Designing a Dedicated Outdoor Air System with Ceiling Radiant Cooling Panels

Jae-Wong Jeong Ph.D.
Stan Mumma, Ph.D., P.E.
ASHRAE Journal, October 2006
Concept

- Born from decoupled ventilation/air-conditioning system concept
- Meet ventilation needs with 100% OA system
- Meet sensible loads using a parallel mechanical cooling system
  - Fan coil units
  - VAV AC units
  - Ceiling Radiant Cooling Panels (CRCP)
Core technologies for DOAS/CRCP systems developed separately – not easily integrated.

Recently, more focus is being put on the integration of the two systems:
- Thermal advantages
- Economical advantages

Unfamiliarity of HVAC designers and contractors is a significant barrier to more widespread use.

Main purpose of paper is to change this.

Outline 8 steps for system design for school in Williamsport, PA.
Figure 1: Typical DOAS/CRCP system configuration.
Step 1: Determine Design Outdoor Air Conditions

- ASHRAE typically gives three design data pairs to follow:
  1. Peak dry bulb with mean coincident wet-bulb
  2. Peak dew point with mean coincident dry-bulb
  3. Peak wet bulb with mean coincident dry-bulb

<table>
<thead>
<tr>
<th>Design Condition</th>
<th>Enthalpy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak DB, Mean Coincident WB</td>
<td>89.4°F DB, 72.5°F WB, 36.1 Btu/lb</td>
</tr>
<tr>
<td>Peak DP, Mean Coincident DB</td>
<td>72.9°F DP, 79.9°F DB, 38.3 Btu/lb</td>
</tr>
<tr>
<td>Peak WB, Mean Coincident DB</td>
<td>75.6°F WB, 84.7°F DB, 39.1 Btu/lb (selected)</td>
</tr>
</tbody>
</table>

*Table 2: Design outdoor air conditions (0.4%, Williamsport, Pa.) (From the 2005 ASHRAE Handbook—Fundamentals)*
Step 2: Determine Target Space Conditions

- Conventional cooling system design
  - 24°C (75°F) / 50% RH
  - Corresponds to 9.34 g/kg HR and 12.9°C (55°F) DPT

- Research shows that a higher design temperature can be used without significant negative impact on thermal comfort when using CRCP
  - 26°C (79°F) / 50% RH used
  - Corresponds to 10.54 g/kg (73.8 gr/lb) HR and 14.8°C (58.6°F) DPT
  - DPT below traditional maximum of 17°C (62°F), acceptable design
Step 3: Determine Design Cooling Load and Required Ventilation Rate for Each Space

- Required Ventilation rates are determined from ASHRAE recommended standards and expected conditions
  - **Standard 62.1-2004**: 10 cfm/student + 0.12 cfm/ floor area (ft²)
Step 3 Continued

<table>
<thead>
<tr>
<th></th>
<th>Classroom 1</th>
<th>Classroom 2</th>
<th>Classroom 3</th>
<th>Classroom 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensible Load ($Q_s$)</td>
<td>23.2 kBTU/h</td>
<td>24.5 kBTU/h</td>
<td>22.7 kBTU/h</td>
<td>23.7 kBTU/h</td>
</tr>
<tr>
<td>Latent Load ($Q_l$)</td>
<td>6.1 kBTU/h</td>
<td>7.2 kBTU/h</td>
<td>5.7 kBTU/h</td>
<td>5.5 kBTU/h</td>
</tr>
<tr>
<td>Number of Occupants</td>
<td>30</td>
<td>35</td>
<td>28</td>
<td>32</td>
</tr>
<tr>
<td>Required Ventilation (By Components)</td>
<td>318 cfm (People)</td>
<td>371 cfm (People)</td>
<td>297 cfm (People)</td>
<td>339 cfm (People)</td>
</tr>
<tr>
<td>Required Ventilation (Each Room) ($V_{rel}$)</td>
<td>81 cfm (Floor)</td>
<td>81 cfm (Floor)</td>
<td>81 cfm (Floor)</td>
<td>81 cfm (Floor)</td>
</tr>
<tr>
<td>Total SA Quantity ($V_{sa,tot}$)</td>
<td>1,649 cfm</td>
<td>452 cfm</td>
<td>376 cfm</td>
<td>420 cfm</td>
</tr>
</tbody>
</table>

Table 3: Design cooling loads and ventilation rate for each space.

<table>
<thead>
<tr>
<th>Location</th>
<th>Williamsport, Pa.</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Description</td>
<td>DOAS/CRCP System</td>
</tr>
<tr>
<td>Serving Four Classrooms</td>
<td></td>
</tr>
<tr>
<td>Room Size</td>
<td>26.2 ft x 26.2 ft x 11.5 ft</td>
</tr>
<tr>
<td>Number of Occupants</td>
<td>30 people (Classroom 1), 35 people (Classroom 2), 28 people (Classroom 3), 32 people (Classroom 4)</td>
</tr>
<tr>
<td>Occupant Heat</td>
<td>Sensible: 256 Btu/h per Person, Latent: 205 Btu/h per Person</td>
</tr>
<tr>
<td>Envelope Wall UA value</td>
<td>123.1 Btu/h·°F</td>
</tr>
<tr>
<td>Roof UA value</td>
<td>18.9 Btu/h·°F</td>
</tr>
<tr>
<td>Lighting Heat</td>
<td>75 Btu/h per Unit Floor Area</td>
</tr>
<tr>
<td>Solar</td>
<td>9.9 kBTU/h per Room</td>
</tr>
<tr>
<td>Other Assumptions</td>
<td>No Infiltration, No Moisture Generation Source Except Occupants</td>
</tr>
</tbody>
</table>

Table 1: Basic design data for conditioned spaces.
Step 4: Determine Supply Air Conditions

- Supply Air must be dehumidified
- Required dryness of Supply Air for each space is different because each experiences different latent loads
- Critical space is that which requires lowest HR (driest air), given by equation:

\[
W_{SA} = W_{SP} - \frac{Q_L}{0.68(V_{SA})}
\]
Step 4: Continued

• Classroom 2 is then the critical space, with lowest required humidity ratio
• HR of 7.26 g/kg (50.4 gr/lb) corresponds to a Supply Air DBT of 9.2°C (48.6°F)
DOAS System Overview
Determine thermodynamic properties at state 2, between enthalpy wheel and cooling coil:

\[
T_2 = T_1 - \varepsilon_s \frac{(mC_p)_{\text{min}}}{(mC_p)_1} (T_1 - T_6) \quad \text{and} \quad W_2 = W_1 - \varepsilon_L \frac{m_{\text{min}}}{m_1} (W_1 - W_6)
\]

Determine required cooling coil capacities

\[
Q_{CC} = 0.06 \rho \dot{V} (h_2 - h_1)
\]
Step 6: Determine Sensible Cooling Load for CRCP

- CRCP should accommodate the remaining sensible load not met by supply air from DOAS

\[
Q_{\text{sen,}SA} = 1.08 \dot{V}_{SA} (T_{sp} - T_{sa})
\]

\[
Q_{\text{sen,P}} = Q_s - Q_{\text{sen,}SA}
\]
Step 7: Select Design Panel based on Required Cooling Capacity

- Design cooling capacity per unit area is determined from panel manufacturer’s catalog data, given in Q/area (q_p)

Step 8: Determine Required CRCP Area

- Required area for panels is easily determined by the relationship:

\[ A_P = \frac{Q_{\text{sen},P}}{q_P} \]