



Considerations for Active Chilled Beam Designs Condensation or 'Indoor Rain'

This design bulletin deals with the scenario of **Unwanted Condensation** and attempts to explain how unlikely condensation really is under good design conditions.

How predictable is unwanted condensation?

Condensation in chilled beams is a popular topic and considered a design risk in many schools of thought. Condensation potential is not well understood and is predictable based on physical condensation failure tests recently conducted in Dadanco's scenario analysis facility.

Scenario:

Let's assume a single Active chilled beam delivers 30 L/s primary air at 12°C 89%rh and is required to deliver 773W secondary coil cooling based on 13.5°C secondary entering water temperature.

Room design condition = 23°C 50%rh

Sensible cooling load per unit = 1190W

Primary air Cooling = 417W

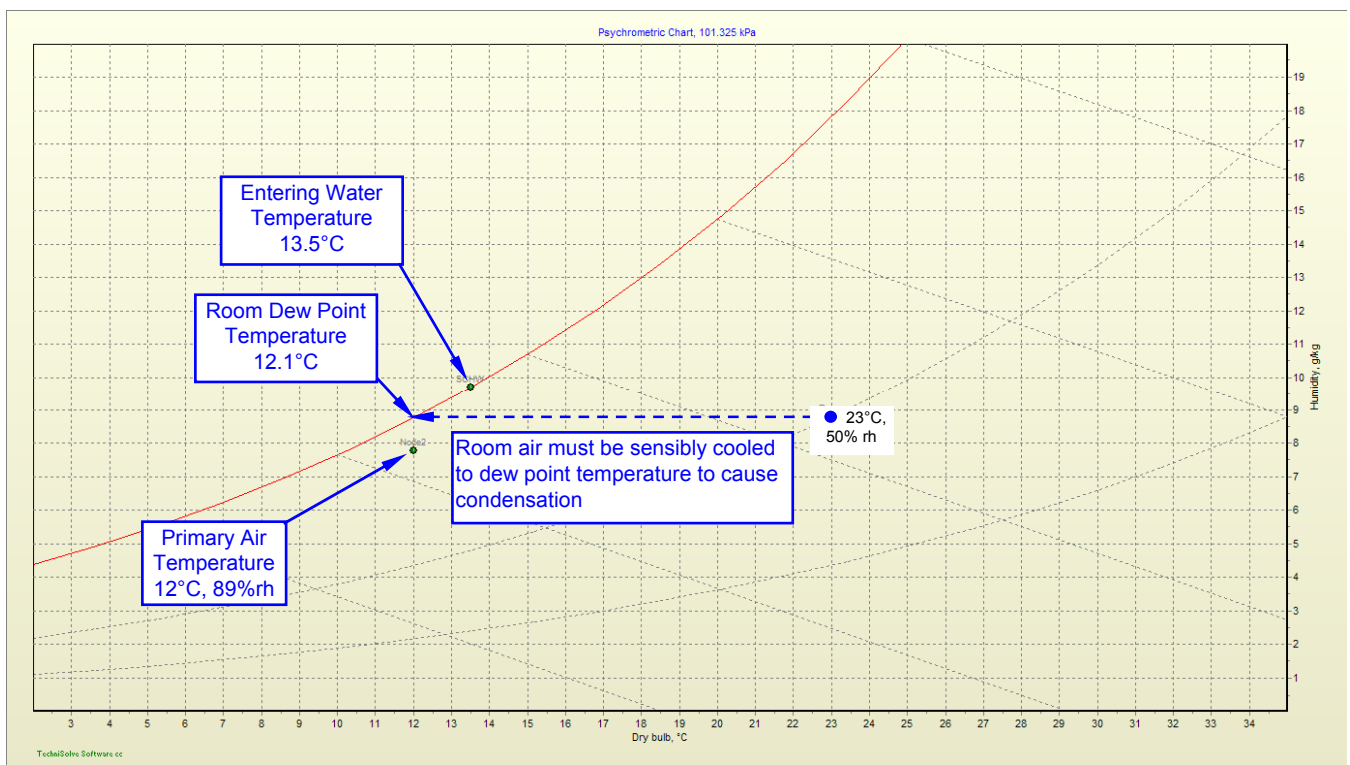
Secondary water temperature = 13.5°C

Room dew point temperature = 12.1°C

Latent cooling load per unit = 78W

Secondary air Cooling = 773W

Secondary water flow rate = 0.06 L/s



To achieve condensation, room air at 23°C must be sensibly cooled to room dew point temperature of 12.1°C or below to reach a saturation condition.

If the entering water temperature is 1.5°C above room dew point temperature this is highly unlikely to occur where fluid velocities are low on both the chilled water and secondary air quantities.

Primary air, with an absolute humidity value lower than room air condition is continually delivering latent cooling (dehumidification) to the space.

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THIS ISSUE:

Unwanted Condensation 1

What Really Happens

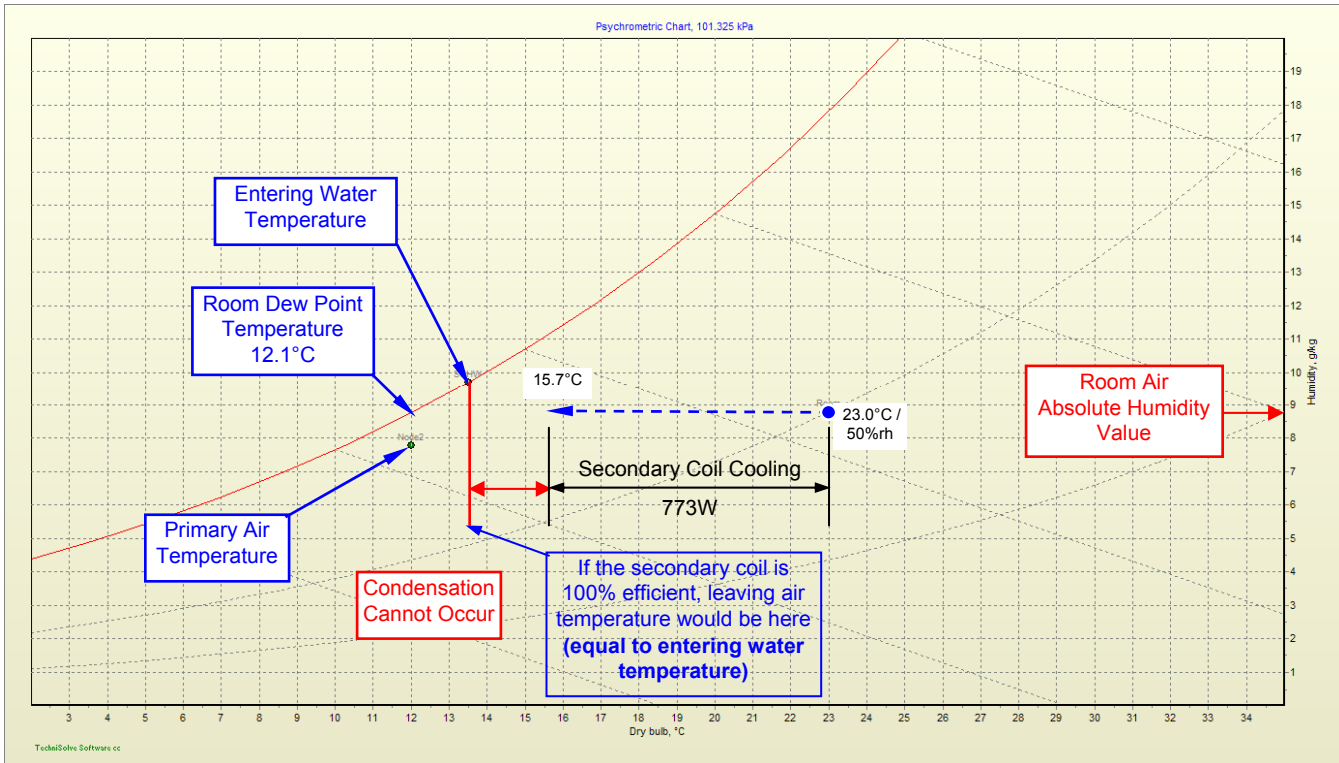
Under the given design conditions, the ACB secondary cooling coil delivers 773W for 87 L/s of secondary air and a coil air-off condition of 15.7°C. Note that this is strictly a sensible cooling process.

The secondary cooling coil air-off condition can be calculated by determining the air temperature differential (ΔT) from the standard energy equation as follows when the secondary air quantity is known:

$$\left[\frac{W / cp}{M} \right] = \Delta T \quad \text{or} \quad \left[\frac{773W / 1.213}{87 \text{ L/s}} \right] = 7.32^\circ\text{C} (\Delta T)$$

Therefore, for 773W of sensible cooling the coil air-off condition is Room Temperature - ΔT , or

$$23^\circ\text{C} - 7.32^\circ\text{C} (\Delta T) = 15.68^\circ\text{C}$$



Under design conditions, 15.7°C secondary cooling coil air-off condition is sufficiently far away from the saturation curve that condensation cannot occur.

Since, no heat exchanger can be 100% efficient, the apparatus temperature of 13.5°C, and a saturated air condition, cannot be achieved.

If the secondary cooling coil were somehow 100% efficient, the lowest off-coil temperature that it could produce against 13.5°C entering water would be 13.5°C which is still 1.4°C above the room dew point temperature and sufficiently far from the saturation curve that condensation still cannot occur while the 23°C & 50%rh room air absolute humidity remains at the value of 8.78 g/Kg or less.

The concepts of primary air latent capacity delivery are discussed at more length in Design Bulletin 2.

Essentially the latent capacity delivered can be determined from the energy equation as $M \cdot cp \cdot \Delta w$, where:

M = Primary Air Mass Flow (L/s)

Cp = AIRAH standard coefficient for latent cooling (2.9)

Δw = Absolute Humidity Differential (Room air g/Kg - Primary Air g/Kg)

In the above example, room air of 23°C & 50%rh has an absolute humidity value of 8.78 g/Kg while primary air of 12°C & 89%rh has an absolute humidity value of 7.79 g/Kg, resulting in an absolute humidity differential (Δw) of 0.99 g/Kg.

Therefore, latent capacity of 86W is delivered

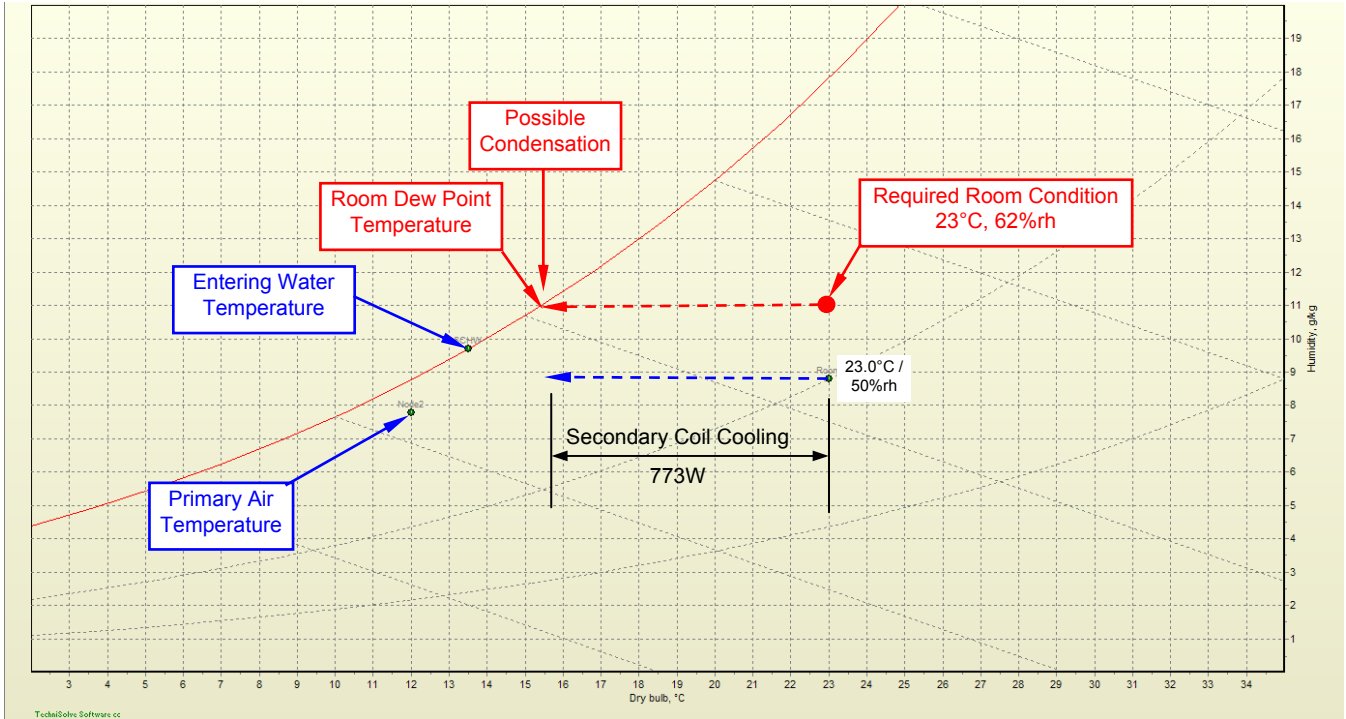
$$(M \times cp) \times \Delta w = W_{\text{latent}} \quad \text{or} \quad (30 \times 2.9) \times 0.99 = 86W_{\text{latent}}$$

The primary air therefore contributes to the stability of the room absolute humidity level.

Therefore, it can be reasonably argued that for condensation to occur, the coil entering air condition (room condition) must be at a condition equal to the temperature differential of the room air minus the dew point temperature for the off-coil air to reach the saturation curve.

To achieve this with steady state sensible cooling performance suggests latent capacity in the conditioned space is far greater than the latent cooling performance delivered by the primary air quantity and/or conditions.

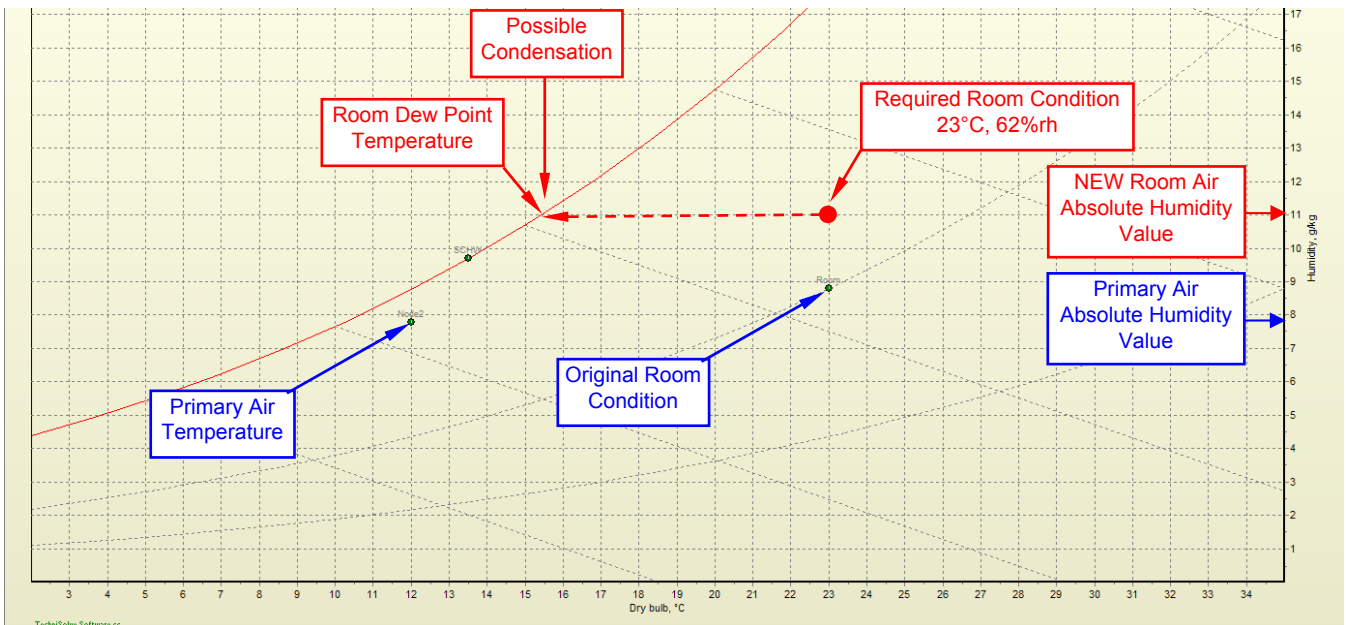
Moving the secondary cooling coil process line vertically on the psychrometric chart to achieve a point on the saturation curve suggests the room condition necessary to achieve condensation against 13.5°C entering water is 23°C, 62%rh as shown below.



In the above example, the secondary entering water temperature of 13.5°C is now lower than the new room dew point temperature of 15.3°C. While the secondary coil air still cannot reach the apparatus temperature of 13.5°C, the off-coil condition meets the saturation curve creating the potential for condensation.

As seen in the psychrometric chart below, the new room condition of 23°C, 62%rh has an increased absolute humidity value of 11.0 g/Kg while the primary air absolute humidity value remains unchanged at 7.79 g/Kg, resulting in the primary air quantity of 30 L/s now delivering 279W of latent cooling versus the original design value of 86W.

It can be concluded that as the room absolute humidity value increases, thereby increasing the absolute humidity differential, latent cooling delivered increases as a function of the primary air quantity and Δw making it more difficult to maintain the elevated room humidity condition and readily achieve condensation at the new higher moisture content room conditions.

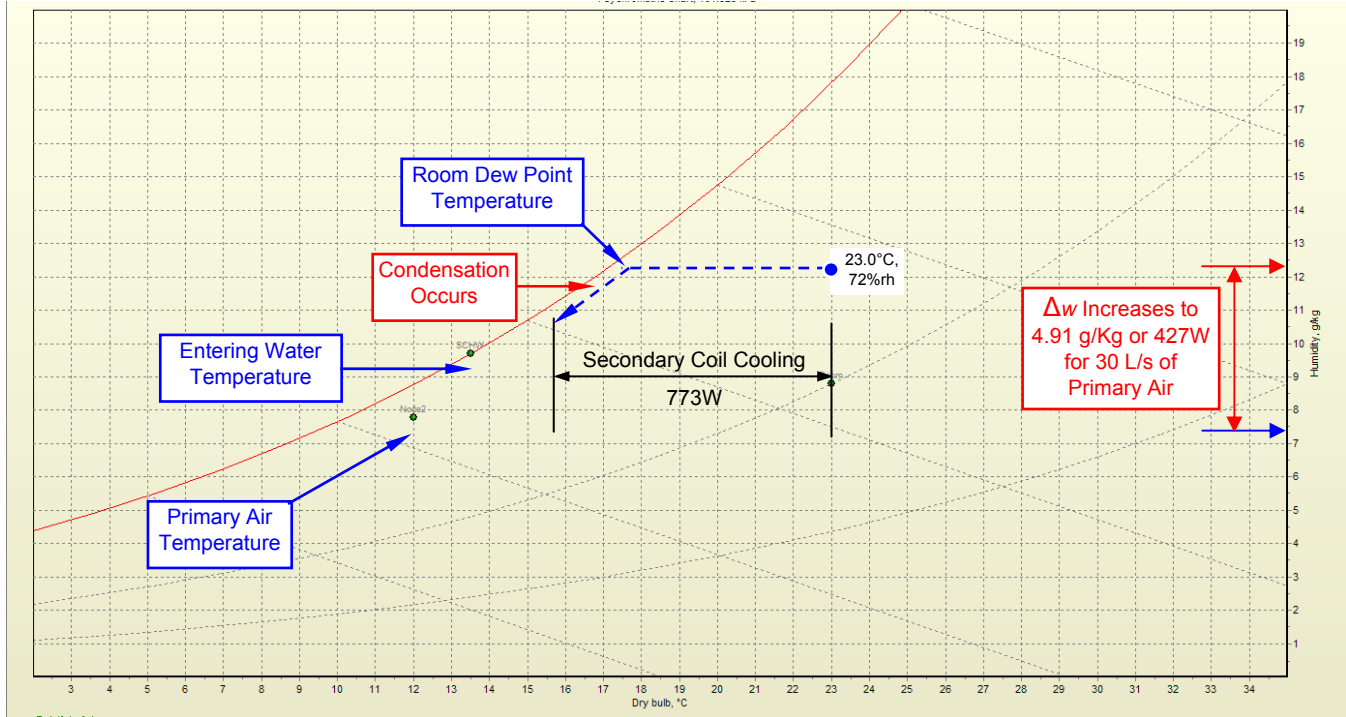


Considerations for Active Chilled Beam Designs

As discussed on page 3, where primary air quantity and conditions remain consistent, latent cooling increases as room absolute humidity increases.

Controlled condition tests show that simply achieving a saturation temperature does not result in condensation from the secondary cooling coil. Although light condensation can be present at this condition, in reality room conditions must further increase to 23°C, 72%rh before the coil cooling process can reduce the absolute humidity of the entering air to produce enough condensation for water droplets to form on the coil.

This produces the 'bent process line' indicating sensible cooling occurs beyond the point of saturation as shown below.



Also observe that as room humidity increases to the 23°C & 72%rh condition, the absolute humidity differential value further increases to a Δw of 4.91 indicating that 30 L/s of primary air is now delivering 427W latent cooling. This significant increase in latent cooling increases the difficulty in maintaining a high humidity condition from which condensation can occur.

It is widely acknowledged that the most efficient latent performance (highest dehumidification) is achieved with low coil face velocity and high fluid velocity designs using cold water with a low apparatus temperature. In the case of Active Chilled Beams, low coil face velocities are combined with relatively low fluid velocities which do not necessarily promote dehumidification or rapid condensation formation.

Condensation failure tests conducted by Dadanco indicate the formation of condensation does not occur on the secondary coil until the room air dew point temperature is approximately 3.5-3.8°C above the secondary chilled water supply temperature due to the evaporative effect of air passing over the coil. Not until the room dewpoint temperature reached 5°C above the secondary chilled water entering temperature was there a threat of condensation coalescing into water droplets.

Furthermore, formation of droplets large enough to drip from the ACB unit did not occur until more than 30 minutes after reaching a point of visible condensation on the coil, suggesting the building BMS and dew point control strategy would have adequate time to deal with such a catastrophic moisture condition should it occur.

From controlled tests and the psychrometric comparisons above, it is easily argued that the formation of condensation is not an inherent active chilled beam design problem but more of a catastrophic failure in the primary air delivery system or high ambient moisture exposure to cause such a significant increase in room humidity.

Even if condensation does occur in Active Chilled Beams, it is more than likely caused by failures other than at the Active Chilled Beam.

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