METHOD AND SYSTEM FOR OPTIMAL COORDINATION CONTROL AND SOFT REPAIR OF MULTIPLE ROOFTOP HEATING AND COOLING UNITS

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Techniques are described that may be implemented in an adaptive control device to regulate multiple zone environmental units based upon multiple temperature values and multiple airflow values, where each temperature value and each airflow value is related to the temperature and the airflow in a specific zone. In an implementation, the input interface of the adaptive control device is configured to receive multiple temperature values and multiple airflow values from multiple zone sensors. The adaptive control device may calculate multiple operational values based on the multiple temperature values and the multiple airflow values from multiple zone sensors. The adaptive control device may calculate multiple operational values based on the multiple temperature values and the multiple airflow values. An operational value indicates a power state (e.g., power on/power off) for a zone environmental unit's fan, compressor, heater, exhaust fan, and damper. The adaptive control device's output interface is operable to transmit multiple sequencing commands to the plurality of zone environmental units.

14 Claims, 3 Drawing Sheets
FIG. 1

Adaptive Control Device 102
- Processor 106
- Memory 108
- Input Interface 110
- Output Interface 112

Environmental Control Unit 104

Network 118
- Zone Sensor 114
- Zone Sensor 114
- Zone Sensor 114
<table>
<thead>
<tr>
<th>RTU 11</th>
<th>RTU 12</th>
<th>RTU 1j</th>
<th>RTU 1m</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTU i1</td>
<td>RTU i2</td>
<td>RTU ij</td>
<td>RTU im</td>
</tr>
<tr>
<td>RTU l1</td>
<td>RTU l2</td>
<td>RTU lj</td>
<td>RTU lm</td>
</tr>
</tbody>
</table>

FIG. 2
300

Receive a temperature value and an airflow value from a zone sensor

302

Calculate an operational state of: a fan, a compressor, a heater, an exhaust fan, and a damper associated with a zone environmental unit

304

Do more zone sensors need to transmit temperature values and airflow values?

306

Yes

No

Transmit a sequence command to the zone environmental units based on the zone environmental unit's calculated operational state

308

FIG. 3
METHOD AND SYSTEM FOR OPTIMAL COORDINATION CONTROL AND SOFT REPAIR OF MULTIPLE ROOFTOP HEATING AND COOLING UNITS

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims the benefit under 35 U.S.C. §119(e) of U.S. Provisional Application Ser. No. 61/228,674, filed Jul. 27, 2009, which is herein incorporated by reference in its entirety.

BACKGROUND

Multi-Roof Top Units (RTUs) are generally used for light commercial buildings with an open space. RTUs are configured as constant air volume systems, which causes these RTUs to be inefficient in ventilation, capacity, and humidity control.

SUMMARY

Techniques are described that may be implemented in an adaptive control device to regulate multiple zone environmental units (RTUs) based upon multiple temperature values and multiple airflow values, where each temperature value and each airflow value is related to the temperature and the airflow in a specific zone. In an implementation, the input interface of the adaptive control device is configured to receive multiple temperature values and multiple airflow values from multiple zone sensors. The adaptive control device may calculate multiple operational values based on the multiple temperature values and the multiple airflow values. An operational value indicates a power state (e.g., power on/power off) for a zone environmental unit's fan, compressor, heater, exhaust fan, and damper. The adaptive control device's output interface is operable to transmit multiple sequencing commands to the plurality of zone environmental units.

This Summary is provided solely to introduce subject matter that is fully described in the Detailed Description and Drawings. Accordingly, the Summary should not be considered to describe essential features nor be used to determine scope of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description is described with reference to the accompanying figures. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number first appears. The use of the same reference numbers in different instances in the description and the figures may indicate similar or identical items.

FIG. 1 is a schematic view of an adaptive controller.

FIG. 2 is a schematic view of an environment having a plurality of environmental zones and corresponding environmental zone units.

FIG. 3 is a flow diagram illustrating a procedure in an exemplary implementation of the adaptive control device of FIG. 1.

DETAILED DESCRIPTION

Zone environmental units, or Heating, Venting, and Air Conditioning systems (i.e. rooftop units), are generally constant air systems, which causes these zone environmental units to be inefficient regulating humidity and ventilation.

Accordingly, techniques are described that may be implemented in an adaptive control device that provides sequencing commands to multiple zone environmental units. In an implementation, the adaptive control device's input interface may receive multiple temperature values and multiple airflow values from a plurality of zone sensors. The zone sensors may be dedicated to a specific zone within an enclosed structure.

The adaptive control device may then calculate multiple operational values based on the received temperature values and airflow values. An operational value may indicate or signify a power state of a zone environmental unit's fan, compressor, heater, exhaust fan, and/or one or more coupled dampers. The adaptive control device's output interface may transmit multiple sequencing commands to the appropriate zone environmental units for sequencing the fans, compressors, heaters, exhaust fans, and dampers. The sequencing commands may be based on the calculated operation values.

For example, an adaptive control device may receive temperature values and airflow values from two zone sensors, one zone sensor dedicated to a first zone in an enclosed structure and the other zone sensor dedicated to a second zone (distinct from the first zone) in the enclosed structure. The adaptive control device may then calculate operational values, based on the temperature values and airflow values from each respective zone, to determine whether the zone environmental units associated with these two zones should be powered on or powered off. The adaptive control device may then transmit a first sequencing command to the zone environmental unit dedicated to the first zone based on the first operational value. This first operational value may be determined from temperature values and airflow values associated with the first zone. The adaptive control device may also transmit a second sequencing command to the zone environmental unit dedicated to the second zone based on the second operational value, where the second operational value may be determined from temperature values and airflow values associated with the second zone. Each operational value may indicate to power on/off the respective zone environmental unit's fan, compressor, heater, exhaust fan, and damper depending the temperature value and airflow value associated with each respective zone.

In the following discussion, an example adaptive control device environment is first described. Exemplary procedures are then described that may be employed with the example environment, as well as with other environments and devices without departing from the spirit and scope thereof.

Example Environment

FIG. 1 illustrates an example adaptive control device environment 100 that is operable to perform the techniques discussed herein. The environment 100 includes an adaptive control device 102 operable to sequence commands to multiple zone environmental units 104. The adaptive control device 102 may be configured in a variety of ways. For instance, an adaptive control device 102 may be configured as a central processing unit, a microcontroller with pre-programmed instructions, a stand-alone computing device, combinations thereof, and so forth. In the following description, a referenced component, such as an adaptive control device 102, may refer to one or more entities, and therefore by convention reference may be made to a single entity (e.g., the adaptive control device 102) or multiple entities (e.g., the mobile electronic devices 102, the plurality of mobile electronic devices 102, and so on) using the same reference number.

In FIG. 1, the adaptive control device 102 is illustrated as including a processor 106 and a memory 108. The processor
US 8,626,345 B2

3 106 provides functionality for the adaptive control device 102 and may include any number of processors, micro
controllers, or other processing systems and resident or external memory for storing data and other information accessed
or generated by the adaptive control device 102. The processor 106 may execute one or more software programs which
implement the techniques and modules described herein. The processor 106 is not limited by the materials from which it is
formed or the processing mechanisms employed therein and, as such, may be implemented via semiconductor(s) and/or
transistors (e.g., electronic integrated circuits (ICs)), and so forth.

The memory 108 is an example of device-readable storage media that provides storage functionality to store various data
associated with the operation of the adaptive control device 102, such as the software program and code segments men-
tioned above, or other data to instruct the processor 106 and

4 An environment 200 is illustrated in FIG. 2. The environment 200 includes a plurality of zones 202 with dedicated, or
associated, zone environmental units 104 (each zone and
zone environmental unit is depicted as an RTU with respect­
ive column and row). As depicted, there are 1 (row)x m (col­
umn) environmental zone units. Each zone 202 may represent
a specific region or specific boundary within an enclosed
structure 204. The enclosed structure 204, for example, may
include a commercial building and the like. The enclosed
structure 204 may include multiple zone environmental units
104. The zone environmental units 104 may include HVAC
units, such as roof top units, and the like. The zone environ­
mental units 104 may include fans, compressors, heaters,

5 exhaust fans, dampers, (not shown) and so forth.

The zone environmental units 104 may be associated with
one specific zone 202 within the enclosed structure 204, or the
zone environmental units 104 may be associated with mul­
tiple specific zones 202 within the enclosed structure 204. For
example, the zone environmental unit 104 may be dedicated
to cooling a first zone 202 only. Conversely, the zone envi­
ronmental unit 104 may be dedicated to cooling the first zone 202
and a second zone 202.

6 The calculation module 116 may calculate or determine the operational values based upon the following equations. The
ideal number of operating fans (n), where one zone environmental unit may include a fan, may be determined by the
minimum total air flow rate required for the whole conditioning
space V, and the average RTU airflow rate, \( \overline{V}_{RTU} \).

\[ n_1 = \frac{\overline{V}_f}{\overline{V}_{RTU}} \quad (1) \]

where

\[ \overline{V}_{RTU} = \frac{1}{1 \times m} \sum_{i=1}^{m} V_i \quad (2) \]

and \( V_i \) is the maximum value for satisfying ventilation, heating, and cooling requirements for the enclosed structure
204. The current baseline is that during the enclosed structure’s hours, all supply fans are operating:

\[ V_f = \text{MAX}(V_1, V_2, V_3) \quad (3) \]

where \( V_1 \) is the minimum airflow rate required by ventilation, \( V_2 \) is the minimum flow by heating, and \( V_3 \) is the
minimum airflow rate by cooling. These parameters, or values, can be calculated by Equations (4), (5) and (6):

\[ V_f = R_a Q_a \quad (4) \]

\[ V_i = R_p P_i + R_h A_i \quad (5) \]

\[ V_f = R_a Q_a \quad (6) \]

where \( R_a \) is the outdoor airflow rate required per person (e.g., 7.5 cfm/person for supermarket); \( P_i \) is the zone population (e.g., 8 person/1000 ft² for supermarket); \( R_p \) is the outdoor airflow rate required per unit area (e.g., 0.06 cfm/ft² for supermarket). For a supermarket application, \( V_f \) is about 15 cfm/person or 0.12 cfm/ft²; \( R_a \) is the supply air flow rate required per unit ton of heating load (about 200 cfm/ton for supermarket); \( R_h \) is the supply airflow rate required per unit ton of cooling load (about 340 cfm/ton for supermarket); \( Q_a \)

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is the instantaneous heating load; and \( Q_c \) is the instantaneous cooling load. \( Q_h \) and \( Q_c \) can be calculated by:
\[
\begin{align*}
Q_h &= k_{env} (T_h - T_{amb}) \\
Q_c &= k_{env} (T_c - T_{amb})
\end{align*}
\]
(7)

where \( k_{env} \) is the enclosed structure’s 204 envelop load coefficient; \( T_{amb} \) is the ambient temperature; \( T_h \) is the balance temperature; \( T_c \) is the zone heating set point; and \( T_c \) is the zone cooling set point.

Each zone environmental unit may include multiple mode settings. For example, the zone environmental unit may have a cool mode for cooling periods, a heating mode for heating periods, economy, or economizer, mode for energy saving periods, and so forth. The locations of operating fans within the enclosed structure 204 may be determined by: Calculating the temperature offsets for each zone from its set points:
\[
\Delta T = \left\{ \begin{array}{ll}
T_i - T_{ref} & \text{for cooling mode} \\
T_{ref} - T_i & \text{for heating mode}
\end{array} \right.
\]
(9)

Start the fans whose \( \Delta T \) belongs to the top \( n_a \) and if
1. \( \Delta T > \Delta T_{top, min} \) (e.g., 5 mins) and
2. \( \Delta T > \Delta T_{top, max} \) (e.g., -2 F)
Start the fans whose \( \Delta T \) does not belong to the top \( n_a \) but if
1. \( \Delta T > \Delta T_{top, max} \) (3 F) or
2. \( \Delta T > \Delta T_{top, max} \) (e.g., 2 hrs) and \( \Delta T_{ij} > \Delta T_{top, min} \) (e.g., -2 F).

The adaptive control device 102 may determine that exhaust fans whose \( w_{ef,ij} \) does not belong to the top \( n_a \) may need to powered on or started.

The damper operation, where each zone environmental unit 204 may be associated with a damper, may be determined by:
- The outdoor damper should be maintained at its possible minimum position (can be up to 100%):

\[
\beta_{min} = \frac{\psi_r}{\psi_t}
\]

The current baseline is during the enclosed structure’s 204 hours, the outdoor damper is maintained at a minimum position \( \beta_{min,b} \) (10-30% according to test and balance) when the economizer is not enabled. Ideally, if the test and balance practice are accurate, \( \beta_{min,b} \leq \beta_{min,a} \), the same amount of outdoor air is delivered to the zone 202, so no additional ventilation load is introduced from the whole enclosed structure perspective.

If mode=cooling, modulate the damper position to meet \( \psi_r = \psi_t \) in terms of the whole enclosed structure.

If mode=economizing, modulate the damper position=100%.

If mode=heating, modulate the damper position to meet \( \psi_r = \psi_t \) in terms of the whole enclosed structure 204.

Generally, any of the functions or equations described herein can be implemented using software, firmware, hardware (e.g., fixed logic circuitry), manual processing, or a combination of these implementations. The terms “module” and “functionality” as used herein generally represent software, firmware, hardware, or a combination thereof. The communication between modules in the adaptive control device 102 of FIG. 1 can be wired, wireless, or some combination thereof. In the case of a software implementation, for instance, the module represents executable instructions that perform specified tasks when executed on a processor, such as the processor 106 with the adaptive control device 102 of FIG. 1. The program code can be stored in one or more device-readable storage media, an example of which is the memory 108 associated with the adaptive control device 102 of FIG. 1.

Example Procedures

The following discussion describes procedures that may be implemented in an adaptive control device providing control functionality. Aspects of the procedures may be implemented in hardware, firmware, or software, or a combination thereof. The procedures are shown as a set of blocks that specify operations performed by one or more devices and are not necessarily limited to the orders shown for performing the operations by the respective blocks. In portions of the following discussion, reference may be made to the environment 100 of FIG. 1. The features of techniques described below are
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platform-independent, meaning that the techniques may be implemented on a variety of control device platforms having a variety of processors.

FIG. 3 depicts a procedure 300 in an example implementation in which an adaptive control device 102 provides sequencing commands to multiple zone environmental units. As shown in FIG. 3, the adaptive control device receives a plurality of temperature values and a plurality of airflow values from a zone sensor 114 (Block 302). The temperature values and the airflow values may represent a temperature reading and an airflow reading from a specific zone(s) 202.

Upon receiving the temperature values and airflow values, the calculation module 116 may calculate an operational value or operational state of a zone environmental unit's fan compressor, heater, exhaust fan, and damper (Block 304). The adaptive control device 102 may then determine whether more zone sensors 114 need to transmit temperature values and airflow values (Decision Block 306) to the adaptive control device 102. If more temperature values and airflow values need to be transmitted (“YES” from Decision Block 306), the adaptive control device may receive these temperature values and airflow values upon/or after transmission (Block 302).

Otherwise (“NO” from Decision Block 308), the adaptive control device 102 may transmit sequence commands to the zone environmental units 104 for sequencing the operation of each zone environmental unit’s fan, compressor, heater, exhaust fan, and damper.

Although techniques to transmit multiple sequencing commands to multiple zone environmental units have been described in language specific to structural features and/or methodological acts, it is to be understood that the appended claims are not necessarily limited to the specific features or acts described. Rather, the specific features and acts are disclosed as exemplary forms of implementing the claimed devices and techniques.

What is claimed is:

1. A method for controlling a conditioning space including a plurality of zones via a plurality of zone environmental units comprising:

- receiving a plurality of temperature values and a plurality of airflow values, the plurality of temperature values and the plurality of airflow values associated with the plurality of zones;
- determining a minimum number of operating supply fans based upon the plurality of airflow values;
- operating a first group of supply fans comprising the minimum number of supply fans, each one of the first group of supply fans having a characteristic time offset difference greater than a minimum time offset difference and a characteristic temperature difference greater than a minimum temperature difference; and
- operating a second group of supply fans, each one of the second group of supply fans having at least one of (A) a characteristic temperature difference greater than a maximum temperature difference or (B) a characteristic time offset difference greater than a maximum time offset difference and a characteristic temperature difference greater than a minimum temperature difference.

2. The method of claim 1, further comprising ceasing operation of the first group of supply fans when at least one of (A) the characteristic temperature difference is less than the minimum temperature difference or (B) the characteristic time offset difference is greater than a maximum time offset difference and the characteristic temperature difference is less than a maximum temperature difference.

3. The method of claim 1, further comprising operating a plurality of compressors associated with the first group of supply fans and the second group of supply fans, each one of the plurality of compressors having a characteristic time offset difference greater than a minimum time offset difference and a characteristic temperature difference greater than a minimum temperature difference.

4. The method of claim 1, further comprising operating a plurality of heaters associated with the first group of supply fans and the second group of supply fans, each one of the plurality of heaters having a characteristic time offset difference greater than a minimum time offset difference and a characteristic temperature difference greater than a minimum temperature difference.

5. The method of claim 1, wherein the plurality of zone environmental units comprise a plurality of rooftop units.

6. The method of claim 1, wherein the plurality of zones comprise a plurality of regions in an enclosed structure.

7. An adaptive control device for controlling a conditioning space including a plurality of zones comprising:

- an input interface operable to receive a plurality of temperature values and a plurality of airflow values, the plurality of temperature values and the plurality of airflow values associated with the plurality of zones;
- a memory operable to store one or more modules to cause the processor to:
  - determine a minimum number of operating supply fans based upon the plurality of airflow values;
  - operate a first group of supply fans comprising the minimum number of supply fans, each one of the first group of supply fans having a characteristic time offset difference greater than a minimum time offset difference and a characteristic temperature difference greater than a minimum temperature difference;
  - operate a second group of supply fans, each one of the second group of supply fans having at least one of (A) a characteristic temperature difference greater than a maximum temperature difference or (B) a characteristic time offset difference greater than a maximum time offset difference and a characteristic temperature difference greater than a minimum temperature difference;
  - an output interface operable to transit a plurality of sequencing commands to a plurality of zone environmental units associated with the first group of supply fans and the second group of supply fans for operating the first group of supply fans and the second group of supply fans.

8. The adaptive control device of claim 7, wherein the processor is further operable to execute the one or more modules to cause the processor to cease operation of the first group of supply fans when at least one of (A) the characteristic temperature difference is less than the minimum temperature difference or (B) the characteristic time offset difference is greater than a maximum time offset difference and the characteristic temperature difference is less than a maximum temperature difference.

9. The adaptive control device of claim 7, wherein the processor is further operable to execute the one or more modules to cause the processor to operate a plurality of heaters associated with the first group of supply fans and the second group of supply fans, each one of the plurality of heaters having a characteristic time offset difference greater than a minimum time offset difference and a characteristic temperature difference greater than a minimum temperature difference.

10. The adaptive control device of claim 7, wherein the processor is further operable to execute the one or more...
modules to cause the processor to operate a plurality of compressors associated with the first group of supply fans and the second group of supply fans, each one of the plurality of compressors having a characteristic time offset difference greater than a minimum time offset difference and a characteristic temperature difference greater than a minimum temperature difference.

11. The adaptive control device of claim 7, wherein the plurality of zone environmental units comprise a plurality of rooftop units.

12. The adaptive control device of claim 7, wherein the plurality of zones comprise a plurality of regions in an enclosed structure.

13. A method comprising:
receiving a plurality of temperature values and a plurality of airflow values, the plurality of temperature values and the plurality of airflow values associated with a plurality of zones within a conditioning space;
determining a minimum number of operating supply fans based upon the plurality of airflow values;
operating a first group of supply fans comprising the minimum number of supply fans, each one of the first group of supply fans having a characteristic time offset difference greater than a minimum time offset difference and a characteristic temperature difference greater than a minimum temperature difference;
operating a second group of supply fans, each one of the second group of supply fans having at least one of (A) a characteristic temperature difference greater than a maximum temperature difference or (B) a characteristic time offset difference greater than a maximum time offset difference and a characteristic temperature difference greater than a minimum temperature difference;
determining a mode of operation for a zone environmental unit associated with the first group of supply fans and the second group of supply fans;
operating a plurality of compressors associated with the first group of supply fans and the second group of supply fans when the mode of operation is cooling, each one of the plurality of compressors having a characteristic time offset difference greater than a minimum time offset difference and a characteristic temperature difference greater than a minimum temperature difference when the mode of operation is cooling; and
operating a plurality of heaters associated with the first group of supply fans and the second group of supply fans when the mode of operation is heating, each one of the plurality of heaters having a characteristic time offset difference greater than a minimum time offset difference and a characteristic temperature difference greater than a minimum temperature difference when the mode of operation is heating.

14. The method as recited in claim 13, further comprising ceasing operation of the first group of supply fans when at least one of (A) the characteristic temperature difference is less than the minimum temperature difference or (B) the characteristic time offset difference is greater than a maximum time offset difference and the characteristic temperature difference is less than a maximum temperature difference.

* * * * *