal mode, the HVAC system 104 may operate to maintain the temperature within the target area 102 at a normal temperature setpoint value. In the setback mode, the HVAC system 104 may operate to maintain the temperature within the target area 102 at a setback temperature setpoint value. In an embodiment, the setback temperature setpoint value may be lesser than the normal temperature setpoint value, such as, when the HVAC system is operated to heat the target area 102.

[0037] The HVAC system 104 may be adapted to switch between the normal mode and the setback mode. The HVAC system 104 may operate in the normal mode, and switch to the setback mode for a predefined period of time, referred to as setback period. At the end of the setback period, the HVAC system 104 may switch to the normal mode. In some embodiments, the HVAC system 104 may have a setback recovery mode such that the HVAC system 104 initially switches from the setback mode to the setback recovery mode before the predefined period of time has expired, and subsequently switches to the normal mode. The setback recovery mode may be associated with recovery of the temperature from the setback temperature setpoint value to the normal temperature setpoint value.

[0038] In some embodiments, the setback temperature setpoint value and the normal temperature setpoint value may be pre-set values stored in the database 118. In some embodiments, the setback temperature setpoint value and the normal temperature setpoint value may be set based on a user input.

[0039] Figures 2a-2b illustrate characteristic graphs 200 and 202 respectively, depicting the relation of interior temperature value of the target area 102 with the thermal capacity required to maintain interior temperature as a function of exterior temperature, and the relation of interior temperature value to available thermal capacity of the first HVAC unit of the HVAC system 104 as a function of exterior temperature.

[0040] With respect to the target area 102, the thermal capacity required to maintain the interior temperature value depends on one or more factors, including, temperature difference between interior of the target area 102 and exterior of the target area 102, thermal conductivity of a barrier separating the interior of the target area 102 and exterior of the target area 102, and an area of the

barrier.

[0041] The thermal capacity required to maintain the interior temperature value, for a fixed set of factors, varies as a function of the exterior temperature (temperature value of the exterior of the target area 102). As seen in FIG. 2a, considering the first HVAC unit for heating the target area 102, for a given exterior temperature, increasing interior temperature value requires increasing the thermal capacity of the first HVAC unit. For a given interior temperature, decreasing exterior temperature requires increasing the thermal capacity of the first HVAC unit.

[0042] Further, as seen in Fig. 2b, the maximum thermal capacity of the first HVAC unit varies with both interior and exterior temperatures. As interior temperature increases, the maximum thermal capacity of the first HVAC unit decreases. As exterior temperature decreases, the maximum thermal capacity of the first HVAC unit decreases.

[0043] Figure 2c illustrates a characteristic graph 204 depicting the relation of thermal capacity of the first HVAC unit of the HVAC system 104 and the capacity required to maintain interior temperature with respect to the exterior temperature.

[0044] As the exterior temperature decreases, the thermal capacity required to maintain interior temperature value increases. Further, as the exterior temperature decreases, the thermal capacity of the first HVAC unit decreases. At one threshold temperature $T_{\text{threshold}1}$, the thermal capacity required to maintain interior temperature value may be same as the maximum thermal capacity of the first HVAC unit. Below the threshold temperature, an additional heating source may be required to maintain an interior temperature.

[0045] In addition to maintaining the interior temperature value, the first HVAC unit may be required to increase the interior temperature value of the target area 102. For instance, the first HVAC unit may operate to increase the interior temperature value at the end of a setback period when the HVAC system 104 switches from the setback mode to the normal mode. To increase interior temperature value, the thermal capacity in excess of that required to maintain interior temperature value may be utilized to increase the interior temperature value in the target area 102. The excess thermal capacity of the first HVAC unit may be represented by a difference between the capacity required to maintain interior temperature value of the target area 102 and the maximum capacity provided by the first HVAC unit.

[0046] Referring again to Fig. 1, the one or more processors 112 may be configured to monitor the interior temperature value of the target area 102. In some embodiments, the one or more processors 112 may be configured to receive temperature readings from the temperature sensor 106 located within the target area 102. In some embodiments, the temperature sensor 106 may be integrated with a thermostat within the target area 102.

[0047] The one or more processors 112 may be con-

figured to monitor the exterior temperature associated with the target area 102. The exterior temperature may be monitored with one or more sensors (not shown) located near the exterior of target area 102 and communicatively coupled to the control system 108. As described above, the exterior temperature refers to temperature value outside the target area 102.

[0048] The one or more processors 112 may be configured to determine an excess capacity of the first HVAC unit of the HVAC system 104. The excess capacity may be determined based on a difference between the capacity required to maintain interior temperature value of the target area 102 and the maximum capacity that can be provided by the first HVAC unit.

[0049] As described above, in the normal mode, the HVAC system 104 may maintain the interior temperature value at the normal temperature setpoint value. For instance, the normal temperature setpoint value may be set at 70 F and the HVAC system 104 may maintain the interior temperature value at 70 F.

[0050] Further, when the HVAC system 104 operates in the setback mode, the HVAC system 104 may maintain the interior temperature value at the setback temperature setpoint value. For instance, the setback temperature setpoint value may be set at 65 F and the HVAC system 104 may stop or reduce heating to allow the interior temperature value to decrease naturally from 70 F to 65 F. When the interior temperature value reaches 65 F, the HVAC system 104 may maintain the interior temperature value at 65 F, for instance, by resuming the operation thereof.

[0051] In order to recover the interior temperature value from the setback temperature setpoint value to the normal temperature setpoint value, the HVAC system 104 may operate to actively raise the interior temperature value. During the setback period, the HVAC system 104 may allow the interior temperature value to decrease from the normal temperature setpoint value to the setback temperature setpoint value. At a particular trigger time during the setback period, the HVAC system 104 may start operation to recover the interior temperature value from the setback temperature setpoint value to the normal temperature setpoint value.

[0052] In some embodiments, the first HVAC unit of the HVAC system 104 may be operated to recover the interior temperature value from the setback temperature setpoint value to the normal temperature setpoint value. The one or more processors 112 may be configured to determine a setback recovery time to recover the interior temperature value to the normal temperature setpoint value using only the first HVAC unit of the HVAC system 104. That is, a current temperature value of the target area 102 presumably at or near the setback temperature setpoint value may be recovered to the normal temperature setpoint value. The setback recovery time may be determined by dividing the heat capacity of the target area 102 by the excess heat capacity of the first HVAC unit to determine the time to recover from the setback. The heat

capacity of the target area 102 may be determined by observing the heat loss as indicated by the capacity required to maintain interior temperature prior to the setback period, and then observing the rate of decay of the interior temperature when the HVAC system 104 reduces or stops heating the target area at the beginning of the setback period.

[0053] The one or more processors 112 may be configured to determine a remaining time in the setback period. The one or more processors 112 may determine the remaining time based on a timer function and the pre-determined value of the setback period. In an embodiment, the one or more processors 112 may be configured to continuously monitor the remaining time during the setback period.

[0054] The one or more processors 112 may be configured to compare the determined recovery time with the determined remaining time. Upon determining that the recovery time is greater than or equal to the remaining time, the one or more processors 112 may be configured to trigger setback recovery. That is, the one or more processors 112 may cause the HVAC system 104 to operate to recover the interior temperature value to the normal temperature setpoint value. As a result, the interior temperature value can recover to the normal temperature value at the end of the setback period, by avoiding the second HVAC unit which has a higher cost of operation. A higher efficiency system operation is thus achieved.

[0055] In other words, the triggering of the setback recovery is determined based on the excess capacity of the first HVAC unit, i.e., the lower cost HVAC unit. The use of setback is optimized to save operating costs, and the setback is managed in a manner such that setback recovery is possible without using the higher cost HVAC unit.

[0056] In an embodiment, the setback recovery may be triggered before the interior temperature value reaches the setback temperature setpoint value while the HVAC system 104 is operating in the setback mode.

[0057] In an embodiment, in the setback recovery, only the first HVAC unit may operate to recover the interior temperature value to the normal temperature setpoint value. That is, operation of the second HVAC unit is avoided during the setback recovery while recovering the interior temperature value to the normal temperature setpoint value. In an embodiment, in the setback recovery, the first HVAC unit as well as the second HVAC unit may operate to recover the interior temperature value to the normal temperature setpoint value.

[0058] In some embodiments, when the HVAC system 104 switches from the normal mode to the setback mode, the interior temperature value is allowed to decrease from the normal temperature setpoint value to the setback temperature setpoint value. The decrease in the interior temperature value may be by virtue of heat loss to the exterior of the target area 102. Once the interior temperature value decreases to the setback temperature

setpoint value, the HVAC system 104 maintains the interior temperature value at the setback temperature setpoint value.

[0059] In some embodiments, the one or more processors 112 may be configured to, at first periodic intervals of time, determine the excess capacity required for setback recovery to the normal temperature setpoint value at the end of the setback period. In a nonlimiting example, the first periodic intervals of time may be 5 minutes. The one or more processors 112 may be further configured to determine a predicted excess capacity available with the first HVAC unit for achieving the setback recovery.

[0060] The one or more processors 112 may be configured to compare the predicted excess capacity available with the first HVAC unit with the excess capacity required for setback recovery. Upon determining that the predicted excess capacity available with the first HVAC unit is within a threshold margin of the excess capacity required for setback recovery, the one or more processors 112 may be configured to trigger the setback recovery. The setback operation is optimized, particularly in conditions with mild to moderate loads which may be less than the maximum thermal capacity of the first HVAC unit, and further, when the relative cost of operation between the first HVAC unit and the second HVAC unit is relatively large, for instance, with a factor of 2.

[0061] In another embodiment, the relative cost of operation between the first HVAC unit and the second HVAC unit may be stored in the database 118. When the HVAC system 104 switches from the normal mode to the setback mode, the interior temperature value is allowed to decrease from the normal temperature setpoint value to the setback temperature setpoint value. The one or more processors 112 may be configured to monitor, at second periodic intervals of time, the relative cost of operation if the setback recovery is triggered at the current time and the relative cost of operation if the setback recovery begins at a future time. The one or more processors 112 may be configured to determine that the relative cost of operation if the setback recovery begins at the future time exceeds the relative cost of operation if the setback recovery begins at the present time. Upon the determination, the one or more processors 112 may be configured to trigger the setback recovery.

[0062] Figure 3a illustrates a graphical representation 300 of operation of the setback control system 108.

[0063] The one or more processors 112 may further be configured to control operation of the HVAC system 104, including the first HVAC unit and the second HVAC unit, based on an operating schedule. In some embodiments, the operation schedule may be stored in the database 118. Referring to Fig. 3a, the setback period begins at a specific starting time, t_1 . Prior to t_1 , the HVAC system operates in the normal mode where the interior temperature value T_{int} is maintained at the normal temperature setpoint value T_{SP1} . Upon initiation of the setback period, the interior temperature value T_{int} gradually decreases from the normal temperature setpoint value T_{SP1} to the

setback temperature setpoint value T_{SP2} . That is, a lower temperature is maintained within the target area 102 during the setback period. The setback period lasts until a designated ending time, t_2 .

[0064] During the setback period, the HVAC system 104 may not be actively working to maintain the interior temperature value T_{Int} . Instead, the interior temperature T_{Int} may decrease naturally due to heat loss from the target area 102. At time t_3 , the interior temperature value T_{Int} may reach the setback temperature setpoint value T_{SP2} . This indicates that the interior temperature value has fallen to the level that was targeted during the setback period and the HVAC system 104 operates to maintain the interior temperature value T_{Int} at the setback temperature setpoint value T_{SP2} .

[0065] During the setback period from time t_1 to time t_2 , the one or more processors 112 may be configured to monitor an estimated setback recovery time t_R and a setback remaining time t_{ESB} . The setback recovery time t_R in the illustrated embodiment may be the time required for the interior temperature T_{Int} to recover, using the first HVAC unit of the HVAC system 104, from the setback temperature setpoint value T_{SP2} back to the normal temperature setpoint value T_{SP1} . The setback recovery time t_R may be continuously tracked by the one or more processors 112. The remaining time t_{ESB} may refer to a time left in the setback period.

[0066] When the remaining time t_{ESB} becomes equal to setback recovery time t_R at time t_4 , the one or more processors 112 may trigger the setback recovery. In the setback recovery, the first HVAC unit may operate to raise the interior temperature value T_{Int} from the setback temperature setpoint value T_{SP2} towards the normal temperature setpoint value T_{SP1} , as seen in Fig. 3a. The optimization of the setback is such that the interior temperature value T_{Int} reaches from the setback temperature setpoint value T_{SP2} to the normal temperature setpoint value T_{SP1} at the time when the setback period is completed, i.e., at time t_2 , as seen in Fig. 3a.

[0067] In some embodiments, the setback recovery may be triggered before the interior temperature value T_{Int} reaches the setback temperature setpoint value T_{SP2} . **Figure 3b** illustrates a graphical representation 302 of operation of the setback control system 108. As seen in FIG. 3b, at time t_4 , the remaining time t_{ESB} becomes equal to setback recovery time t_R prior to the interior temperature value T_{Int} reaching the setback temperature setpoint value T_{SP2} . Accordingly, the one or more processors 112 trigger the setback recovery at time t_4 , as seen in Fig. 3b.

[0068] In some embodiments, the second HVAC unit of the HVAC system 104 may be required during the setback recovery so as to complete the setback recovery by the end of the setback period. The first HVAC unit may be a low cost heating power source and the second HVAC unit may be a high cost heating power source. **Figure 3c** illustrates a graphical representation 304 of operation of the setback control system 108. As seen in Fig. 3c, the

operation during time t_1 , t_3 , and t_4 is the same as described with reference to Fig. 3a. At time t_5 , the second HVAC unit is operated in addition to the first HVAC unit in order to complete the setback recovery at the end of the setback period, i.e., at time t_2 . Figure 3c further depicts power usage graph 306 of the HVAC system in operation.

[0069] Before the setback period, i.e., before time t_1 , the HVAC system operates at power level P1, with both the first HVAC unit and the second HVAC unit in operation. When the setback period begins, the HVAC system may be turned off and power consumption drops to zero. The interior temperature value T_{Int} drops to the setback temperature setpoint value T_{SP2} . When the interior temperature value T_{Int} reaches the setback temperature setpoint value T_{SP2} , the first HVAC unit is operated at power level P2 to maintain the interior temperature value T_{Int} at the setback temperature setpoint value T_{SP2} . When the setback recovery is triggered at time t_4 , the power of the first HVAC unit is increased to the maximum power level P3 until the time t_5 when the second HVAC unit must be engaged to complete the setback recovery at the end of the setback period. Between the time t_5 and t_2 , the power level of the HVAC system 104 may be P4 which may be a power level greater than the power level P1. At the end of the setback period, i.e., after time t_2 , the HVAC system returns to power level P1. The energy saved during the setback period between t_1 and t_5 is indicated by the area below P1 power label and shown as $P_{reduced}$. The extra power used during setback recovery between t_5 and t_2 is indicated by the area above P1 and shown as P_{extra} . $P_{reduced}$ is greater than P_{extra} indicating that there is a net energy saving during the setback period compared to operating without a setback at power level P1 for the entire period.

[0070] In some operating scenarios, the power P1 prior to the beginning of the setback period may not include the operation of the second HVAC unit, but operation of the second HVAC unit may be required only during the setback recovery, as described with reference to Figure. 3d. In still other operating scenarios, operation of the second HVAC unit may be required to maintain temperature during the setback period and operating the second HVAC unit at a higher power may be required during the setback recovery, as described with reference to Figure 3e.

[0071] **Figure 3d** illustrates a graphical representation 308 of operation of the setback control system 108. The first HVAC unit may be a low cost heating power source and the second HVAC unit may be a high cost heating power source. As seen in Fig. 3d, the operation during time t_1 , t_3 , and t_4 is the same as described with reference to Fig. 3a. During setback recovery, i.e., between time t_4 and time t_2 , the second HVAC unit is operated in addition to the first HVAC unit Figure 3d further depicts power usage graph 310 of the HVAC system in operation.

[0072] Before the setback period, i.e., before time t_1 , the HVAC system operates at power level P1, with only the first HVAC unit in operation. When the setback period

begins, the HVAC system may be turned off and power consumption drops to zero. The interior temperature value T_{int} drops to the setback temperature setpoint value T_{SP2} . When the interior temperature value T_{int} reaches the setback temperature setpoint value T_{SP2} , the first HVAC unit is operated at power level P2 to maintain the interior temperature value T_{int} at the setback temperature setpoint value T_{SP2} . When the setback recovery is triggered at time t_4 , the power of the first HVAC unit is increased to the maximum capacity of the first HVAC unit, i.e., power level P3. Further, at time t_5 , the second HVAC unit must be engaged to complete the setback recovery at the end of the setback period. Thus, the second HVAC unit is also operated and the power level is P4 by virtue of operation of both the first HVAC unit and the second HVAC unit.

[0073] The power level P3 and P4 during the setback recovery is greater than P1, as shown by P_{extra} , in order to complete the setback recovery at time t_2 . At the end of the setback period, i.e., after time t_2 , the HVAC system returns to power level P1 and only the first HVAC unit is operated. The energy saved during the setback period between t_1 and t_5 is indicated by the area below P1 power label and shown as $P_{reduced}$. The extra power used during setback recovery between t_4 and t_2 is indicated by the area above P1 and shown as P_{extra} . $P_{reduced}$ is greater than P_{extra} indicating that there is a net energy saving during the setback period.

[0074] Figure 3e illustrates a graphical representation 312 of operation of the setback control system 108. The first HVAC unit may be a low cost heating power source and the second HVAC unit may be a high cost heating power source. As seen in Fig. 3e, in normal operation prior to time t_1 , both the first HVAC unit and the second HVAC unit are in operation. In the setback mode between time t_1 and t_3 , the indoor temperature may fall to the setback temperature setpoint value T_{SP2} . During the setback period between time t_3 and time t_4 , both the first HVAC unit and the second HVAC unit are in operation to maintain the indoor temperature at the setback temperature setpoint value T_{SP2} . Further, during setback recovery between time t_4 and time t_2 , both the first HVAC unit and the second HVAC unit are in operation. Figure 3e further depicts power usage graph 314 of the HVAC system in operation.

[0075] Before the setback period, i.e., before time t_1 , the HVAC system operates at combined power level P1, with both the first HVAC unit and the second HVAC unit in operation. When the setback period begins, the HVAC system may be turned off and power consumption drops to zero. The interior temperature value T_{int} drops to the setback temperature setpoint value T_{SP2} . When the interior temperature value T_{int} reaches the setback temperature setpoint value T_{SP2} , the first HVAC unit and the second HVAC unit are operated at combined power level P2 to maintain the interior temperature value T_{int} at the setback temperature setpoint value T_{SP2} .

[0076] When the setback recovery is triggered at time

t_4 , the first HVAC unit and the second HVAC unit are operated at combined power level P3. Further, at time t_5 , the power level of the second HVAC unit is increased in order to complete the setback recovery at the end of the setback period. As seen in Figure 3e, the power level is P4 between the time t_5 and time t_2 which is greater than power level P1. The extra power used during setback recovery between t_5 and t_2 is indicated by the area above P1 and shown as P_{extra} . The energy saved during the setback period between t_1 and t_5 is indicated by the area below P1 power label and shown as $P_{reduced}$. $P_{reduced}$ is greater than P_{extra} indicating that there is a net energy saving during the setback period.

[0077] In some embodiments, the system 108 may be associated with multiple recovery profiles. The recovery profiles may be stored in the database 118. In some embodiments, the recovery profiles may be associated with corresponding costs. The system 108 may be configured to select an optimal profile from among the multiple recovery profiles for setback recovery. The optimal profile may be, for instance, a profile with the lowest overall cost. For example, a first recovery profile may be determined using only the first HVAC unit and a second recovery profile may be determined using both the first and second HVAC units together. The second recovery profile may operate at a higher instantaneous cost in order to run at a higher capacity, but may achieve a lower overall cost by operating for a shorter period of time in recovery mode thus enabling a longer time of low power operation in setback before recovery begins.

[0078] In some embodiments, the operation of the second HVAC unit may be required in case of changes in the exterior temperature which affects the thermal capacity of the first HVAC unit. In some embodiments, the operating cost of a setback recovery may be based on anticipated exterior temperatures. Anticipated temperatures may be developed from a current trend in temperature change, recent historic temperature trends as observed over a period of time such as the most recent 1-5 days, a weather forecast of temperature, or some combination of the same. In some embodiments, an intermediate threshold temperature value may be set between the setback temperature setpoint value and the normal temperature setpoint value, and the operation of the second HVAC unit may be required only when the interior temperature value has not reached the intermediate threshold temperature value at the end of the setback period.

[0079] In some embodiments, the database 118 may store the normal temperature setpoint value, the setback temperature setpoint value, and the operation schedules for different modes of the HVAC system 104. The database 118 may also store a history of temperature recovery rates (i.e., one or more previously recorded temperature recovery rates) corresponding to the target area 102. A given temperature recovery rate is a rate at which the actual temperature is changed during the setback recovery period to reach the normal temperature setpoint

value.

[0080] Figure 4 illustrates a process flow depicting a method 400 for controlling setback of the HVAC system 104. The method 400 may be implemented by the setback control system 108.

[0081] At step 402, the method 400 includes monitoring an interior temperature of a target area associated with the HVAC system.

[0082] At step 404, the method 400 includes monitoring an exterior temperature of the target area associated with the HVAC system.

[0083] At step 406, the method 400 includes determining one or more operating parameters associated with the first HVAC unit of the HVAC system. The one or more operating parameters may include at least one of an excess capacity of the first HVAC unit or a relative cost of operation of the first HVAC unit with respect to the second HVAC unit.

[0084] At step 408, the method 400 includes determining a recovery time based on the determined one or more operating parameters. The recovery time indicates a time required to recover an interior temperature value of the target area from a setback temperature setpoint value to a normal temperature setpoint value by the first HVAC unit.

[0085] At step 410, the method 400 includes triggering a setback recovery based on the determined recovery time and a remaining time in a setback period associated with the setback of the HVAC system.

[0086] While the above steps of Figure 4 are shown and described in a particular sequence, the steps may occur in variations to the sequence. Further, a detailed description related to the various steps of Figure 4 is already covered in the description related to Figures 1-3c and is omitted herein for the sake of brevity.

[0087] The system and method provide an optimized setback of HVAC systems in which the setback recovery can be optimized for the lowest operating cost of an HVAC system during a setback period. The setback can be planned such that the interior temperature can recover to normal at the end of the setback period with the use of only a low-cost heating source.

[0088] It is appreciated that although the details are explained with reference to heating of the target area, analogous details are applicable when cooling of the target area.

[0089] As would be apparent to a person in the art, various working modifications may be made to the methods disclosed herein in order to implement the inventive concept as taught herein.

[0090] Moreover, the actions of any flow diagram need not be implemented in the order shown; nor do all of the acts necessarily need to be performed. Also, those acts that are not dependent on other acts may be performed in parallel with the other acts.

[0091] The drawings and the forgoing description give examples of embodiments. Those skilled in the art will appreciate that one or more of the described elements

may well be combined into a single functional element. Alternatively, certain elements may be split into multiple functional elements. Elements from one embodiment may be added to another embodiment. For example, orders of processes described herein may be changed and are not limited to the manner described herein.

[0092] Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any component(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature or component of any or all the claims.

Claims

1. A setback control system (108) for controlling setback of a heating, ventilation, and air conditioning (HVAC) system (104) comprising a first HVAC unit and a second HVAC unit, the setback control system comprising:

a memory (110); and
one or more processors (112) communicatively coupled to the memory, the one or more processors being configured to:

monitor an interior temperature of a target area (102) associated with the HVAC system (104);

monitor an exterior temperature of the target area (102) associated with the HVAC system (104);

determine one or more operating parameters associated with the first HVAC unit of the HVAC system (104), wherein the one or more operating parameters include at least one of an excess capacity of the first HVAC unit or a relative cost of operation of the first HVAC unit with respect to the second HVAC unit;

determine a recovery time based on the determined one or more operating parameters, the recovery time being indicative of a time required to recover an interior temperature value of the target area (102) from a setback temperature setpoint value to a normal temperature setpoint value by the first HVAC unit; and

trigger a setback recovery based on the determined recovery time and a remaining time in a setback period associated with the setback of the HVAC system (104).

2. The system of claim 1, wherein, the one or more processors (112) are configured to, prior to triggering

the setback recovery:

continuously monitor the remaining time in the setback period, wherein the setback period is indicative of a time period when the HVAC system (104) operates in a setback mode, and wherein the remaining time is indicative of a time left in completion of the setback period.

3. The system of claim 1 or claim 2, wherein to trigger the setback recovery, the one or more processors (112) are configured to:

compare the determined recovery time with the determined remaining time; and upon a determination that the determined recovery time is equal to the determined remaining time, trigger the setback recovery.

4. The system of any preceding claim, wherein the normal temperature setpoint value is indicative of a temperature value maintained when the HVAC system (104) operates in a normal mode, and wherein the setback temperature setpoint value is indicative of a temperature value maintained during the setback period when the HVAC system (104) operates in a setback mode.

5. The system of claim 4, wherein the one or more processors (112) are configured to trigger the setback recovery prior to the interior temperature value of the target area (102) reaching the setback temperature setpoint value.

6. The system of any preceding claim, wherein to determine the recovery time, the one or more processors (112) are configured to determine the recovery time based on one or more of: a current interior temperature value, a maximum capacity of the first HVAC unit, an operating cost of the first HVAC unit, a temperature difference between the interior temperature and the exterior temperature, and a thermal conductivity of a barrier separating the target area (102) and an area exterior to the target area (102).

7. A method (400) for controlling setback of a heating, ventilation, and air conditioning (HVAC) system (104) comprising a first HVAC unit and a second HVAC unit, the method being performed by a setback control system (108), the method comprising:

monitoring (402) an interior temperature of a target area (102) associated with the HVAC system (104);

monitoring (404) an exterior temperature of the target area (102) associated with the HVAC system;

determining (406) one or more operating parameters associated with the first HVAC unit of the HVAC system (104), wherein the one or more

operating parameters include at least one of an excess capacity of the first HVAC unit or a relative cost of operation of the first HVAC unit with respect to the second HVAC unit;

determining (408) a recovery time based on the determined one or more operating parameters, the recovery time being indicative of a time required to recover an interior temperature value of the target area (102) from a setback temperature setpoint value to a normal temperature setpoint value by the first HVAC unit; and triggering (410) a setback recovery based on the determined recovery time and a remaining time in a setback period associated with the setback of the HVAC system (104).

8. The method of claim 7, wherein the method comprises, prior to triggering the setback recovery: continuously monitoring the remaining time in the setback period, wherein the setback period is indicative of a time period when the HVAC system (104) operates in a setback mode, and wherein the remaining time is indicative of a time left in completion of the setback period.

9. The method of claim 7 or claim 8, wherein triggering the setback recovery comprises:

comparing the determined recovery time with the determined remaining time; and upon a determination that the determined recovery time is equal to the determined remaining time, triggering the setback recovery.

10. The method of any of claims 7 to 9, wherein the normal temperature setpoint value is indicative of a temperature value maintained when the HVAC system (104) operates in a normal mode, and wherein the setback temperature setpoint value is indicative of a temperature value maintained during the setback period when the HVAC system (104) operates in a setback mode.

11. The method of claim 10, comprising triggering the setback recovery prior to the interior temperature value of the target area (102) reaching the setback temperature setpoint value.

12. The method of any of claims 7 to 11, wherein determining the recovery time comprises determining the recovery time based on one or more of: a current interior temperature value, a maximum capacity of the first HVAC unit, an operating cost of the first HVAC unit, a temperature difference between the interior temperature and the exterior temperature, and a thermal conductivity of a barrier separating the target area (102) and an area exterior to the target area (102).

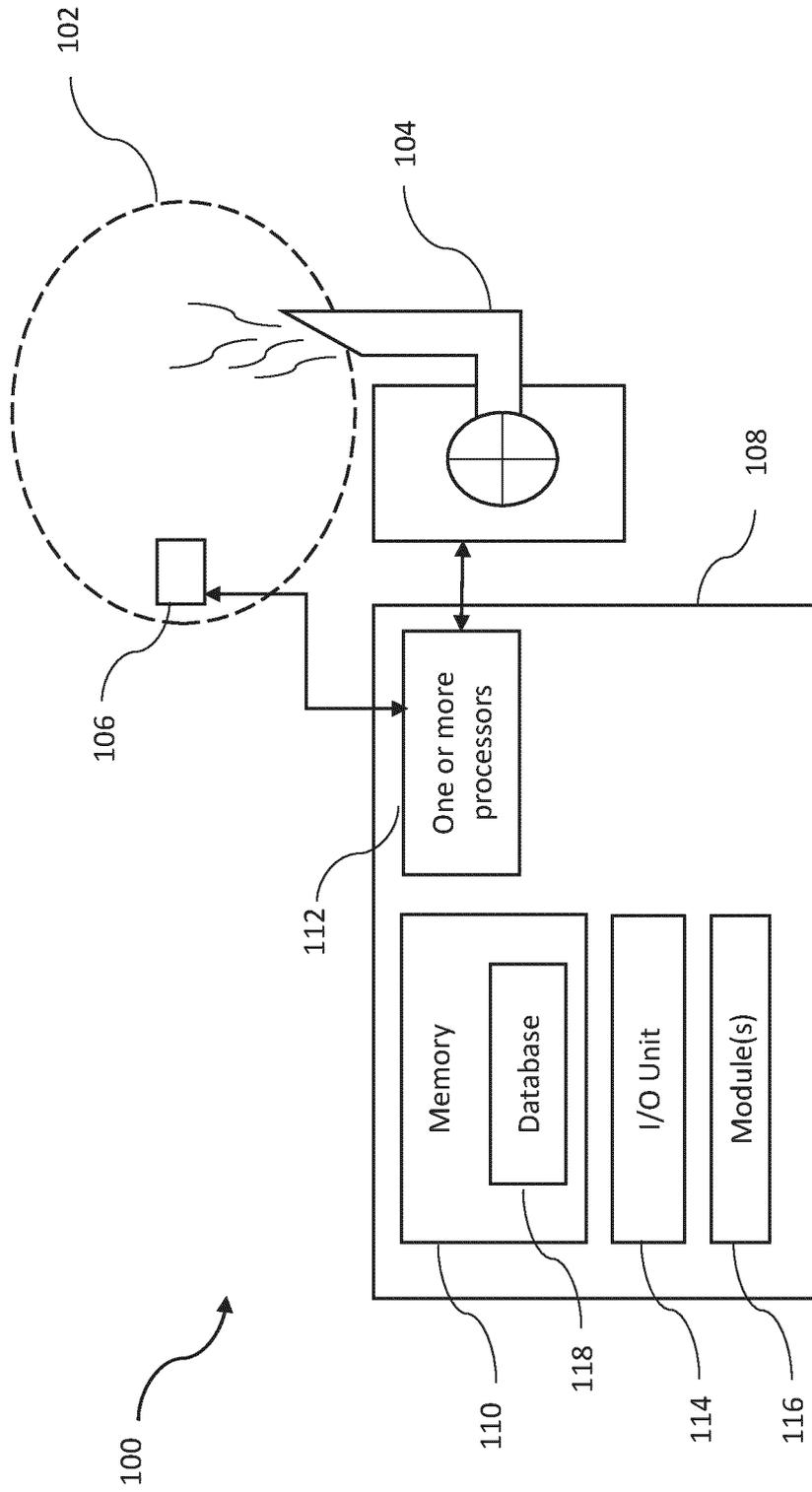


Figure 1

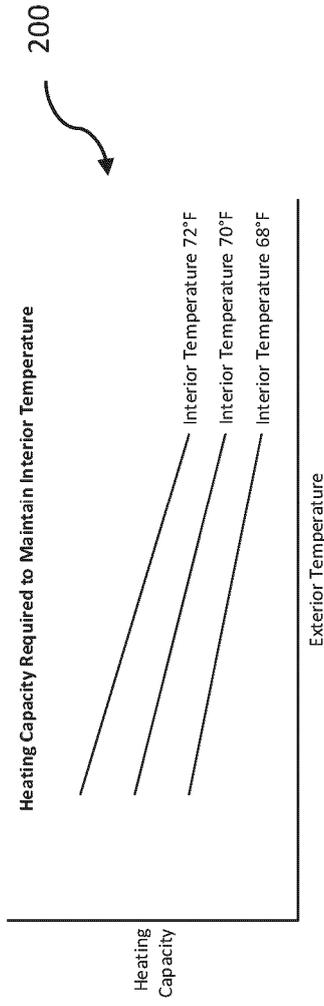


Figure 2a

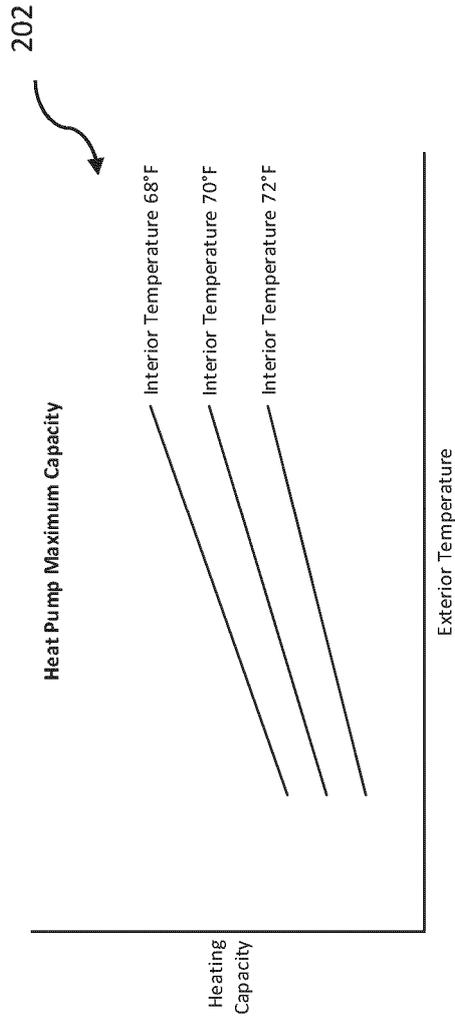


Figure 2b

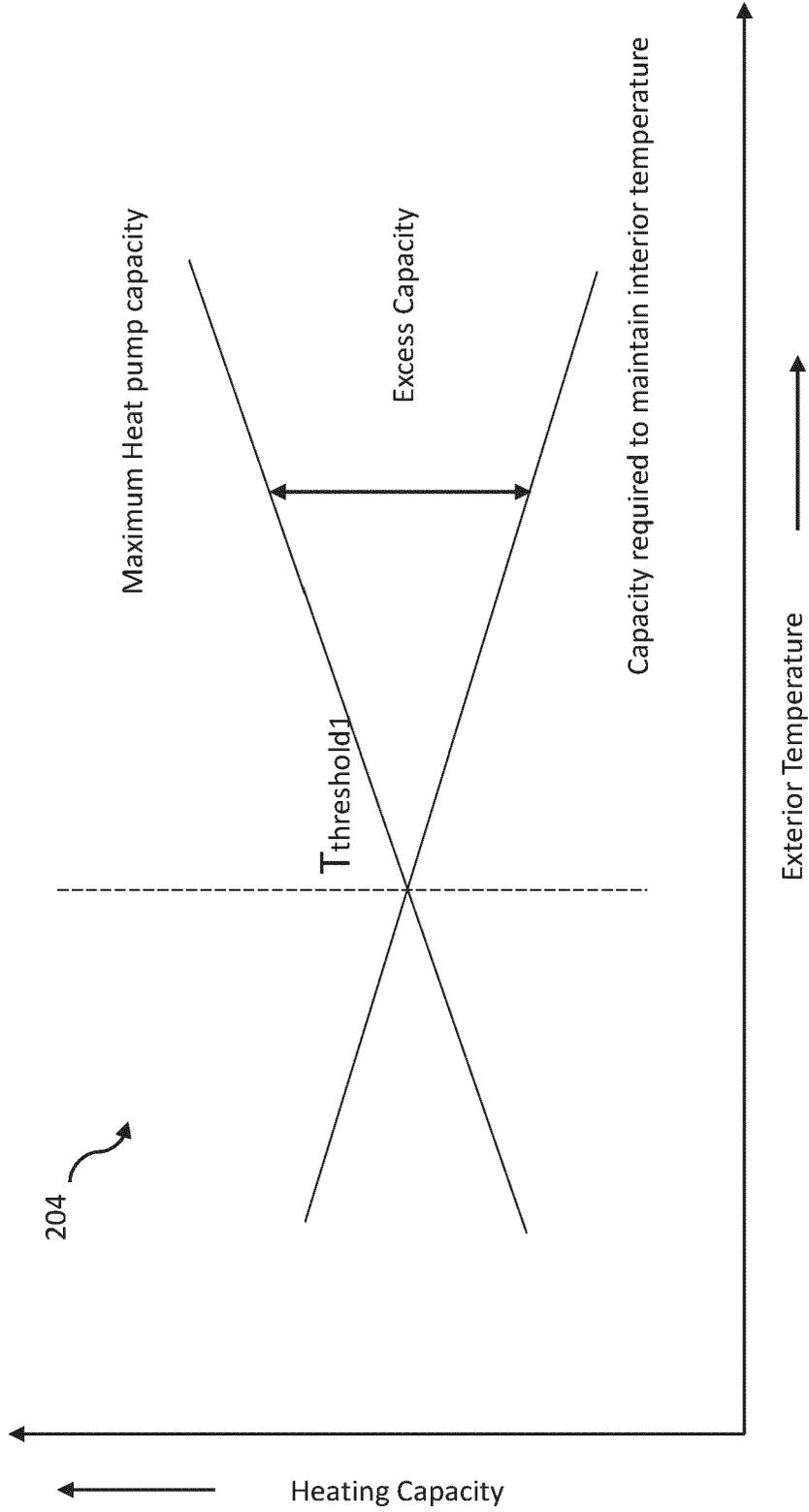


Figure 2c

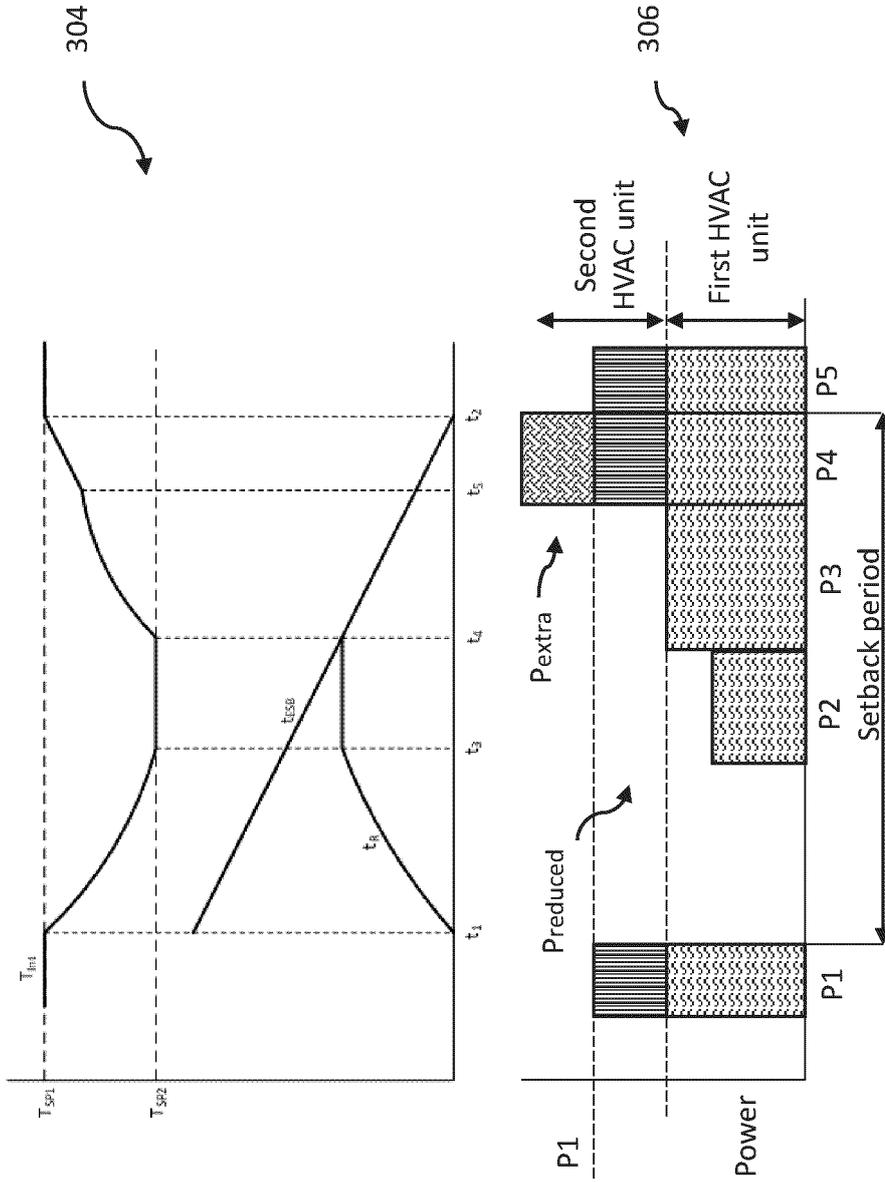


Figure 3c

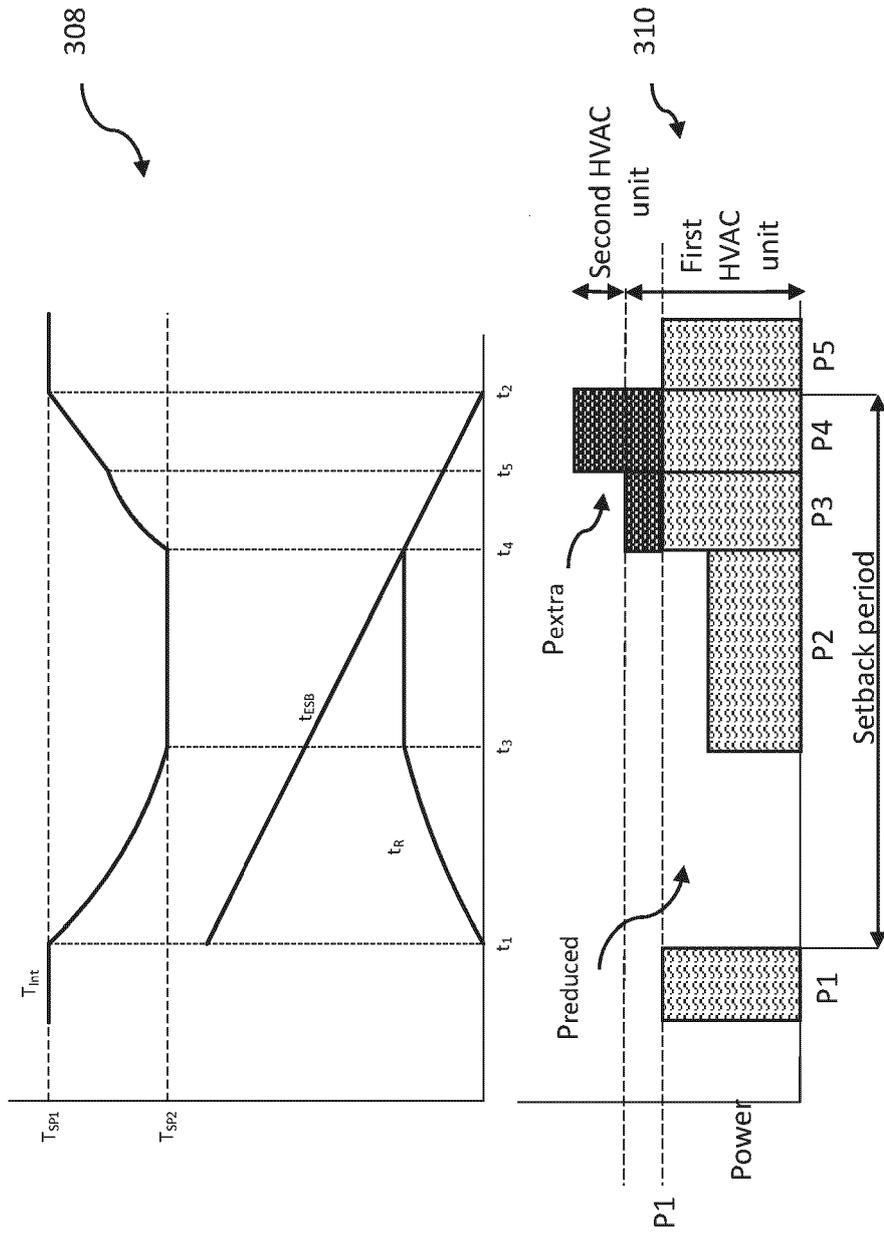


Figure 3d

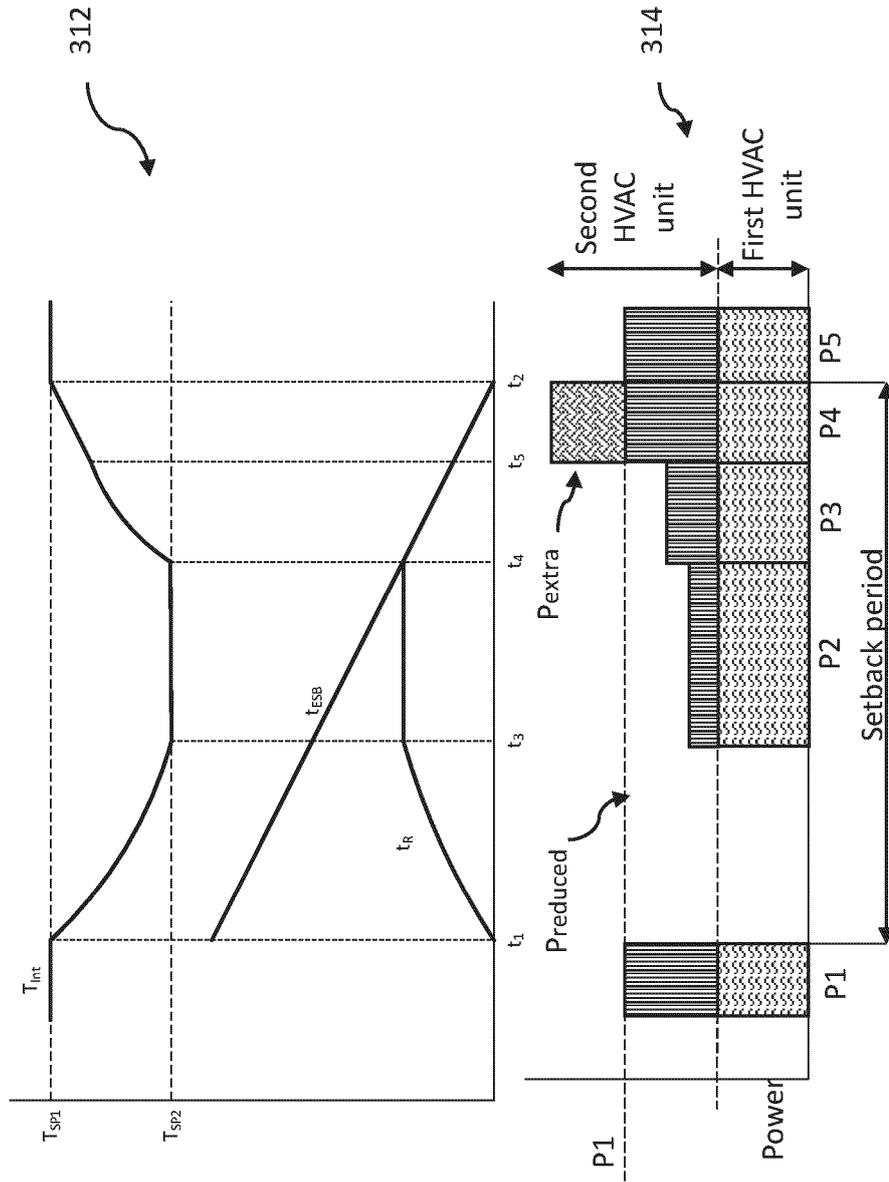


Figure 3e

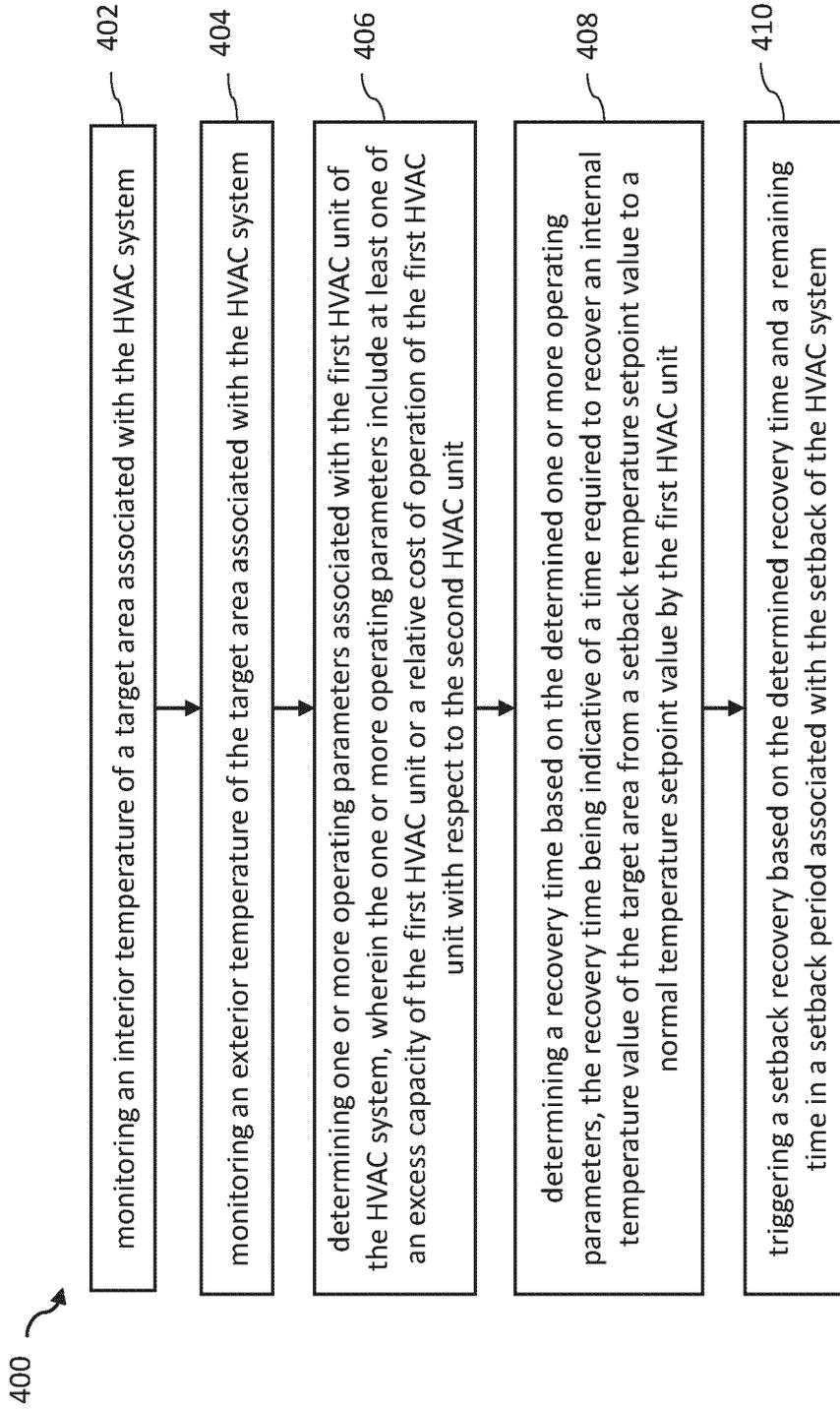


Figure 4



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EP 24 20 6751

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Place of search Munich		Date of completion of the search 12 February 2025	Examiner Anconetani, Mirco
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