Measured Impacts of Supermarket Humidity Level on Defrost Performance and Refrigeration System Energy Use

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Hugh Henderson, Jr., P.E.
CDH Energy Corp.
www.cdhenergy.com

Mukesh K. Khattar, PhD., PE
EPRI
www.epri.com

Introduction

- Collected detailed monitored data *continuously* at two stores for more than 12 months
- Used direct digital control (DDC) system to collect data every 15 minutes
- Two typical supermarkets in the Midwest
  - Store A: 33,400 ft^2, Minneapolis, MN
  - Store B: 50,000 ft^2, Indianapolis, IN

Test Objectives

- Quantify the impact of store humidity on refrigeration energy use
- Understand the factors that impact affect energy use
  - latent loads, defrost, anti-sweat heaters
- Develop easy-to-understand rules-of-thumb to predict the impact of enhanced dehumidification systems on refrigeration energy use

Impact of Space Humidity

Expected Impact of Lower Humidity:

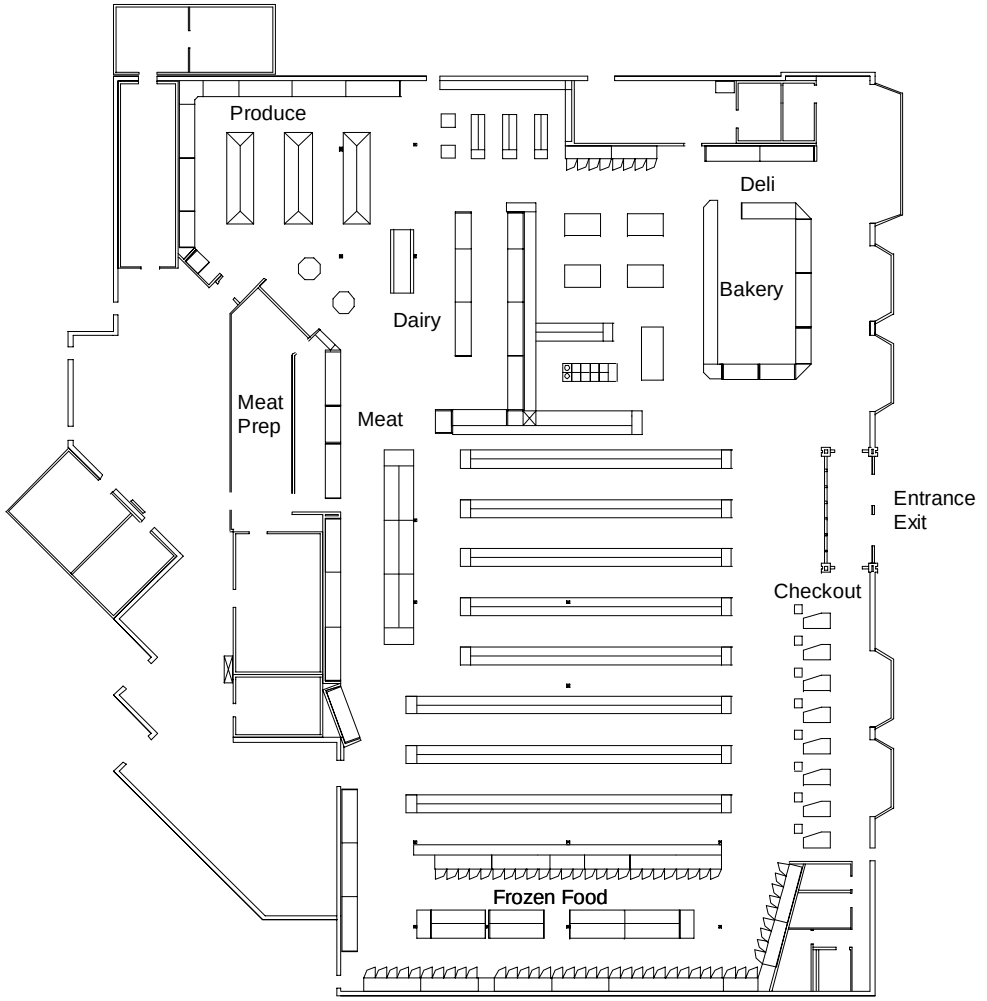
- Reduced moisture load on display cases (and compressors)
- Reduced defrost energy use and imposed refrigeration loads
- Reduced anti-sweat heater energy use and imposed refrigeration loads

Refrigeration Systems

Characteristics	Store A	Store B
Type of System	Parallel Racks Rack A – low temp (R502) Racks B, C, D medium temp (R22)	Single Comp. Racks 25 Racks (R22)
Number of Compressors	18	25
Number of Zones	34	45
Total Case Length Total Cooler/Freezer Area	716 ft 2,849 ft^2	938 ft 3,685 ft^2
Total Refrigeration Load	60 tons	80 tons
Active Defrost Method	Hot Gas 16 zones, time terminated	Electric 16 zones, pressure terminated, 160 kW
Controlled Anti-Sweat Heaters	10 kW	9 kW 22 kW total

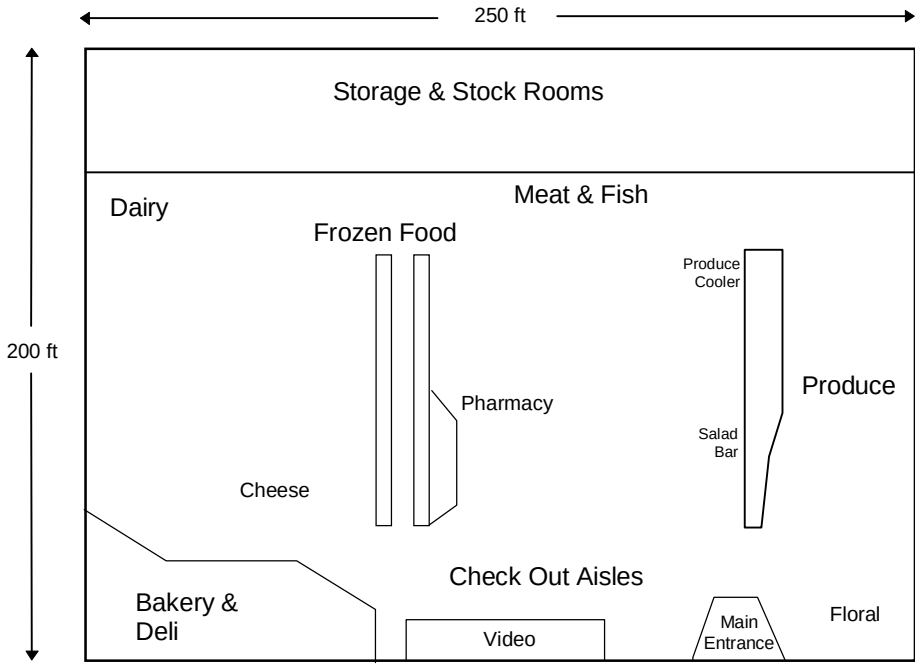
Store A

- Minneapolis, MN
- 33,400 ft^2 gross area (sales area 77%)
- open 24 hours, 7 days
- Built in 1985



Store B

- Indianapolis, IN
- 50,000 ft^2 gross area (sales area 73%)
- open 24 hours, 7 days
- Built in 1992

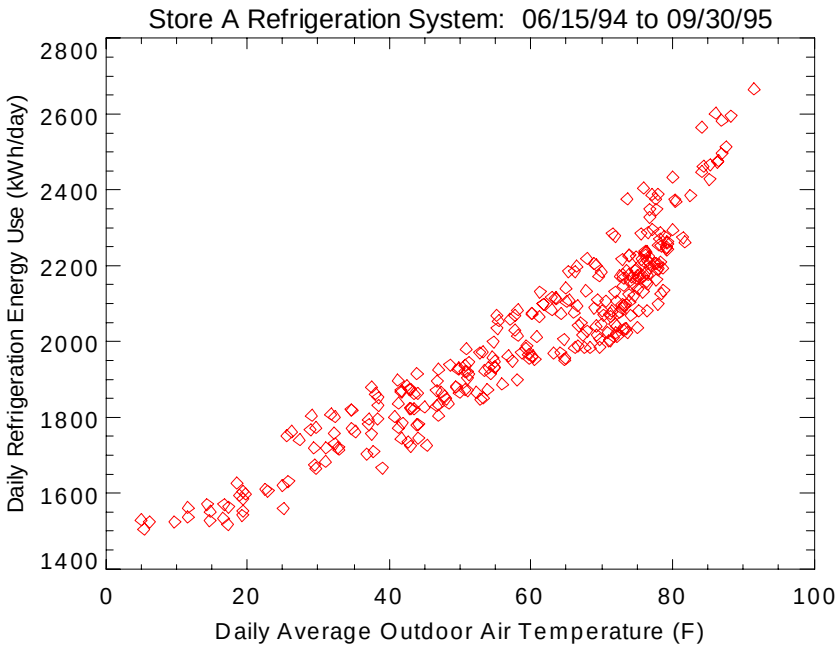


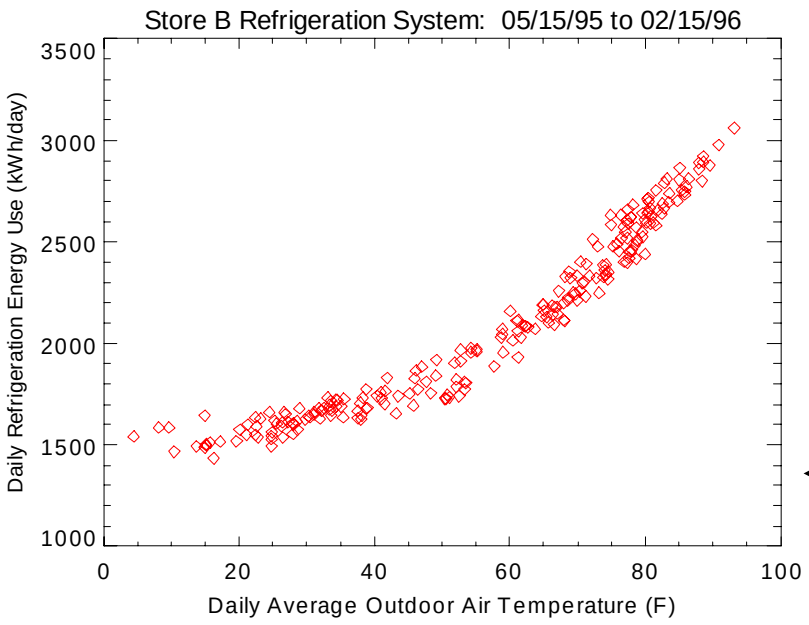
Monitored Data

Description	Store A	Store B
Outdoor Air Temperature	Yes	Yes
Outdoor Relative Humidity	Yes	Yes
Sales Area Temperature	Yes	Yes
Sales Area Humidity	Yes	Yes
Frozen Food Aisle Temperature	Yes	-
Refrigeration System Power	Yes (compressor racks and condenser fans)	Yes (racks, condenser fans, electric defrost)
Anti-Sweat Heater Power	Yes (status of controlled heaters)	Yes (total anti-sweat heater power)
Display Case Temperatures	Yes	-
Defrost Control Parameters	Yes	-

Refrigeration Energy Use

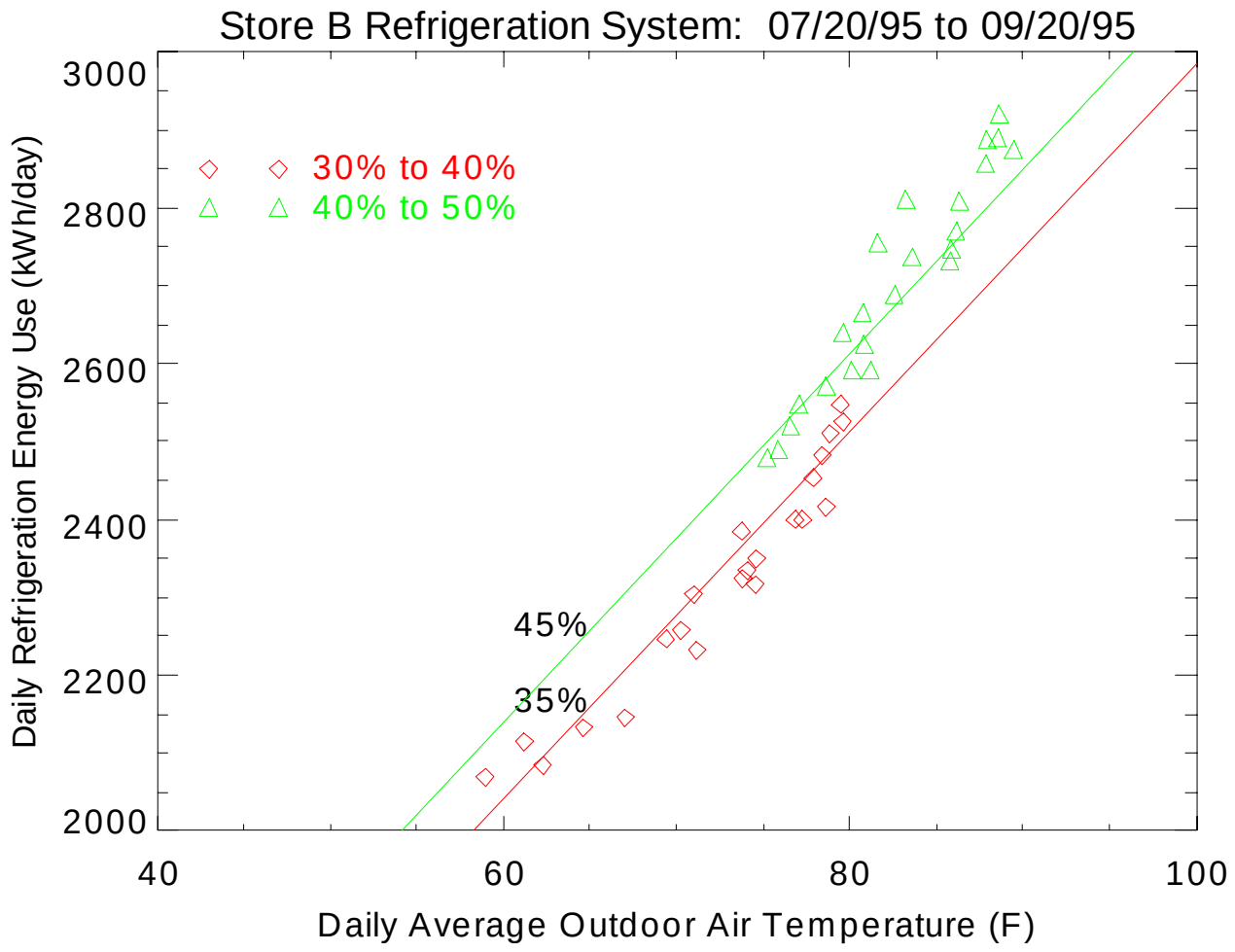
STORE A: Parallel Racks
60 tons →





← STORE B: Single Racks
80 tons

Quantifying the Impact of Humidity



Impact of Humidity on Energy Use

- Multi-Linear Regression Analysis of Refrigeration Energy Use at **Store B**:

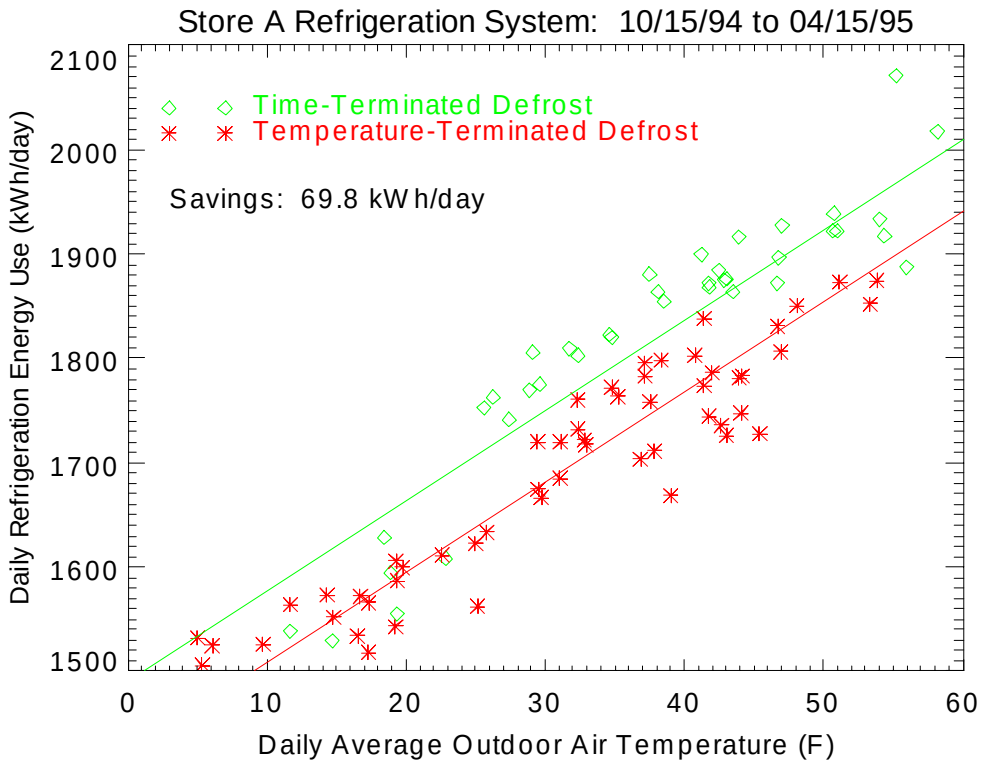
$$KWh_{REF} = \underset{\langle 4.7 \rangle}{268.39} + \underset{\langle 23.0 \rangle}{23.72 \bullet TAO} + \underset{\langle 9.4 \rangle}{9.88 \bullet RH,} \qquad R^2 = 0.98$$

t-ratios

- Impact of Humidity: 9.9 kWh/day per %RH
- Data for period with step change in humidity…so there is little auto-correlation

The Impact of Terminated Defrost

- **Store A** originally used time-terminated hot gas defrost
- Converted to temperature-terminated defrost



Defrost Analysis - Store A

- SIMPLE Multi-linear regression analysis (6 months of data):

$$kWh_{REF} = 1490.2 + 8.7 \bullet TAO - 69.8 \bullet DEF, \quad R^2 = 88$$

<99> <24> <7.4> t-ratios

- COMPLEX regression analysis (12 months of data):

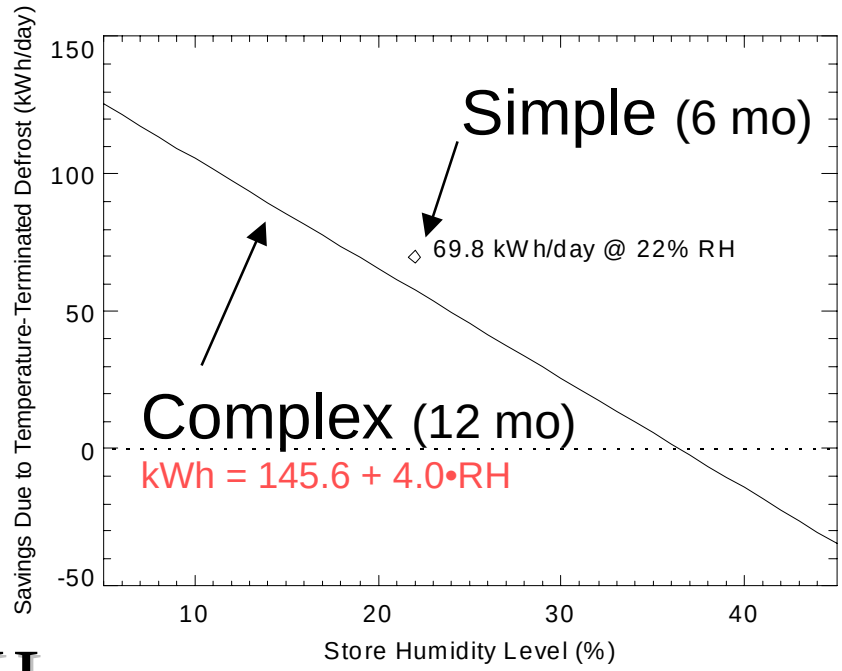
$$kWh_{REF} = 1597.7 + 2.1 \bullet TAO + 0.83 \bullet TAO^2 - DEF \bullet (145.6 - 4.0 \bullet RH), \quad R^2 = 92\%$$

<52> <2.0> <7.4> <3.8> <3.0> t-ratios

DEF = defrost dummy variable (0=time-terminated, 1=temp-terminated)

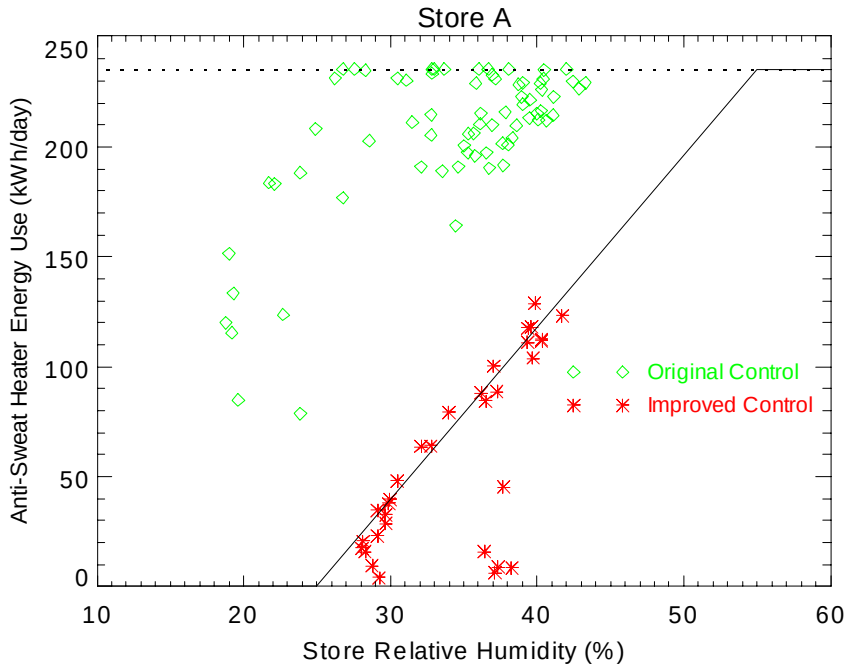
Defrost Analysis - Store A (cont.)

- Complex and simple analysis agree
- Complex analysis implies that energy use increases by 4 kWh/day per % RH with hot gas defrost (due to impact of defrost heat on load)



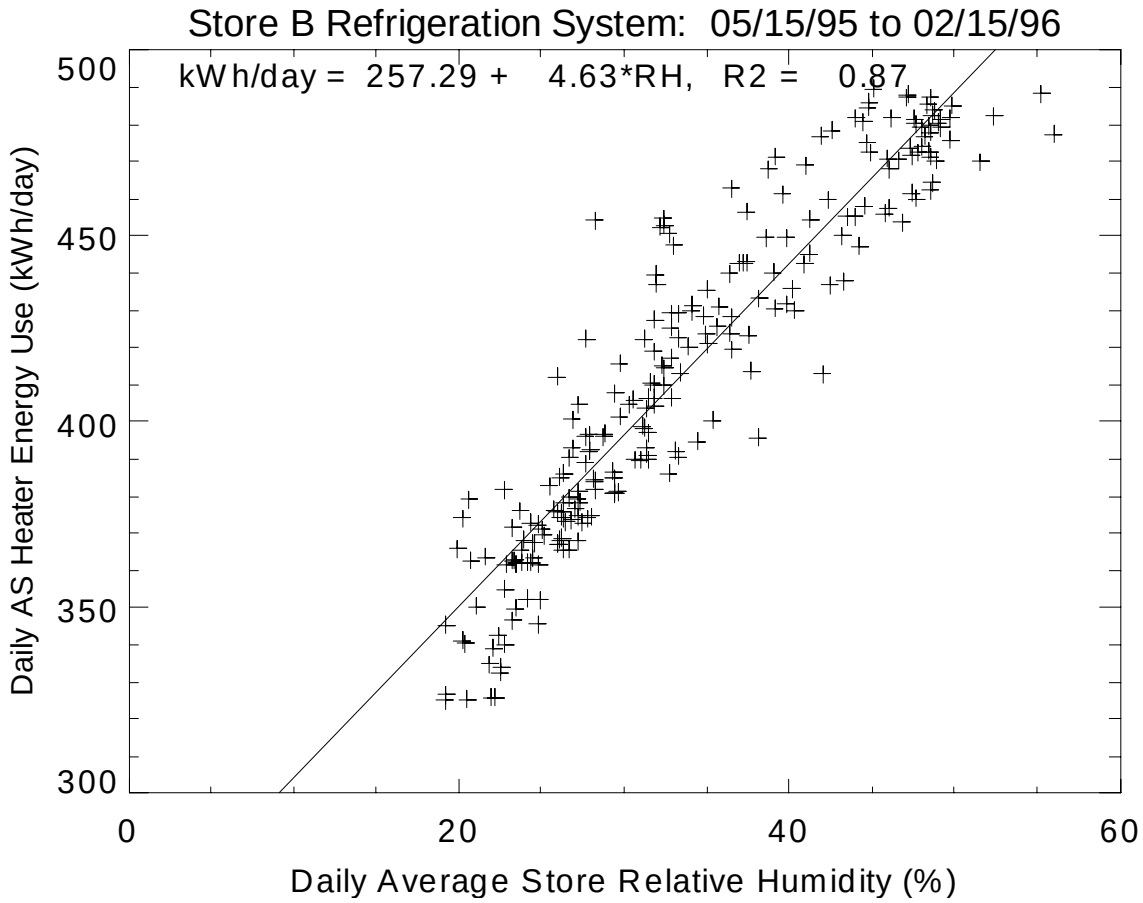
Anti-Sweat Heater Energy Use

- In **Store A** the original electro-mechanical controls were replaced with DDC controls
- **Store B** used standard electro-mechanical controls



Reduction per each % RH Drop in Space Humidity	Store A (kWh/day per %RH)	Store B (kWh/day per %RH)
Electro-Mechanical Controls	**3.5**	**4.6**
DDC Controls	**7.8**	**-**

Store B Anti-Sweat Heaters



Net Impact of Humidity

Energy Reduction Factor (kWh/day-%RH)	Store A Hot Gas Defrost 60 tons	Store B Electric Defrost 80 tons
Moisture Load	Not Determined	9.9
Load Imposed by Defrost	4.0	
Direct Defrost Energy Use	-	
Load Imposed by Anti-Sweat Heaters	Not Determined	
Direct Anti-Sweat Heater Energy Use	7.8	4.6
TOTAL	**11.8**	**14.5**

- Hot Gas Defrost: 9-12 kWh/day-%RH
- Electric Defrost: 15-18 kWh/day-%RH

Comparison to Howell Method

- Calculated Energy Reduction Factor for Store B by method developed in ASHRAE 596-RP: 8 kWh/day-%RH
- Measured Energy Reduction Factor (without AS Heaters): 10 kWh/day-%RH
- Measured value is higher due to impact of AS heaters on case load
  - calculated to be 2 kWh/day-%RH (assuming 2.0 kW/ton compressor efficiency)

Seasonal Implications

- What are the potential savings for enhanced dehumidification systems?
- Assume maintain 35% RH for summer in Indianapolis, IN
  - equivalent to decreasing space humidity by 15% RH for 2,000 hours/yr
- With factor of 15 kWh/day-%RH, annual refrigeration savings: 18,750 kWh.
  - $700 to $2,000/yr (at $0.03 to $0.11 per kWh)

Conclusions

- Humidity impacts refrigeration system energy use by 10-20 kWh/day-%RH in a average store
- Refrigeration system features with big impact:
  - anti-sweat heaters (direct & indirect)
  - electric defrost (direct & indirect)
- Features with less impact:
  - moisture loads & hot gas defrost