Comparison of Dehumidification Alternatives in Cold Storage Warehouse Docks

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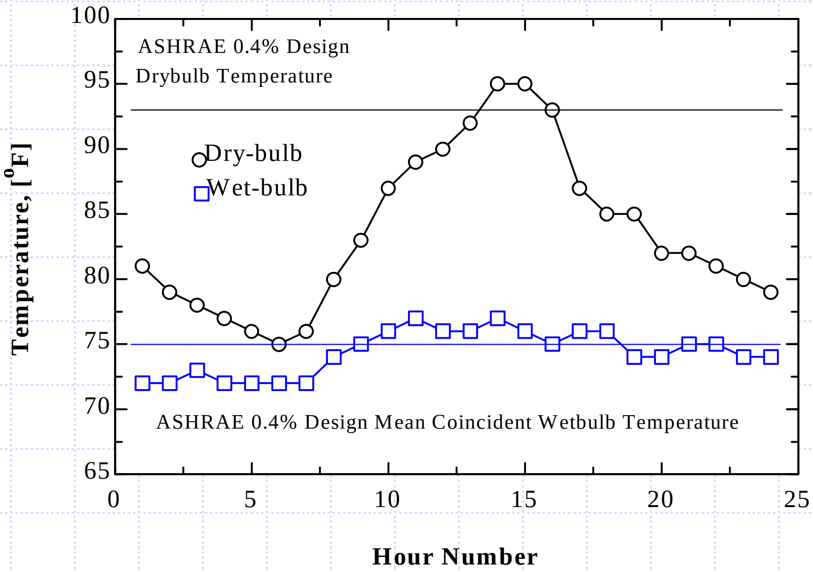
Objective

- Develop a modeling tool for freezer and dock loads associated with dock operation
- Investigate dock setpoint on total refrigeration system energy use
- Investigate effect of adding a desiccant dehumidifier to the dock
- Parametric investigation of largest assumptions (infiltration and defrost)

Simulation of the Loads

- Weather
  - NOAA surface observations of temperature and wetbulb
- Dock
  - People
  - Equipment (fans, forks, lights)
  - Infiltration (ambient load and freezer credit)
  - Transmission
  - Defrost
- Freezer (incremental)
  - Load from dock plus door heat (to avoid snow/frost)
  - Defrost associated with latent load from dock
- Quasi-steady state energy and mass balance in the dock



Infiltration

- Ambient air that enters the conditioned space
  - Uncontrolled
  - Unconditioned
- Importance in refrigerated spaces
  - Largest source of humidity (i.e. frost)

Infiltration through an unprotected door

- The amount of air flow through a doorway as a function of only temperature difference is impressive
  - Truck bay door 10' wide x 10' high
  - Dock 35^{o}F/86%, Ambient 93^{o}F/75^{o}F[1] wetbulb
  - Results in:[2]
    - equivalent of 85 ft/min velocity through the door
    - 44 tons sensible, 38 tons latent
    - In other words, 1.4 ton-hrs per minute of open door

[1] ASHRAE 0.4% Design conditions for Atlanta

[2] No influence of pressure difference from wind, etc.

Freezer infiltration

- 10’ wide x 10’ high
- Usually have a protective device
  - Strip curtain or door, air curtain, or both
- Doorway effectiveness, η
  - Fraction of unprotected doorway air exchange that is protected from exchange
  - In other words, multiply the unprotected doorway exchange by $(1 – \eta)$ to determine the estimated protected doorway air exchange

Freezer doorway effectiveness

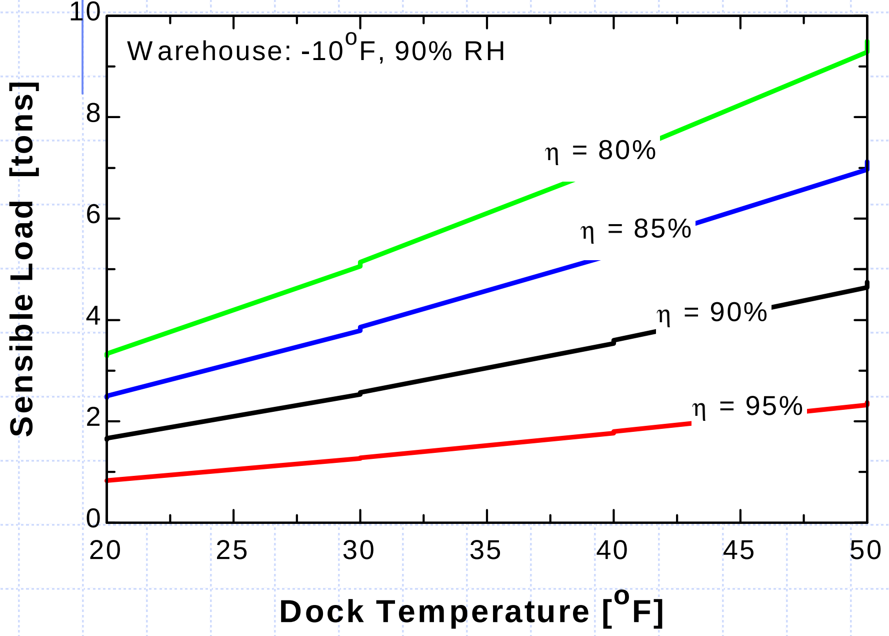
Strip curtain	82-94%
Vertical air curtain	49-80%
Dual horizontal air curtain	65-78%
Fast sliding doors	78-93%

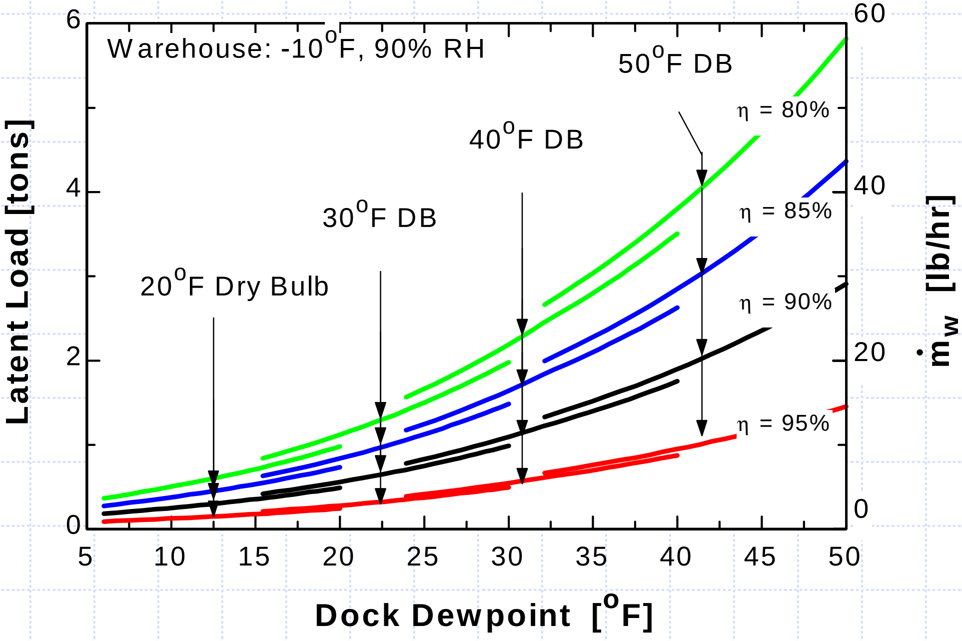
Values taken from:

Downing, C.C., W.A. Meffert, 1993, "Effectiveness of cold-storage door infiltration protective devices," *ASHRAE Transactions*, vol. 99, part 2, pp. 356-366.

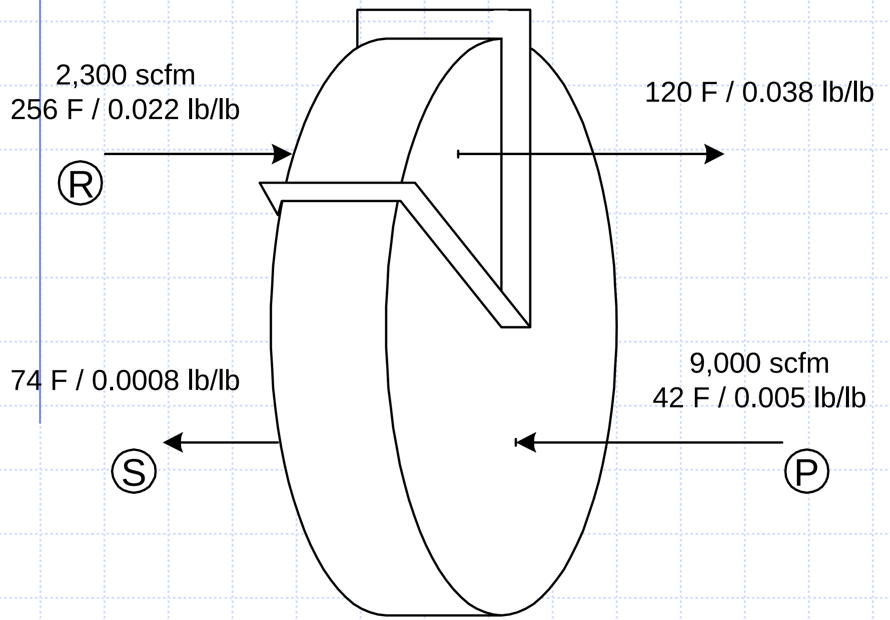
Freezer loads

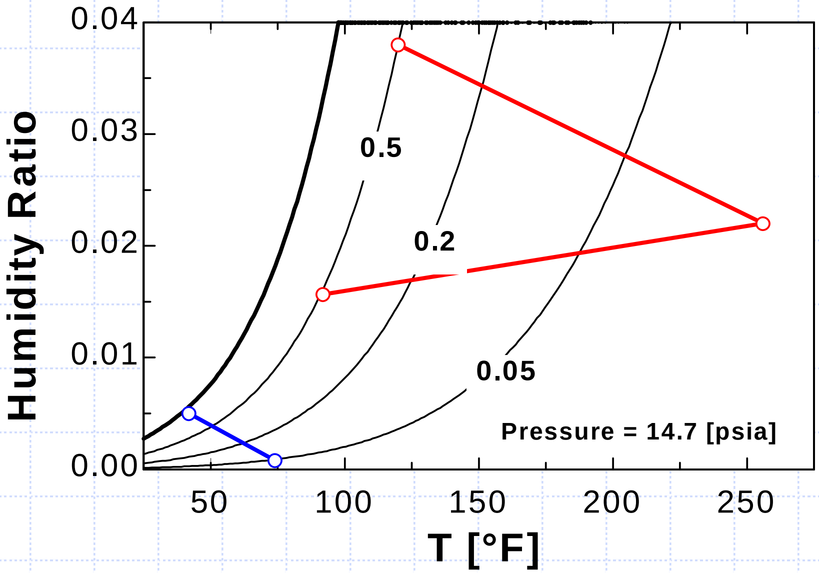
- Plots of sensible and latent load on freezer as a function of door effectiveness and dock conditions





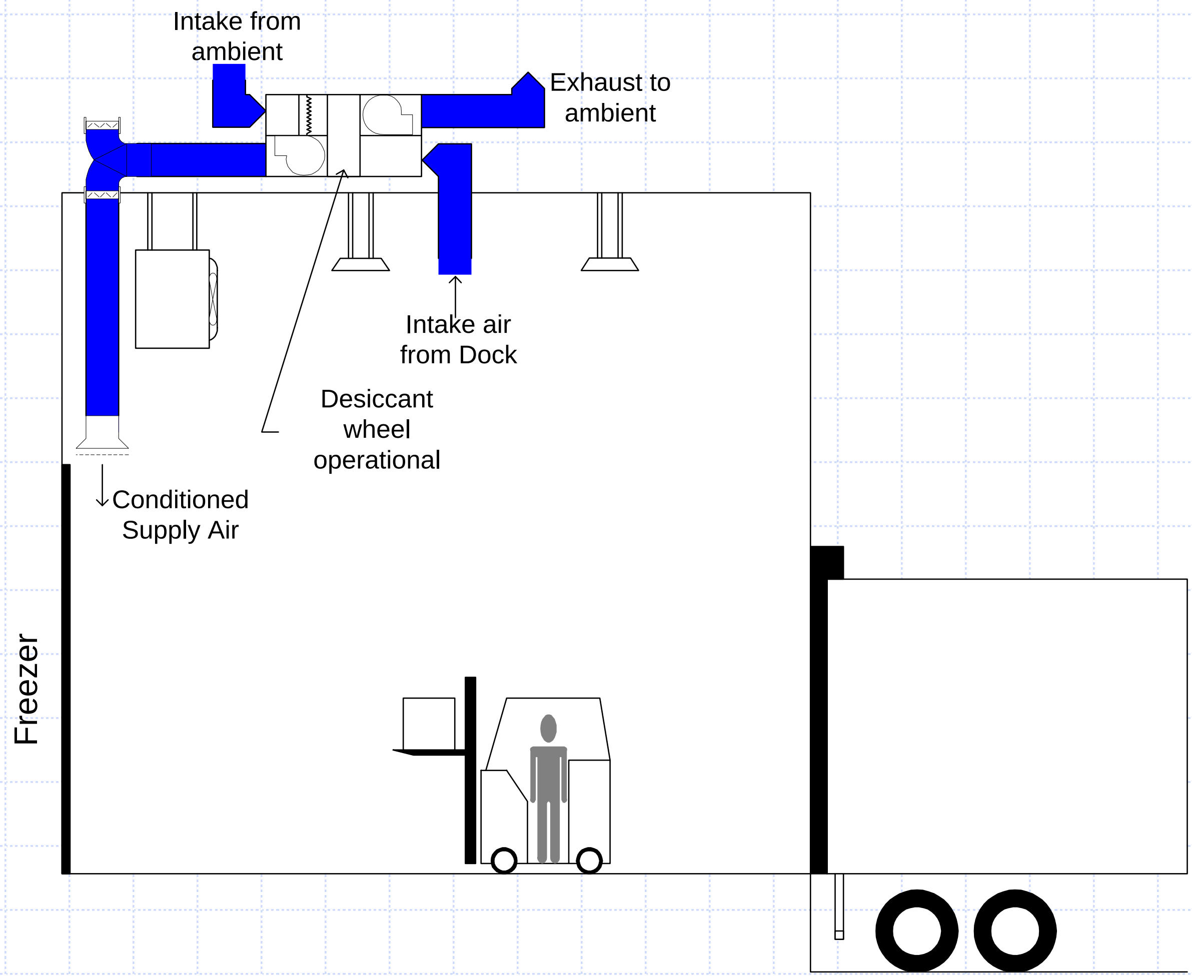
Schematic and Psychrometric Representation of Desiccant





- Assume regeneration flow rate scales with process flow rate
- Calculated simple effectivenesses from manufacturer's data
- Controlled the regeneration outlet temperature to maintain 120^{o}F

Desiccant System Schematic



Simulated Dock Details

- Located in Atlanta, GA
- Dock setpoint of 35^oF
- Attached to a –10^oF warehouse
- 12,000 ft^2 dock (40’x300’ South facing)
  - 2 10’x10’ freezer doors (assume η = 85%)
  - 8 10’x10’ truck bay doors (assume open 2 minutes per hour)

Design Day Energy Use

- Mechanical-refrigeration only
  - Freezer load: 2.6 ton-hr/ft^2 of door/SHR = 0.8
  - Peak dock load 340 ft^2/ton
  - 0.15 kWh/ft^2 per design day
  - \$0.013/ft^2 per design day[1]
- With desiccant (flow rate 0.50 cfm/ft^2 of dock)
  - Freezer load: 2.3 ton-hr/ft^2 of door/SHR = 0.99[2]
  - Peak dock load 290 ft^2/ton
  - 0.17 kWh/ft^2 and 0.006 therms/ft^2 per design day
  - \$0.017/ft^2 per design day[1]

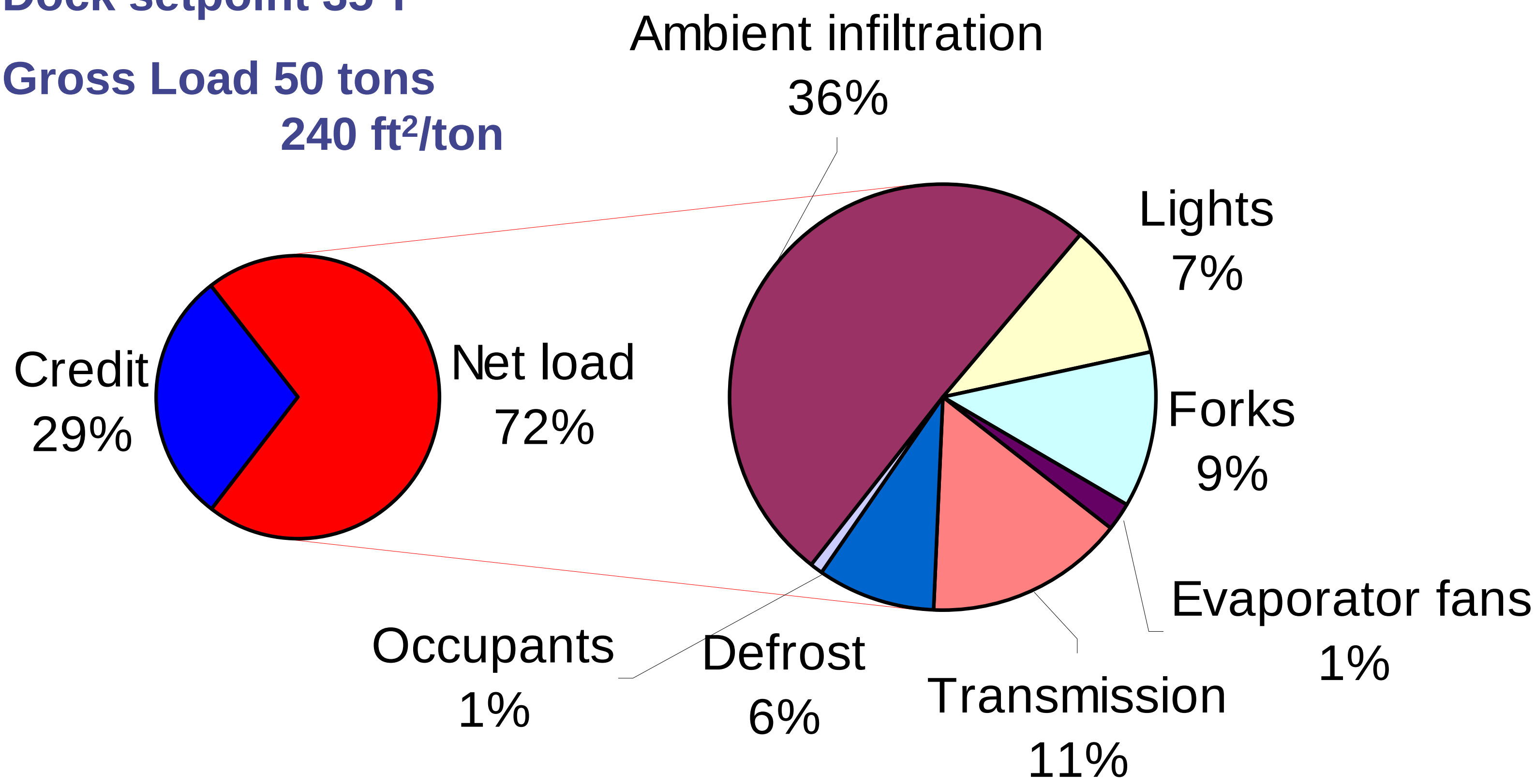
[1] Assume \$0.087/kWh and \$0.35/therm

[2] Assume the statepoint entering the freezer is the desiccant outlet state

Mechanical-only Load Breakdown

Dock setpoint 35°F

Gross Load 50 tons
240 ft²/ton

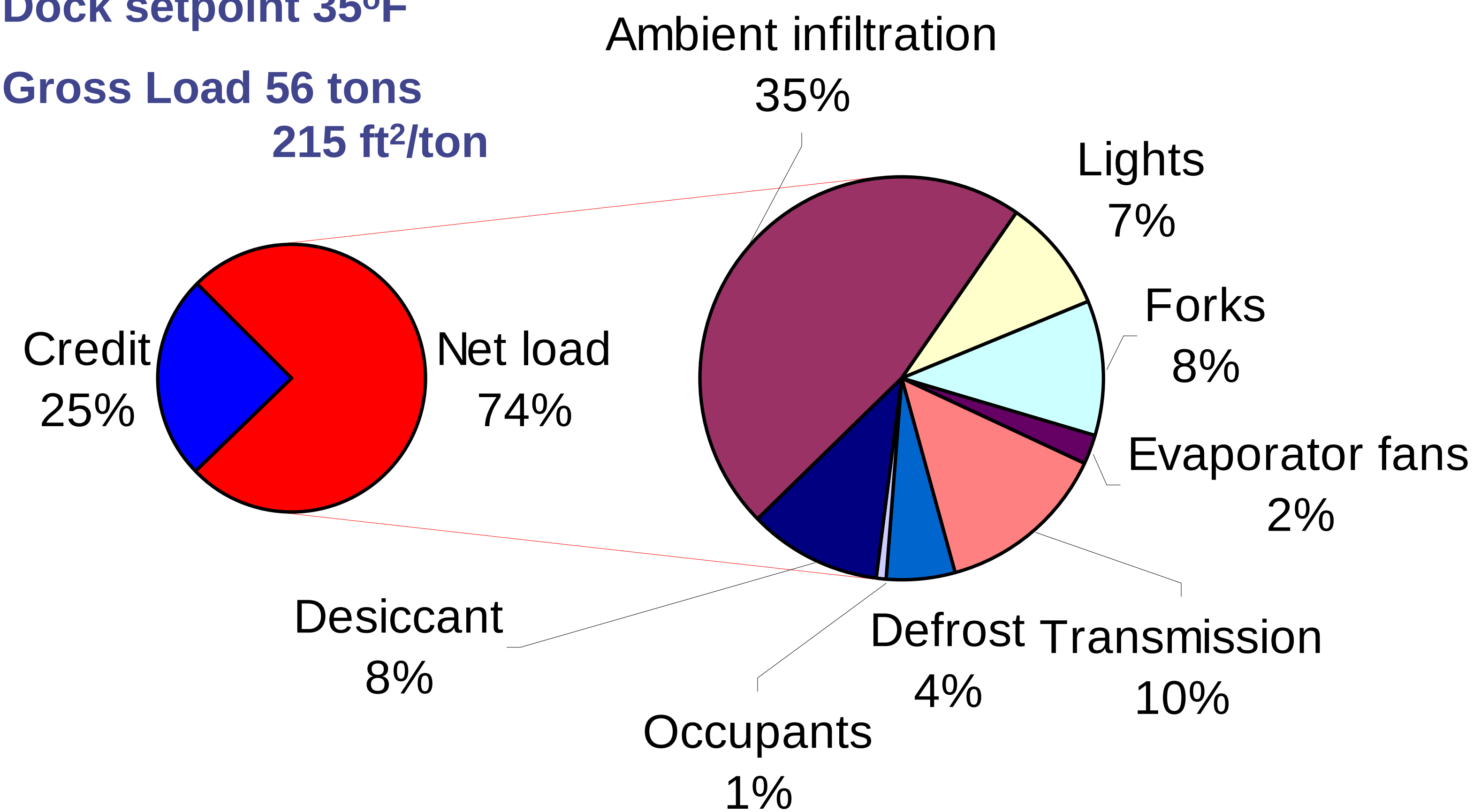


Note: Load component percentage is of the gross load, the pie chart fraction is of the net load.

Desiccant Load Breakdown

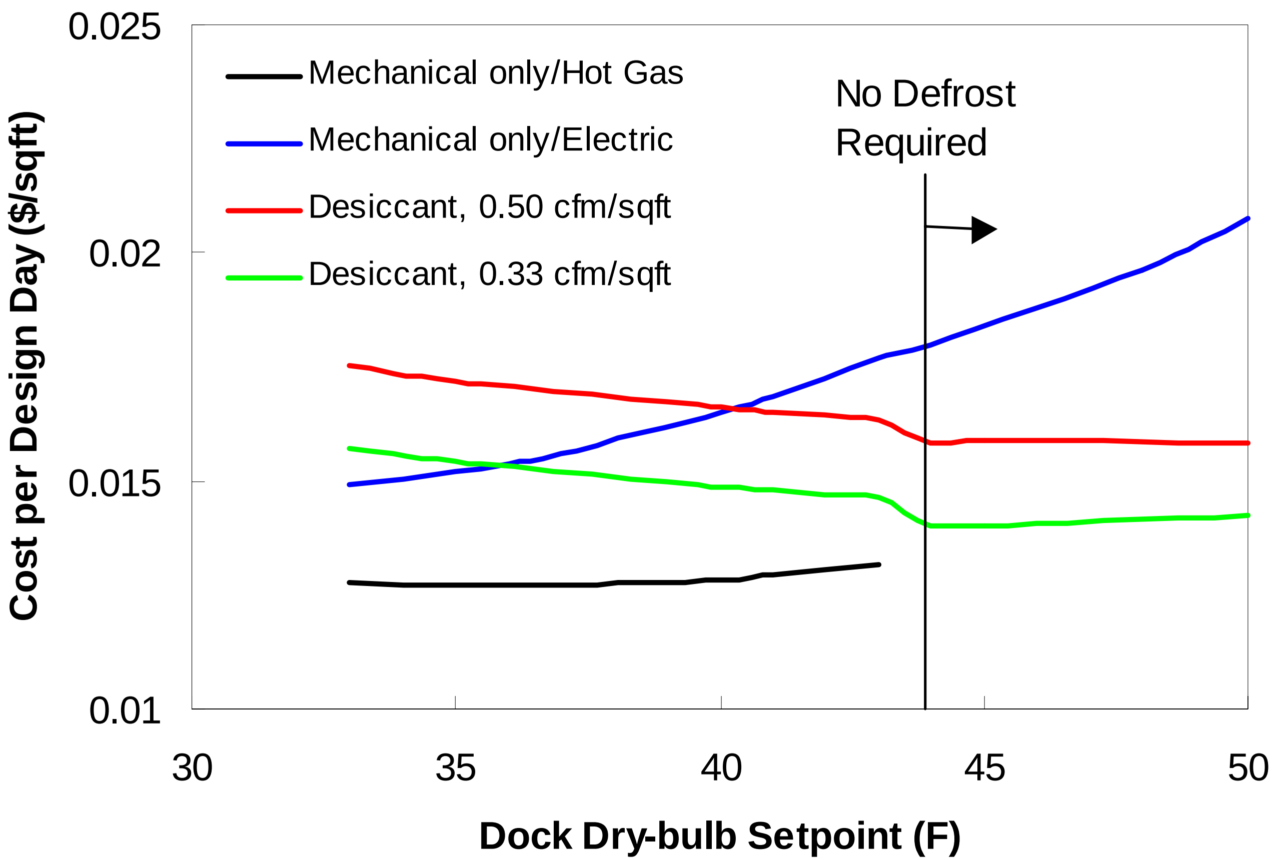
Dock setpoint 35ºF

Gross Load 56 tons
215 ft²/ton



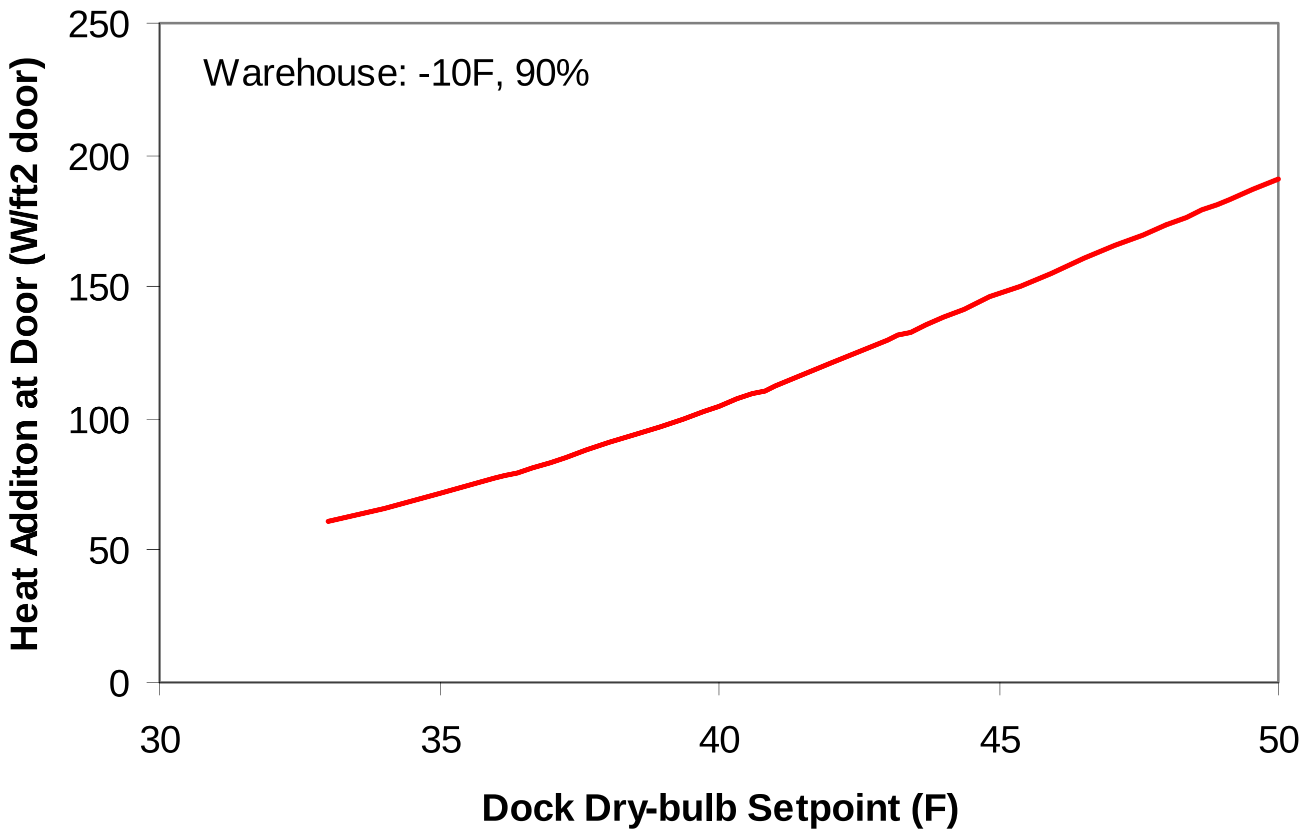
Note: Load component percentage is of the gross load, the pie chart fraction is of the net load.

Effect of Dock Setpoint

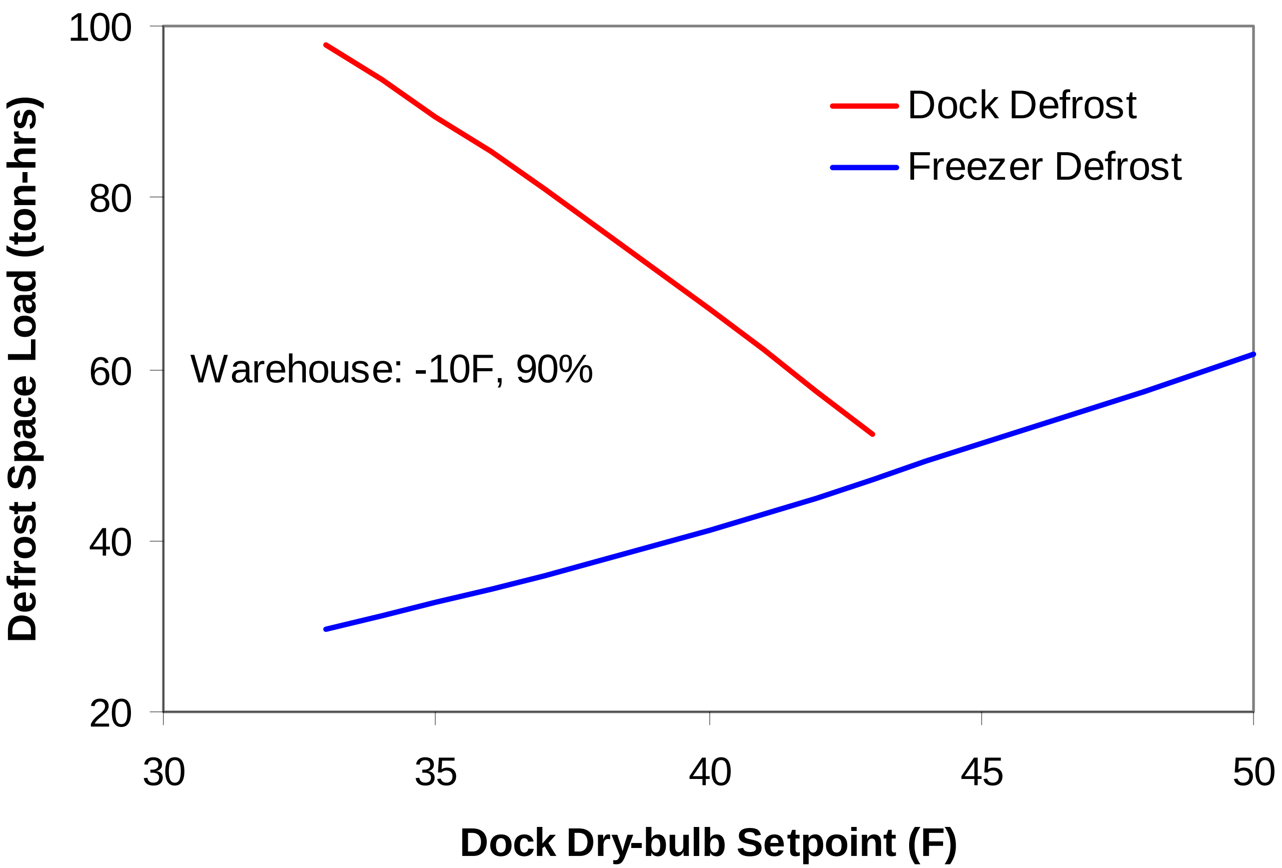


Note: “Hot Gas” and “Electric” refer to the method of applying dock/freezer door heat to avoid frost, etc.

Heat Addition at Freezer Door



Defrost Space Loads



Effects of Ambient Infiltration

- Increase assumed ambient infiltration by 50%
  - Mechanical Refrigeration-only

	2 min/h	3 min/h
Peak dock load	35 tons	50 tons
Peak freezer load	21 tons	24 tons
Energy cost/ft^2	$0.013	$0.016

  - With 0.50 cfm/ft^2 desiccant

	2 min/h	3 min/h
Peak dock load	42 tons	57 tons
Peak freezer load	19 tons	20 tons
Energy cost/ft^2	$0.017	$0.020

Note: all parametric reductions are for 35^{o}F dock setpoint.

Effects of Freezer Infiltration

- Decrease assumed freezer infiltration by 33%
  - Mechanical Refrigeration-only

	85%	90%
Peak dock load	35 tons	40 tons
Peak freezer load	21 tons	16 tons
Energy cost/ft^2	$0.013	$0.011

  - With 0.50 cfm/ft^2 desiccant

	85%	90%
Peak dock load	42 tons	47 tons
Peak freezer load	19 tons	13 tons
Energy cost/ft^2	$0.017	$0.016

Effects of Defrost Load

- Double the energy associated with defrost
  - Mechanical Refrigeration-only

	20%[1]	10%
Peak dock load	35 tons	39 tons
Peak freezer load	21 tons	22 tons
Energy cost/ft^2	\$0.013	\$0.014

  - With 0.50 cfm/ft^2 desiccant

	20%	10%
Peak dock load	42 tons	44 tons
Peak freezer load	19 tons	19 tons
Energy cost/ft^2	\$0.017	\$0.018

[1] Defrost efficiency

Conclusions

- Created a relatively simple load calculation tool
- Estimates all the factors that influence the fair comparison of mechanical refrigeration and desiccant dehumidification
  - Mechanical refrigeration-only[1]
    - ~35^{o}F dock setpoint is near optimum
    - Lower design day system energy use than with desiccant
  - Desiccant opportunities
    - Benefits from higher setpoint in the dock
    - Size is important (possibly size near estimated freezer infiltration rate)

[1] Using hot-gas door heat

Future work

- General
  - Optimum dock temperature determination as a function of ambient conditions.
- Freezer door
  - Dock/freezer air exchange conditions that result in “no frost” condition in the freezer.
  - Methods for control of door heat addition to prevent freezer frost.
- Desiccant
  - Investigate sizing of desiccant system.
  - Investigate siting of desiccant system inlets and outlets.
  - Investigate alternative control of desiccant system.