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Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

[Continued on next page]

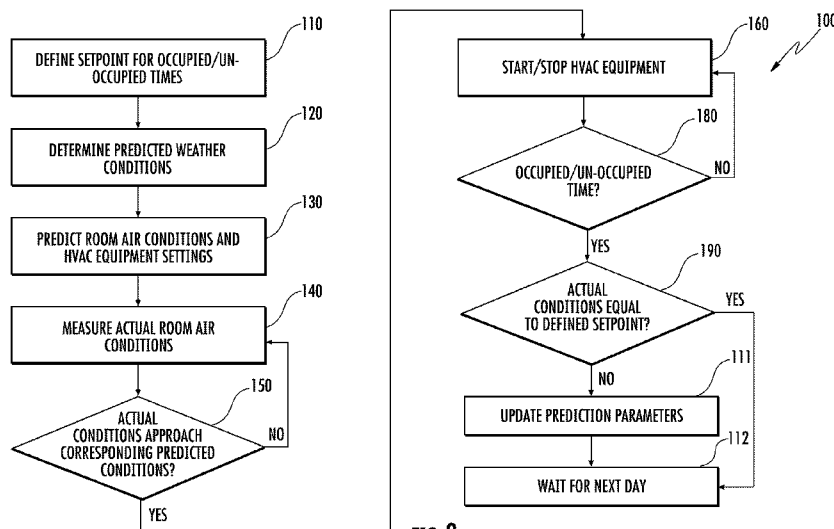
(54) **Title:** HVAC SYSTEM START/STOP CONTROL

FIG. 3

(57) **Abstract:** A control system for an HVAC system having at least one HVAC component, the control system comprising: a controller having a processor and a memory, the controller in signal communication with the at least one HVAC component, the controller configured to: determine a startup/shut-down setpoint and the time associated with a beginning or an end of a building occupancy period; determine a predicted weather condition for outside air at a location of the HVAC system; predict a set of indoor air conditions over the period from the current time until the building being occupied/unoccupied based on the determined setpoint and time and the predicted weather condition; and start/stop the at least one HVAC component when an actual room air condition approaches the predicted indoor air condition.



— *of inventorship (Rule 4.17(iv))*

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HVAC SYSTEM START/STOP CONTROL

TECHNICAL FIELD

[0001] The subject matter disclosed herein relates to HVAC systems and, more specifically, to control of HVAC system equipment.

BACKGROUND

[0002] Existing start/stop strategies for heating, ventilation, and air conditioning (HVAC) systems are based on fixed start/stop schedules, gradient methods, and unoccupied setpoint adjustment methods. These strategies estimate the start/stop times for an HVAC system required to meet comfort conditions at the beginning and end of daily building occupancy. The gradient method predicts the required start time for the HVAC system based on a single linear approximation of the indoor temperature, at the beginning or end of the occupancy period. An example of the gradient method is described in U.S. Pat. Nos. 4,660,759 and 4,106,690. The setpoint adjustment method regularly updates the unoccupied setpoints of the HVAC system to reach the required comfort setpoint at the beginning or end of the occupancy period. An example of the setpoint method is described in U.S. Pat. No. 1,463,988. However, these methods do not take into account zone and outdoor air temperatures forecasting or HVAC equipment efficiency, which may result in comfort violations and increase energy usage.

[0003] Accordingly, it is desirable to provide a control system to improve HVAC system efficiency and maintain building comfort levels.

BRIEF DESCRIPTION

[0004] In one embodiment, a control system for an HVAC system having at least one HVAC component is disclosed. The control system comprises a controller having a processor and a memory, the controller in signal communication with the at least one HVAC component, the controller configured to: determine a first setpoint and a first time associated with a beginning of a building occupancy period; determine a predicted weather condition for outside air at a location of the HVAC system; predict a first indoor air condition based on the determined first setpoint and time and the predicted weather condition; and start the at least one HVAC component when an actual room air condition approaches the first predicted indoor air condition.

[0005] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the first setpoint is one or more condition of air supplied to a zone.

[0006] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the one or more condition includes at least one of a temperature, a humidity, and a CO₂ level of the air supplied to the zone.

[0007] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the one or more condition includes a temperature, a humidity, and a CO₂ level of the air supplied to the zone.

[0008] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the controller is further configured to: determine a second setpoint and a second time associated with an end of the building occupancy period; predict a second indoor air condition based on the determined second setpoint and time and the predicted weather condition; and shutdown the at least one HVAC component when the actual room air condition approaches the predicted second indoor air condition.

[0009] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the at least one HVAC component is a capacity generation plant, an air handling unit, and at least one terminal unit.

[0010] In another embodiment, an HVAC system comprises at least one HVAC component and a controller in signal communication with the at least one HVAC component. The controller includes a processor and a memory and is configured to determine a first setpoint and a first time associated with a beginning of a building occupancy period; determine a predicted weather condition for outside air at a location of the HVAC system; predict a first indoor air condition based on the determined first setpoint and time and the predicted weather condition; and start the at least one HVAC component when an actual room air condition approaches the first predicted indoor air condition.

[0011] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the controller is configured to update the operational setpoints at predetermined time intervals.

[0012] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the first setpoint is one or more condition of air supplied to a zone.

[0013] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the one or more condition includes at least one of a temperature, a humidity, and a CO₂ level of the air supplied to the zone.

[0014] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the one or more condition includes a temperature, a humidity, and a CO₂ level of the air supplied to the zone.

[0015] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the controller is further configured to determine a second setpoint and a second time associated with an end of the building occupancy period; predict a second indoor air condition based on the determined second setpoint and time and the predicted weather condition; and shutdown the at least one HVAC component when the actual room air condition approaches the predicted second indoor air condition.

[0016] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the at least one HVAC component is a capacity generation plant, an air handling unit, and at least one terminal unit.

[0017] In another embodiment, a method of controlling an HVAC system having at least one HVAC component is disclosed. A controller is in signal communication with the at least one HVAC component. The method comprises determining a first setpoint and a first time associated with a beginning of a building occupancy period; determining a predicted weather condition for outside air at a location of the HVAC system; predicting a first indoor air condition based on the determined first setpoint and time and the predicted weather condition; and starting the at least one HVAC component when an actual room air condition approaches the first predicted indoor air condition.

[0018] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the first setpoint is one or more condition of air supplied to a zone.

[0019] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the one or more condition includes at least one of a temperature, a humidity, and a CO₂ level of the air supplied to the zone.

[0020] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the one or more condition includes a temperature, a humidity, and a CO₂ level of the air supplied to the zone.

[0021] In addition to one or more of the features described above, or as an alternative, the method may further include determining a second setpoint and a second time associated with an end of the building occupancy period; predicting a second indoor air condition based on the determined second setpoint and time and the predicted weather condition; and shutting down the at least one HVAC component when the actual room air condition approaches the predicted second indoor air condition.

[0022] In addition to one or more of the features described above, or as an alternative, further embodiments may include configurations wherein the at least one HVAC component is a capacity generation plant, an air handling unit, and at least one terminal unit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] The foregoing and other features, and advantages of embodiments are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

[0024] FIG. 1 is a schematic view of an exemplary HVAC system;

[0025] FIG. 2 is a schematic illustration of an exemplary operation of the system shown in FIG. 1; and

[0026] FIG. 3 is a flow chart illustrating an exemplary method of controlling the system shown in FIG. 1.

DETAILED DESCRIPTION

[0027] FIG. 1 illustrates an exemplary HVAC system 10 that generally includes HVAC equipment such as a capacity generation plant 12, an air handling unit (AHU) 14, one or more terminal units 16, and a controller 18. Capacity generation plant 12 conditions (i.e., heats/cools) a heat transfer fluid such as water and supplies the conditioned fluid to AHU 14 and terminal units 16 via a supply conduit 20. The conditioned fluid is utilized to condition air forced through AHU 14 and terminal units 16. The conditioned air is then used to adjust the temperature of a building or structure associated with HVAC system 10. The fluid is returned to capacity generation plant 12 via a return conduit 24 where the fluid is re-conditioned. Controller 18 is configured to predict and implement a start/stop time of HVAC system equipment (e.g., capacity generation plant 12, AHU 14, and terminal units 16) to meet a desired comfort at the beginning and end of daily building occupancy, which reduces energy consumption and improves system efficiency.

[0028] Capacity generation plant 12 may be, for example a heat pump, a chiller, or a boiler. However, capacity generation plant 12 may be any type of capacity generation plant that enables HVAC system 10 to function as described herein. Capacity generation plant 12 is configured to heat or cool a heat transfer fluid (e.g., water) to facilitate environmental conditioning of the building. As such, capacity generation plant 12 may be controlled to selectively adjust the temperature of the heat transfer fluid.

[0029] AHU 14 is configured to receive outside air and supply the outside air to the one or more terminal units 16, which condition the air and supply it to the zone(s) or area(s) associated with the respective terminal unit(s) 16. The conditioned air is subsequently returned to AHU 14 where it may be recycled or exhausted to the atmosphere. In the illustrated embodiment, terminal units 16 are fan coil units. However, terminal units 16 may be any suitable equipment that enables HVAC system 10 to function as described herein. For example, terminal units 16 may be fan coil units (FCUs), air terminal units (ATUs), variable air volume systems (VAV), or even AHUs.

[0030] Controller 18 may be a system-level controller configured to adjust the start/stop operation of the HVAC equipment, such as capacity generation plant 12, AHU 14, and terminal units 16, based on predicted environmental conditions and predetermined building comfort property setpoints, as is described herein in more detail. As used herein, the term controller refers to an application specific integrated circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that executes one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality.

[0031] In the exemplary embodiment, controller 18 is in signal communication with the HVAC equipment whose start/stop operation will be controlled. In the illustrated embodiment, controller 18 is in signal communication with capacity generation plant 12, AHU 14, and terminal unit 16. In the exemplary embodiment, each day the HVAC equipment may be started to provide thermal conditioning of the building before or when occupants arrive. The HVAC equipment may then be shut down before or when the occupants leave the building and the thermal conditioning is not required. As such, controller 18 controls the start/stop time of the HVAC equipment to respect user comfort during occupied time, while conserving energy and increasing system efficiency. In the exemplary embodiment, controller 18 controls the start/stop time of equipment 12, 14, 16 based on a first input (Input 1), a second input (Input 2) and a third input (Input 3).

[0032] Input 1 is a predetermined setpoint (i.e., condition) to be reached in one or more zones of the building at a predetermined time. The predetermined setpoint may include a predetermined temperature, humidity, and/or CO₂ level of the air supplied to the zones. The predetermined setpoint represents the building comfort condition. The predetermined setpoint may be evaluated based on a single zone setpoint as a reference zone (that represents the whole building condition) or using fusion method for many zone setpoints (for example, average or weighted average based on each zone area). For example, Input 1 may be a predetermined setpoint room temperature of 72 °F at 8:00 a.m. and a room temperature of 70 °F at 6:00 p.m. The predetermined setpoint may be input into controller 18 by an authorized user or by building management system (BMS).

[0033] Input 2 is a predicted weather forecast of the outside air that the building will utilize to condition the zones. For example, the predicted weather conditions may be the predicted weather conditions at the building's location for the following day. The predicted weather conditions may include a predicted temperature, humidity, and/or CO₂ level of the air at that building location.

[0034] Input 3 is a measured comfort condition. The comfort condition may include one or more of temperature, humidity, and/or CO₂ level for one or many zones. The measured comfort condition represents the current building comfort condition. Similar to Input 1, measured comfort condition may be measured for a single zone as a reference zone (that represents the whole building condition) or based on fusion method for many zone conditions (for example, average or weighted average based on each zone area). The measured comfort condition may be input into controller 18 by each FCU sensors or by building management system (BMS).

[0035] FIG. 2 illustrates a graphical representation of the building temperature over time. The graph illustrates a startup period 40 of the HVAC equipment, an occupied period 42 when the building is generally occupied, and a shutdown period 44 of the HVAC equipment.

[0036] Controller 18 subsequently predicts the indoor air temperature, humidity, and/or CO₂ in the zones based on successive linear approximations of the temperature, humidity, and/or CO₂ (Input 1) and the predicted weather conditions (Input 2). The successive linear approximations are illustrated by Line A in FIG. 2. Controller 18 monitors the actual room air conditions in the zones (Input 3), and the HVAC equipment 12, 14, 16 is started or shut down when the actual indoor temperature, humidity, and/or CO₂ measurements (Line B) reach or approach the predicted conditions (Line A). For example, the HVAC equipment is started at Point C, where the actual measurement (Line B) approaches the predicted

conditions (Line A). Similarly, the HVAC equipment is shut down at Point D, where the actual measurement (Line B) approaches the predicted conditions (Line A).

[0037] Controller 18 uses backward prediction model for the indoor condition. The backward prediction model may use predetermined setpoint target for the occupied or unoccupied time as the starting point of the prediction and the weather forecast for a day prior to the occupied or unoccupied time. The predicted indoor condition may be calculated for one or many backward step(s), for example each step may be for 15 mins (Line A). The predicted condition of one step (i.e., prediction model output) may be the input of the next step. Backward prediction model uses one or more parameter(s) that represent the building envelop and HVAC equipment characteristics.

[0038] Controller 18 schedules the HVAC equipment 12, 14, 16 operation settings, for example water flow, supplied water and supplied air setpoints, during the startup and shutdown periods to increase the equipment efficiency and minimize energy usage while meeting a predefined user comfort. The scheduling of the equipment settings uses a model (e.g., a model for improving efficiency). The model uses the predicted indoor condition and the predetermined setpoint as input, and then it determines the operation settings for one or more period(s) over the period from startup to occupied time or from shutdown to unoccupied time.

[0039] FIG. 3 illustrates an exemplary method 100 of controlling HVAC system 10 that begins at step 110, where controller 18 receives or determines setpoints and associated times for the zones (Input 1). At step 120, controller 18 receives or determines the predicted weather conditions (Input 2) such as for the following day.

[0040] At step 130, controller 18 predicts successive linear approximations of the room air conditions over time and the corresponding HVAC equipment settings based on Input 1 and Input 2. Controller 18 uses a backward prediction model to predict the indoor condition at the previous prediction step based the current indoor condition, the current forecasting weather condition and the building and HVAC equipment parameters. At the beginning, the controller 18 assumes that the current indoor condition is the zone setpoint and weather forecast at the beginning or end of occupied time. Then, controller 18 predicts what would be the indoor condition one step backward for example at the previous 15 min. The predicted indoor condition from this step will be used as the current indoor condition with the associated weather forecasting to predict the other previous step, and so on. Based on the difference between the targeted setpoint and the predicted indoor condition, the HVAC equipment setting is updated in the prediction model to maintain maximum equipment

efficiency. At step 140, controller 18 monitors or measures the actual room air conditions in the zones (Input 3).

[0041] At step 150, controller 18 determines to execute step 160 if the actual conditions approach the predicted condition, otherwise execute step 140. At step 160, controller 18 starts or stops one or more or all of the HVAC equipment 12, 14, 16 when the actual room air conditions reach the predicted linear approximations (prior to building occupancy/unoccupied). At step 180, controller 18 determines to execute step 190 if the occupied/un-occupied time is reached, otherwise execute step 160. At step 190, controller 18 determines to execute step 111 if actual condition at occupied/unoccupied time is not matched to the predicted conditions, otherwise controller 18 remains the prediction parameters for the next day at step 112. At step 111, controller 18 tunes the building and HVAC equipment parameters based on the difference between the targeted setpoint the actual indoor conditions.

[0042] Described herein are systems and methods for controlling HVAC system equipment such as a capacity generation plant, an AHU, and a terminal unit. The controller predicts start and stop times of the HVAC equipment based on a predetermined setpoint for a predetermined time, and predicted weather conditions for outside air at the location of the HVAC system. As such, the system provides a scalable optimal start/stop methodology that provides user comfort at the beginning and end of a building occupancy time, while increasing HVAC equipment efficiency.

[0043] While the disclosure has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the disclosure is not limited to such disclosed embodiments. Rather, the disclosure can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the disclosure. Additionally, while various embodiments have been described, it is to be understood that aspects of the disclosure may include only some of the described embodiments. Accordingly, the disclosure is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

CLAIMS:

What is claimed is:

1. A control system for an HVAC system having at least one HVAC component, the control system comprising:
 - a controller having a processor and a memory, the controller in signal communication with the at least one HVAC component, the controller configured to:
 - determine a first setpoint and a first time associated with a beginning of a building occupancy period;
 - determine a predicted weather condition for outside air at a location of the HVAC system;
 - predict a first indoor air condition based on the determined first setpoint and time and the predicted weather condition; and
 - start the at least one HVAC component when an actual room air condition approaches the first predicted indoor air condition.
2. The control system of claim 1, wherein the first setpoint is one or more conditions of air supplied to a zone.
3. The control system of claim 2, wherein the one or more conditions includes at least one of a temperature, a humidity, and a CO₂ level of the air supplied to the zone.
4. The control system of claim 2, wherein the one or more conditions includes a temperature, a humidity, and a CO₂ level of the air supplied to the zone.
5. The control system of claim 1, wherein the controller is further configured to:
 - determine a second setpoint and a second time associated with an end of the building occupancy period;
 - predict a second indoor air condition based on the determined second setpoint and time and the predicted weather condition; and
 - shutdown the at least one HVAC component when the actual room air condition approaches the predicted second indoor air condition.
6. The control system of claim 1, wherein the at least one HVAC component comprises a capacity generation plant, an air handling unit, and at least one terminal unit.
7. An HVAC system comprising:
 - at least one HVAC component;

a controller having a processor and a memory, the controller in signal communication with the at least one HVAC component, the controller configured to:

determine a first setpoint and a first time associated with a beginning of a building occupancy period;

determine a predicted weather condition for outside air at a location of the HVAC system;

predict a first indoor air condition based on the determined first setpoint and time and the predicted weather condition; and

start the at least one HVAC component when an actual room air condition approaches the first predicted indoor air condition

8. The HVAC system of claim 7, wherein the controller is configured to update the operational setpoints at predetermined time intervals.

9. The HVAC system of claim 7, wherein the first setpoint is one or more conditions of air supplied to a zone.

10. The HVAC system of claim 9, wherein the one or more conditions includes at least one of a temperature, a humidity, and a CO₂ level of the air supplied to the zone.

11. The HVAC system of claim 9, wherein the one or more conditions includes a temperature, a humidity, and a CO₂ level of the air supplied to the zone.

12. The HVAC system of claim 7, wherein the controller is further configured to:

determine a second setpoint and a second time associated with an end of the building occupancy period;

predict a second indoor air condition based on the determined second setpoint and time and the predicted weather condition; and

shutdown the at least one HVAC component when the actual room air condition approaches the predicted second indoor air condition.

13. The HVAC system of claim 7, wherein the at least one HVAC component comprises a capacity generation plant, an air handling unit, and at least one terminal unit.

14. A method of controlling an HVAC system having at least one HVAC component, and a controller in signal communication with the at least one HVAC component, the method comprising:

determining a first setpoint and a first time associated with a beginning of a building occupancy period;

determining a predicted weather condition for outside air at a location of the HVAC system;

predicting a first indoor air condition based on the determined first setpoint and time and the predicted weather condition; and

starting the at least one HVAC component when an actual room air condition approaches the first predicted indoor air condition.

15. The method of claim 14, wherein the first setpoint is one or more conditions of air supplied to a zone.

16. The method of claim 15, wherein the one or more conditions includes at least one of a temperature, a humidity, and a CO₂ level of the air supplied to the zone.

17. The method of claim 15, wherein the one or more conditions includes a temperature, a humidity, and a CO₂ level of the air supplied to the zone.

18. The method of claim 14, further comprising:

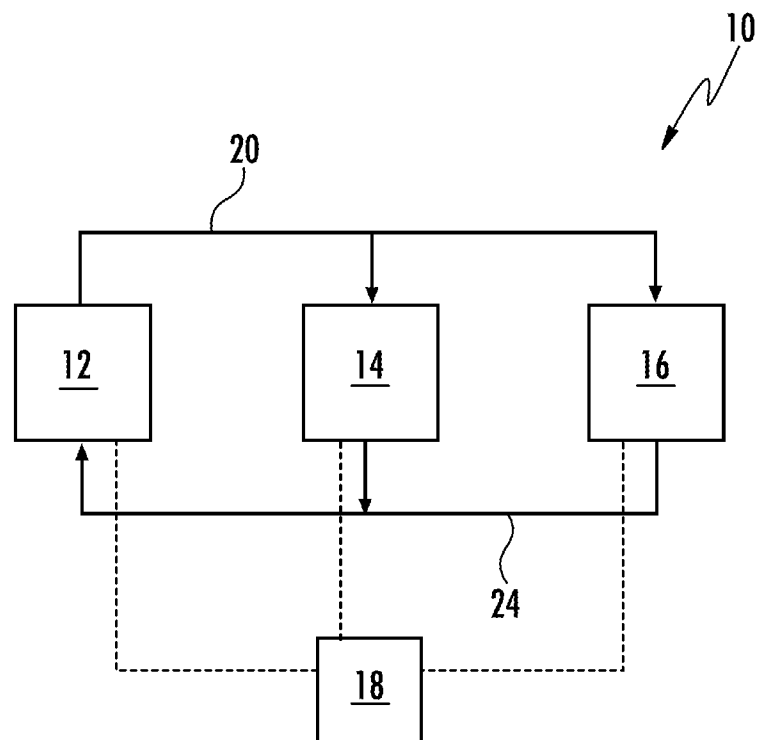
determining a second setpoint and a second time associated with an end of the building occupancy period;

predicting a second indoor air condition based on the determined second setpoint and time and the predicted weather condition; and

shutting down the at least one HVAC component when the actual room air condition approaches the predicted second indoor air condition.

19. The method of claim 14, wherein the at least one HVAC component comprises a capacity generation plant, an air handling unit, and at least one terminal unit.

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**FIG. 1**

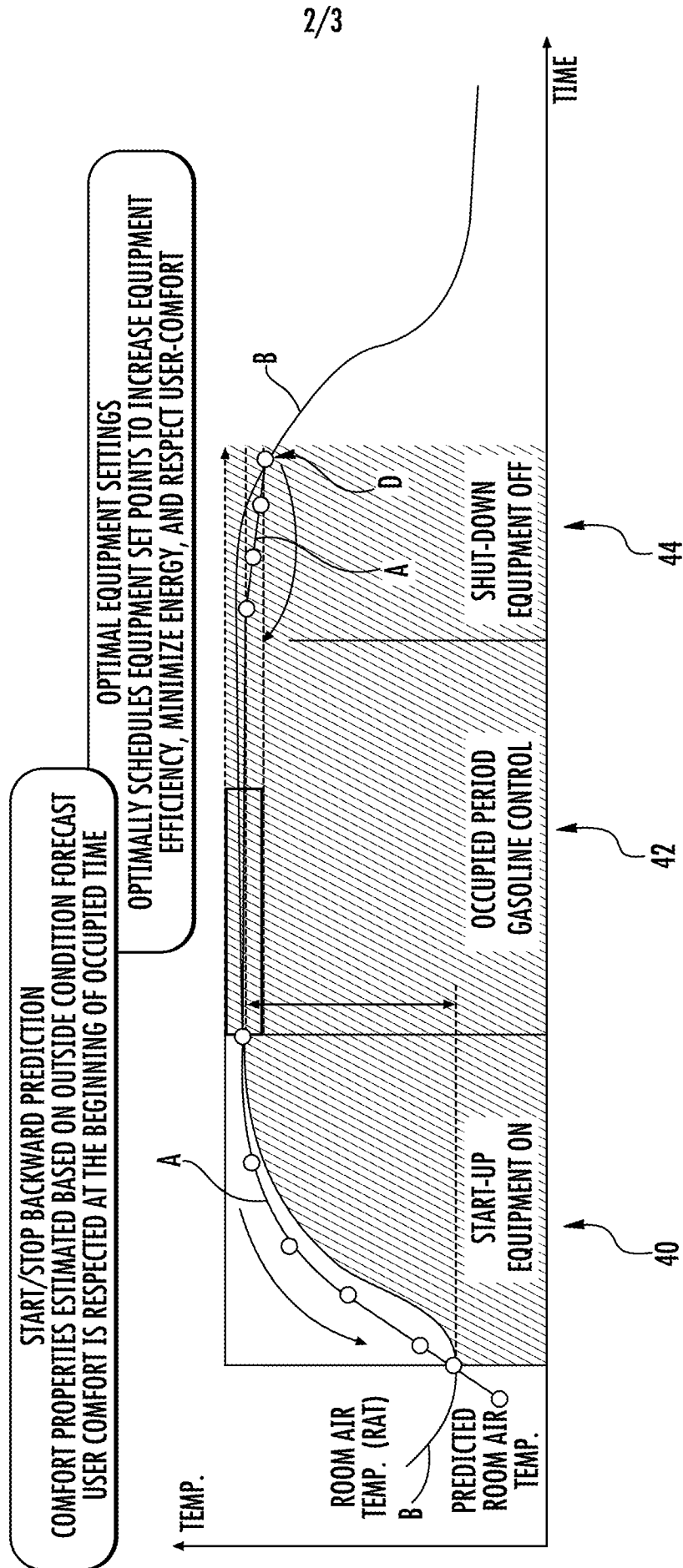


FIG. 2

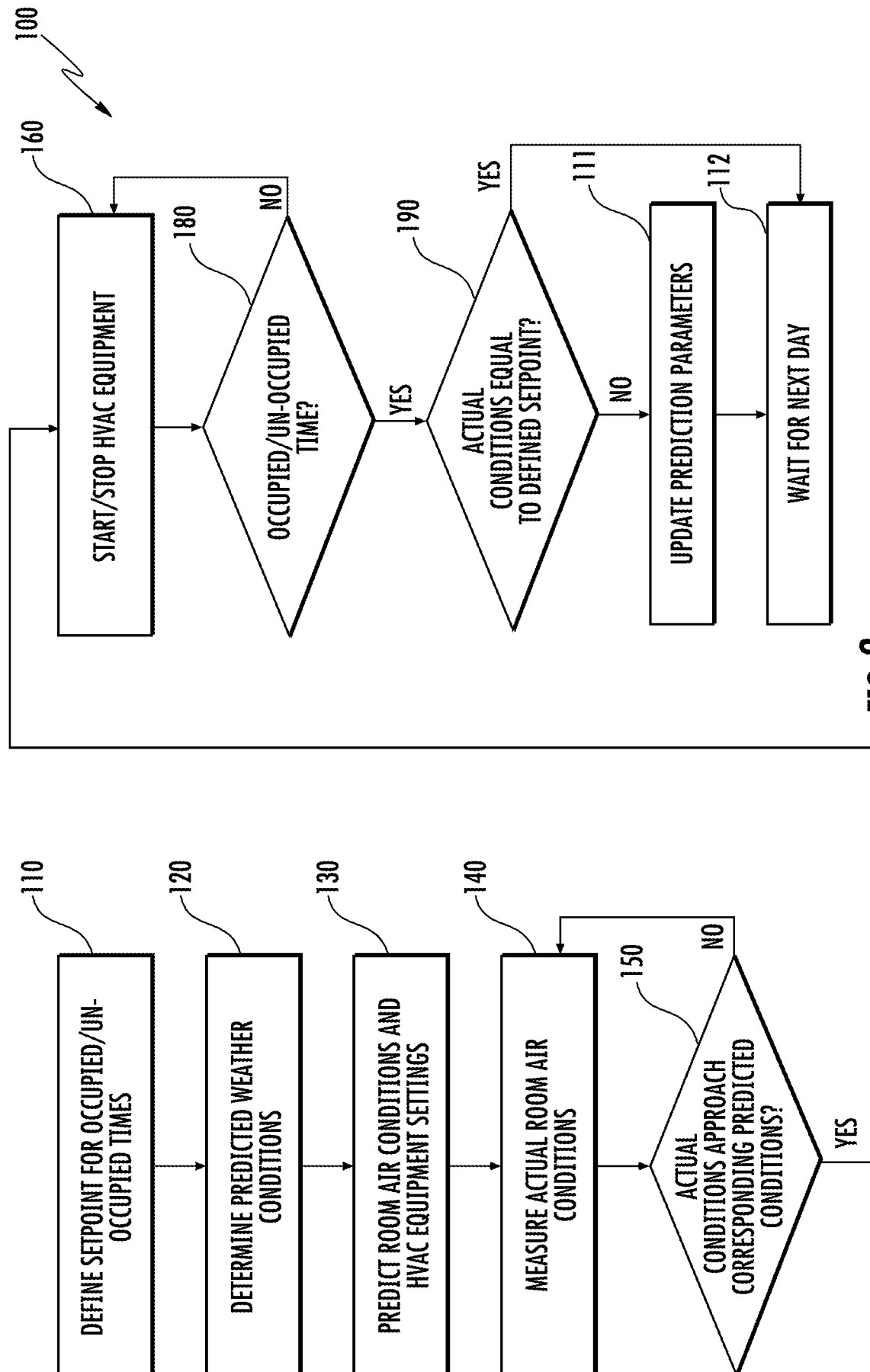


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/036300

A. CLASSIFICATION OF SUBJECT MATTER
INV. F24F11/00 G05D23/19
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F24F G05D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2011/149600 A2 (ECOFACOR INC [US]; STEINBERG JOHN DOUGLAS [US]) 1 December 2011 (2011-12-01) paragraphs [0098] - [0122]; claim 1; figures 10-14	1-19
A	----- US 2010/262299 A1 (CHEUNG LEO [US] ET AL) 14 October 2010 (2010-10-14) abstract	1,14
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A	----- US 2012/065783 A1 (FADELL ANTHONY MICHAEL [US] ET AL) 15 March 2012 (2012-03-15) paragraphs [0038] - [0077]; figures 3-11	1,14



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/036300

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