APPENDIX B. TECHNICAL DESCRIPTION OF THE COST ESTIMATION METHODOLOGY

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APPENDIX B. TECHNICAL DESCRIPTION OF THE COST ESTIMATION METHODOLOGY

B.1 INTRODUCTION

The manufacturing cost estimation methodology is a detailed, component-focused, activity-based technique for rigorously estimating the manufacturing cost of a product, which includes direct materials, direct labor, and plant overhead costs.

This appendix describes the technical aspects of the approach as they apply to commercial unitary air conditioners and heat pumps. Refer to chapter 5 in the body of the Technical Support Document (TSD) for more information on assumptions and context.

B.2 GATHERING PRODUCT INFORMATION

B.2.1 Teardown of Physical Units

The first step was to perform reverse-engineering, or teardowns, on equipment samples that are typical of today's commercial air-conditioning equipment. A teardown is a thorough disassembly of the equipment, followed by a detailed inspection of the parts and subassemblies. The unit selection process is described in detail in section 5.5.1.

There were a few cases where individual manufacturer practice differed from industry-wide practice; DOE captured these differences in the analysis by using manufacturer-specific assumptions. Sub-assembly allocation practice varies between manufacturers. For example, some manufacturers stage sub-assemblies elsewhere and then add them to the final assembly line, while others build all assemblies directly on the final assembly line. The Department evaluated the typical practice and then assigned a range to account for any variation. Assembly times varied on the order of minutes and were well within the uncertainty range of the analysis. The Department also assessed standard industry practice with regard to outsourcing of various manufacturing processes.

The Department disassembled representative units from different manufacturers, as discussed in sections 5.4 and 5.5. The Department made every effort to perform the disassembly in reverse of the actual assembly process, and the bill of materials (BOM) reflects the order of these operations. From observations of industry practice, the Department assumed that major sub-assemblies arrive pre-assembled at the final assembly line.

B.2.2 Catalog Information

In order to expand the sample size, the Department estimated the cost of several additional units on the basis of catalog information. The Department selected representative units, as described in sections 5.4 and 5.5, and obtained the necessary physical information from drawings, descriptions, and tables publicly available in catalogs and supplementary component information. Using the data and information gathered during the physical teardowns, the Department was able to reproduce BOMs for the selected models and arrive at reliable cost estimates.

B.2.3 Design Option Analysis

Although the Department had detailed information on the products considered in the analysis, it was still interested in gathering data for those efficiency levels where products were not commercially available - between an 11.5 and 12.0 energy efficiency ratio (EER). To estimate the cost of equipment between 11.5 and 12.0 EER, the Department created "hypothetical" units. For these units, the Department started from a calibrated teardown BOM, and then modified the BOM to obtain the desired efficiency level. Typically, for any efficiency level improvement, there are many design options available and different components that can be used to achieve a particular efficiency level. This process is discussed in section 5.8 and in this appendix.

B.3 CREATING A STRUCTURED BILL OF MATERIALS

The previous section described three ways to obtain physical information concerning commercial unitary air conditioners and heat pumps at predetermined efficiency levels. After gathering the product information, the Department characterized every part according to its weight, dimensions, material, and quantity, and the manufacturing processes used to fabricate and assemble it.

A structured BOM consists of information and data concerning all materials, components, and fasteners used in a unit and includes estimates of raw materials, purchased parts, and sub-assemblies. The Department based its assumptions about the sourcing of parts and in-house production on its previous industry experience, recent information in trade publications, and discussions with high- and low-volume original equipment manufacturers (OEMs). To reinforce its understanding of the industry's current manufacturing practices, the Department visited several manufacturing plants. These visits focused on observing and characterizing current manufacturing practices.

Figure B.3.1 illustrates a small section from a structured BOM. It shows:

1. Part number: Assigned during disassembly.

2. Description: A description of the part. The step-like outline approach identifies logical groupings of parts to denote which go together where in the assembly process. A reverse indentation denotes parts that are sub-assembled onto a part prior to final assembly on the manufacturing line.

3. Category: Primary part material for raw material costing and sorting purposes.

4. V: This entry denotes whether a part is a purchased component or fabricated in-house. The Department assumed that all plastic components were outsourced.

5. #: How many parts are assembled in a given assembly step.

6. OD, Length, Depth, Thickness: Physical parameters that describe the finished part.

7. Painted surface: Describes how many square inches of paint are required for each part. The Department assumed that any plant would rely exclusively on pre-painted steel and priced the paint coatings accordingly.

8. Weight: Final weight of part in pounds.

9. Material cost: Final material cost of the part (calculated), accounting for scrap losses but excluding required assembly, painting, fabrication, and joining costs.

10. Labor: The manual labor (in seconds) required to handle all parts or assemble them into the unit. Some parts, such as fasteners, require additional tool time, which is accounted for in the later section of the BOM spreadsheet.

Part No.	Description	Category	V ?	#	OD or Width	Length (in)	Depth	Thickness	Painted Srfce A	Weight (lbs)	Scrap %	Material Cost, $	LWor (s)
1.00	**Cabinet Assy**												
1.01	Packaging Corner Screws	Fastener	Y	8	0.44	0.785		0.15		0.054		$0.08	16
1.02	Packaging Corners	GCRS		4	4	4	1.125	0.055		1.527		$0.46	32
1.03	Sticker	Misc.	Y	1	5	8						$0.05	8
1.04	Outside Wrap	HDPE	Y	1	**33.5**	**385.5**		0.003		**1.390**		**$1.30**	15
1.06	Air Filter Panel Screws	Fastener	Y	2	0.44	0.785		0.15		0.014		$0.02	4
1.07	Air Filter Panel Fiberglass	FG		1	**22**	**29.875**		**0.75**		**0.600**		**$2.10**	2
1.08	Air Filter Panel Stickers	Misc.	Y	2	2	5.5						$0.06	16
1.09	Air Filter Access Panel	GCRS		1	**23.5**	**30.75**	0.5	**0.04**	**10.036458**	**6.930**	1%	**$2.10**	8
1.10	Evap Fan Panel Screws	Fastener	Y	2	0.44	0.785		0.15		0.014		$0.02	4
1.11	Evap Fan Panel Fiberglass	FG		1	**18**	**30**		**0.75**		**0.477**		**$1.67**	2
1.12	Evap Fan Panel Stickers	Misc.	Y	1	3.5	2.5						$0.03	8
1.13	Evap Fan Access Panel	GCRS		1	**18.5**	**29.5**	0.5	**0.04**	**7.5798611**	**5.738**	1%	**$1.74**	8
1.14	Condenser Panel Screws	Fastener	Y	2	0.44	0.785		0.15		0.014		$0.02	4
1.15	Condenser Panel Stickers	Misc.	Y	2	2.5	10						$0.10	16
1.16	Condenser Access Panel	GCRS		1	**18.25**	**30.75**	0.5	**0.04**	**7.7942708**	**5.725**	1%	**$1.73**	8
1.17	Top Cover Screws	Fastener	Y	**6**	0.44	0.785		0.15		**0.042**		**$0.06**	**12**
1.70	**Top Cover Assy**												15
1.18	Condenser Middle Panel Screws	Fastener	Y	**3**	0.44	0.785		0.15		**0.021**		**$0.03**	**6**
1.19	Condenser Middle Panel	GCRS		1	**3.25**	**31**	0.5	**0.035**	**2.0451389**	**1.320**		**$0.40**	8
1.20	Large Condenser Grid Screws	Fastener	Y	**3**	0.44	0.785		0.15		**0.021**		**$0.03**	**6**
1.21	Large Condenser Grid	GCRS		1	**37.625**	**31**			**0.8099826**	**2.730**		**$0.82**	8

Figure B.3.1 Sample Structured Bill of Materials

A structured BOM also captures the major manufacturing processes required to make selected parts. Table B.3.1 lists these processes.

Table B.3.1 Manufacturing Processes Captured in a BOM

Fabrication	Assembly/Joining
Fixturing	Adhesive bonding
Stamping	Spot welding
Brake forming	Brazing
Cutting/shearing	Press fitting
Collaring	Integral fasteners
Deburring	Other fasteners
	Quality assurance

B.4 ADDITIONAL PRODUCTION COST DATA

The teardown process and development of the structured BOMs provided a starting point for estimating production costs, but DOE still needed information on manufacturing operations, part and material prices, wages, plant equipment amortization, and plant overhead. Section 5.6 describes the assumptions and data sources used for production activities and factory costs. This section briefly describes the processes used to gather the data, and how the Department used the data.

B.4.1 Labor and Factory Overhead

The Department obtained information concerning equipment and tooling costs, typical process cycle times, and materials used for fabrication from manufacturing databases compiled during previous work. Plant equipment suppliers provided the Department with details concerning equipment capabilities and processing parameters (e.g., cycle times, scrap rates). Fabrication cycle rates, which depend on the complexity of a part and the processes used, are directly entered into the model.

B.4.2 Depreciation

Depreciation and amortization are used to allocate capital costs to production over a certain period of time. For example, if a manufacturer produces one million air conditioners over ten years and amortizes a $10 million investment over the same ten years, each air conditioner produced during that time would include $10 in amortization charges. The methodology that the Department used to allocate depreciation depended on its assumption as to whether or not a particular piece of plant machinery was dedicated to the production of a product. Dedicated machinery is machinery assumed to be tied solely to the production of the product. During times when a piece of dedicated machinery is not needed for that product, it sits idle. The capital cost of a piece of dedicated machinery is amortized across the annual production volume of the product. Conversely, non-dedicated machinery can be used to produce different products and is not likely to sit idle. Only a fraction of the capital cost of non-dedicated machinery is allocated to a particular product; this fraction is based on the time the machinery is used to produce that product. For example, a non-dedicated press that was used 55 percent of the time to produce a particular product would have 55 percent of its depreciation charges allocated to that product and 45 percent of the charges allocated to any other products for which it is used. A dedicated press, on the other hand, would have 100 percent of its depreciation allocated to a single product, even if its utilization rate was only 55 percent, because the press would not be used for any other production.

The Department assumed that fabrication machinery was non-dedicated, unless it was part of an assembly line (e.g., welding directly on the line). Because of the seasonal nature of the air-conditioning business, some manufacturers have off-season uses for their fabrication machinery; for example, some may use it to make furnaces in the winter.

In addition, DOE allocated labor costs to the operation of machinery based on whether the machinery was dedicated or non-dedicated.

In general, as machinery utilization rates approach 100 percent, the costs associated with dedicated and non-dedicated machinery become equal. However, few dedicated pieces of machinery ever achieve 100 percent utilization because of lack of demand, capacity mismatches between process steps, and scheduled downtime. Thus, non-dedicated machinery results in lower overall costs per part, since depreciation, maintenance, and other costs are only assessed according to the amount of time the machinery is used to produce a particular part. As types of products vary, so do their manufacturing machinery and labor requirements. Also, depreciation charges vary across product types.

B.4.3 Parts and Materials

The Department obtained cost estimates for raw materials and purchased components from manufacturing databases compiled during previous work, and supplemented them with information obtained from manufacturer and supplier sources. The Department adjusted the cost estimates as appropriate to include price discounts typically seen in the industry as the result of high-volume purchases.

Because purchased components make up much of the unit costs, DOE gave special consideration to establishing accurate OEM-level price data. Through manufacturer submissions, industry literature, and active research, the Department was able to ascertain the exact specifications for the majority of components used in the units under investigation. For the relatively few purchased components the Department could not identify, it substituted parts from comparable equipment.

For example, a manufacturer's technical data sheet might indicate that an air-conditioner product uses a certain type of motor supplied by a particular company, but may not state the precise size or part number. In the cases where distributors could not positively identify the part, the Department compared the known attributes of similar units (e.g., horsepower, torque, frame size, voltage) with those of the equipment under question. The Department then selected a specific motor size and type based on an interpolation of the available data.

The Department then consulted local distributors, wholesalers, parts suppliers, and OEMs to determine high-volume pricing. The Department applied a discount to the prices it received from each of those sources, based on their place in the distribution chain. The Department based these discounts on markup data and previous experience in the industry. The many different data sources and the large purchased-parts list also allowed for some cross-checking of price data and discounts. The Department selected those that most likely reflected actual prices to OEMs. The discounts on each component were a function of the total dollar volume of a typical OEM's account with a typical supplier. When the Department modeled high volume OEMs who deal with one supplier for each component, this resulted in substantial discounts relative to retail or wholesale prices.

B.5 STRUCTURE OF THE COST MODELS

Once the Department had collected all of the information required to estimate production costs for each product, it used spreadsheet models to perform the required calculations. The Department calculated the costs for each commercial air-conditioning unit with the help of two cost models: the main model and the coil model. Figure B.5.1 illustrates the structure and relationship of the spreadsheets that comprise these two models.

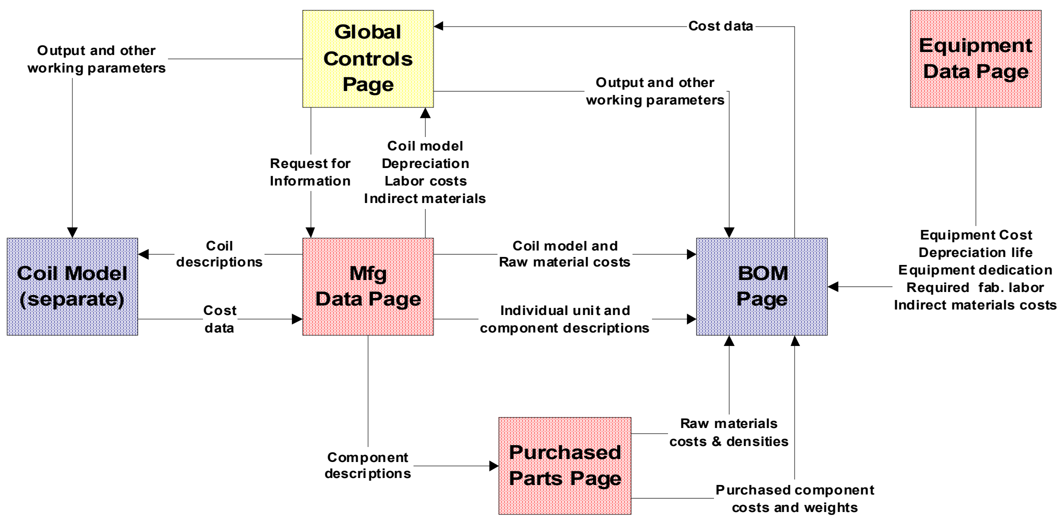


Figure B.5.1 Overall Model Structure

B.5.1 Main Cost Model

The main model holds data and performs the calculations that determine the production cost of the final assembled equipment. It contains worksheets that perform different functions.

B.5.1.1 Global Controls Sheet

This worksheet sets parameters, such as production volume and wages, while displaying the cost results by sub-assembly. The basic parameters (e.g., days available per year) of the Global Controls page are linked to the coil model. A sample section of those controls is shown below in Figure B.5.2.

Global Controls	Units spread across Fabrication		Fabrication				Equipment	Assy Worker	Labor
	Yearly Output across all SEER levels	Output per day	Work Days per Year	Shifts per Day	Runtime per Shift	Press Lot Size (Work Days)	Uptime (%)	Downtime (%)	Wages ($/hr)
Designed	150,000	625	240	2	8	1	90%	20%	$17.00
Actual	145,000	604	240	1.9333333					

Indirect Labor Cost as % of Direct Labor $	Average Depreciation Life	Investment Relativity Factor	Auxiliary Equipment Cost (%)	Capital Recovery Rate (%)	Maintnce. (% of Dep)	Utility Cost (% of dep)	Tax (% of ttl)	Insurance (% of ttl)	Powder Paint Cost/ft2	% Premium for Purchased Parts	Purch. Parts Price Variability (% from quote)
33%	100%	1	68%	14%	4%	20.0%	0.9%	0.8%	$0.04	100%	0%

Building	
Size (sq feet)	50,000
Cost/sq foot ($)	$120.22
Expected Life (years)	25
Annual Depreciation	$240,434
Annual Finance Charge	$874,569

Conveyors	
Length (feet)	5,000
Cost/foot	$222
Expected Life (years)	15
Annual Depreciation	$74,134
Annual Finance Charge	$181,045

Figure B.5.2 Sample of Global Controls Page

The Global Controls page also shows costs broken down by sub-assembly and cost category. The results are shown in the form of a table (Figure B.5.3) that features costs by major sub-assembly and cost type by efficiency level. Another, more detailed table is also available in the spreadsheet but is not shown in this appendix. Cost breakdowns to this fine level enabled discernment of the differences between equipment across efficiency levels and facilitated the calibration and industry review processes.

Unit Cost ($/unit)	Condensing Unit	Evaporator Unit	Controls	Misc.	Condenser Coil Assy	Evaporator Coil Assy	Total
Assy Labor Cost							
Fabrication Labor							
Indirect Labor Cost							
Direct Material Costs							
Indirect Material Costs							
Ann Equipm Dep							
Ann Bldg Dep.							
Equipment Maintenance							
Utilities							
Taxes							
Insurance							
Total							

Figure B.5.3 Sample Table showing Major Sub-Assembly and Plant Overhead Costs

B.5.1.2 Manufacturer Data Sheet

The data tables in this worksheet define most equipment-specific attributes of the commercial air-conditioning samples. For example, coil parameters are stored here for use by the coil model, and the quantity, weight, and cost results from the coil model are returned. These values are then stored for use by the BOM and Global Controls worksheets.

The headings in Figure B.5.4. show the type of information available in the manufacturer data sheet. Other data tables capture parameters such as cost per hairpin tube and volume of enclosure. These parameters form the basis for several calculations. For example, in the Global Controls page, the total enclosed volume of a commercial air-conditioning unit drives the size of the manufacturing facility and the assembly line. This reflects the assumption that, all else being equal, a plant dedicated to producing larger equipment requires more storage and assembly space than a plant dedicated to producing smaller equipment.

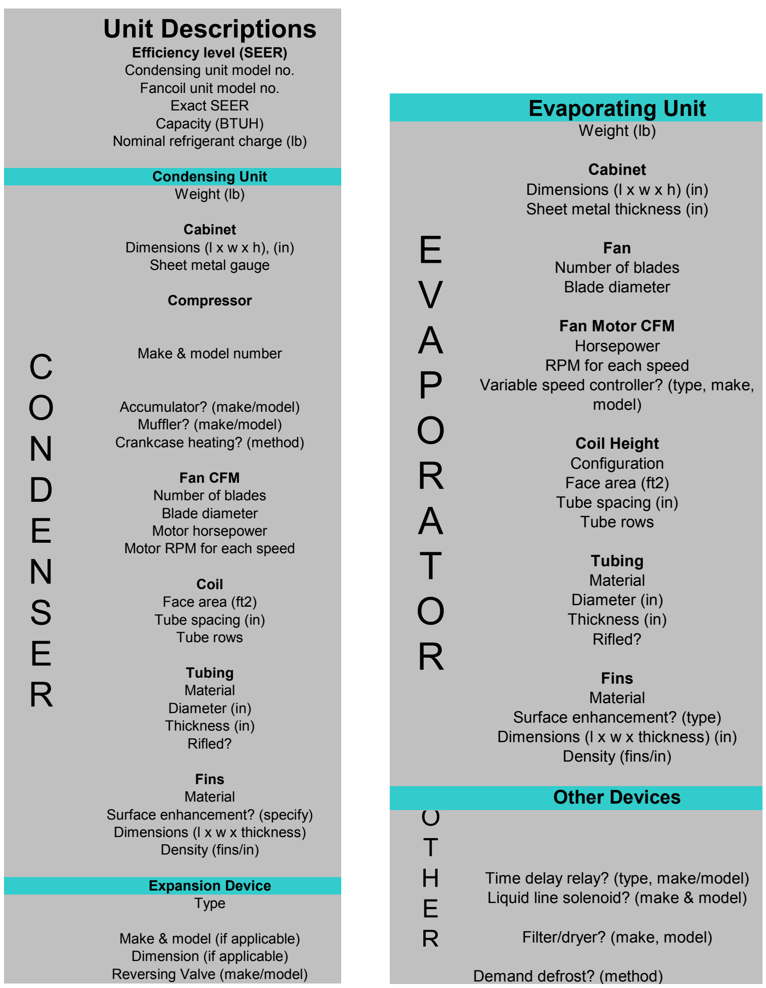


Figure B.5.4 Sample Data Fields from Manufacturing Data Sheet

B.5.1.3 Purchased Parts Sheet

Three types of data are found on the Purchased Parts page: major purchased components unique to each model; minor, common purchased components used by every model; and raw material costs for parts that are fabricated in-house.

Major Purchased Components

Every major purchased part has its own data table, and every sample draws its information from a line item in its table. The exact model numbers for major purchased parts are entered here along with multiple price quotations and part weights in pounds. The quotations come from multiple sources and are discounted as appropriate. These tables determine at least 45 percent of total cost. The weight and minimum cost for each line item is passed to the BOM page, which queries the results by unit number.

Minor, Common Purchased Components

These include items such as connectors, wire, fasteners, board transformers, and other smaller parts that OEMs are likely to purchase from outside suppliers. The Department gathered price quotations from multiple sources (suppliers, distributors, prior experience) in quantities that are typical for OEMs. The Department then used the lowest price for the BOM entry.

Raw Material Costs

When parts are made in-house from materials such as pre-painted sheet metal, the main model estimates the cost of the part from the cost of its raw material. The Department obtained raw material prices from common suppliers in volumes typical for OEM requirements. The BOM scales the material price for each fabricated part based on the calculated weight of the part and its price per unit of weight.

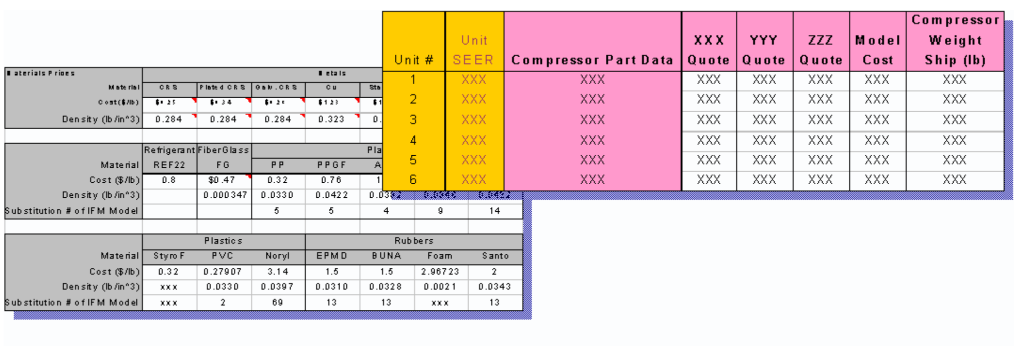
The Department assumes that OEMs fabricate most of these parts themselves. One general exception is plastic parts, which require a different set of skills and facilities than typical OEMs possess. The price of a plastic part is a function of the underlying value of the resin, and an assumed cost to manufacture the part (including the tool) plus an applied gross margin. A purchased part premium applies to any fabricated part, including a plastic part, that is manufactured elsewhere. The purchased parts premium is set at 150 percent over the underlying material cost. Given that few parts meet this description, this simplification has only a slight impact on the overall cost estimate for the equipment.

B.5.1.4 Bill-of-Materials Sheet

The BOM (as illustrated in Figure B.3.1 and discussed in section B.3) serves as a structured assembly tree, summarizes fabrication and assembly tool data, and calculates production costs based on the price of the part or material and the labor and machinery required to fabricate or assemble it.

The BOM sheet also adjusts many other costs in response to changes in physical parameters. For example, the model adjusts baseline sheet metal sizes to incorporate different enclosure sizes. The size of the fiberglass (FG) insulation is a function of the sheet metal it has to cover and the efficiency level of the unit. For example, insulation is thicker at higher efficiencies. Fastener quantities and labor costs are also a function of the sheet metal walls they are to secure. The result is that every unit cost estimate is unique, using the initial BOM as a starting point.

Labor, parts, materials, and depreciation costs are aggregated by sub-assembly and linked back to the Global Controls page. Figure B.5.5 is a sample of a raw material data table and part list from the purchased parts sheet.



Unit #	Unit SEER	Compressor Part Data	XXX Quote	YYY Quote	ZZZ Quote	Model Cost	Compressor Weight Ship (lb)
1	XXX	XXX	XXX	XXX	XXX	XXX	XXX
2	XXX	XXX	XXX	XXX	XXX	XXX	XXX
3	XXX	XXX	XXX	XXX	XXX	XXX	XXX
4	XXX	XXX	XXX	XXX	XXX	XXX	XXX
5	XXX	XXX	XXX	XXX	XXX	XXX	XXX
6	XXX	XXX	XXX	XXX	XXX	XXX	XXX

Materials Prices	Metals			
Material	CRS	Plated CRS	Galv. CRS	Cu
Cost ($/lb)	[illegible]	[illegible]	[illegible]	[illegible]
Density (lb/in^3)	0.284	0.284	0.284	0.323

	Refrigerant	FiberGlass					
Material	REF22	FG	PP	PPGF	A		
Cost ($/lb)	0.8	$0.47	0.32	0.76	1		
Density (lb/in^3)		0.000347	0.0330	0.0422	[illegible]	[illegible]	[illegible]
Substitution # of IFM Model			5	5	4	9	14

	Plastics			Rubbers			
Material	Styro F	PVC	Noryl	EPMD	BUNA	Foam	Santo
Cost ($/lb)	0.32	0.27907	3.14	1.5	1.5	2.96723	2
Density (lb/in^3)	xxx	0.0330	0.0397	0.0310	0.0328	0.0021	0.0343
Substitution # of IFM Model	xxx	2	69	13	13	xxx	13

Figure B.5.5 Sample Raw Material Data Tables and Part Price List from the Purchased Parts Sheet

B.5.1.5 Equipment Data Sheet

Figure B.5.6 is a sample from an equipment data sheet and lists the installed costs for all the plant machinery involved in the production of the commercial air-conditioning unit samples. An implicit assumption is that the plant equipment required to produce lower-efficiency samples is also able to produce higher-efficiency samples without any modification. The equipment data show installed equipment costs, depreciation life, whether equipment is dedicated, labor requirements per station, and consumables costs. The installed costs include price quotations for the equipment plus markups to account for installation labor and auxiliary equipment.

				Fixturing	Powder Coating	Lg Press (1500 ton)	Med Press (600 ton)	Sm Press (100 ton)
Equipment Cost ($/Unit)				$231,105	$0	$2,734,747	$1,309,597	$153,814
Depreciation Life				5	12	20	15	10
Straight Depreciation per piece of Equipment / Year				$58,250	$0	$172,322	$110,027	$19,384
Finance Cost per piece per year				$79,811	$0	$437,561	$232,148	$33,312
Dedicated Equipnment?				Y	N	N	N	N
People per Machine				1.00	0.00	1.50	1.00	1.00
Consumables Cost ($/sec)					See Below	$0.20	$0.10	$0.05

Figure B.5.6 Sample from Equipment Data Sheet

B.5.2 Coil Model

The coil model converts each coil's physical descriptors into coil costs by calculating the number of fins, hairpin bends, U-bends, take-offs, and coil ends. The model accounts for tube diameters, spacing, material choices and thickness, rifling, and other physical characteristics that affect coil cost. It relies on a process-based cost model that accounts for every fabrication and assembly step. The Department obtained fabrication equipment costs and processing times from equipment vendors, and obtained raw material prices from vendors, based on their pricing at the time.

The coil flow diagram (Figure B.5.7) represents a coil manufacturing facility sized for high-volume production. While this coil line may not be representative of all manufacturing facilities, it is representative of the industry in general.

The coil and main cost models work together. The equipment data sheets in the main model supplied the coil parameters, and the coil cost and weight results were returned to the main cost model. Any update in either model is automatically reflected in the other.

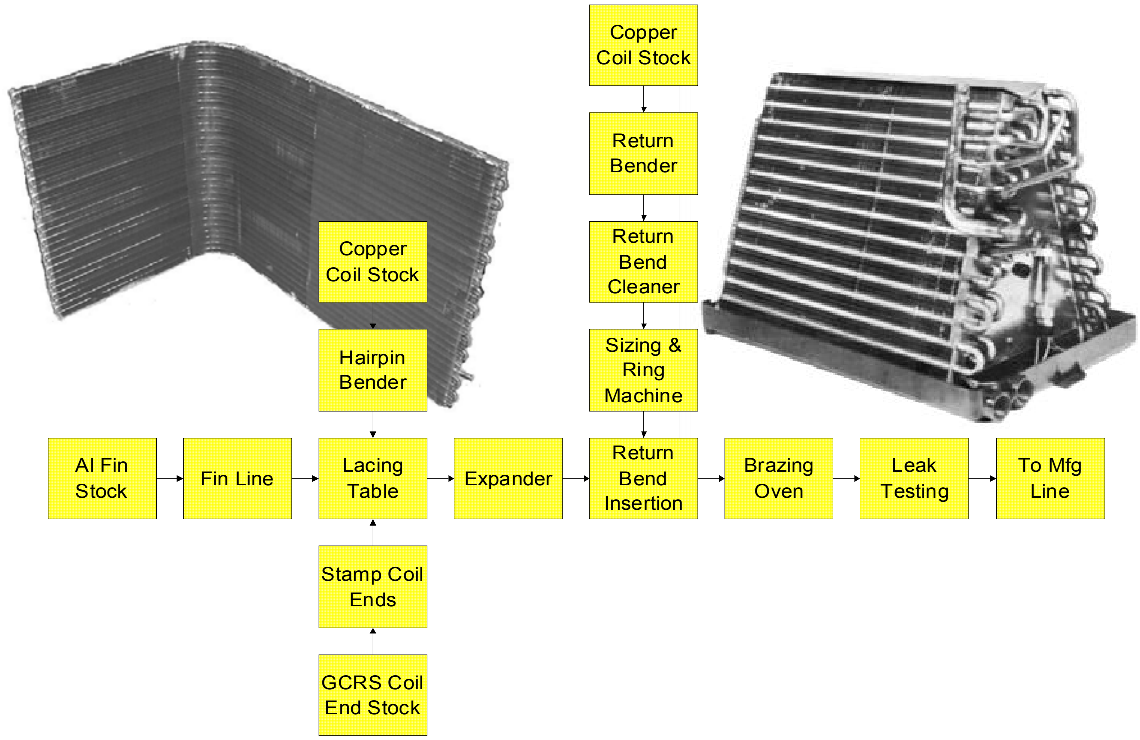


Figure B.5.7 Flow Diagram for Coil Model

Figure B.5.8 is a section of a row header for an indoor coil unit showing fin and U-bend parameters. Weights and quantities are sent to the Manufacturing Data Sheet in the main model.

Final Mass of Single Fin (lb)
of Fins per Unit
Annual Fin Production (K)
Evap. Coil Fin Material
Evap. Fin Material Scrap (%)
Evap. Coil Fin Length (in)
Evap. Coil Fin Width (in)
Evap. Coil Fin Thckness (in)
Evap. Coil Density (fins/in)
of Large U-Bend per Unit
Mass per U-Bend (lb)
of U-Bends per Unit
Annual Production of U-Bends (K)
Length of U-Bends (in)
of Coil Ends
Mass of each Coil End

Figure B.5.8 Coil Model Output Fields

The manufacturing costs for coils are also captured in a table. Figure B.5.9 illustrates the header of the table that is linked back to the Manufacturer Data Sheet. Some of these costs are direct costs, such as material costs used by the BOM Sheet, while others are overhead costs referenced by the Global Controls page.

Condenser Assy										
1	2	3	4	5	6	7	8	9	10	11
Low Level Labor		Material Prices				Indirect	Maintenance	Utilities	Depreciation	
Direct	Indirect	Coil Ends	Tube	Fin	U-Bend	Materials			Equipment	Bldg

Figure B.5.9 Coil Manufacturing Costs Calculated in the Coil Model