



U.S. Department of Energy  
Energy Efficiency and Renewable Energy

# Energy Conservation Standards for Commercial Refrigeration Equipment

## ANOPR Public Meeting

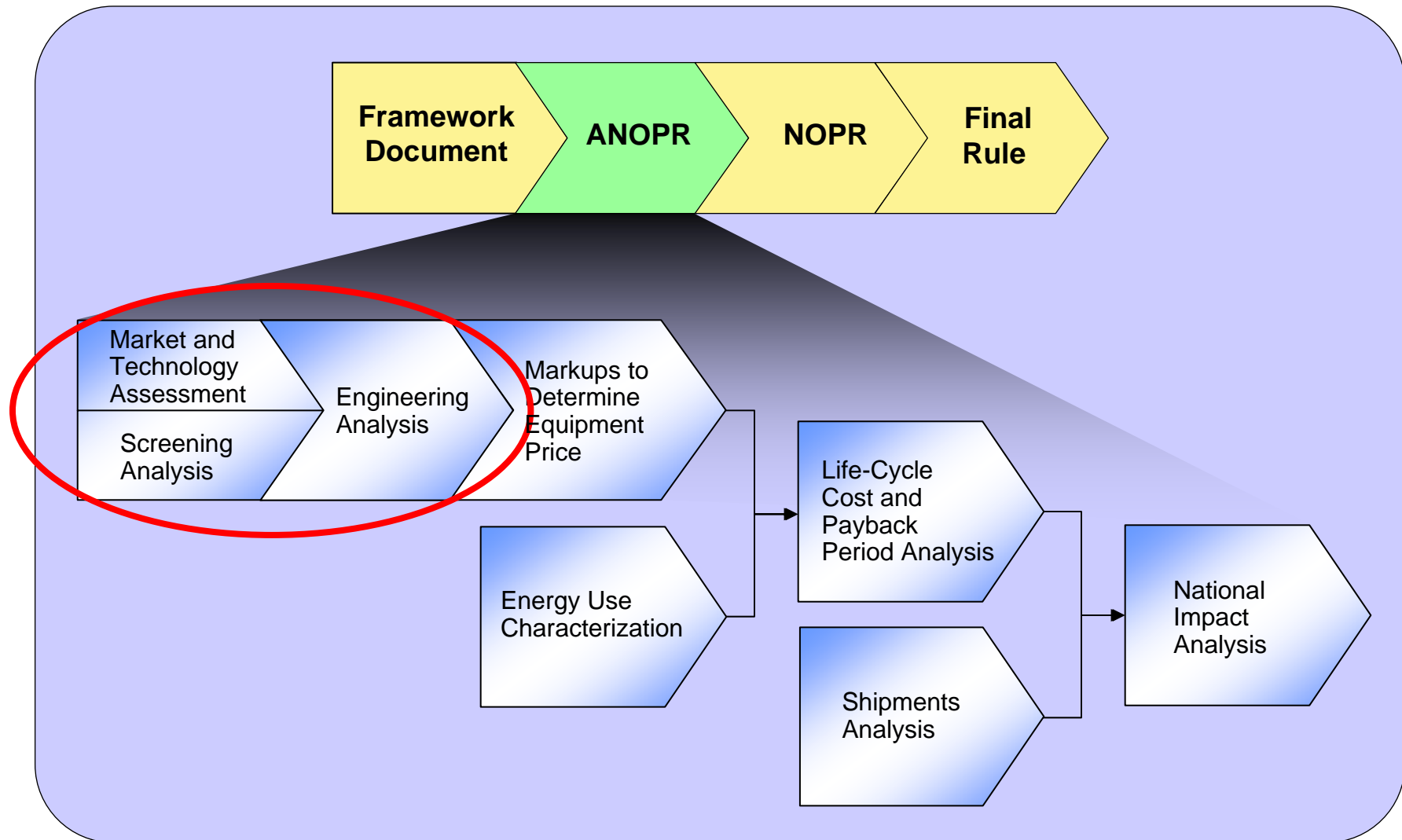
## Engineering Analysis

Building Technologies Program  
Office of Energy Efficiency and Renewable Energy  
U.S. Department of Energy

August 23, 2007



## ANOPR Analyses Flow Diagram





## Purpose

### ■ Market & Technology Assessment

- To characterize the commercial refrigeration equipment market to determine available equipment efficiencies and shipments by equipment class

### ■ Screening Analysis

- To identify design options that increase efficiency and to apply screening criteria established by DOE to determine which design options to evaluate and which to screen out

### ■ Engineering Analysis

- To characterize manufacturer cost-efficiency relationships for higher efficiency equipment
- To evaluate design options that improve efficiency relative to the baseline units
- Sensitivity analyses



## **ANOPR Issues for Public Comment**

- **Equipment Class Prioritization and Extending Analyses (Issue #1)**
- **Air-Curtain Angle (Issue #2)**
- **Door Angle (Issue #3)**
- **Equipment Classes for Equipment with Door (Issue #4)**
- **Equipment Class Organization (Issue #5)**



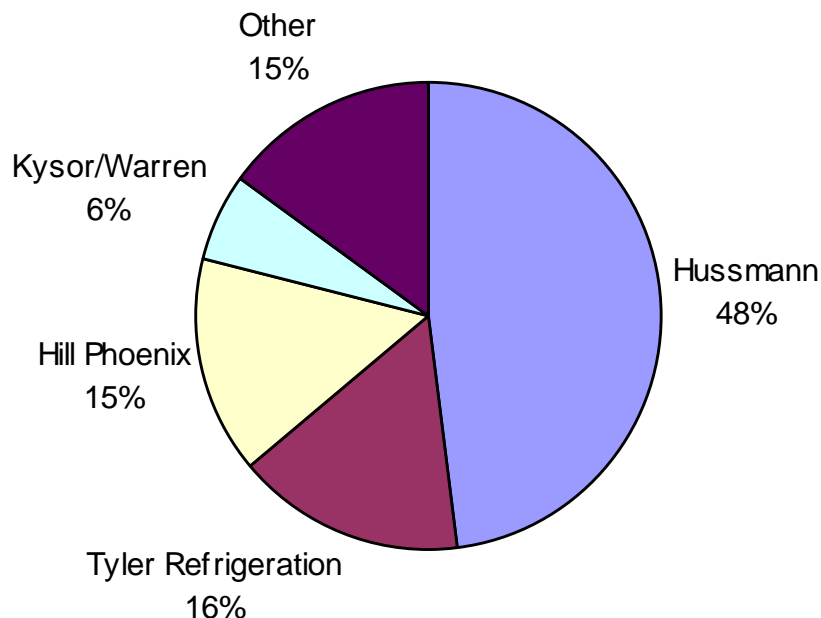
## Equipment Categories

- **Remote Condensing Commercial Refrigerators, Commercial Freezers, and Commercial Refrigerator-Freezers**
- **Self-Contained Commercial Refrigerators, Commercial Freezers, and Commercial Refrigerator-Freezers Without Doors**
- **Commercial Ice-Cream Freezers**



## Market Shares and Unit Shipments

- Four manufacturers account for approximately 85% of the domestic market share of all types of commercial refrigeration equipment
- Approximately 170,000 units covered by this rulemaking were shipped in 2005 (2006 ARI and 2005 Appliance Magazine data).
- Remote condensing equipment accounts for about 80% of the covered market, while self-contained equipment accounts for the remaining 20%.



Source: *Appliance Magazine, 28th Annual Portrait of the U.S. Appliance Industry*, September 2005.



## Equipment Class Designations

Equipment Family	Designation
Vertical Open	VOP
Semivertical Open	SVO
Horizontal Open	HZO
Vertical Closed Transparent	VCT
Vertical Closed Solid	VCS
Horizontal Closed Transparent	HCT
Horizontal Closed Solid	HCS
Service Over Counter	SOC

Condensing Unit Configuration	Designation
Remote condensing	RC
Self-contained	SC

Rating Temperature	Designation
38°F	M
0°F	L
-15°F	I



## Equipment Class Organization

Equipment Category	Condensing Unit Configuration	Equipment Family	Rating Temperature (°F)	Equipment Class Designation
Remote Condensing Commercial Refrigerators, Commercial Freezers, and Commercial Refrigerator Freezers	Remote	Vertical Open	38	VOP.RC.M
			0	VOP.RC.L
		Semivertical Open	38	SVO.RC.M
			0	SVO.RC.L
		Horizontal Open	38	HZO.RC.M
			0	HZO.RC.L
		Vertical Closed Transparent	38	VCT.RC.M
			0	VCT.RC.L
		Horizontal Closed Transparent	38	HCT.RC.M
			0	HCT.RC.L
		Vertical Closed Solid	38	VCS.RC.M
			0	VCS.RC.L
		Horizontal Closed Solid	38	HCS.RC.M
			0	HCS.RC.L
		Service Over Counter	38	SOC.RC.M
			0	SOC.RC.L



## Equipment Class Organization (Cont.)

Equipment Category	Condensing Unit Configuration	Equipment Family	Rating Temperature (°F)	Equipment Class Designation
Self-Contained Commercial Refrigerators, Commercial Freezers, and Commercial Refrigerator-Freezers Without Doors	Self-Contained	Vertical Open	38	VOP.SC.M
			0	VOP.SC.L
		Semivertical Open	38	SVO.SC.M
			0	SVO.SC.L
		Horizontal Open	38	HZO.SC.M
			0	HZO.SC.L



## Equipment Class Organization (Cont.)

Equipment Category	Condensing Unit Configuration	Equipment Family	Rating Temperature (°F)	Equipment Class Designation
Commercial Ice-Cream Freezers	Remote	Vertical Open	-15	VOP.RC.I
		Semivertical Open		SVO.RC.I
		Horizontal Open		HZO.RC.I
		Vertical Closed Transparent		VCT.RC.I
		Horizontal Closed Transparent		HCT.RC.I
		Vertical Closed Solid		VCS.RC.I
		Horizontal Closed Solid		HCS.RC.I
		Service Over Counter		SOC.RC.I
	Self-Contained	Vertical Open		VOP.SC.I
		Semivertical Open		SVO.SC.I
		Horizontal Open		HZO.SC.I
		Vertical Closed Transparent		VCT.SC.I
		Horizontal Closed Transparent		HCT.SC.I
		Vertical Closed Solid		VCS.SC.I
		Horizontal Closed Solid		HCS.SC.I
		Service Over Counter		SOC.SC.I



## Equipment Class Organization (Issue #5)

*DOE invites comments on the selected equipment class organization  
(see slides 8-10).*

- Eight equipment families
- Two condensing unit configurations
- Three rating temperatures



## Equipment Class Prioritization

- DOE analyzed the 14 equipment classes with at least 100 annual shipments
- Added the VOP.RC.L class at the recommendation of manufacturers

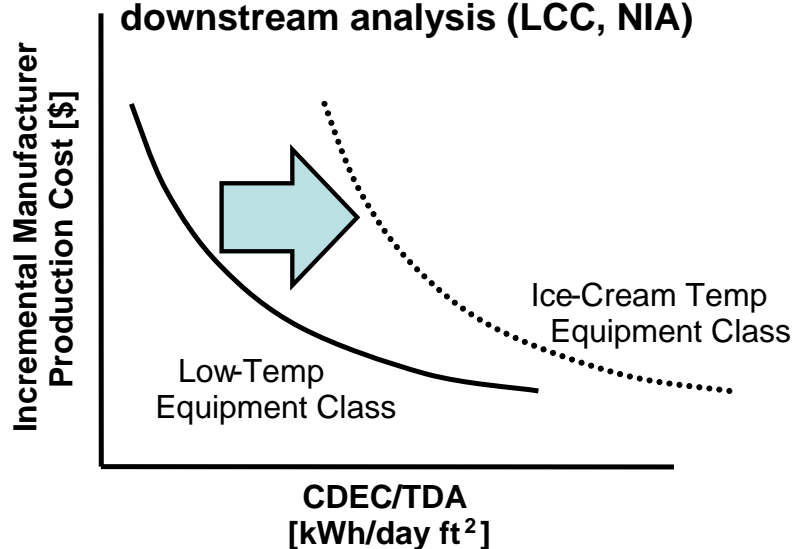
 <b>VOP.RC.M</b> 38,743	 <b>VCT.RC.L</b> 38,483	 <b>VOP.RC.L</b> 0	 <b>VOP.SC.M</b> 6,512	 <b>HCT.SC.I</b> 9,056
 <b>SVO.RC.M</b> 29,552	 <b>HZO.RC.L</b> 14,278	 <b>SOC.RC.M</b> 9,312	 <b>SVO.SC.M</b> 9,750	 <b>VCS.SC.I</b> 470
 <b>HZO.RC.M</b> 4,541	 <b>VCT.RC.M</b> 2,767	 <b>HZO.SC.L</b> 1,738	 <b>HZO.SC.M</b> 838	 <b>VCT.SC.I</b> 1,898



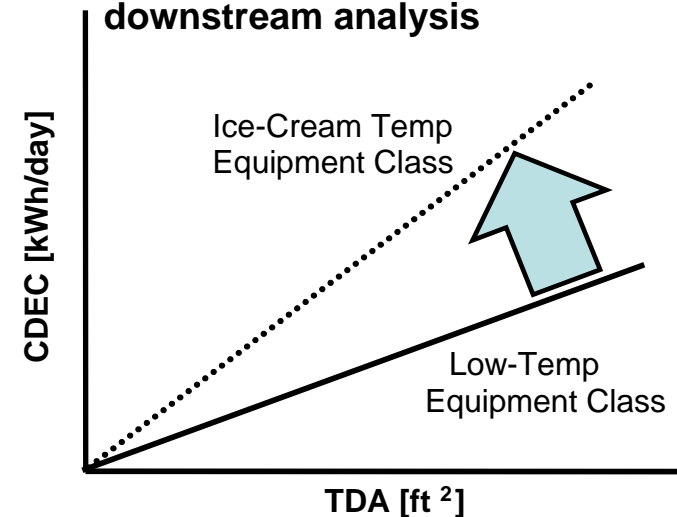
## Extension of Standards (Issue #1)

- This approach is intended to streamline the analysis by focusing on the high shipment volume equipment classes
- Uses one of two approaches:

**OPTION 1:** Translation of cost-efficiency curves, followed by full downstream analysis (LCC, NIA)



**OPTION 2:** Translation of standard equation, avoiding additional downstream analysis



***DOE invites comments on the extension of standards from low temperature equipment classes to similar low shipment volume ice-cream temperature equipment classes.***



## Air-Curtain Angle (Issue #2)

- Air curtains divide the refrigerated compartment from the ambient space on equipment without doors
- The energy consumption of equipment without doors is affected by the air-curtain angle
- Equipment without doors can therefore be broadly categorized by the air-curtain angle
- DOE is considering defining air-curtain angle as
  - “the angle between a vertical line and the line formed by the points at the center of the discharge air grille and the center of the return air grille, when viewed in cross-section.”

*DOE invites comments on the proposed definition of air-curtain angle.*



## Door Angle (Issue #3)

- Equipment with doors can be broadly categorized by the angle of the door and whether the door is solid or transparent
- DOE is considering defining door angle as
  - “the angle between a vertical line and the line formed by the plane of the door, when viewed in cross-section .”

*DOE invites comments on the proposed definition of door angle.*



## Equipment Classes for Equipment with Doors (Issue #4)

- **DOE is proposing to define two equipment families each for equipment with solid and transparent doors**
    - 0° to 45° (vertical)
    - 45° to 90° (horizontal)
- \*ranges given with respect to the vertical

*DOE invites comments on the proposed ranges of door angles for vertical and horizontal equipment families.*



## Screening Analysis Method

- **Design options screened using the following criteria:**
  - Technological feasibility
  - Practicability to manufacture, install and service
  - Adverse impacts on product utility or product availability
  - Adverse impacts on health or safety



## Technologies Selected for Further Consideration

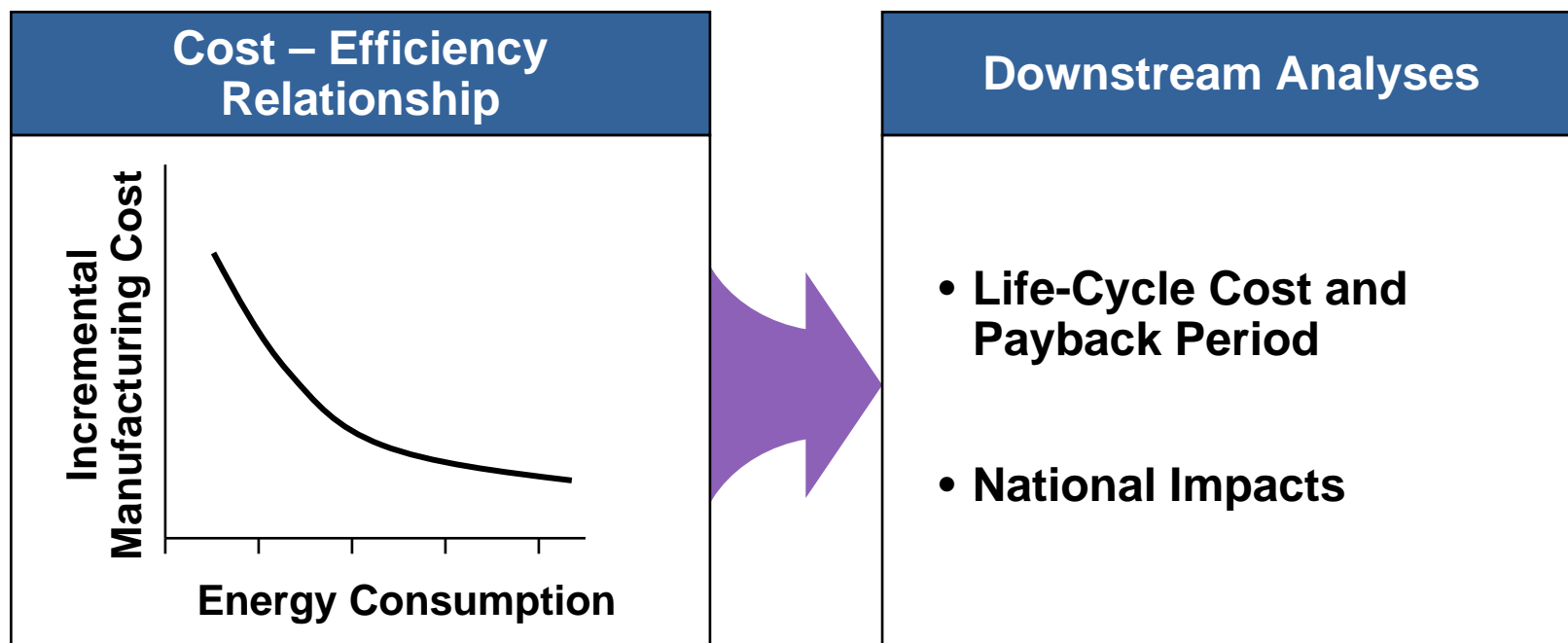
### Technologies that can improve Calculated Daily Energy Consumption

- higher-efficiency lighting
- higher-efficiency lighting ballasts
- remote lighting ballast location
- higher-efficiency evaporator fan motors
- evaporator fan motor controllers
- higher-efficiency evaporator fan blades
- increased evaporator surface area
- low-pressure differential evaporators
- improved or thicker insulation
- defrost mechanism
- defrost cycle control
- higher-efficiency compressors (self-contained equipment only)
- increased condenser surface area (self-contained equipment only)
- higher-efficiency condenser fan motors (self-contained equipment only)
- higher-efficiency condenser fan blades (self-contained equipment only)



## Purpose of the Engineering Analysis

- Characterize the relationship between manufacturer cost and efficiency (or energy consumption)





## Engineering Analysis Method

### ■ Equipment classes analyzed

- DOE prioritized the analysis by focusing on the classes with the highest shipment volumes
- Equipment classes with at least 100 shipments per year were analyzed

### ■ Efficiency-level approach

- Industry-supplied cost-efficiency curves (see slides 25-28)
- Used for the 4 highest shipment-volume equipment classes analyzed by DOE

### ■ Design-option approach

- DOE analytically derived cost-efficiency curves
- Used to supplement and validate the industry data
- Used for the other 11 equipment classes analyzed by DOE



## Efficiency-Level Approach

- 4 cost-efficiency curves supplied to DOE by ARI
- Curves represent aggregated industry cost-efficiency relationship at discrete efficiency levels

VOP.RC.M



VCT.RC.L



HZO.RC.L

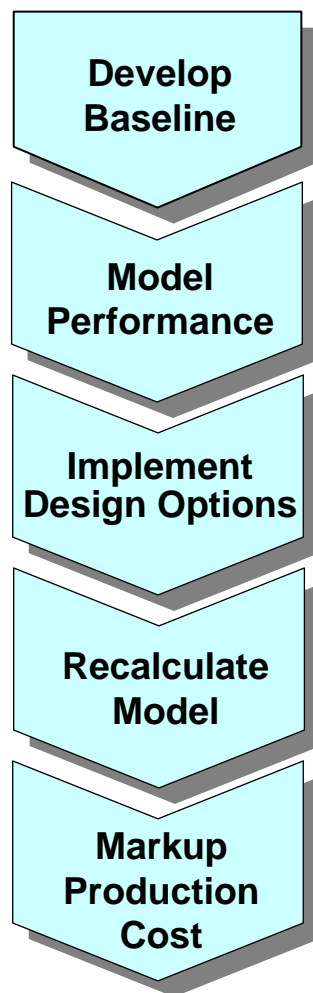


SVO.RC.M





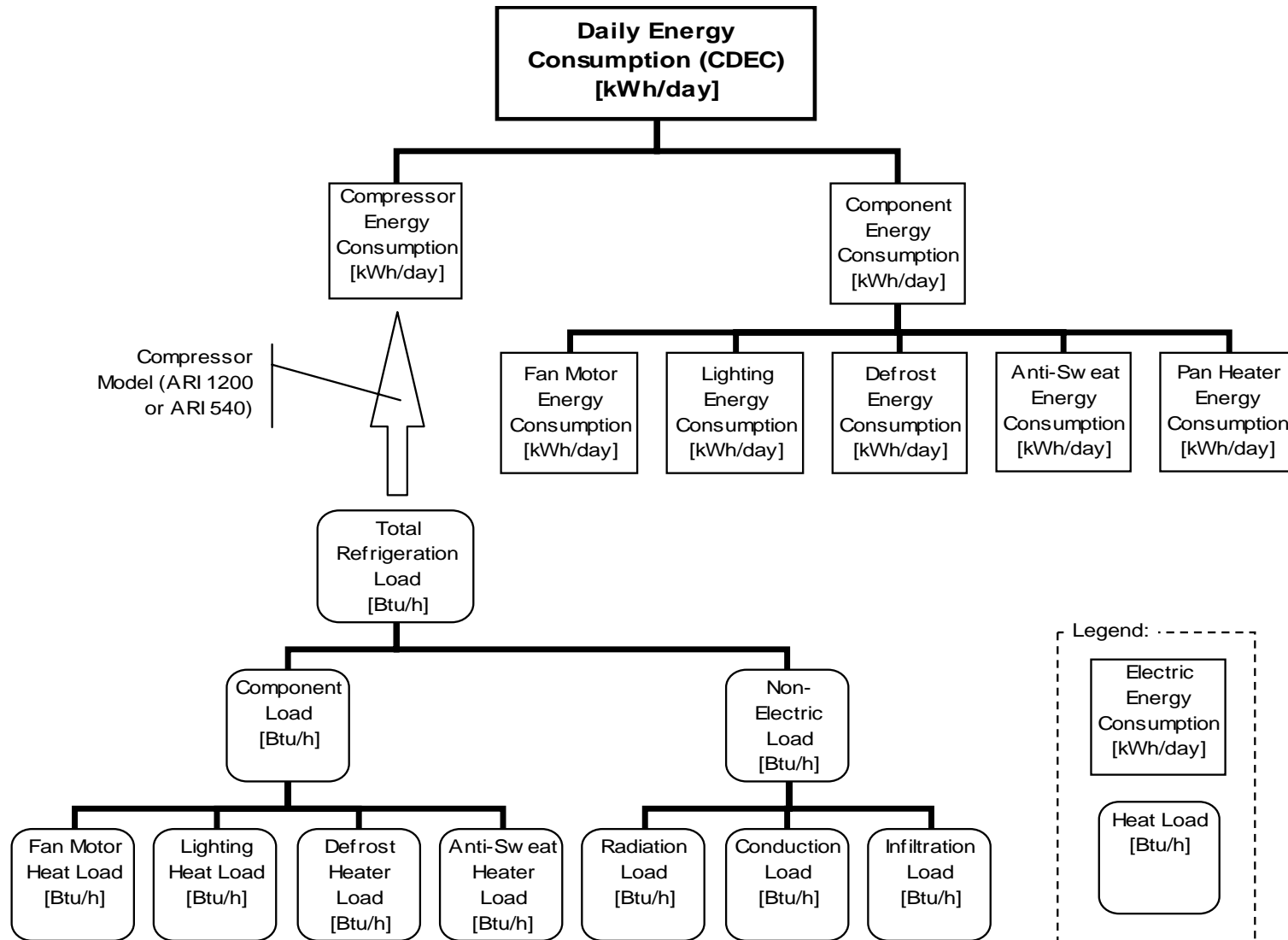
## Design-Option Approach



- Define baseline specifications for each equipment class
- Model manufacturer production cost (MPC) and calculated daily energy consumption (CDEC) of baseline units
- Implement design options one-by-one in order of shortest payback to longest payback
- Add the incremental cost of each design options to the baseline and recalculate CDEC with design options in place
- Markup the MPC to manufacturer selling price using manufacturer markup



# Energy Consumption Model





## Cost Model

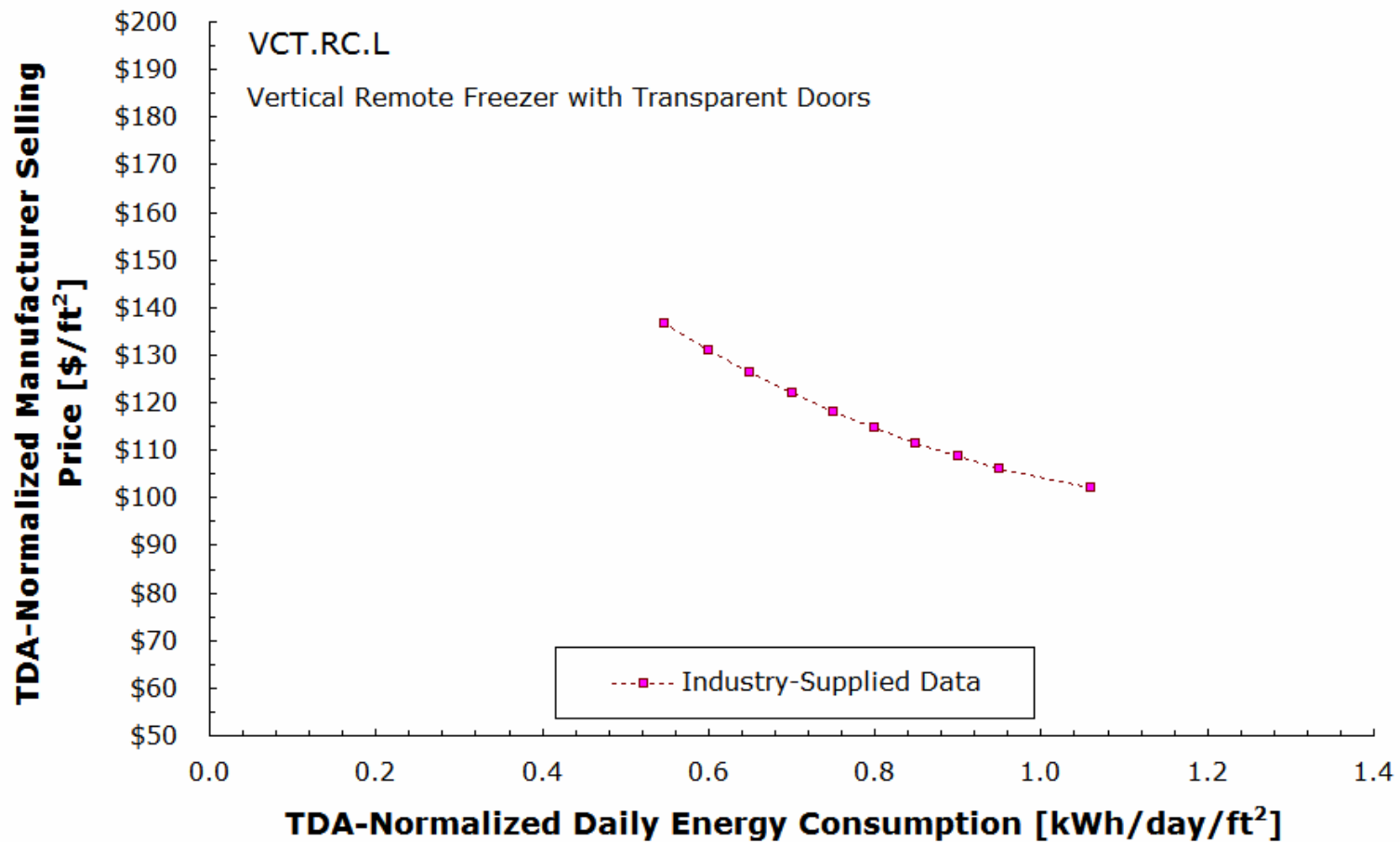


## Qualifying Industry Data

- Industry-supplied cost-efficiency curves were provided in the form of CDEC versus list price, normalized by total display area (TDA)
- Industry list price data was marked down to manufacturer selling price using a list price discount to allow direct comparison with DOE's analytically derived curves

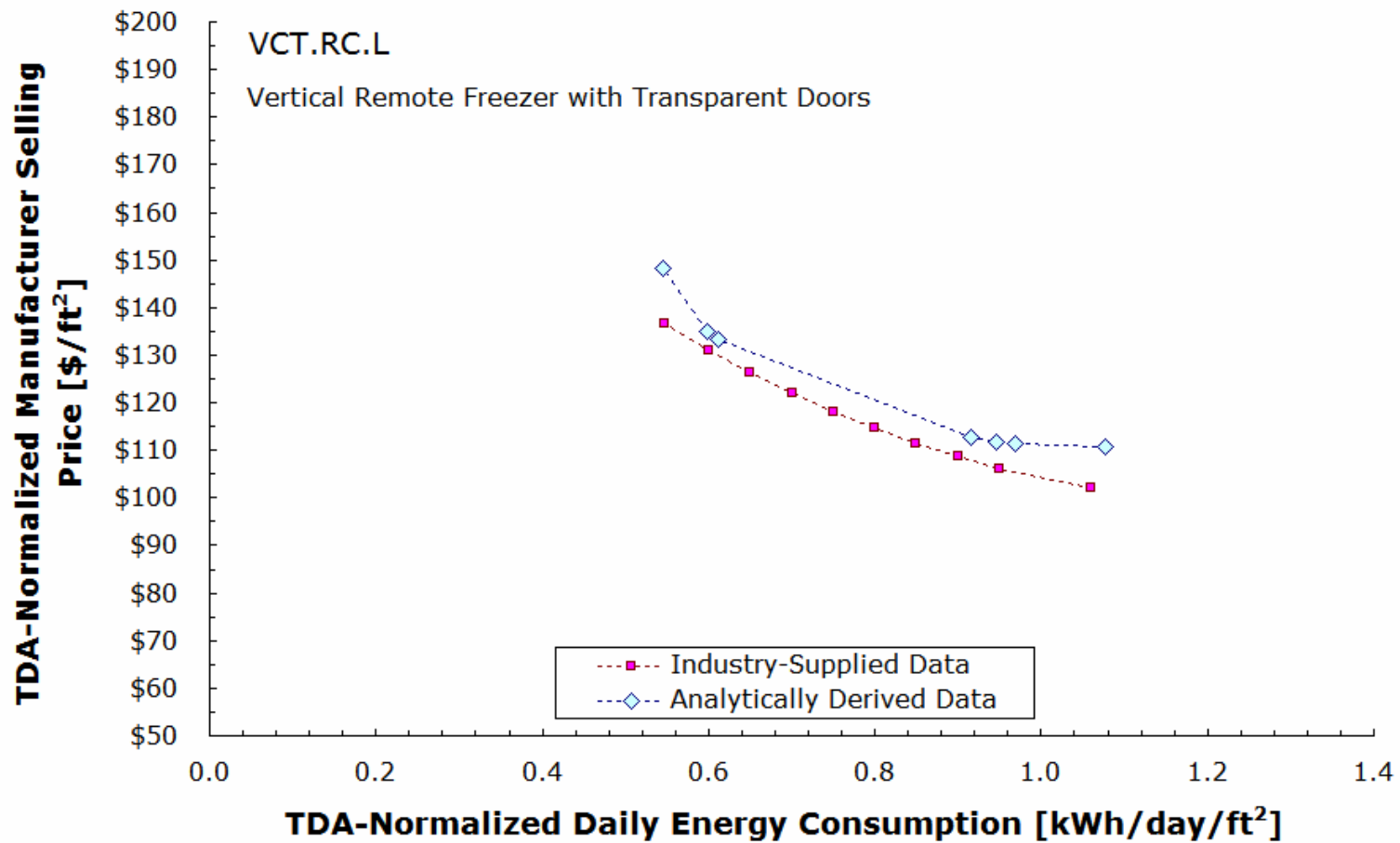


## Results VCT.RC.L



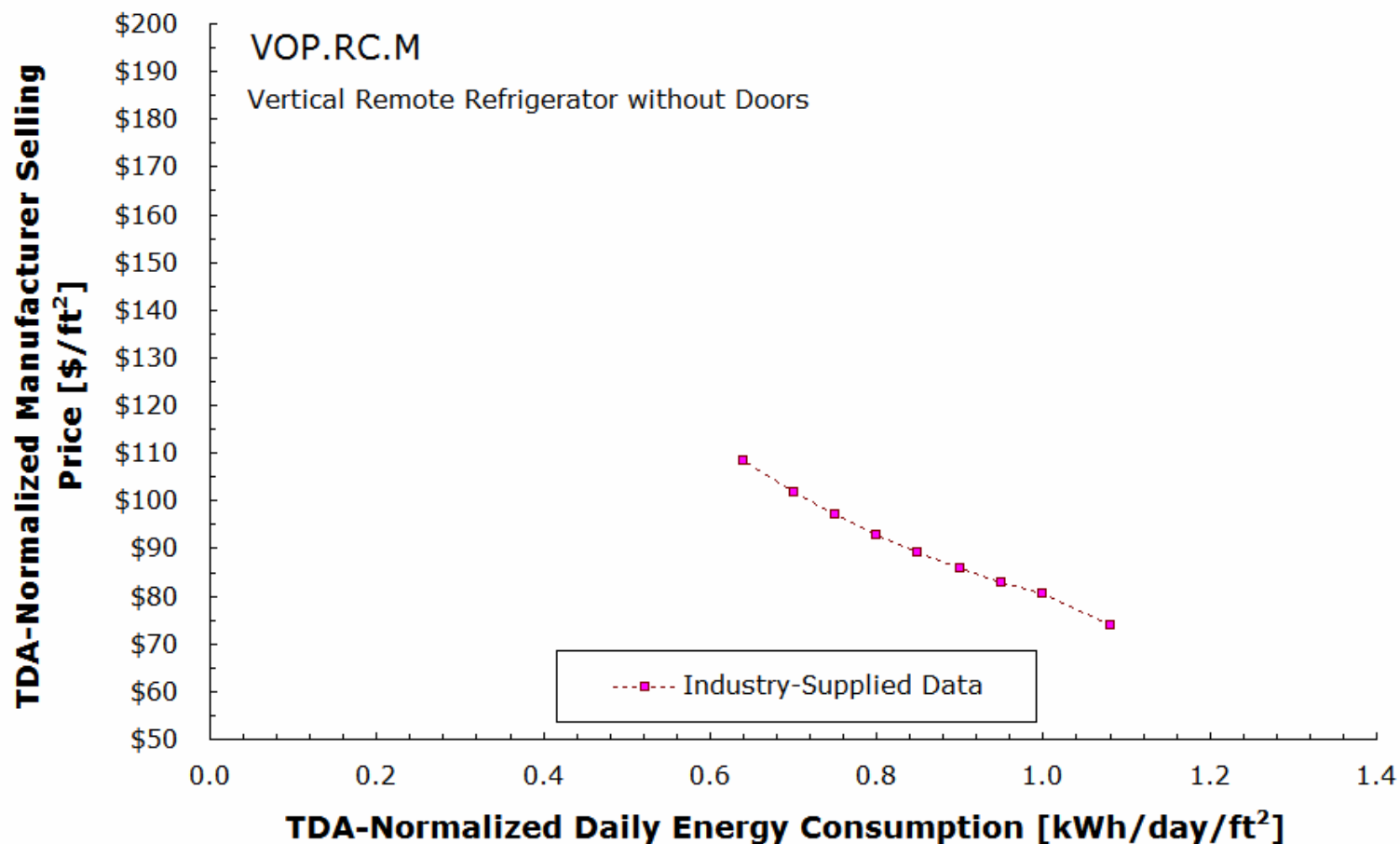


## Results VCT.RC.L



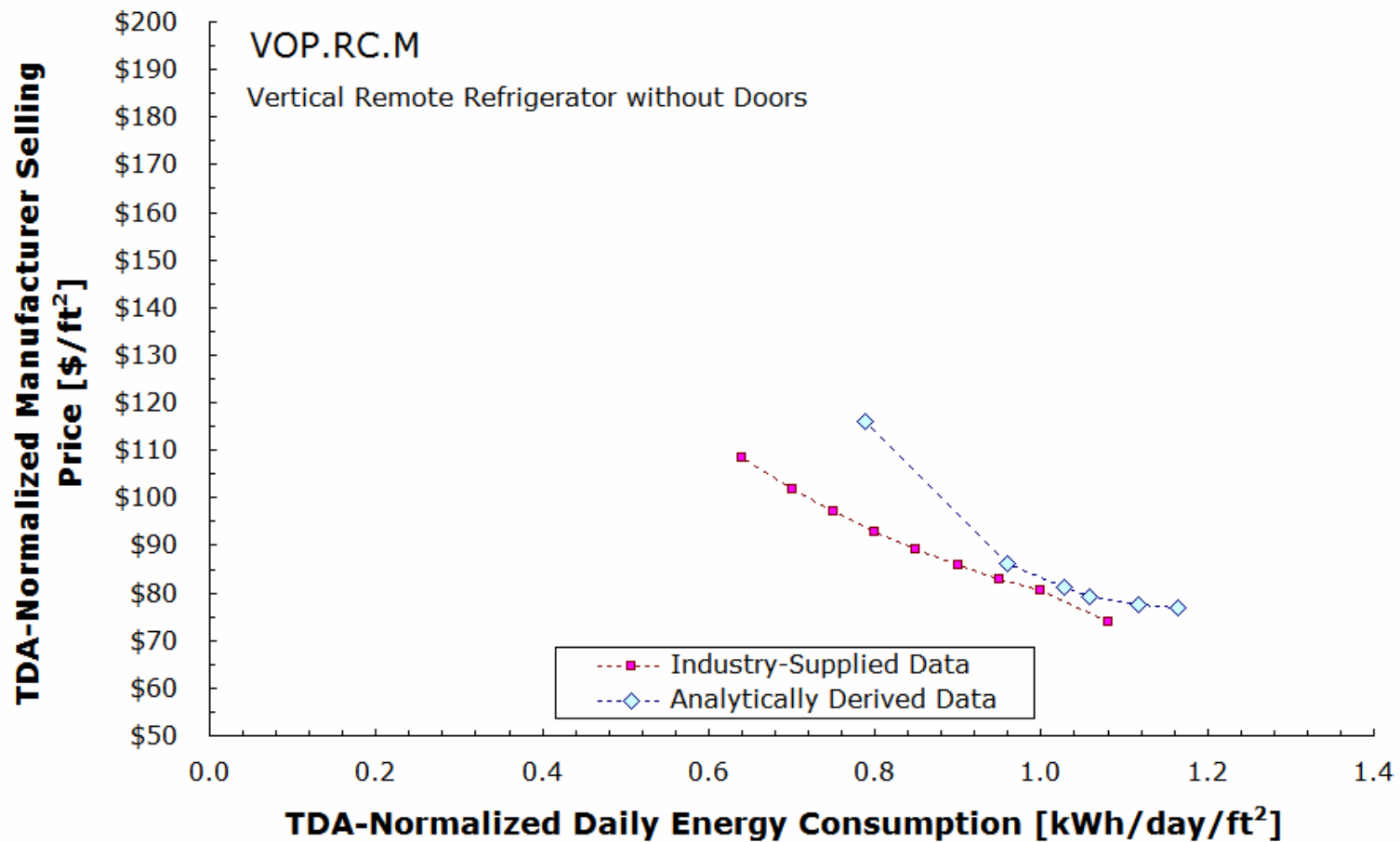


## Results VOP.RC.M



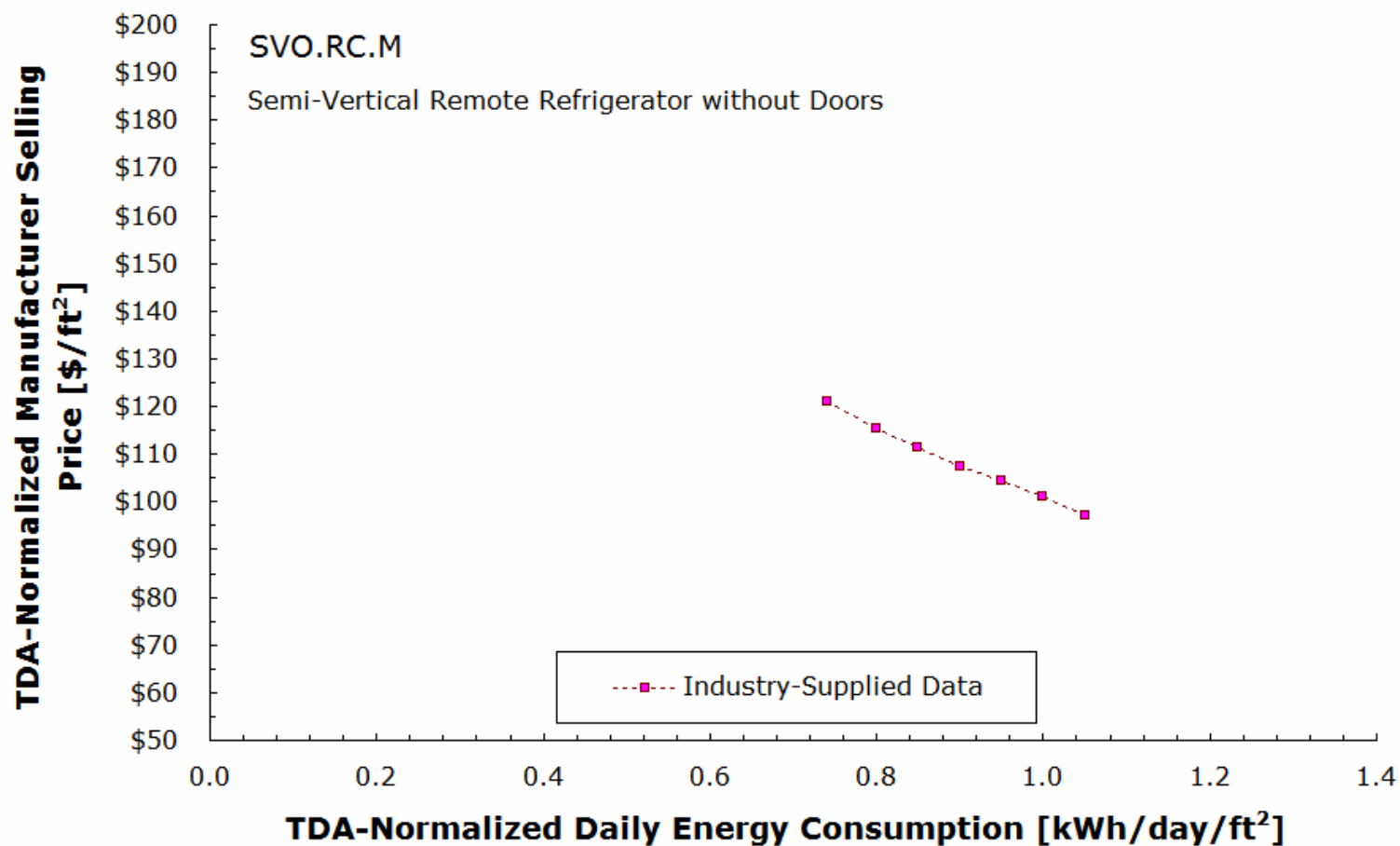


## Results VOP.RC.M



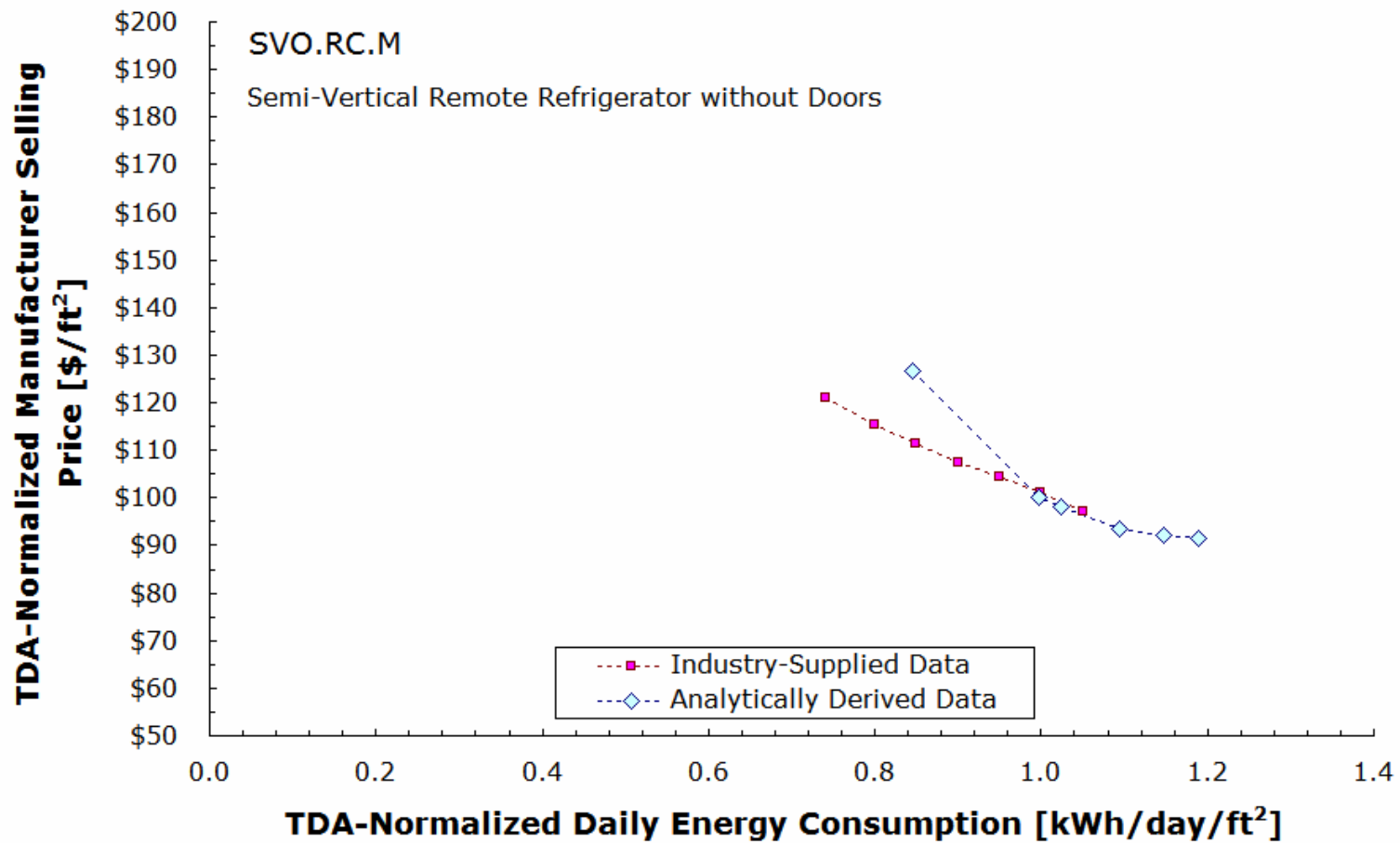


## Results SVO.RC.M



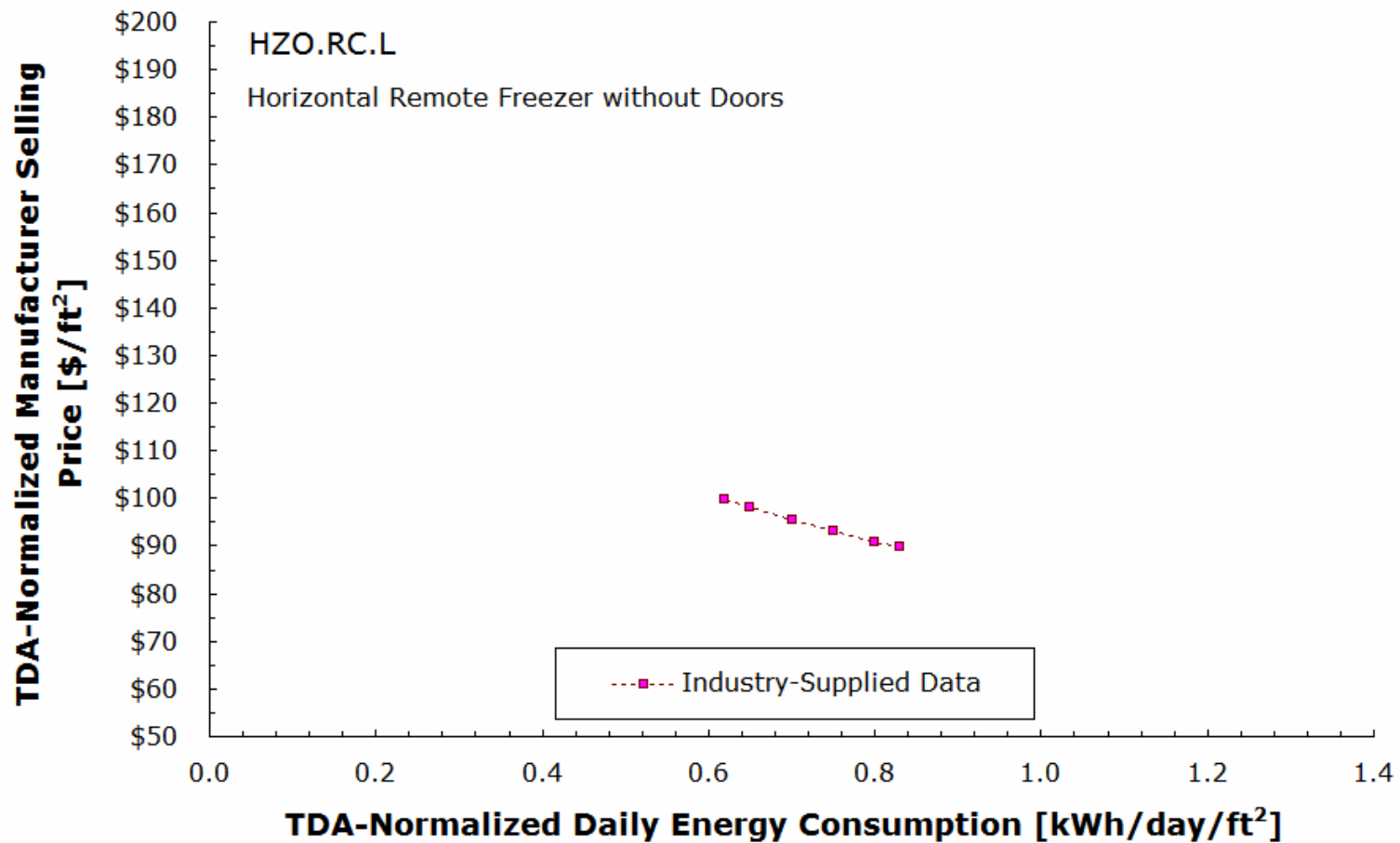


## Results SVO.RC.M



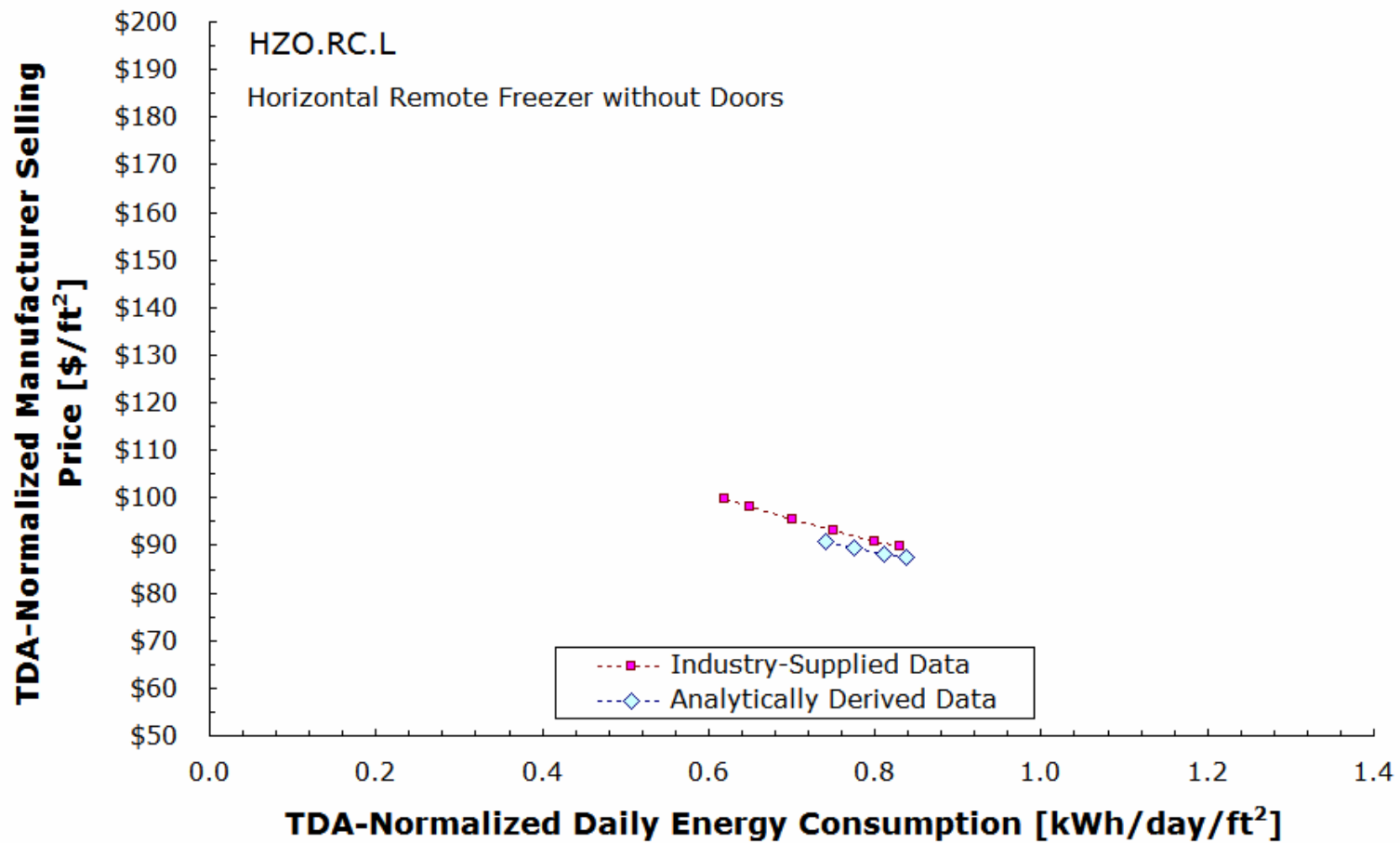


## Results HZO.RC.L





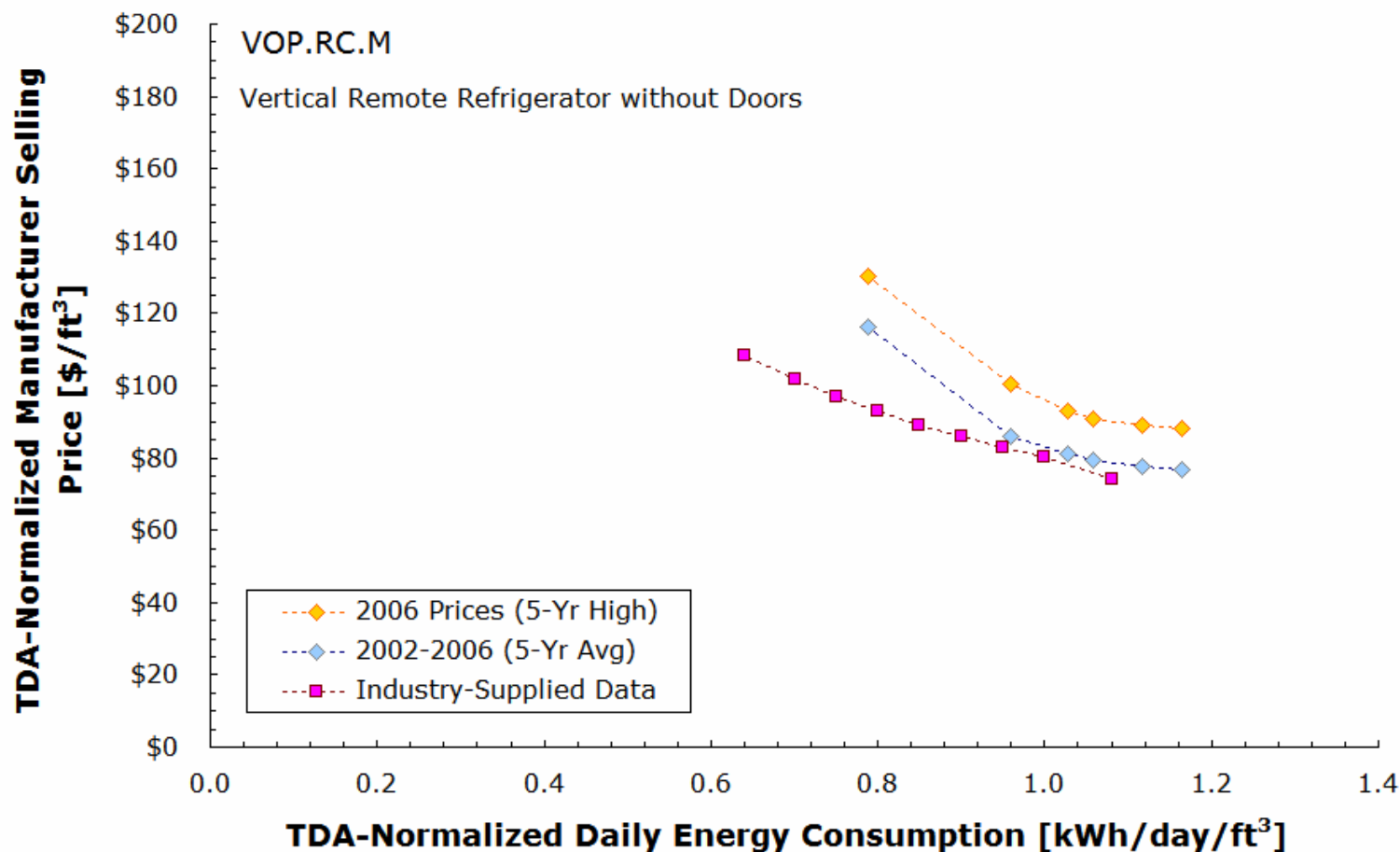
## Results HZO.RC.L





## Sensitivity to Material Prices

- Comparison of 5-year average prices to 5-year high prices (2002-2006)





## Sensitivity to Alternative Refrigerants

- **Most of the CRE industry has transitioned to HFC-based refrigerants to comply with EPA regulations**
  - Remote condensing equipment – R404a, R507
  - Self-contained equipment – R134a, R404a
  
- **ARI-1200 compressor efficiency table is based on R404a refrigerant**



## Other Issues

*DOE invites comments and recommendations from stakeholders on any other aspects related to the Engineering Analysis.*