Condensation: Refrigerated Processing and Cold Storage Operations

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Why condensation, not conventional roof leaks, is the leading cause of enclosure failures in refrigerated processing and cold storage facilities, and how the right air-seal strategy prevents it.

Active water or ice accumulation, food-safety exposure, and steel corrosion in refrigerated facilities are frequently reported as roof leaks. In many cases, the roof membrane isn't failing at all. Based on a 30-year study of leaks, repairs, and roof system replacements across the industrial food manufacturing sector, condensation, not membrane failure, was identified as the leading cause of reported failures, particularly where the roof system forms part of the refrigerated enclosure.

Refrigerated processing and cold storage areas are conditioned to maintain interior temperatures below 50°F (10°C), with some areas designed as low as -50°F (-45°C). Condensation forms whenever moisture-laden air contacts a surface at or below its dew point, through three distinct mechanisms, each with a different failure signature and a different fix.

Ice accumulation at a roof-deck-to-wall transition — a signature of condensation caused by air infiltration.

Three Sources of Condensation, Only One Dominates

Infiltration, conductance, and saturation each produce condensation differently, and distinguishing between them is the first step in any credible diagnosis.

- **Infiltration.** Warm, moist air is drawn through unsealed roof-to-wall transitions, penetrations, and doorways, mixing with cold interior air and condensing on steel surfaces. Refrigeration-driven negative pressure and downward cold-air movement intensify the pull. Infiltration is the most common cause of reported system failures.
- **Conductance.** A continuous material, such as a structural beam, joist, or suspended-ceiling support rod, runs from the cold interior through the enclosure into warm air outside, condensing where its surface temperature drops below the dew point. Conductance is localized, easy to diagnose, and far less frequent than infiltration.
- **Saturation.** The area's dew point sits close to the interior temperature, producing widespread surface condensation or ice on walls, ceilings, or roof structure. Saturation is the most visually dramatic cause and the least frequent, typically tied to maintenance activity or mechanical malfunction.

> *"The cold air within the building wants to wring the water out of the air entering from the outside."*
>
> — Ray Wetherholt, on infiltration-driven condensation in freezer buildings[1]

Steel roof decking corroded through by prolonged, unmanaged condensation exposure.

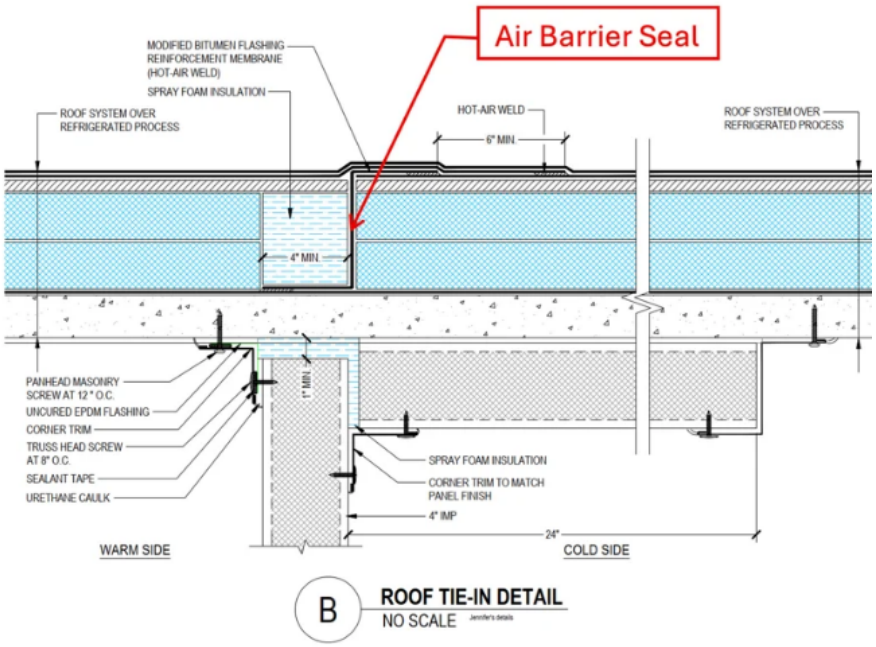
Infiltration isn't limited to poorly sealed transitions. Mass infiltration occurs every time a door between a cooled space and a semi-cooled or unconditioned space opens for forklift or pedestrian traffic. Even brief, automated door cycles introduce enough warm air to drive corrosion on the steel deck and framing nearby.

Left unmanaged, that infiltration adds mechanical load, encourages microbial growth, and drives unplanned production downtime, well before it registers as a roofing issue.

Getting the Air Seal in the Right Place

More moisture is transported by air movement than by diffusion or any other mechanism. Stopping air movement stops moisture migration, and with it, the resulting condensation. The counterintuitive part is placement: even though infiltration-driven condensation shows up on the cold side of the assembly, the air barrier seal belongs on the warm side, at the pressure boundary where infiltration originates.

In most refrigerated roof systems, that boundary sits at the roof membrane's junction with adjacent walls and penetrations, and at its termination against the exterior wall. Nearly any roof membrane can provide an effective air seal when detailed properly, modified bitumen and single-ply systems installed in full adhesion have a strong track record, provided the seal is continuous and positively terminated so it cannot slip or loosen over time.



Roof tie-in detail showing the air barrier seal positioned at the warm-side pressure boundary between the refrigerated roof system and the adjoining structure.

What Effective Air-Seal Design Requires

An air barrier assembly built for a refrigerated enclosure has to clear a specific bar: an air permeability rating below 0.02 L/(s·m²) per ASTM E 2178, a Class II vapor rating under 1.0 perm per ASTM E 96, full continuity across every joint and transition, and enough flexibility and durability to withstand normal building movement and temperature swings over the life of the system. Every wall penetration, vertical corner, and IMP side-lap joint has to be sealed with the same rigor, or the seal is only as good as its weakest gap.

The Cost of Getting It Wrong

Unchecked infiltration doesn't stay a surface-level nuisance. Cyclical condensation, repeated every time outside air is warmer than the refrigerated interior, corrodes steel decking over time. Left unaddressed, that corrosion progresses to structural failure of the decking itself, and in severe cases, to a roof blow-off.

Roof blow-off caused by severe deterioration of steel decking along a brick parapet wall — the end state of unmanaged, cyclical condensation.

Renovation and occupancy changes raise the stakes further. Converting a standard freezer to a blast freezer, for example, can lower the design interior temperature by as much as 30°F. Without a corresponding update to insulation and the air seal, that single operational decision can introduce infiltration and saturation problems that didn't exist before. Multi-wythe masonry walls with a traditional air gap present some of the most difficult retrofit conditions in the industry, and typically require either fully sealing the exterior wall face or structural modification to eliminate the air path entirely.

A Proactive, Assessment-Led Approach

Diagnosing condensation after the fact often requires destructive investigation to trace the source through both interior and exterior factors. Getting ahead of it, at design, at reroofing, or before an occupancy change, is far less costly than solving it after a failure. Benchmark's building envelope consultants work through each phase of that process directly with facility teams:

- **Assessment.** Identify existing sources of infiltration, conductance, and saturation, and the operational conditions driving them.

- **Analysis.** Distinguish true roof or wall failures from condensation being misreported as a leak.
- **Design.** Detail air barrier placement, material selection, and penetration sealing to meet ASTM permeability and vapor standards.
- **Construction Management.** Verify that air-seal continuity is achieved in the field, not just on paper.
- **Ongoing Asset Management.** Monitor performance through operational and occupancy changes that can shift the balance over time.

Protecting Product, People, and Performance

Condensation in refrigerated and cold storage facilities is rarely a roofing defect. It's a building physics problem, and one with a well-understood, preventable cause. A properly placed, properly specified air seal, verified through design and construction, protects the roof system, the product inside, and the operational continuity the facility depends on.

Reference

[1] Wetherholt, Ray. 2015. “Considerations in Design and Construction of Freezer Buildings for Building Envelope Consultants.” Interface 33 (11): 22–26.