Coil Icing and Other Opportunities within Freezer/Anteroom Complexes

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ABSTRACT

This treatise concerning moisture precipitation under freezing conditions proceeds from similarity between the coil-frost formations of a recent coil-frost testing program and coil-frost formations frequently found in freezers coincident with frost accumulations around doorways or elsewhere within the room. Calculated data involving dehumidification alternatives applicable to the two (or more) temperature/humidity environments typical of freezer/anteroom complexes are presented, which reveal the paramount role of applied psychrometrics with respect to air-side engineering at freezer temperatures and which, in conjunction with modern control-system technology, prepare the way for a future treatise that promises significant logistics-related benefits through the integration of all refrigeration loads of these high-usage facilities into an overall refrigeration-system design within which coil-frosting need not occur.

BACKGROUND—CONVENTIONAL DEHUMIDIFICATION

ASHRAE Technical Committee 10.8, Refrigeration Load Calculations, was formed from a Task Group circa 1983. Coincident with its formation, the ASHRAE director of technology directed questions to the new TC of contradictory refrigeration-system performance where snowlike coil frost was seen regardless of the location at which the ice-crystals first appeared. All questions involved freezer/anteroom complexes. Contradictory instances occurred where the addition of artificial sensible-heat load—with no other change—was accompanied by significantly lowered freezer temperature. Other contradictory instances of lowered freezer temperature occurred simply in response to raised suction temperature, sometimes dramatically, typically a week or so following the change. Such observations in conjunction with one member (Cole 1989) having recently published a paper describing aerosol emissions commonly seen during coil-defrosting, which had expanded upon earlier coil-icing research (Stoecker et al. 1983), prompted an early decision by the new TC to prepare and ask the society to fund a testing program for the measurement of freezer heat gain due to coil defrosting under the various circumstances of coil design and operation customarily found in industry. Following forums, seminars, and symposia considering such a program, a Work Statement was eventually approved in 1997 that became ASHRAE RP-1094, "A Study to Determine Heat Loads Due to Coil-Defrosting—Phase II."

Coincident with the contradictory performance described above, Technical Committee 10.5, Refrigerated Distribution and Storage Facilities, sponsored an infiltration-air study for which the 1984 Work Statement read as follows:

> In recent years the size and number of refrigerated distribution and storage facilities have grown significantly and it is now estimated that refrigerated warehouses use 1×10^{14} Btu's of energy per year. In spite of this large use of energy and *the fact that infiltration represents 50% or more of the refrigeration load*, the method of calculation for this load is fundamentally *left to the experience* [emphasis added] of the design engineer.

However, the resulting study (Hendrix and Henderson 1988) produced data that fell far short of corroborating the 50% or more conclusion of TC 10.5, which was seen to not only reinforce reasons for the TC 10.8 coil-frost study but to lend confirmation as well to the great harm to frosted-coil cooling performance that had been surmised.

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Omitted Psychrometric Analysis

The coil-frost studies of RP-1094 experienced discord stemming from differences in perspective throughout most of the undertaking. To explain this circumstance, it was apparent in 1983 at the time of TC 10.8's formation that refrigeration air-side engineering was universally lacking throughout the low-temperature dry-surface-coil refrigeration sector of the industry. Unlike customary engineering practice at air-conditioning levels, consideration of phenomena associated with moist-air precipitation on dry-surface-type coils at freezer temperatures was simply being omitted.

This omission, a quirk among an otherwise demanding category of highly proficient engineers, was found to consist of tacit agreement throughout the low-temperature industry—established in earlier days—that applied psychrometrics, the authoritative engineering basis for the efficient sensible and latent conditioning of moist air to any particular need, could be safely ignored at freezer temperatures. However, originating without wide-scale problems in the pre-computerized age of low-doorway-usage freezers, the omission had resulted, with the introduction of computerized warehousing and associated high-usage doorways, in the exceedingly large tonnage increases (*de facto* because of very sizable refrigeration-equipment additions found necessary with no other explanation), which prompted the 1984 Work Statement of TC 10.5. The omission had similarly resulted in moisture precipitation at freezer doorways in quantities that not only created safety hazards due to fog, frost, and ice at those locations but in serious warehousing productivity interference as well. Clearly, the high-usage doorways that coincided with the computerization of food storage-and-retrieval operations underway in the 1970s, and with logistical improvements generally, had resulted in moist-air infiltration well into the range where psychrometric effects and their overall consequence on good refrigeration-system design could no longer be ignored. These refrigeration-related consequences, typical of the early 1980s, are illustrated by Figures 1 through 4. Figure 5 contains an additional refrigeration-related element to be addressed later.

Addressing Psychrometric Principles

The RP-1094 testing program was guided by the straight-line principle of applied psychrometrics as expounded in the US government-financed manual GRP-158 (ASHRAE 1978) and its successors (e.g., Pedersen et al. [1998]).[1] A hoped-for testing outcome of value to system-design engineers was establishment of a dry-bulb/wet-bulb, coil-entering-air demarcation representable on the psychrometric chart between the formation of favorable (icelike) and unfavorable (snowlike) coil frost, which, prior to the efforts of RP-1094, had been postulated for freezers generally by Smith (1989) and tested, though at high freezer temperatures only, by Cleland et al. (1993). Although achieving the hoped-for demarcation during either program did not occur, a more useful visualization for refrigeration-system designers (and operators) was observed to be the light to very dense frosting that occurred on the test coil's inlet face but not within the coil.

The same light to very dense inlet-face frosting of the test coil had been consistently observed in the industry during the early 1980s at the time of TC 10.8's formation and the ad hoc 50% or more observation of TC 10.5 quoted above. However, simply on the basis of attention to cause and effect on the part of most refrigeration-system operators by the end of the 1980s, it had become customary practice (1) to introduce sensible heat to ice-crystal-laden doorway infiltration by means of large electric heaters—amazingly so because of usable, hot-gas waste heat generally available nearby—and (2) to limit coil TD (coil entering-air temperature minus coil-refrigerant temperature) to approximately 10°F(5.6°C) maximum, each action independently having been found contributory, if not singularly effective, toward the formation of coil icing rather than coil frosting. The phenomena at play are readily demonstrated by means of the two lines drawn on Figure 12 and discussed later under "Comparisons Generally." These phenomena were expanded upon earlier by Smith (1992, 1998).

The Ambiguity of Coil-Frost Testing

Regarding the failure to establish demarcation mathematically, reference is made to Chung and Algren (1959) who wrote with respect to coil performance: "the density and the thermal conductivity of the frost vary unpredictably and through a wide range. It is clear that no mathematical solution to the problem is possible...." Consistent therewith, it was written 43 years later by Sherif et al. (2002) with respect to the RP-1094 coil-frost testing: "In the middle section of the coil . . . significant deviations (up to 34%) between the calculated and the straight-line paths were observed." Three companion references by Mago and Sherif (2005a, 2005b, 2005c) further expand upon this topic. Thus, a sufficiently clear-cut, comprehensive demarcation between icelike and snowlike coil-frosting conditions was found realistically unattainable, but the testing is seen to have confirmed industry's current practice of (1) limiting coil TD (see Figure 12 in this respect) and (2) eliminating airborne ice crystals by means of sensible-heat addition wherever ice crystals appear.

BACKGROUND—DESICCANT DEHUMIDIFICATION

Coincident with the coil-defrosting study, TC 10.5 sponsored a seminar with a view toward ascertaining to what extent desiccant dehumidification should be recommended in its chapter of the *ASHRAE Handbook—Refrigeration.* Very simply, with freezer-doorway and related frosting problems increasing at the time, desiccant dehumidification was increasingly serving as corrective. Thus, with over-cooling-plus-reheat dehumidification of freezer anterooms being customary textbook-wise where latent-heat ratio (LHR) of room load exceeds LHR of the evaporator-unit selection (i.e., where sensible-heat ratio [SHR] of room load is less than SHR of the air-cooling process), gas-heat-reactivated desiccant dehumidification was contrasted, in discourse-style at the seminar, against the textbook solution and against employment of a freezer vestibule in each case. The loading-dock

[1] As GRP-158 is out of print, all subsequent references herein will refer readers to Pedersen et al. (1998)—this publication provides all of the information from GRP-158 with relatively no changes.

Figure 1 *Gravitational and psychrometric effects. Airborne ice-crystal infiltration as seen in the field can be seen beforehand in the office on a psychrometric chart.*

Figure 2 *Psychrometric effects complete.*

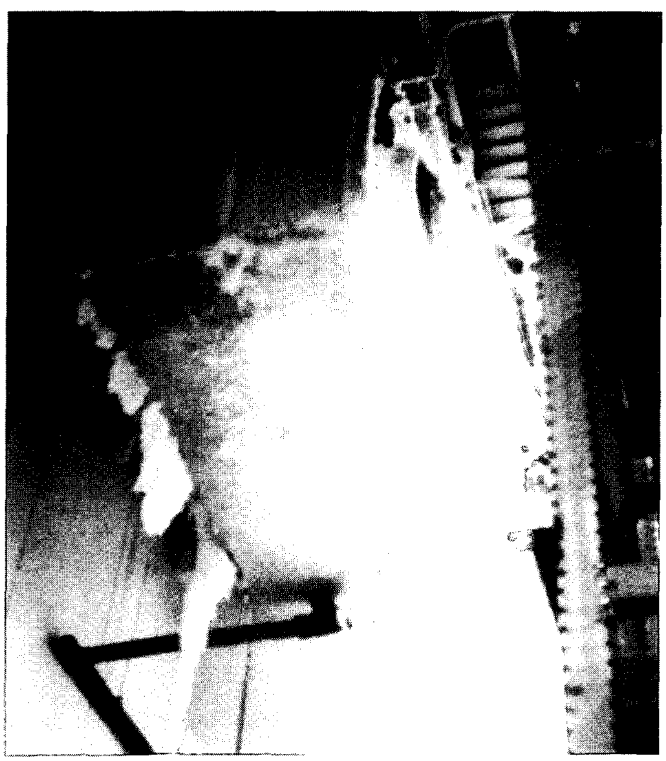

Figure 3 *Evaporator unit close to doorway.*

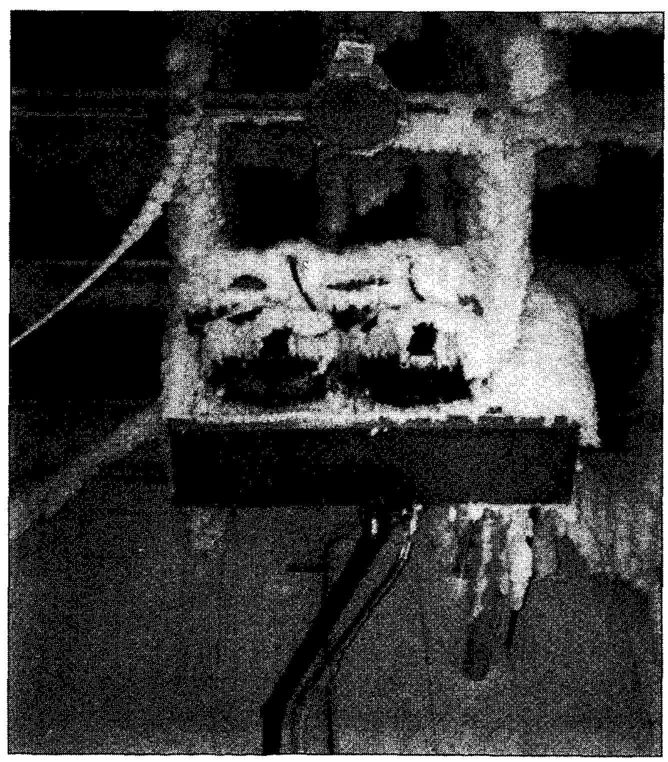

Figure 4 *"Stripper unit" within a vestibule.*