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(54) **SYSTEM AND METHOD FOR BUILDING CLIMATE CONTROL**

(57) A method (200) of controlling the climate of a building (18) includes determining (204) a difference between a current aspect of a climate in a building and a set point for the aspect of climate in the building for one or more zones of the building, summing (206) the differ-

ences at a climate system controller, and determining (208) a set point for one or more operating variables of one or more components of a climate system (20) in the building based on the sum of the differences. A climate system for a building is also disclosed.

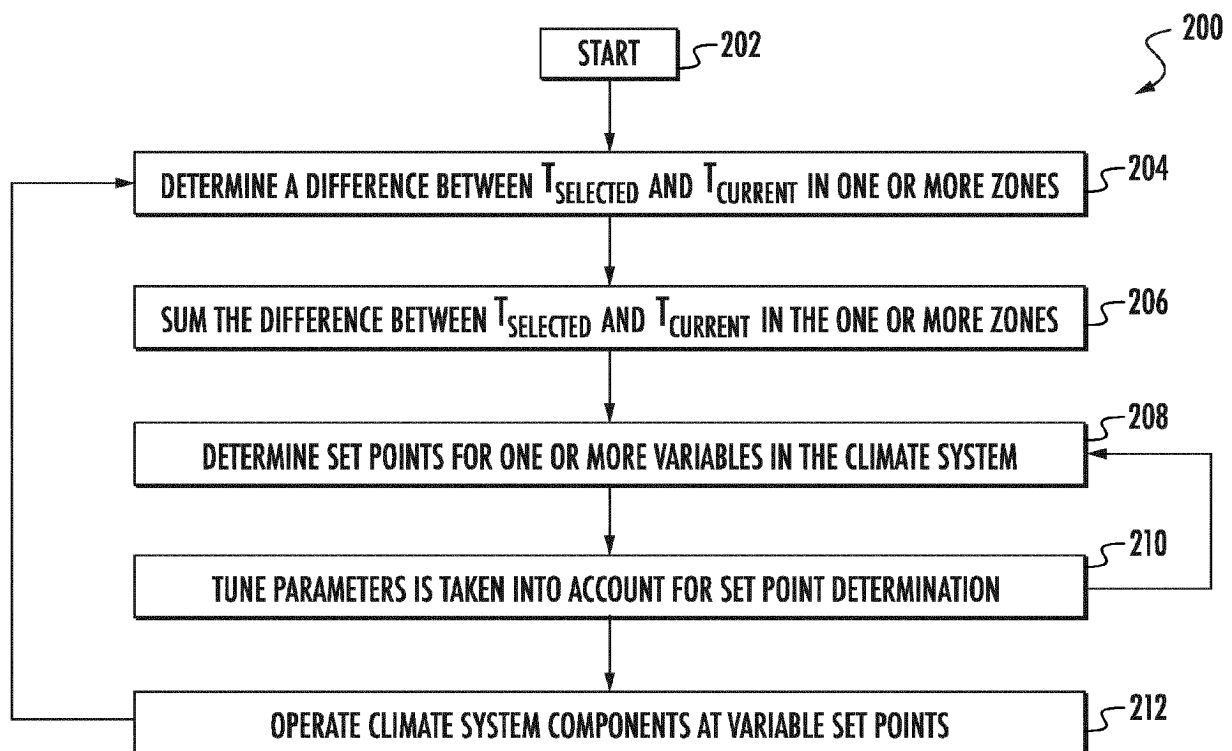


FIG. 2

Description**BACKGROUND**

5 **[0001]** Buildings, such as university buildings, office buildings, residential buildings, commercial buildings, and the like, include climate systems which are operable to control the climate inside the building. Some buildings have climate requirements which vary over time. The climate systems are operable to maintain a desired climate in the building.

SUMMARY

10 **[0002]** A method of controlling the climate of a building according to an exemplary embodiment of this disclosure, among other possible things includes determining a difference between a current aspect of a climate in a building and a set point for the aspect of climate in the building for one or more zones of the building. The method also includes summing the differences at a climate system controller and determining a set point for one or more operating variables of one or more components of a climate system in the building based on the sum of the differences.

15 **[0003]** In a further example of the foregoing, the step of determining the set points for the one or more operating variables is based on one or more tunable parameters.

[0004] In a further example of any of the foregoing, the method includes tuning the one or more tunable parameters based on real-time dynamic information about the climate system.

20 **[0005]** In a further example of any of the foregoing, the current aspect of the climate in the building is the current air temperature inside the building. The set point for the aspect is a temperature set point.

[0006] In a further example of any of the foregoing, the one or more operating variables includes a temperature of conditioned air from an air handling unit.

25 **[0007]** In a further example of any of the foregoing, the one or more components of the climate system include at least one of a chiller, a pump, and an air handling unit.

[0008] In a further example of any of the foregoing, the one or more operating variables includes a temperature of conditioning air from the air handling unit.

30 **[0009]** A climate system for a building according to an exemplary embodiment of this disclosure, among other possible things includes a computing device configured to determine a difference between a current aspect of a climate in a building and a set point for the aspect of climate in the building for one or more zones in the building, sum the differences, and determine a set point for one or more operating variables of one or more components of a climate system in the building based on the sum of the differences.

[0010] In a further example of the foregoing, the computing device is a climate system controller.

35 **[0011]** In a further example of any of the foregoing, the computing device includes a first computing device configured to determine a difference between a current aspect of a climate in a building and a set point for the aspect of climate in the building and sum the differences.

[0012] In a further example of any of the foregoing, the computing device includes a second computing device configured to determine a set point for one or more operating variables of one or more components of a climate system in the building based on the sum of the differences.

40 **[0013]** In a further example of any of the foregoing, the first computing device is a climate system controller and the second computing device is a controller of the one or more components of the climate system.

[0014] In a further example of the foregoing, the computing device is configured to determine the set points for the one or more operating variables based on one or more tunable parameters.

45 **[0015]** In a further example of any of the foregoing, the computing device is configured to tune the one or more tunable parameters based on real-time dynamic information about the climate system.

[0016] In a further example of any of the foregoing, the real-time dynamic information about the climate system is provided to the computing device by one or more sensors in the building.

[0017] In a further example of any of the foregoing, the one or more components of the climate system includes at least one of a chiller, and pump, and an air handling unit.

50 **[0018]** In a further example of any of the foregoing, the current aspect of the climate in the building is the current air temperature inside the building. The set point for the aspect is a temperature set point.

[0019] In a further example of any of the foregoing, the one or more operating variables includes a temperature of conditioned air from an air handling unit.

55 **[0020]** In a further example of any of the foregoing, the one or more components of the climate system includes at least one of a chiller, and pump, and an air handling unit.

[0021] In a further example of any of the foregoing, the one or more operating variables includes a temperature of conditioned air from an air handling unit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Certain exemplary embodiments will now be described in greater detail by way of example only and with reference to the accompanying drawings in which:

- Figure 1a schematically shows a building with a climate system;
- Figure 1b schematically shows the building of Figure 1a with multiple climate zones; and
- Figure 2 schematically shows a method for controlling the climate of the building of Figures 1a-b.

DETAILED DESCRIPTION

[0023] Figure 1 schematically illustrates an example climate system 20 for a building 18. The climate system 20 includes one or more chillers 22. The chiller 22 can be any known type of chiller. Though one chiller 22 is shown in Figure 1, it should be understood the climate system 20 can include more than one chiller 22. The chiller 22 includes a chiller controller 24. The chiller 22 is operable to chill water for cooling the building. One or more pumps 26 pump chilled water from the chiller 22 to one or more air handling units 28 which utilize the chilled water to cool air for the building 18. Though one pump 26 and one air handling unit 28 are shown in Figure 1a, it should be understood that the climate system 20 can include more pumps 26 and/or more air handling units 28. For example, the building 18 may include an air handling unit 28 on each level. The pump 26 and air handling unit 28 also include controllers 30, 32 (respectively). Though the example climate system 20 includes chiller 22, pump 26, and air handling unit 28, other climate systems 20 can include other components as would be known in the art.

[0024] Each of the chiller 22, the pump 26, and the air handling unit 28 can include one or more electrical sub-components 36, as would be known in the art. For instance, the air handling unit 28 can include one or more motors, heat exchangers, dehumidifiers, etc. that enable the air handling unit 28 to condition air, as are known in the art. The respective controllers 24, 30, 32 are operable to control these sub-components 36.

[0025] The climate system 20 also includes a climate system controller 34. The chiller controller 24, pump controller 30, and air handling unit controller 32 are operable to communicate with the climate system controller 34. The climate system controller 34 is also operable to communicate with an electrical power source, which is in some examples an electrical grid, and a thermal power source, such as a gas utility. The subcomponents 36 of the chiller 22, pump 26, and air handling units 28 utilize electrical power and/or thermal power, and the climate system controller 34 controls distribution of electrical/thermal power to the chiller 22, pump 26, and air handling units 28. The climate system controller 34 is also operable to control the operation of the chiller 22, pump 26, and air handling units 28 via their respective controllers 24, 30, 32 to control the climate in the building 18. Each of the controllers discussed herein includes a computing device such as a processor and/or electronics which are programmed so that the controllers are operable to perform as discussed herein. Furthermore, the controllers discussed herein may include automatic PID (proportional integral derivative) capability, which utilizes a control loop feedback mechanism to control processes and variables, as is known in the art.

[0026] Figure 1b shows an example building 18 with three zones Zone 1, Zone 2, and Zone 3. Each zone includes an air handling unit 28 (AHU). In one example, the air handling units 28 in each zone acts in concert to cumulatively effect the temperature of air in the building 18. In another example, individual air handling units 28 serve their respective zones of the building 18. A zone may be defined as a level of the building 18, a room of a building 18, or in another way. In some examples, each zone has its own climate requirements. The air handling units 28 in each zone are in communication with the climate system controller 34. In this example, each zone has a temperature sensor 44 and an interface 46 (discussed in more detail below).

[0027] Various aspects of the building 18 climate are affected by the climate system 34. For example, the temperature of air inside the building, the humidity of air inside the building 18, the temperature of water in the building 18, or other parameters as would be apparent to one of ordinary skill in the art. Though the subsequent disclosure is made with respect to the temperature inside the building 18 for exemplary purposes, it should be understood this disclosure is applicable to any aspect of building 18 climate.

[0028] With respect to the temperature inside the building 18, the air handling units 28 receive air from an air supply 38, which in some examples draws or mixes air from outside the building 18. The air handling units 28 condition (e.g., cool or heat) the air from the air supply 38 via the sub-components 36 such as heat exchangers as is known in the art. For example, a heat exchanger in the air handling units 28 can cool air using cooled water provided by pump 26 from chiller 22 as discussed above. As another example, a heat exchanger in the air handling units 28 can heat air using thermal energy from the thermal energy source.

[0029] The air handling units 28 provide the conditioned air to the building 18 via conduits 40 which are connected to vents 42 throughout the building 18. The air handling unit controller 32 is configured to control its respective air handling unit 28 to provide a selected flowrate and temperature to the building 18 via vents 42 to affect the temperature of air inside the building 18 air. For instance, to cool air inside building 18, the air handling unit 28 provides conditioned air

that is colder than the air inside the building 18. To heat air inside building 18, the air handling unit 28 provides conditioned air that is hotter than the air inside the building 18. The flowrate of conditioned air provided by the air handling units 28 is inversely related to the temperature, as will be discussed in more detail below.

[0030] More particularly, the building 18 has a selected air temperature T_{selected} (also known as a set point). The set point can be predetermined and programmed in to the air handling unit controllers 32 and/or climate system controller 34. The set point can change over time. In some examples, a temperature is predetermined according to the time of day. For instance, a temperature during times of building 18 high occupancy can be predetermined to accommodate occupant comfort. A temperature during times of low or no occupancy can be predetermined to reduce energy consumption of the climate system 20. In another example, the selected air temperature can be input by a user in the building 18 via an interface 46, e.g., a thermostat, in the building 18, and communicated to the air handling unit controller 32 directly or via the climate system controller 34. As shown in Figure 2, in one example, each zone includes an interface 46, and the interface 46 in each zone is in communication with the air handling unit controller 32 in that zone and/or the climate system controller 34. In another example, the selected air temperature is selected by the climate system controller 34 based on occupant comfort requirements (either predetermined, inputted, or self-learned) and information from the electrical power source. In yet another example, the set point is selected according to any combination of the preceding examples. T_{selected} may vary in each zone to accommodate the use of the individual zone and position in the building (e.g. zones exposed to direct sunlight).

[0031] The building also has a current air temperature T_{current} . The current air temperature T_{current} can be provided directly to the climate system controller 34 from a temperature sensor 46 in the building 18. As shown in Figure 2, in one example, each zone includes a sensor 44, and the sensor 44 in each zone is in communication with the air handling unit controller 32 in that zone and/or the climate system controller 34.

[0032] The climate system controller 34 is configured to direct the air handling unit controllers 32 to operate the air handling units 28 in order to bring the current temperature in the building 18 T_{current} towards the temperature set point T_{selected} according to the method 200, shown in Figure 2. As discussed above, the air handling units 28 can either act in concert or can act individually according to the climate requirements of particular zones.

[0033] Turning now to Figure 2, in step 202, the method 200 starts. In some examples, the method 200 starts automatically, or without any user input. In other examples, the method 200 can start at predetermined times. In other examples, the method 200 can proceed continuously.

[0034] In step 204, the climate system controller 34 determines a difference ΔT_i between the temperature set point T_{selected} and a current air temperature T_{current} in one or more zones of building 18. Depending on the difference ΔT_i , the climate system controller 34 determines whether cooling or heating is required for each zone of building 18.

[0035] In step 206, the climate system controller 34 sums the ΔT_i for each zone of the building 18 that requires heating to provide an aggregate ΔT_{heat} for the building 18 according to Equation 1, where n_{heat} is the number of zones in the building 18 that require heating:

$$\Delta T_{\text{heat}} = \frac{\sum_{i=1}^{n_{\text{heat}}} \Delta T_i}{n_{\text{heat}}}$$

[0036] In step 206, the climate system controller 34 also sums the ΔT_i for each zone of the building 18 that requires cooling to provide an aggregate ΔT_{cool} for the building 18 according to Equation 2, where n_{cool} is the number of zones in the building 18 that require cooling:

$$\Delta T_{\text{cool}} = \frac{\sum_{i=1}^{n_{\text{cool}}} \Delta T_i}{n_{\text{cool}}}$$

[0037] The aggregate ΔT_{heat} and ΔT_{cool} are related to an electrical/thermal power demand for the building 18. That is, the larger aggregate ΔT_{heat} and ΔT_{cool} , the more electrical/thermal power will be required to operate the components of the climate system 20 to bring the current temperature in the building (or in individual zones) 18 T_{current} towards the temperature set point T_{selected} .

[0038] Each component of the building 18 includes various outputs which have controllable variables. For instance, the air handling unit 28 outputs air, which has controllable variables of target conditioned air temperature and flowrate. As another example, the chiller 22 outputs cooled water, which has a controllable variable of cooled water temperature. As a third example, the pump 26 outputs water, which has a controllable variable of water pressure. The outputs also depend on the heating or cooling mode selected for the components in the zones of the building 18. For instance, during

warm months, the building 18 components may be in a cooling mode that is associated with certain building 18 components and their respective outputs/controllable variables, and during cold months, the building 18 components may be in a heating mode that is associated with certain building 18 components and their respective outputs/controllable variables. In another example, the components may be configured to operate in multiple heating or cooling modes.

[0039] The direction from the climate system controller 34 can include the target set points for these variables. In another example, the direction from the climate system controller 34 includes information such that the respective controllers 24, 30, 32 can select the set points for the variables based on the information.

[0040] For any variable V, the set point V_{sp} is defined at a time (t) according to Equation 3, where τ_s is sampling time, and K_p and α are tuneable parameters for optimizing control of the climate system 20.

$$V_{sp}(t) = V_{sp}(t-1) + \frac{\Delta T(t) - \Delta T(t-1)}{\tau_s \alpha} + \frac{K_p}{\alpha} \Delta T(t)$$

[0041] In one example, the sampling time τ_s is selected according to Equation 4:

$$\tau_s \geq \left\lceil 0.5 \frac{V_{building} \rho}{m_{\dot{max}}} \right\rceil$$

where $m_{\dot{max}}$ is the maximum flowrate of air into the building 18 from vents 42.

[0042] The parameter K_p is a proportional correction parameter, e.g., it is related to the amount of correction, or change, that will result in V_{sp} at time t as compared to V_{sp} at time t-1. In other words, K_p is related to the speed at which variable V is changed in order to bring the current temperature in the building 18 $T_{current}$ towards the temperature set point $T_{selected}$. More particularly, K_p is related to an acceptable error for control of the building 18 climate. If occupant discomfort is high, more error is acceptable, and K_p is higher so that the amount of correction is larger, and in turn, $T_{current}$ is more quickly brought towards the temperature set point $T_{selected}$. In this example, K_p is calculated according to Equation 5:

$$K_p = \frac{1 - \lambda}{\lambda * \tau_s}$$

where λ is a parameter capturing the % error at steady-state for the building 18 climate. For example, if an error of 5% is acceptable, $\lambda = 0.05$. If less error is acceptable, λ is a lower value. However, in other examples, λ can be expressed as a first or second order model for error, as is known in the art.

[0043] When occupant comfort is met, e.g., $T_{current}$ is the same as or very close to $T_{selected}$, the sampling time τ_s can be tuned, as will be discussed in more detail below. The sampling time τ_s is defined according to Equation 6:

$$\tau_s \geq \left\lceil 0.5 \frac{V_{building} \rho}{m_{\dot{min}}} \right\rceil$$

where $V_{building}$, ρ , and $m_{\dot{min}}$ are known parameters related to the physical characteristics of building 18. $V_{building}$ is the total volume of the building 18, ρ is the density of air inside the building 18, and $m_{\dot{min}}$ is the minimum flowrate of air into the building 18 from vents 42.

[0044] As shown above in Equation 5, the parameter K_p depends on the sampling time τ_s . Therefore, if a new sampling time τ_s is defined according to the tuning, a new parameter K_p can result as well.

[0045] In another example, τ_s is a continuously adaptive parameter that is calculated continuously by the climate system controller 34 according to Equation 7:

$$\tau_s \geq \left\lceil 0.5 \frac{V_{building} \rho}{m_{\dot{measured}}} \right\rceil$$

where $m_{\dot{measured}}$ is the current delivered flowrate of air into the building 18 from vents 42, which can be provided to the climate system controller via sensors or monitors at one or more of the vents 34.

[0046] The parameter α is a sizing parameter that is applied so that the temperature values in Equation 3 above are on at the same or similar orders of magnitude. For instance, $\Delta T(t)$ may be on the order of 0-5 degrees Celsius, whereas

$V_{sp}(t)$ where the variable V is air handling unit 28 output temperature is 20-30 degrees Celcius. In this example, α can be selected to be 0.1.

[0047] In step 208, the set point for one or more variables V are determined according to Equation 3. As discussed above, the set point for the variable V can be determined by the climate system controller 34 and communicated to the controllers 24, 30, 32. In another example the set point for the variable V is determined by the controllers 24, 30, 32 based on information from the climate system controller 34.

[0048] In step 210, the tuneable parameters K_p and α which are taken into account for variable set point determination in Equation 3 are tuned in real time using dynamic information about the climate system 20. For instance, new τ_s values are selected based on occupant comfort/discomfort as discussed above, or updated as in Equation 7 above based on information from the sensors or monitors at vents 42. In turn, the parameter K_p can be updated when a new τ_s value is selected as discussed above. In one example, tuning is achieved by PID at the controllers 24, 30, 32, as discussed above. In a more particular example, the PID control problem is in a velocity form, meaning that the rate of change is explicitly taken into account.

[0049] The method 200 continuously performs step 208 as the tuneable parameters are tuned in step 210.

[0050] In step 212, the controllers 24, 30, 32 operate their respective components according to variable V set points to bring the current temperature in the building 18 $T_{current}$ towards the temperature set point $T_{selected}$.

[0051] The method 200 then returns to step 204.

[0052] The quantification of set points for variables V allows for fast response of the climate system 20 when a new temperature set point $T_{selected}$ is selected because the variable V set point is continually updated as the method 200 repeats. As the climate system 20 operates, there may be a lag before $T_{current}$ meets the temperature set point $T_{selected}$ as the $T_{current}$ approaches the temperature set point $T_{selected}$. The continual updating of the variable V takes into account this lag, and avoids overshooting the temperature set point $T_{selected}$. This in turn leads to more efficient use of the electrical/thermal power by the climate system 20 and reduces the possibility of occupant discomfort in building 18 (e.g., due to overshoot from the desired temperature set point $T_{selected}$). Furthermore, other than defining the temperature set point $T_{selected}$ in some examples (as discussed above) no other user input is required for tuning the control of the climate system 20.

[0053] Furthermore, it should be understood that the preceding method is applicable to control the climate system 20 to meet building set points other than temperature set point $T_{selected}$. For example, the preceding method can also be used to control the climate system 20 to meet an air humidity set point, building air pressure set points, building water set points (e.g., temperature, flowrate, etc.), or other set points.

[0054] The preceding description is exemplary rather than limiting in nature. Variations and modifications to the disclosed examples may become apparent to those skilled in the art that do not necessarily depart from the essence of this disclosure. The scope of legal protection given to this disclosure can only be determined by studying the following claims.

Claims

1. A method of controlling the climate of a building (18), comprising:

determining (204) a difference between a current aspect of a climate in a building and a set point for the aspect of climate in the building for one or more zones of the building;
summing (206) the differences at a climate system controller (34); and
determining (208) a set point for one or more operating variables of one or more components of a climate system (20) in the building based on the sum of the differences.

2. The method of claim 1, wherein the step of determining (208) the set points for the one or more operating variables is based on one or more tunable parameters.

3. The method of claim 2, further comprising tuning (210) the one or more tunable parameters based on real-time dynamic information about the climate system (20).

4. The method of claim 1, 2 or 3, wherein the current aspect of the climate in the building (18) is the current air temperature inside the building and wherein the set point for the aspect is a temperature set point.

5. The method of any preceding claim, wherein the one or more operating variables includes a temperature of conditioned air from an air handling unit (28).

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6. The method of any preceding claim, wherein the one or more components of the climate system (20) includes at least one of a chiller (22), and pump (26), and an air handling unit (28).
7. A climate system (20) for a building (18), comprising:
a computing device configured to determine a difference between a current aspect of a climate in a building and a set point for the aspect of climate in the building for one or more zones in the building, sum the differences, and determine a set point for one or more operating variables of one or more components of a climate system in the building based on the sum of the differences.
8. The climate system (20) of claim 7, wherein the computing device is a climate system controller (34).
9. The climate system (20) of claim 7 or 8, wherein the computing device includes a first computing device configured to determine a difference between a current aspect of a climate in a building (18) and a set point for the aspect of climate in the building and sum the differences.
10. The climate system (20) of claim 9, wherein the computing device includes a second computing device configured to determine a set point for one or more operating variables of one or more components of a climate system in the building (18) based on the sum of the differences, optionally, wherein the first computing device is a climate system controller (34) and the second computing device is a controller (24, 30, 32) of the one or more components of the climate system.
11. The climate system (20) of any of claims 7 to 10, wherein the computing device is configured to determine the set points for the one or more operating variables based on one or more tunable parameters.
12. The climate system (20) of claim 11, wherein the computing device is configured to tune the one or more tunable parameters based on real-time dynamic information about the climate system, optionally, wherein the real-time dynamic information about the climate system is provided to the computing device by one or more sensors (44) in the building (18).
13. The climate system (20) of any of claims 7 to 12, wherein the current aspect of the climate in the building (18) is the current air temperature inside the building and wherein the set point for the aspect is a temperature set point.
14. The climate system (20) of claim 13, wherein the one or more operating variables includes a temperature of conditioned air from an air handling unit (28).
15. The climate system (20) of any of claims 8 to 13, wherein the one or more components of the climate system includes at least one of a chiller (22), a pump (26), and an air handling unit (28), optionally, wherein the one or more operating variables includes a temperature of conditioned air from an air handling unit (28).

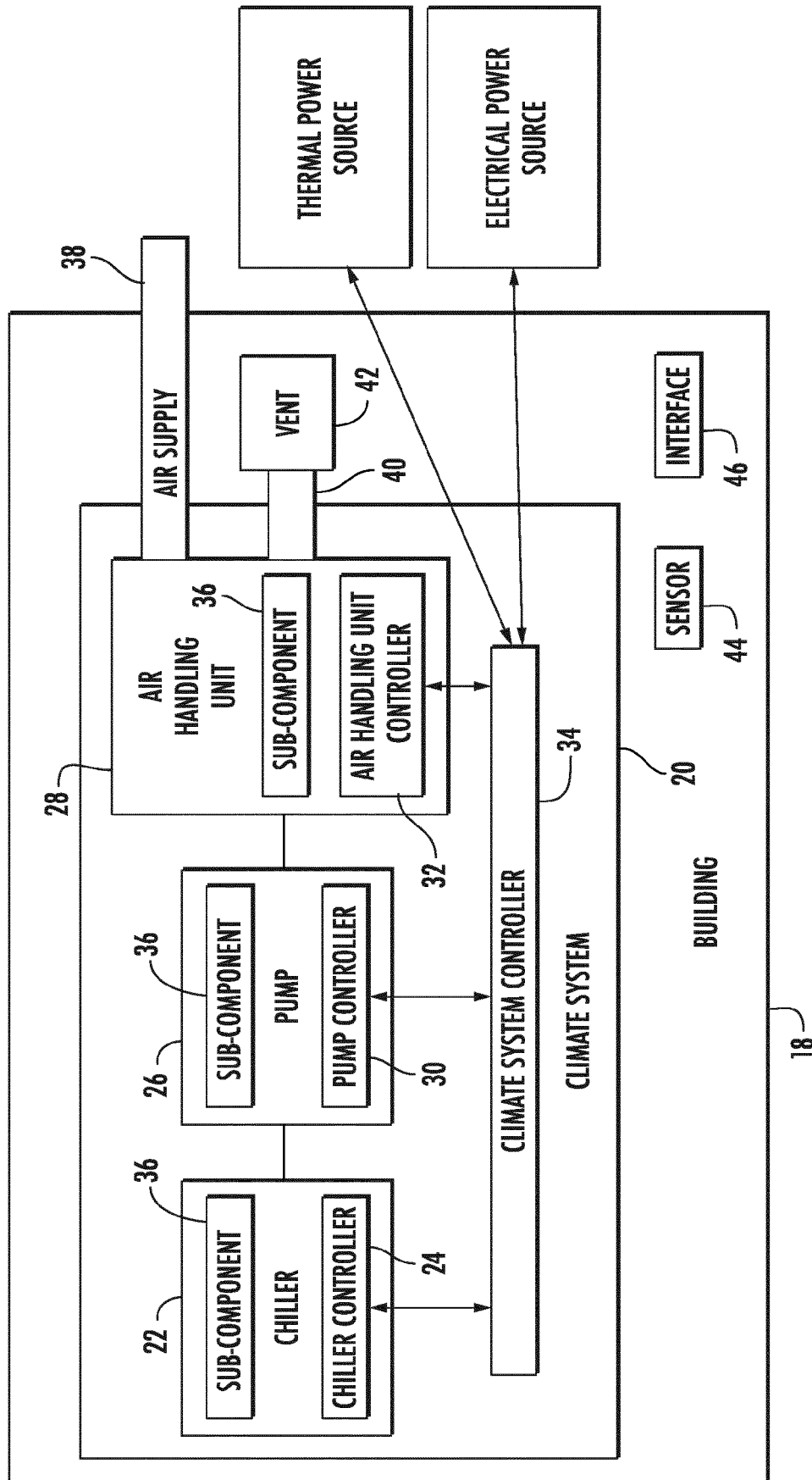


FIG. 1A

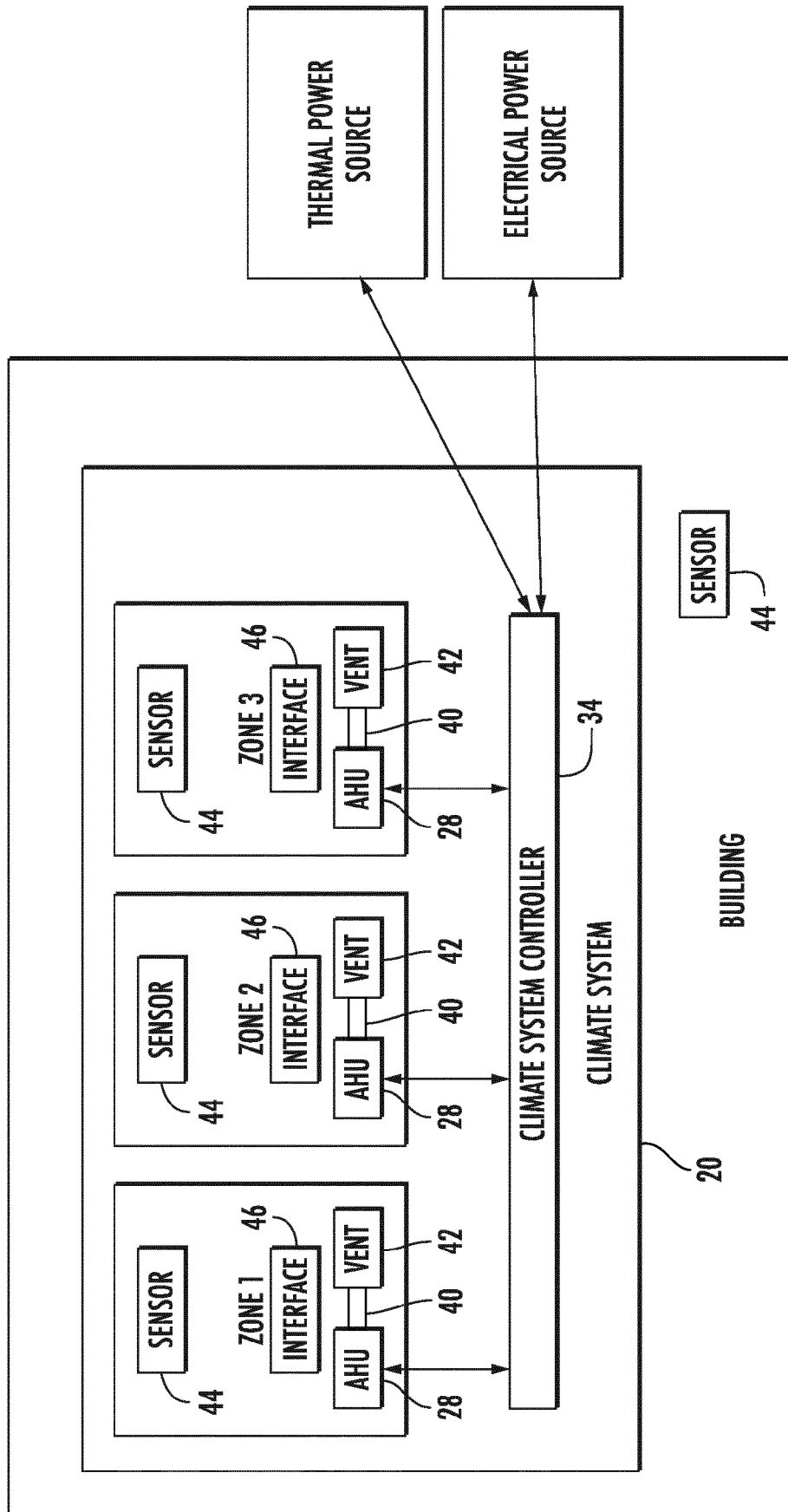


FIG. 1B

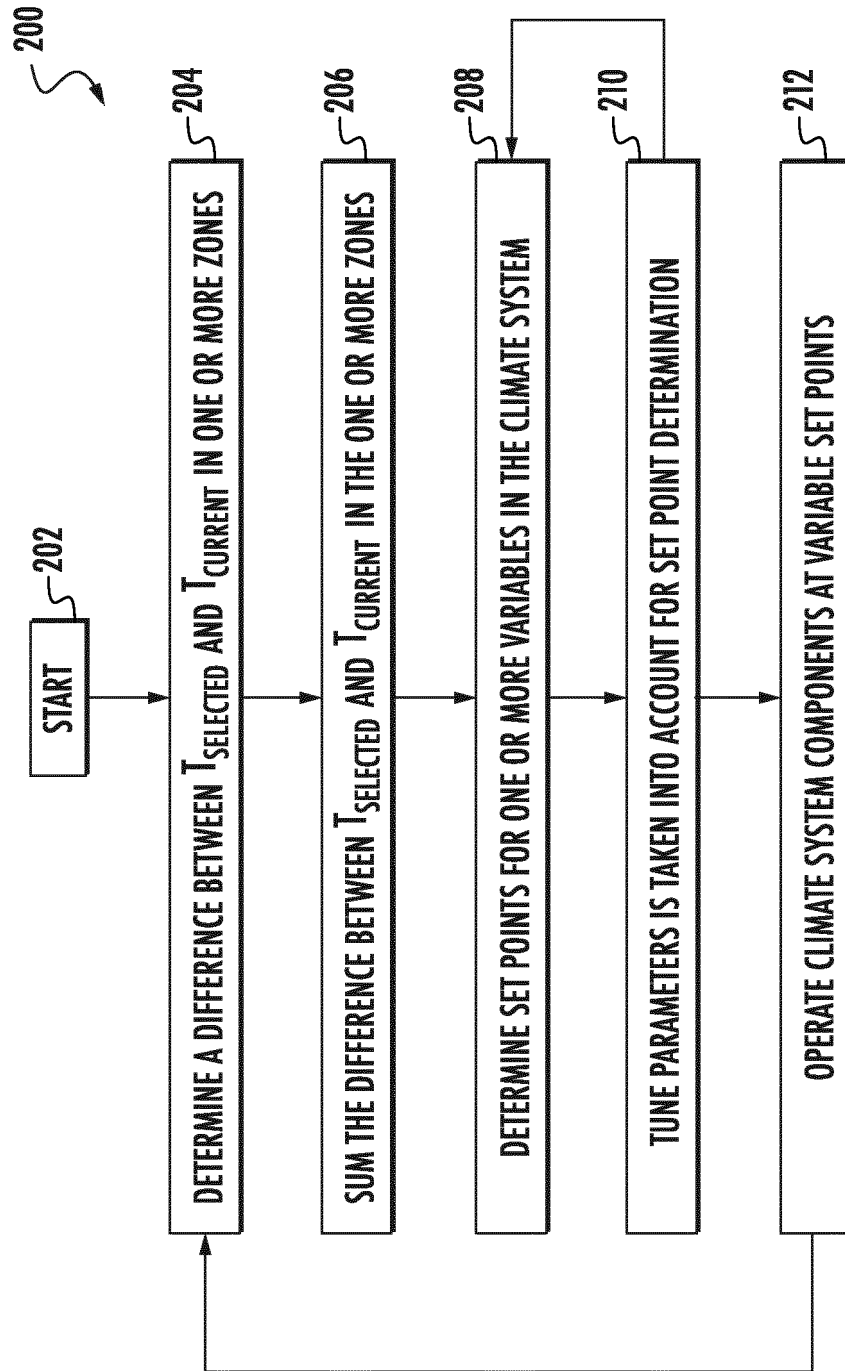


FIG. 2



EUROPEAN SEARCH REPORT

Application Number
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EPO FORM 1503 03.82 (P04C01)

DOCUMENTS CONSIDERED TO BE RELEVANT			
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 28 August 2020	Examiner Silex, Anna
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 20 17 1162

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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