A New Dedicated Outdoor Air System with Exhaust Air heat recovery

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A New Dedicated Outdoor Air System with Exhaust Air heat recovery

• Background

• Exhaust air heat recovery module for ASHP

• Modeling approach and validation

• System performance analysis

• Conclusions
Background
Dedicated outdoor air system (DOAS)

- Tasks of dedicated outdoor air system
  - Ventilation
  - Air filtration and disinfection
  - Cooling and dehumidification in summer
  - Heating in winter
  - Heat recovery from exhaust air
Background
Air source heat pump in DOAS

• Air source heat pump (ASHP) for OA cooling and heating
  × Frost on outdoor coil in winter
  × Without heat recovery from exhaust air
Exhaust air heat recovery module for ASHP

Compressor

- Outdoor coil
- Outdoor coil EXV
- Outdoor coil

Pressure regulating valve

EA coil EXV

Exhaust air coil

Cooling EXV

Supplementary air coil

Return air

Supply air
Winter operation

- Winter operation at warm condition
  - Frost-free operation when evaporating temperature is over frost point
  - High heating COP because exhaust air is high quality heat source
  - Make full use of the sensible and latent heat of exhaust air for outdoor air heating
Winter operation

- Winter operation at extra-low ambient temperature
  - Heating capacity increasing due to dual heat source
  - Low-frost or frost-free operation with two evaporating temperature
Dual evaporating pressure

- Winter operation at extra-low ambient temperature
  - Outdoor coil could be light frost even frost-free, because the air would be very dry at extra low ambient temperature (ISO 16358: when the ambient temperature is lower than –7 °C, the frost effect could be ignored in APF calculation)
  - The evaporating temperature of exhaust air coil is kept above frost point by the pressure regulation valve
Summer operation

- Summer operation with exhaust air heat recovery module

✓ Condensing pressure decreased by exhaust air
Prototype design

• Design condition of the new DOAS

<table>
<thead>
<tr>
<th></th>
<th>Heating mode</th>
<th>Cooling mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return air (Dry-bulb/ Wet-bulb)</td>
<td>22 °C / 17.8 °C</td>
<td>27 °C / 19 °C</td>
</tr>
<tr>
<td>Outdoor air (Dry-bulb/ Wet-bulb)</td>
<td>7 °C / 6 °C</td>
<td>35 °C / 28 °C</td>
</tr>
<tr>
<td>Supply air</td>
<td>28 °C</td>
<td>11 °C</td>
</tr>
<tr>
<td>Supply air flow rate</td>
<td>400 m³/h</td>
<td>400 m³/h</td>
</tr>
<tr>
<td>Exhaust air flow rate</td>
<td>320 m³/h</td>
<td>320 m³/h</td>
</tr>
</tbody>
</table>
Modeling approach

- In-house software GREATLAB for component selection and design
### Modeling approach

**Specifications of the optimum system**

<table>
<thead>
<tr>
<th>Name</th>
<th>Specification</th>
<th>Simulation model type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerant</td>
<td>R410A</td>
<td>REFPROP</td>
</tr>
<tr>
<td>Compressor</td>
<td>Rotary, variable-speed</td>
<td>Curve-fitting model</td>
</tr>
<tr>
<td>Expansion device</td>
<td>Electronic expansion valves (EXVs)</td>
<td>Manufacturer curve</td>
</tr>
<tr>
<td>Outdoor condenser</td>
<td>7 mm tube; 3 rows; FL = 800mm</td>
<td></td>
</tr>
<tr>
<td>Exhaust air coil</td>
<td>8 mm tube; 8 rows; FL = 200mm</td>
<td>Incremental tube-by-tube model</td>
</tr>
<tr>
<td>Evaporator</td>
<td>8 mm tube; 10 rows; FL= 250mm</td>
<td></td>
</tr>
<tr>
<td>Reheating coil</td>
<td>8 mm tube; 1 row; FL=250mm</td>
<td></td>
</tr>
<tr>
<td>Fan</td>
<td>Two centrifugal fans for EA and OA, One axial fan for outdoor condenser</td>
<td>Manufacturer curve</td>
</tr>
</tbody>
</table>

Note: Fin length is for short with FL
Prototype and model validation

- Prototype was tested in a standard psychrometric testing room
Prototype and model validation

• Cooling and heating COP of prototype achieved 3.21 and 4.71 at design conditions

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Cooling design condition</th>
<th>Heating design condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>capacity / kW</td>
<td>Simulation: 7.29</td>
<td>Simulation: 3.25</td>
</tr>
<tr>
<td></td>
<td>Test: 7.18</td>
<td>Test: 3.30</td>
</tr>
<tr>
<td></td>
<td>Error: +1.5 %</td>
<td>Error: -1.5 %</td>
</tr>
<tr>
<td>Total power / kW</td>
<td>Simulation: 2.22</td>
<td>Simulation: 0.68</td>
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<tr>
<td></td>
<td>Test: 2.24</td>
<td>Test: 0.70</td>
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<tr>
<td></td>
<td>Error: -0.9 %</td>
<td>Error: -2.8 %</td>
</tr>
<tr>
<td>COP</td>
<td>Simulation: 3.28</td>
<td>Simulation: 4.78</td>
</tr>
<tr>
<td></td>
<td>Test: 3.21</td>
<td>Test: 4.71</td>
</tr>
<tr>
<td></td>
<td>Error: +2.1 %</td>
<td>Error: +1.4 %</td>
</tr>
<tr>
<td>Evaporating temperature / °C</td>
<td>Simulation: 7.9</td>
<td>Simulation: 5.5</td>
</tr>
<tr>
<td></td>
<td>Test: 8.2</td>
<td>Test: 5.9</td>
</tr>
<tr>
<td></td>
<td>Error: -0.3 °C</td>
<td>Error: -0.4 °C</td>
</tr>
<tr>
<td>Condensing temperature / °C</td>
<td>Simulation: 46.1</td>
<td>Simulation: 30.4</td>
</tr>
<tr>
<td></td>
<td>Test: 47.9</td>
<td>Test: 29.9</td>
</tr>
<tr>
<td></td>
<td>Error: -1.8 °C</td>
<td>Error: +0.5 °C</td>
</tr>
</tbody>
</table>

Note: the reheating coil wasn’t switched on in cooling test.
System performance analysis

- Winter: while the tube wall temperature of EA could stay over frost point, the new DOAS could achieve frost-free operation in warm condition.
System performance analysis

- Winter: low frost operation at extra-low ambient temperatures
- The evaporating temperature of the exhaust air coil is controlled over frost point by the pressure regulation valve

![Graph showing tube wall temperature vs. outdoor dry-bulb temperature](image)
**System performance analysis**

- Owing to efficient heat recovery the heating COP of new DOAS reaches 2.7, when outdoor temperature drops to 
  
  \(-20 \, ^\circ C\)

Note: the ASHP takes the same outdoor coil and fans as the new DOAS. When the ambient temperature is lower than \(-15 \, ^\circ C\), the ASHP couldn’t achieve supply air temperature \(28 \, ^\circ C\).
System performance analysis

- Summer: the new DOAS achieving higher cooling COP than ASHP
- the exhaust air is used for decreasing the condensing temperature

Note: all simulation results are under OA relative humidity 60%
the ASHP takes the same outdoor coil and fans as the new DOAS
Conclusions

- A new dedicated outdoor air system with exhaust air heat recovery module and pressure regulation valve was proposed in this study.

- The new DOAS can maintain the desired supply temperature, while the pressure regulation valve keep both the outdoor evaporator and exhaust air coil frost free in heating mode (ambient temperature -20°C to 10°C).

- The heat recovery module could improve heating and cooling COP of DOAS and the prototype achieved 4.71 and 3.21 at design conditions, which 26.9% and 10.5% higher than the ASHP.

◆ Acknowledgement

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Thanks for your attention!

For more details, please read our paper
The limited heating recovery capacity

- Because of frost preventing control, the heat recovery capacity of exhaust air is limited. In general, its capacity is effected by the state of return air and the ratio of air flow rate between EA and SA.

\[ \frac{V_{EA}}{V_{SA}} = 0.8 \]

\[ \frac{V_{EA}}{V_{SA}} = 1 \]