Simultaneous control of indoor air temperature and humidity using a variable speed air conditioner

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1 Introduction

- Direct expansion (DX) A/C systems
  - **Advantages:** simple configuration, lower cost to own and maintain, and suitability for energy consumption apportionment by individual end-users. Popular with residential application.
  - **Control problems:** compared with central A/C systems, satisfying both indoor air temperature and humidity control simultaneously is more difficult
    - Cooling coil in a DX A/C system perform both air cooling and dehumidification simultaneously
    - Single speed compressor and supply fan & on-off control
1 Introduction

- Efficient thermal environment control using DX A/C systems
  - Advancement of variable speed drive technology offers tremendous opportunities for improving indoor thermal environmental control and energy efficiency
  - Key to the successful development of efficient thermal environment control using DX A/C systems is to develop advanced control strategies that enable the simultaneous control of indoor air temperature and humidity
1 Introduction: previous related work

• Inherent operating characteristics for DX A/C systems, which are the basis of the simultaneous control of air T and RH

• Simultaneous control of indoor air temperature and humidity: controller developments
2 Operating characteristics of VS air conditioners

Inherent operating characteristics for DX A/C systems

The total output cooling capacity and Equipment SHR are correlated but mutually constrained within a trapezoid.
Inherent operating characteristics for DX A/C systems

Constant T Varying RH

Varying T Constant RH
3 Simultaneous control of indoor air temperature and humidity: example controller developments

- ANN-based control
- H – L control
3.1 ANN-based control

Why use ANN-based control

- Artificial neural network (ANN) has a powerful ability in recognizing accurately inherent relationship between any set of input and output without requiring a physical model.

- ANN has been successfully applied to a DX A/C system, and the ANN-based dynamic model developed is then used to develop an ANN-based controller.

- The ANN-based controller can only work as expected near the system operating point at which the ANN-based dynamic model is off-line trained.
3.1 ANN-based control

- Principle of the ANN-based on-line adaptive controller
  - Applying the concept of adaptive control to the ANN-based controller developed
  - The ANN-based dynamic model is trained on-line using the data real time collected and thus updated on a regular basis as the system operation goes on
  - The ANN-based inverse model could be updated correctly to adapt to the change in operating conditions
3.1 ANN-based control

Four steps:

1. Training an initial ANN-based dynamic model
2. Training an initial ANN-based inverse model
3. On-line updating the ANN-based dynamic model
4. On-line updating the ANN-based inverse model

The operating principle of the ANN-based on-line adaptive controller
3.1 ANN-based control

- Controllability tests
  - Initial start-up stage
  - Indoor air settings
    - dry-bulb temperature: $30 \, ^\circ C \rightarrow 24 \, ^\circ C$
    - wet-bulb temperature: $27 \, ^\circ C \rightarrow 17 \, ^\circ C$
ANN-based control

- Controllability tests
  - Command following with disturbances
  - Indoor air settings
    - dry-bulb temperature: 27 °C → 25 °C
    - wet-bulb temperature: 20 °C → 18 °C
  - Disturbances
    - sensible heat load: 3.3 kW → 2.4 kW,
    - latent heat load: 2.2 kW → 1.7 kW
3.2 H-L control

Why use H-L control

- Control systems for simultaneously controlling indoor air temperature and humidity using a DX A/C system are both complicated and costly.

- The conventional on-off control algorithm, although simple and thus not costly, always does not perform well in indoor humidity control.

- H-L control algorithm is compatible with the conventional on-off control algorithm in terms of cost and complexity, but would produce a better control performance.
3.2 H-L control

- Principle of the H-L control strategy
  
  • Under the H-L control, a DX A/C system will be operated at a high speed or full speed when the indoor air temperature setting is not reached, which is the same as the operating mode in the on-period for an on-off controlled DX A/C system.

  • When the indoor air temperature setting is satisfied, the compressor in an H-L controlled DX A/C system will be however operated at a low speed, which is expected to be less than half of the high or full speed.
3.2 H-L control: indoor air temperature

(a) H-L control

- Indoor air settings
  - Temperature: 26 °C
  - Dead band: 0.7 °C

(b) On-off control

- H-L control
  - H period: 60% - 90%
  - L period: 20% - 30%
3.2 H-L control: indoor RH

(a) H-L control

(b) On-off control

• H-L control can lead to a higher energy efficiency, better indoor thermal environment (compressor will not be stopped)
4 Future of residential humidity control

It is challenging and difficult for a conventional DX A/C system to be satisfactorily operated in hot and humid climates to provide variable dehumidification ability, without employing complicated and costly supplementary measures, such as variable speed operation;

Therefore, for large scale future application for better residential dehumidification, to reduce complexity and cost, new system configurations should be further explored.

Therefore, an enhanced dehumidification (ED) AC system was proposed based on multi-evaporator technology
EDAC system

HX1 - the first heat exchanger
HX2 - the second heat exchanger
EEV - electronic expansion valve (1-2)
SV - solenoid valve (1-3)
VCD - volume control damper (1-2)

Air state:
I - mixed air
II - outlet air from HX1
II' - bypassed air from VCD1
III - inlet air to HX2
IV' - bypassed air from VCD2
IV - outlet air from HX2
S - supply air
## EDAC system; operational mode

<table>
<thead>
<tr>
<th>Mode</th>
<th>Air dehumidification only (ADO)</th>
<th>Enhanced dehumidification Air Conditioning (EDAC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Status</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>SV1</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>SV2</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>SV3</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>VCD1</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>VCD2</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Compressor speed</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Supply fan speed</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Condenser fan speed</td>
<td>S</td>
<td>L</td>
</tr>
</tbody>
</table>

**Note:**  
O: fully open  
C: fully close  
O*: partially open  
H: high capacity/speed  
L: low capacity/speed  
S: shutdown
An experimental EDAC system with instrumentation

BF - booster fan
CF - condenser fan
C2 - controller for outdoor chamber
C4 - controller for VCD2
C6 – controller for FRMA
FRMA - airflow rate measuring apparatus
H - air humidity meter
RA - return air
SD - sampling device
VSD - variable speed drives

CC - cooling coil
C1 - controller for indoor chamber
C3 - controller for VCD1
C5 - controller for condensing unit
C7 - data acquisition and control unit
DP - differential pressure transducer
F1 - hot film anemometer
LGU - load generating unit
SF - supply fan
T - air dry-bulb temperature sensor
Operational characteristics of the EDAC system

\[
R_r = \frac{m_{r1}}{m_r}
\]

the ratio of the refrigerant mass flow rate through HX1 to the total refrigerant mass flow rate

\[
R_a = \frac{m_{a1}}{m_a}
\]

the ratio of the air mass flow rate through HX1 to the total air flow rate
Operational characteristics of the EDAC system

• TCC and E SHR were correlated but mutually constrained within an irregular area of ABCDEF shown in the figure.

• At a constant $R_a$ value, an increase in $R_r$ would lead to a decrease in E SHR. However, an increase in $R_r$ would lead to an increase in TCC at lower $R_r$ values, but a decrease in TCC at higher $R_r$ values.

• At a constant $R_r$ value, an increase in $R_a$ would lead to increase in both E SHR and TCC.
Inlet air T and RH significantly influence the operational characteristics of the EDAC system, resulting in shifted position of, and varied shape of an irregular area of TCC - E SHR relationship in a TCC - E SHR diagram.
Comparison: a modeling study

- An On-Off controlled A/C system could only provide a fixed E SHR at a fixed TCC.
- The EDAC system was able to produce a relative wide range of E SHR.
- A so-called enhanced dehumidification (ED) region, in which the EDAC system can have a better dehumidification ability.
Controllability tests for ADO mode (Status 1 & 2)

Indoor air settings: 26 °C / 50%
Sensible / Latent load (W): 0 / 900 → 200 / 900
→ 300 / 1100

Indoor air settings: 26 °C / 50% → 25 °C / 50%
Sensible / Latent load (W): 0 / 1000

Directly controlling indoor air temperature, but passively controlling indoor air RH
EDAC system

Controllability tests for EDAC mode (Status 4&5)

Indoor air settings: 26 °C / 50%
Sensible / Latent load (W) : 2000 / 900
→ 2100 / 1100

✓ Directly controlling indoor air temperature, but passively controlling indoor air RH

Indoor air settings: 26 °C / 50% → 25 °C / 50%
Sensible / Latent load (W) : 2000 / 1000
Controllability tests at EDAC mode (Status 3)

Simultaneous control both indoor air temperature and RH

Indoor air settings:
26 °C / 50%

Sensible / Latent load (W) :
3100 / 1550 → 3200 / 1750
Controllability tests at EDAC mode (Status 3)

Indoor air settings: 26 °C / 50% → 25 °C / 50%
Sensible / Latent load (W): 3100 / 1650

Indoor air settings: 26 °C / 50% → 26 °C / 40%
Sensible / Latent load (W): 3100 / 1650

Simultaneous control both indoor air temperature and RH
EDAC system: further developments

• For the existing EDAC system, the airside of the two HXs are in series. A new EDAC system has also been proposed, with the two HX’ air sides being in parallel, so as to maintain a constant total air flow rate, for better indoor air distribution

• The work is being planned and funding obtained