APPENDIX C: TECHNICAL DESCRIPTION OF THE REVERSE ENGINEERING COST ESTIMATION METHODOLOGY

C.1 INTRODUCTION

The manufacturing cost estimation methodology, or "reverse engineering", is a detailed, component focused, activity based technique for rigorously estimating the manufacturing cost of a product (direct materials, direct labor, and plant overhead costs). Arthur D. Little (ADL), a Department of Energy contractor, has applied its technology based cost assessment successfully to a broad range of products in various stages of development from early R&D to production. This Appendix describes the technical aspects of the approach as applied to residential central air conditioners and heat pumps (CACs). Refer to Chapter 4 in the body of the Technical Support Document (TSD) for more information on assumptions and context.

C.2 TEAR-DOWNS

Our first step was to perform "tear-downs" on equipment samples that are typical of today's minimum efficiency air conditioners. A tear-down is a thorough disassembly of the equipment followed by a detailed inspection of the parts and subassemblies. We performed the minimum number of tear-downs required to assess all four CAC product classes. Since split and packaged equipment have different configurations, we selected one baseline (10 SEER) model from each class--both from the same manufacturer. Since heat pumps (HPs) and cooling-only air conditioners (ACs) have similar configurations differing only by additional HP components, we selected only HPs rather than a combination of HPs and ACs.

C.2.1 Split Air Conditioner Tear-down

Initially, a representative 10 SEER split AC outdoor unit with a indoor fan-coil unit served as the basis for the bill-of-materials (BOM) used by both split system products (AC and HP). We disassembled the outdoor unit first and then the indoor fancoil unit. We made every attempt to perform the disassembly in reverse of the actual assembly process, and the BOM reflects the order of these operations. We assumed that major sub-assemblies arrive pre-assembled at the final assembly line. For example, most outdoor units feature fans and wiring that are integrated into the top cover subassembly. The model assumes that a assembly worker on the final assembly line receives the top cover assembly as a single piece, places it atop the rest of the completed outdoor unit, and attaches the wiring leads and screws. Sub-assemblies can also feed into other sub-assemblies before being integrated on the final assembly line. This mimics cellular manufacturing techniques often found in today's state-of-the-art plants.

C.2.2 Packaged Heat Pump Tear-Down

We used the same processes and cost models to establish costs for 3 ton packaged systems as we had for split systems. Since packaged systems have a significantly different configuration, however, we tore down a representative 10 SEER packaged HP (PHP) model. We derived the packaged AC cost model directly from the PHP cost model by removing HP-specific parts. We used HP-specific information from the PHP teardown to supplement our bill-of-materials for split HPs which was based primarily on the split AC teardown.

C.2.3 Confirming the Tear-Down Results

We confirmed our cost and weight predictions using a number of methods. Initially, we compared shipping weight predictions with published shipping weights. Since cost and weight tend to be highly correlated in manufactured goods, the ability to accurately predict weight is usually an important indication of the accuracy of the cost model. However, we discovered that at least one equipment manufacturer had published erroneous weight data. For example, the discrepancies at 16 and 17 SEER for evaporators are caused by inaccurate OEM submissions. Since we could not verify all the published weights, we could not place as much confidence in the weight verification as we would like.

Table C.1 below shows the degree to which the equipment weights we predict differ from the weight listed by the manufacturer. Positive values denote where the model calculates weight in excess of reported shipping weights.

Table C.1 Predicted versus Listed Equipment Weight

	Split AC		Split HP		Packaged AC	Packaged HP
Efficiency Level (SEER)	**Outdoor Unit**	**Indoor Unit**	**Outdoor Unit**	**Indoor Unit**		
10	3%	7%	0%	-2%	1%	2%
11	-6%	8%				
12	6%	8%	6%	-7%	-2%	3%
13	-3%	18%	1%	-4%	2%	
14	-9%	-1%	-7%	4%		
15	-14%	-14%	-22%	-11%		
16	-8%	1%	-22%	-16%		
17	-8%	-3%				

We attributed under-predictions primarily to the weight of non-efficiency items such as sound blankets, cosmetic grilles, etc. found on today's high efficiency equipment that we assume would be omitted from those units once they became commodity units. Section 4.2.5 in the TSD describes this concept more fully.

After the PHP tear-down and the quotation process, we also tore down a 12 SEER split HP outdoor unit to verify some of our assumptions regarding split HPs and higher efficiency equipment. Even though different OEMs produced our 10 and 12 SEER equipment samples the physical similarities between the two models were striking. This tear-down was not meant to establish a BOM since we based the BOM solely on the 10 SEER baseline. Rather, we wanted to confirm the components used in the design and that the BOM model was using the correct component data. Our coil model predicted the weight of the 12 SEER coil within ½ pound of its actual weight. The difference was due to the larger end-plates of the coil which, being made of galvanized cold rolled steel, do not contribute significantly to equipment cost. Furthermore, the 10 and 12 SEER defrost controllers were quite similar despite being manufactured by different companies.

C.3 SELECTING ADDITIONAL EQUIPMENT SAMPLES

Although we had detailed information on the three tear-down samples, we needed many more samples to span a broad range of efficiency levels in each of the four product classes. That approach would provide us discrete cost points to compare against the cost curves that ARI would provide. We asked OEMs to provide us with a list of equipment models, one model at each efficiency level, that they felt best represent baseline equipment. We then asked for detailed information on the components and physical parameters that we identified as being related to the efficiency of the product.

Four OEMs responded to our request and provided data to us directly for equipment they considered to most closely represent baseline models at each efficiency level. That yielded information on 62 samples. We supplemented that data with nine more selections from ARI's *Unitary Directory* and associated physical data from ARI's *Product Attribute* database and OEM literature. Where possible, we obtained exact specifications for purchased parts.

Our subsequent cross-checking exposed a few errors in the data we had collected. We corrected all aberrations either by replacing them with correct values or by omitting the unit altogether if we determined that the entire configuration did not represent a prospective baseline system. For example, one 11-SEER SAC unit that we selected was comprised of a 10 SEER outdoor unit and a variable speed fan-coil unit. Because such combinations would be significantly more expensive than a more efficient outdoor unit coupled with a less sophisticated fancoil unit, that sample was an obvious outlier. We therefore omitted it on the presumption that the mass market will not sustain large price differences at the baseline efficiency level.

C.4 CREATING THE BILL-OF-MATERIALS

We used the tear-down process to create a complete and structured bill-of-materials (BOM) for the baseline equipment. We built four separate BOMs from our two tear-downs--one for each of the four product classes. While we completely dismantled each piece of equipment, we characterized every part according to weight, dimensions, material, quantity, and, the manufacturing processes used to fabricate and assemble it.

As a simplification, we assumed that the structure of the BOMs we developed for the tear-down samples also applied to the samples that we did not tear down. This allowed the physical parameters and parts to vary across samples, but fixed the assembly process (and the associated plant equipment) for each sample. Since a typical OEM manufacturers a wide range of products in the same plant and assembly line, we consider this a valid simplification for isolating efficiency-related changes within a product platform and within a single manufacturer. Our simplification cannot reproduce cost variability across OEMs due to differences in assembly processes or product platforms.

The BOMs incorporate all materials, components, and fasteners with estimates of raw materials and purchased parts and sub-assemblies. We based our assumptions on the sourcing of parts and in-house production on our previous industry experience, recent information in trade publications, and discussions with high and low-volume original equipment manufacturers (OEMs). To reinforce our understanding of the industry's current manufacturing practices, we also visited several manufacturing plants. These visits focused on observing and characterizing current manufacturing practices.

Figure C.1 illustrates a small section from a structured bill of materials. It shows:

1. Part number: Assigned during disassembly
2. Description: A description of the part. The step-like ladder 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. We 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. We assumed that any "green field" 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, or 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 also 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 C.1 Sample structured bill of materials

The BOMs also capture the major manufacturing processes required to make selected parts. Table C.2 lists these processes.

Table C.2 Manufacturing Processes Captured in the Bills-of-Material

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

C.5 ADDITIONAL PRODUCTION COST DATA

The tear-down process and the development of the structured BOMs provide the starting points for estimating production costs, but we still needed information on manufacturing operations, part and material prices, wages, plant equipment amortization, and plant overhead. The TSD (Chapter 4) describes our assumptions and data sources. This section briefly describes the processes we used to gather the data and how we used them.

C.5.1 Labor and Factory Overhead

Information on equipment and tooling costs, typical process cycle times, and materials used for fabrication were obtained from the ADL manufacturing databases. Plant equipment suppliers provided us with details concerning equipment capabilities and processing parameters (cycle times, scrap rates, etc.). Fabrication cycle rates are directly entered into the model and depend on part complexity and the processes used.

C.5.2 Depreciation

Depreciation, or amortization, is the accounting process by which capital costs are allocated to production volume. Amortization occurs over a period of time so that at the end of that time, all capital costs are accounted for in the full cost of producing the product over that time. For example, if a manufacturer produces 1 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 we used to allocate depreciation depended on whether we assumed the plant machinery to be dedicated or non-dedicated to the production of the sample product.

Dedicated machinery is tied solely to the production of the sample product. During times when a piece of dedicated machinery is not needed for that product, it sits idle. The entire capital cost of a piece of dedicated machinery is amortized across the annual volume of the sample product. Conversely, non-dedicated machinery may be used to produce another product when it is not needed for the sample product. Only a fraction of the capital cost of non-dedicated machinery is allocated to the sample product based on the time the machinery was used to produce the sample product. For example, a non-dedicated press that was used 55 percent of the time to produce the sample product would allocate 55 percent of its depreciation charges to the sample product and 45 percent to the other products to which it is associated. A dedicated press, on the other hand, would allocate 100 percent of its depreciation to the sample product, even if its utilization was 55 percent, since the press is not used for any other production.

We assumed that all coil fabrication machinery is non-dedicated. Given the substantial equipment and space investment costs associated with coil lines, OEMs install universal, high volume machinery to achieve high production efficiencies and low costs. The total coil volume and the many configurations manufactured by OEMs ensure that no one coil type dominates the coil production centers. Thus, every type of product will only be a fraction of the total output, and amortization charges are based on that fraction.

We assumed that machinery other than coil assembly machinery is dedicated. Unlike old plant designs, new facilities usually feature several production lines under one roof that handle almost every part of fabrication and assembly. Instead of belonging to a functional department, all employees and equipment are dedicated to individual product lines. The industry is moving to this manufacturing philosophy. Our model reflects the possibility that a piece of production machinery can be used to produce different parts for the same product. That is, each product, not each part, has a set of dedicated machinery. All equipment and process costs are spread across the entire production volume, unlike the coil model where costs are assigned on the basis of utilization.

We also allocated labor to operate a piece of machinery based on whether the machinery is dedicated or non-dedicated.

As equipment utilization rates approach 100 percent, the costs associated with dedicated vs. non-dedicated equipment costs become equal. However, few dedicated pieces of equipment ever achieve 100 percent utilization due to lack of demand, capacity mismatches between process steps, scheduled downtime, etc. Thus, non-dedicated equipment results in lower overall costs per part, as depreciation, maintenance, and other costs are only assessed on the basis of how much time each part uses a piece of equipment.

As equipment samples vary, so do the manufacturing equipment and labor requirements. Depreciation charges therefore also vary across equipment samples. Figure C.2 shows how the model allocates depreciation and labor to a sample product.

					Manufacturing							Connecting					
	Fixturing	Powder Coating	Large Press	Medium Press	Small Press	Brake Form	Cut & Shear	Collar	Deburr	Adhesive Bonding	Spot-Welding	Brazing	Press Fits	Integral Fastner	Other Fastners
Seconds	**17**	**13**	**25**	**25**	**21**	**10**	**0**	**20**	**0**	**45**	**0**	**1080**	**4**	**0**	**279**
# of Distinct Parts per Operation	4.00	13.00	5.00	14.00	16.00	1.00	2.00	1.00	0.00	11.00	1.00	14.00	1.00	0.00	37.00
# Total Equipment Required for Non-Dedicated Use	1	1	1	1	1	1	0	1	0	1	0	14	1	0	4
Model Input (Depends on dedication)	4	1	1	1	1	1	0	1	0	11	0	14	1	0	37
#People/Machine	1.00	0.00	1.50	1.00	1.00	0.50	0.50	0.50	0.50	1.00	0.50	1.00	1.00	1.00	1.00
#Operators Required when Operating	4	0	2	1	1	1	0	1	0	11	0	x	x	x	x
Equipment Depreciation ($MM/Year)	$.23	$.00	$.17	$.11	$.02	$.06	$.00	$.01	$.00	$.02	$.00	$.00	$.00	$.00	$.21
Total Equipment Investment ($MM)	$1	$	$3	$1	$	$	$	$	$	$	$	$	$	$	$
Material Cost/Unit	0.0	2.6	5.0	2.5	1.1	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Equipment Usage(%)	5%	16%	39%	55%	48%	12%	0%	24%	0%	5%	0%	94%	5%	0%	9%
Actual #Operators Required per Shift	0.2	**0.0**	0.8	0.6	0.5	0.1	0.0	0.2	0.0	0.6	0.0	x	x	x	x

Figure C.2 Sample Fabrication and Assembly Summary Table

C.5.3 Parts and Materials

Cost estimates for raw materials and purchased components were drawn from ADL's manufacturing databases and supplemented with information obtained from manufacturer and supplier sources. We adjusted our cost estimates as appropriate to include price discounts typically seen in the industry as the result of high-volume purchases.

As purchased components make up the bulk of the unit costs, special consideration was given to establishing accurate OEM-level price data. Through manufacturer submissions, industry literature, and active research, we were able to ascertain the exact specifications for the majority of components used in the AC and HP units under investigation. For the relatively few purchased components we could not identify, we substituted parts from comparable equipment.

For example, a manufacturer's technical data sheet may convey that a sample condenser uses a certain type of compressor supplied by a particular company, but may not state the precise size or part number. In the cases when distributors could not positively identify the part, our industry experts would compare the known attributes of similar condenser units (such as coil size, compressor specs, capacities, etc.) and those of the equipment under question. We would then select a specific compressor size based on an interpolation of the available data.

We then consulted local distributors, wholesalers, parts suppliers, and OEMs to determine high-volume pricing. We applied a discount to the prices we received from each of those sources based on their place in the distribution chain.

These discounts were based on markup data and our 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. We selected those that, in our best judgement, most likely reflected actual prices to OEMs. The discount on each component were a function of the total dollar volume of a typical OEM's account with a typical supplier. Since we are modeling high volume OEMs who deal with one supplier for each component, this results in substantial discounts relative to retail or wholesale prices.

C.5.4 Coil Fabrication Costs

While purchased components make up the largest part of costs in AC and HP units, coils, generally fabricated by the OEM, also are important. To model the fabrication cost of both the indoor and outdoor coils, we constructed a second cost model for each of the four product classes. These costs were then fed back into the main cost models.

C.6 STRUCTURE OF THE COST MODELS

Once we had collected all of the information required to estimate production costs for each sample, we used spreadsheet models to perform the required calculations. As stated earlier, the costs for each CAC unit are calculated with the help of two cost models: the main model and the coil model. Figure C.3 illustrates the structure and relationship of the spreadsheets that comprise the two models.

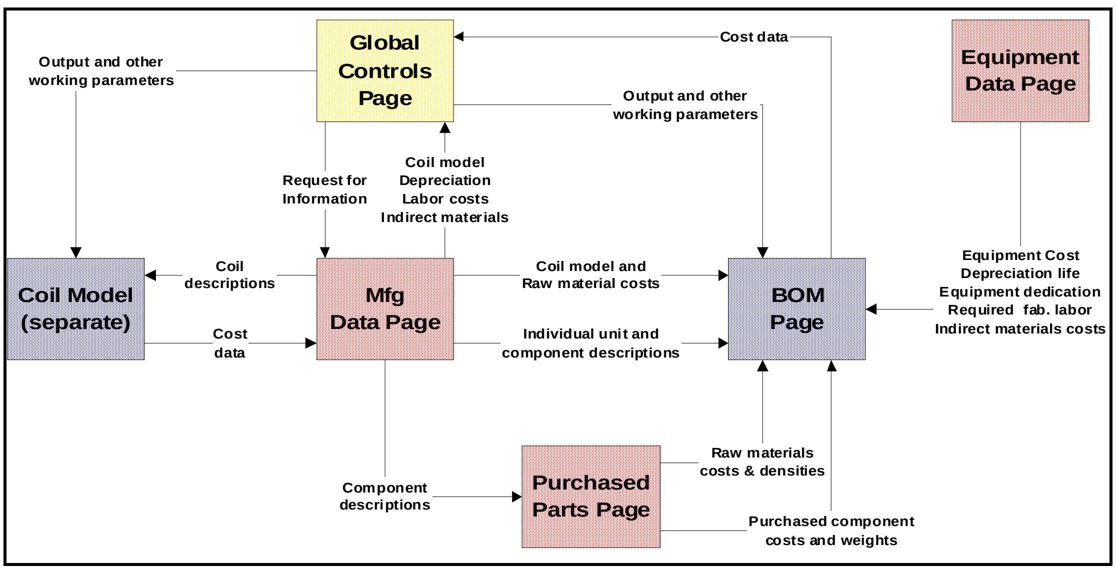

Figure C.3 Overall Model Structure

C.6.1 Main Cost Model

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

C.6.1.1 Global Controls Sheet

This worksheet sets parameters such as production volume and wages while also 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 C.4. Shaded fields are also varied in the Monte-Carlo analysis (refer to Appendix A in the TSD).

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	Auxilliary Equipment Cost (%)	Capital Recovery Rate (%)	Maintncne. (% 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 C.4 Sample of Global Controls Sheet

The Global Controls page also shows costs broken down by sub-assembly and cost category. The results were shown in two tables. One table (Figure C.5) featured costs by major sub-assembly and cost type by efficiency level. Another more detailed table formed the basis for the *CAC Cost* spreadsheets (see Appendix B in the TSD). Cost breakdowns to this fine level allowed us to zero on 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 C.5 Sample table showing major sub-assembly and plant overhead costs

C.6.1.2 Manufacturer Data Sheet

The data tables in this worksheet define most equipment-specific attributes of the CAC 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 and stored for use by the BOM and Global Controls worksheets.

The headings in Figure C.6 are taken from our questionnaire. Further data tables capture individual parameters such as cost per hairpin tube, volume of enclosure, and other physical parameters. These parameters form the basis for several calculations. For example, in the Global Controls page the total enclosed volume of a CAC unit drives the size of the manufacturing facility and the assembly line. This reflects the assumption that, all else equal, a plant dedicated to producing larger equipment requires more storage and assembly space than a plant dedicated to producing smaller equipment.

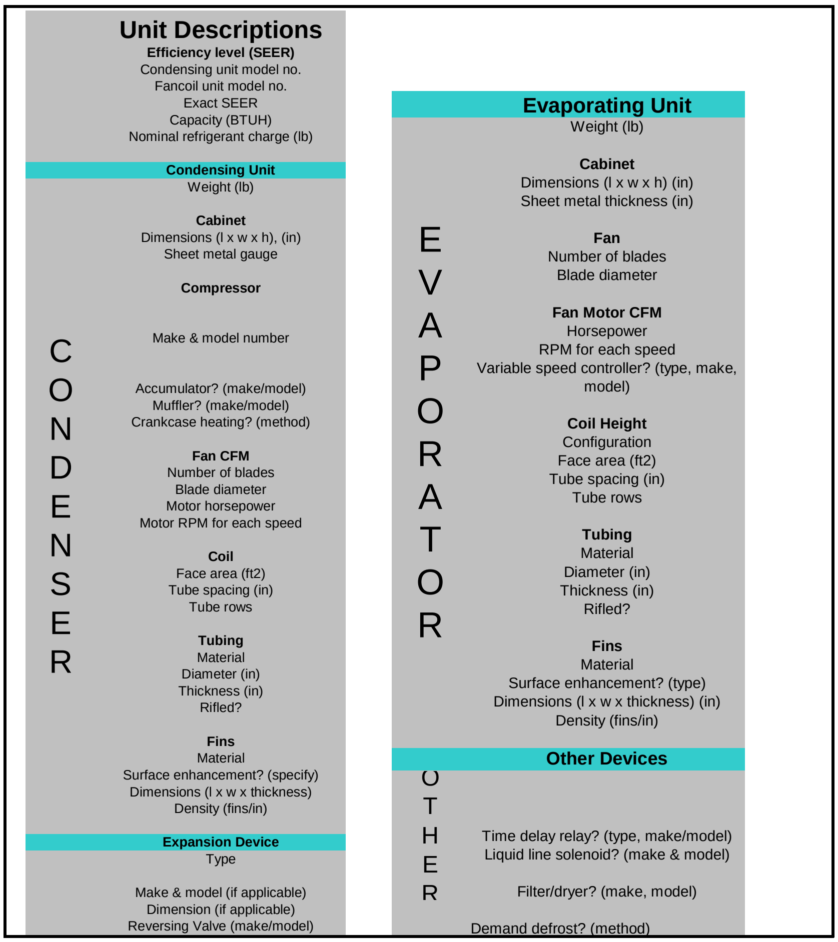

Figure C.6 Sample Data Fields from Manufacturing Data Sheet

C.6.1.3 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. 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 on 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. We gathered price quotations from multiple sources (suppliers, distributors, prior experience) in quantities that are typical for OEMs. We then passed the lowest price on to the BOM entry which queries the table unless we had reason to believe that a higher price was more credible.

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. We 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.

We assume 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) with an applied gross margin. A purchased part premium applies to any fabricated part, including a plastic part, that we assume 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.

Materials Prices	Metals				
Material	CRS	Plated CRS	Galv. CRS	Cu	Sta
Cost($/lb)	$.25	$.34	[illegible]	$1.23	$1
Density (lb/in^3)	0.284	0.284	0.284	0.323	0.

	Refrigerant	FiberGlass	Pla				
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	0.03	[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

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

Figure C.7 Sample Raw Material Data Tables and Part Price List from the Purchased Parts Sheet

C.6.1.4 Bill-of-Materials Sheet

The Bill-of-Material (as illustrated in Figure C.1 and discussed in Section C.4), 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 (insulation is thicker at higher efficiencies). Many 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.

C.6.1.5 Equipment Data Sheet

This page is a list of the installed costs for all the plant machinery involved in the production of the CAC 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 shows 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 C.8 Sample from Equipment Data Sheet

C.6.2 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. We obtained fabrication equipment costs and processing times from equipment vendors and raw material prices from vendors based on their pricing at the time.

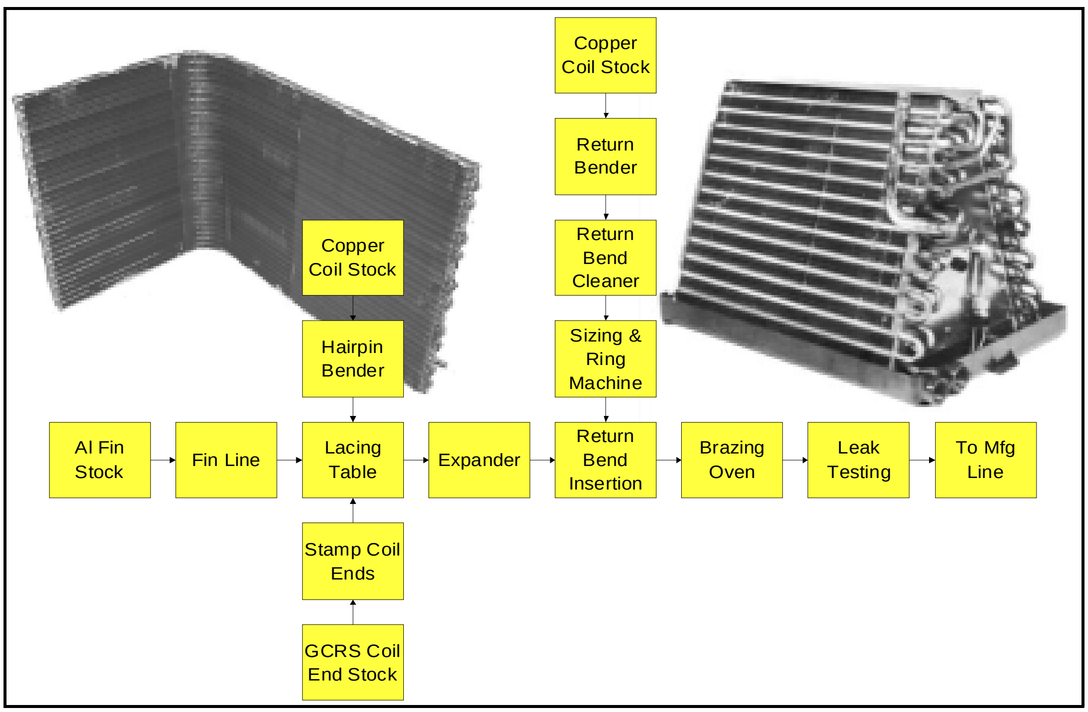

Figure C.9 Flow Diagram for Coil Model

Our coil flow diagram (Figure C.9) represents a state-of-the-art coil manufacturing facility sized for high-volume production. While this coil line may not be representative of all manufacturing facilities, we assume it to be representative 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 model. Any update in either model is automatically reflected in the other model.

Because our computational power was limited, we severed the links between the main model and the coil model during a Monte Carlo analysis. However, the effects of the Monte Carlo analysis on coil results were easily incorporated within the main model. For example, if when labor costs varied in the main model, the labor costs components of a coil would simply vary in proportion. Thus, a large number of Monte Carlo trials (2,500 to 3,000) could be accommodated over the span of a few hours.

Figure C.10 is a section of a row header for a 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 C.10 Coil model output fields

The manufacturing costs for coils are also captured in a table. Figure C.11 illustrates the header of the table which 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 C.11 Coil manufacturing costs calculated in the coil model