CHAPTER 9. SHIPMENTS ANALYSIS

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CHAPTER 9. SHIPMENTS ANALYSIS

9.1 INTRODUCTION

Commercial unitary air-conditioning equipment shipments estimates are a necessary input to the national energy savings (NES) and net present value (NPV) calculations and the manufacturer impacts analysis (MIA). This chapter describes the Department's methodology for projecting annual shipments and presents results.

The Shipments Model results are driven primarily by historical shipments data for the two size categories of commercial unitary air-conditioning equipment under consideration (≥65,000 Btu/h to <135,000 Btu/h, and ≥135,000 Btu/h to <240,000 Btu/h). The Shipments Model explicitly accounts for the combined effects of changes in purchase price, annual operating cost, and the value of commercial floor space on the purchase decision. The model also accounts for decisions to extend the life of broken equipment through repairs rather than replacing it. These decisions depend on purchase price, annual operating cost, and commercial floor-space value.

The Shipments Model considers three market segments: (1) new commercial buildings acquiring unitary equipment, (2) existing buildings replacing broken equipment, and (3) existing buildings acquiring new equipment for the first time. It considers two stock categories: (1) equipment that has received only normal maintenance repairs, and (2) equipment that has had its useful life extended through additional repairs. Both sets of stock are represented by a distribution giving the number of units as a function of the units' age.

The flow chart presented in Figure 9.1.1 outlines the structure of the Shipments Model. The model assumes that, in each year, the existing commercial unitary air-conditioning equipment stock either ages by one year or breaks. Broken equipment is either replaced or repaired. In addition, new equipment can be shipped into new or existing commercial floor space, and old equipment can be removed through demolitions (not shown in the diagram).

The Shipments Model is in a Microsoft Excel spreadsheet format that is accessible on the Internet at: http://www.eere.energy.gov/buildings/appliance_standards/commercial/ac_hp.html. Further, Chapter 10, section 10.5 of this Technical Support Document (TSD) discusses how to access the Shipments Model spreadsheet and other related spreadsheets, and provides basic instructions for using them. The rest of this chapter explains the Shipments Model in more detail. Section 9.2 presents the mathematical formulation of the model, section 9.3 describes the data inputs to the model, and section 9.4 presents the results for different energy-efficiency standard-level scenarios.

Shipments forecasts were determined for all of the candidate standard levels for which NES and NPV are required. Candidate standard levels of 10.5, 11.0, 11.5, and 12.0 EER are being considered for the ≥65,000 Btu/h to <135,000 Btu/h equipment class while candidate standard levels of 10.0, 10.5, 11.0, 11.5, and 12.0 EER are being considered for the ≥135,000 Btu/h to <240,000 Btu/h equipment class. In addition, the Department determined the NES and NPV due to quick adoption of the ASHRAE/IESNA 90.1-1999 candidate standard levels. Quick adoption in this case is defined as an effective date of 2004 as opposed to an assumed effective date of 2008 for the more stringent standard levels currently under consideration by the Department. In this way, the Department can assess the national benefits of adopting more stringent standards at a later effective date relative to adopting the ASHRAE/IESNA 90.1-1999 standard levels almost immediately.

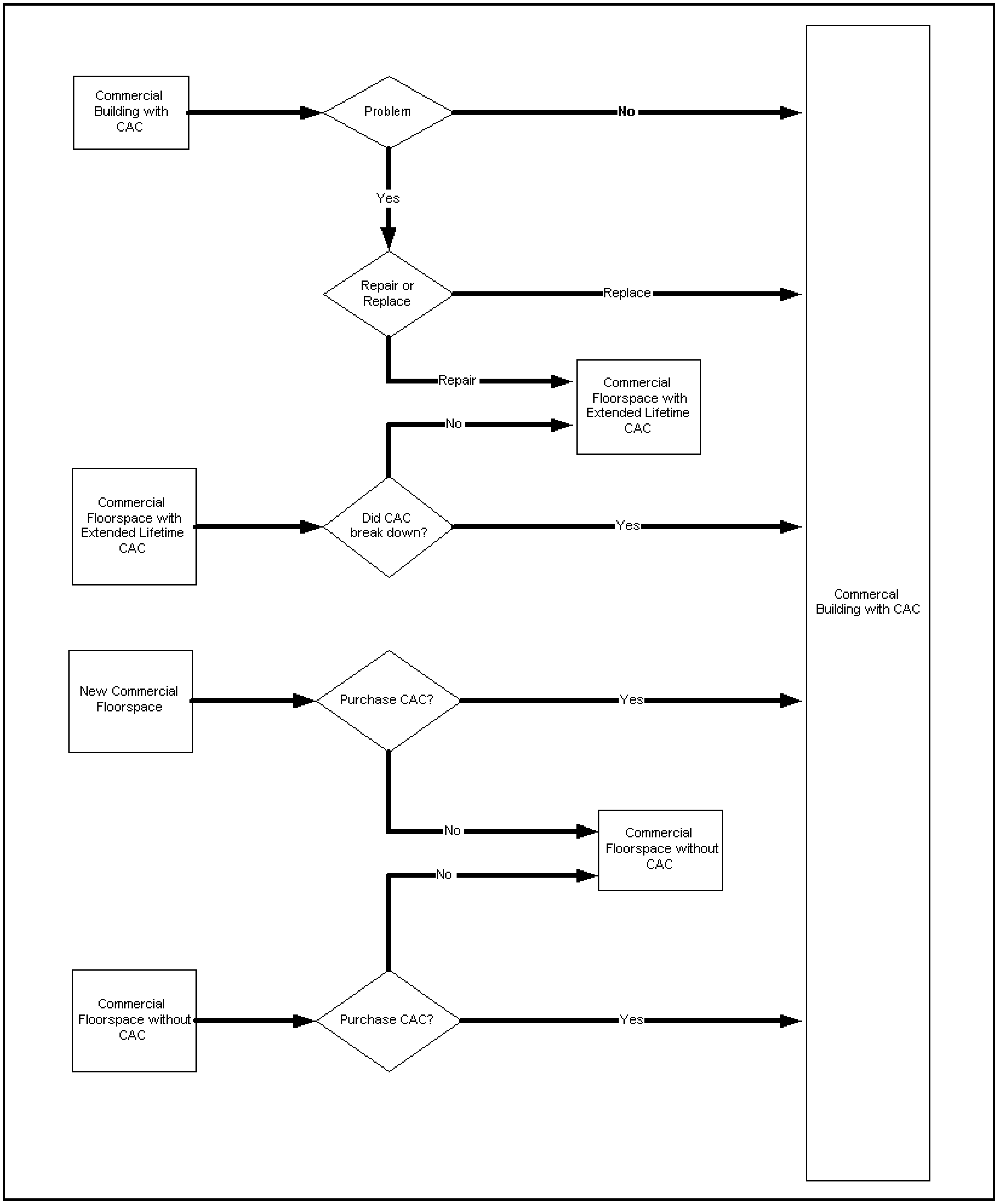

Figure 9.1.1 Flow Chart Showing Inputs to the Shipments Model. (The boxes on the left correspond to the building or customer categories. The diamonds represent stock events and decisions – for example, equipment breaks and is repaired.)

9.2 SHIPMENTS MODEL EQUATIONS

The Shipments Model is a description of commercial unitary air-conditioning equipment stock flows as a function of year and age. The Department calibrated the model to historical data for shipments of unitary air-conditioning equipment classes covered by the energy-efficiency standards. While there are two equipment classes, there is no coupling between them, so the equations describe each type of equipment independently.

This section begins with a definition of the different commercial unitary air-conditioning stock categories. The Department formulates the equations as updates of the distribution of stock in year *y* as a function of age *a* to year *y+1*. Then the Department presents the probabilities of different purchase decisions and, in the following section, provides a description of the data sources. In the equations below, DOE has converted the equipment units to square feet of air- conditioned space cooled by those units by taking the tonnage of unitary air-conditioning equipment and dividing by the national average value of equipment capacity per square foot of commercial building floor space.

9.2.1 Mathematical Formulation of the Shipments Model

The Department uses two commercial unitary air-conditioning equipment stock categories. The category $U_0(y,a)$ is the stock of existing units that have never had life-extending repairs. Whereas these units will undergo normal repairs that do not affect the lifetime of the equipment, such repairs are not explicitly modeled here. The category $U_1(y,a)$ is the stock of existing units that have had their useful life extended by additional repairs. In the model, repair extends the life of the unit by six years (consistent with values used in the residential air-conditioning equipment Shipments Model[1]).

The total stock of age *a* in a given year *y* is represented by

$$U(y,a) = U_0(y,a) + U_1(y,a)$$

and the average age of the stock in year *y* is defined as

$$StockAge(y) = \frac{\sum_a U(y,a) \cdot a}{\sum U(y,a)}$$

where:

$U(y,a)$	=	total stock of age *a* in a given year *y*,
$U_0(y,a)$	=	stock of existing units without life-extending repairs,
$U_1(y,a)$	=	stock of existing units with extended life,
$StockAge(y)$	=	average age of stock in year *y*,
a	=	age of stock, and
y	=	year.

The shipments of new stock in a given year are *Uship(y)*. By definition, the age of the equipment is zero in the year that it is shipped, so that *Uship(y) = U(y,0)*.

9.2.2 Stock Events

In the transition from year *y* to year *y+1*, six things could happen to the stock of commercial unitary air-conditioning equipment:

- existing equipment could break and be replaced,
- existing equipment could break and be repaired,
- new equipment could be purchased to go into a new building,
- new equipment could be purchased to go into a building that did not previously have it,
- a building containing the equipment could be demolished, or
- the stock could simply age by one year.

In the model, early replacements (i.e., existing equipment that is replaced before it has broken) are not considered, and all broken equipment is replaced. The following sections present the equations used to represent each possible event.

9.2.2.1 Broken equipment

The Department determines the probability that commercial unitary air-conditioning equipment of age *a* from stock U_0 will break using a known function $PB_0(a)$. Similarly, the probability that equipment of age *a* from stock U_1 will break is given by a known function $PB_1(a)$. These probabilities do not depend on the model year *y*. The Department defines the quantities of broken equipment as

$$UB_0(y,a) = PB_0(a) \cdot U_0(y,a)$$

$$UB_1(y,a) = PB_1(a) \cdot U_1(y,a)$$

where:

$UB_0(y,a)$	=	stock of existing units without life-extending repairs that have broken,
$UB_1(y,a)$	=	stock of existing units with extended life that have broken,
$PB_0(a)$	=	probability that stock of existing units without life-extending repairs will break,
$PB_1(a)$	=	probability that stock of existing units with extended life will break,
$U_0(y,a)$	=	stock of existing units that have never had life-extending repairs,
$U_1(y,a)$	=	stock of existing units with extended life,

a	=	age of stock, and
y	=	year.

The stock UB_1 represents commercial unitary air-conditioning equipment that has broken for a second time, and will be entirely replaced. The stock UB_0 is divided into two parts: stock that is repaired (and so becomes part of U_1), and stock that is replaced. The Department defines the probability that the broken stock represented by UB_0 will be repaired as $PR_0(y)$. This probability depends on the year, because the decision to repair depends implicitly on assorted cost parameters that vary with time. The probability does not depend on the age of the equipment, which has already been accounted for in the probability of breakdown. The Department then represents the number of repaired units, $UR_o(y,a)$, by

$$UR_0(y,a) = PR_0(y) \cdot U_0(y,a)$$

where:

$UR_0(y,a)$	=	number of repaired units,
$PR_0(a)$	=	probability that broken stock of existing units without life-extending repairs will be repaired,
$U_0(y,a)$	=	stock of existing units that have never had life-extending repairs,
a	=	age of stock, and
y	=	year.

The total number of *replaced* units is the sum $UB_0(y,a) - UR_0(y,a) + UB_1(y,a)$.

9.2.2.2 New equipment

New commercial unitary air-conditioning equipment will be purchased to replace the broken units described above. The Department assumes that the purchase of new equipment to go into new buildings, or into existing buildings acquiring this type of equipment for the first time, is driven by the rate of construction of commercial floor space. By definition:

$$EFS(y+1) = EFS(y) + NFS(y) - DFS(y)$$

where:

$EFS(y)$	=	the square footage of existing commercial floor space in year y,
$NFS(y)$	=	the square footage of new commercial floor space added in year y (described in section 9.3.3), and
$DFS(y)$	=	the square footage demolished in year y (described in section 9.3.3).

$PP(y)$ is the probability of purchasing new commercial unitary air-conditioning equipment to go into a new building in year y. This probability depends on the utility of the equipment and is defined in section 9.2.4. The number of units going into new buildings is defined by:

$$UN(y) = A_0 \cdot PP(y) \cdot NFS(y)$$

where:

UN(y)	=	the number of units going into new buildings,
A_0	=	an overall scale factor which accounts for the number of units covered by the standard which are not used in all commercial building types, and
PP(y)	=	probability of purchasing new units that to go into a new building in year *y*.

As stated above, the overall scale factor, A_0, accounts for unitary air-conditioning equipment covered by the standard which is not used in all commercial building types, so that the eligible market share or maximum possible saturation is less than one. The Department will determine the value of A_0 by a fit to a model of the market saturation for the given equipment category.

To describe the purchase of new units to go into existing buildings that did not previously use this type of unitary air-conditioning equipment, DOE must consider various factors. Generally, the probability of purchase is proportional to *PP(y)*, defined above, and to the quantity of existing floor space *EFS(y)*. This probability should be at its maximum in the years when the equipment is first introduced to the market, and should decline eventually to zero as purchase of the equipment for new buildings becomes more common. The simplest form this decline can take is a linear function that is at the maximum in year zero of the model (y_0), and at zero in some later year. The number of new units that are bought for the first time for existing buildings is defined by,

$$UEx(y) = E_0 \cdot \frac{2000 - y}{2000 - y_0} \cdot PP(y) \cdot EFS(y)$$

where:

UEx(y)	=	the number of new units that are bought for the first time for existing buildings,
E_0	=	is a second scale factor that DOE determined from the model fit, and
y_0	=	the year 1960.

For years $y > 2000$, *UEx* is zero.

9.2.2.3 Demolitions

A number of commercial air-conditioning units—*UDem(y,a)*—will disappear with the demolished floor space *DFS(y)*. Since it is more likely that older units will disappear with older buildings, the age distribution of *UDem* should look like the age distribution for broken units. The rate at which buildings are demolished in a given year is the ratio of *DFS* to *EFS*, so for the two stock categories, the number of demolished units is

$$UDem_0(y,a) = UB_0(y,a) \cdot \frac{DFS(y)}{EFS(y)}$$

$$UDem_1(y,a) = UB_1(y,a) \cdot \frac{DFS(y)}{EFS(y)}$$

where:

$UDem_0(y,a)$	=	stock of existing units without life-extending repairs that have been removed due to demolished floor space,
$UDem_1(y,a)$	=	stock of existing units with extended life that have been removed due to demolished floor space,
$UB_0(y,a)$	=	stock of existing units without life-extending repairs that have broken, and
$UB_1(y,a)$	=	stock of existing units with extended life that have broken.

9.2.3 Stock Equations

The Department separated the equations for the unitary air conditioner stock transition from y to $y+1$ into two components: $U(y+1,a = 0)$, representing new equipment (in year y), and $U(y+1,a > 0)$, representing non-new equipment (i.e., equipment from earlier years with age greater than zero). The equations for the never-repaired stock U_0 are:

$$U_0(y+1,a=0) = UN(y) + UEx(y) + \sum_a \left(UB_0(y,a) - UR_0(y,a) + UB_1(y,a)\right)$$

$$U_0(y+1,a=0) = Uship(y)$$

$$U_0(y+1,a>0) = \left(1 - PB_0(a)\right) \cdot U_0(y,a-1) - UDem_0(y,a-1)$$

For the stock U_1,

$$U_1(y+1,a=0) = 0$$

$$U_1(y+1,a>0) = \left(1 - PB_1(a)\right) \cdot U_1(y,a-1) - UDem_1(y,a-1) + UR_0(y,a)$$

These equations must be initialized with $U_0(y_0,a)$ and $U_1(y_0,a)$. Because of the life-extending repairs, the age of units in stock U_1 may exceed the formal definition of the maximum physical lifetime of the unitary air-conditioning equipment. As a calibration, replacements should constitute about 70 percent of the annual shipments in the year 2000.

9.2.4 Probability Equations

To complete the description of the Shipments Model, this section provides equations for the probabilities $PP(y)$, $PB_0(a)$, $PB_1(a)$, and $PR_0(y)$. In this analysis, the Department used a logit equation to model customer purchase decisions. In this model, the probability of purchase depends on the utility of the unitary air-conditioning equipment, which in turn depends on time-varying economic and equipment parameters. The purchase probability is constrained to be between 0 and 1, and relative changes in the probability of purchase are proportional to changes in the utility of the appliance. The Department defines the utility of the equipment in year *y* as

$$Utility(y) = \frac{Price(y) + OpCost(y)}{Income(y)}$$

The components of the utility are defined as follows:

- *Price(y)* is the price of a unitary air conditioner of average efficiency in year *y*.
- *OpCost(y)* is the operating cost of the unitary air conditioner, including maintenance. It depends on the unit efficiency and on the price of electricity.
- *Income(y)* is a normalization factor which is necessary because customer decisions to purchase unitary air-conditioning equipment depend on the purchase cost relative to the value of commercial floor space. The Department used the rental income per square foot for commercial buildings as a measure of this value.

The logit model takes the following function form:

$$\ln\left[\frac{PP(y)}{1 - PP(y)}\right] = \alpha_1 + \beta_1 \cdot Utility(y)$$

An increase in purchase price with no change in income or operating cost would lead to a lower probability of purchase, which constrains the coefficients α_1 and β_1 to be negative.

The probability that a broken unit will be repaired versus replaced is also represented using a logit model, with the same utility but different coefficients. The Department defined the replacement probability to be

$$\ln\left[\frac{1 - PR_0(y)}{PR_0(y)}\right] = \alpha_2 + \beta_2 \cdot Utility(y)$$

The equation takes this form because PR_0 is the probability that a unit will be repaired, so $(1 - PR_0)$ is the probability that a new unit will be purchased. Because the probability that the unitary air conditioner will be repaired should increase as the purchase price increases (i.e., customers will be more likely to repair an existing unit if replacement unitary air conditioners are more expensive than expected), the coefficients α_2 and β_2 must be positive. The Department determined all four coefficients—α_1, β_1, α_2, and β_2—by fitting the Shipments Model to historical shipments data.

To determine the probability that the stock U_0 of as-yet unrepaired equipment will break, DOE used a Weibull distribution function for the physical age of the stock. The Weibull distribution requires two parameters that are determined in the model by setting the average lifetime of the equipment to be approximately 15 years, and the maximum lifetime to be 30 years. Defining the lifetime function *LT(a)* to be the fraction of units that would survive to age *a* with only normal repairs, the probability that the unit will break is the probability that it will not survive past age *a*. This gives:

$$PB_0(a) = \int_0^a LT(s)ds$$

For the stock of unitary air conditioners, U_1, which have received life-extending repairs, DOE defined the lifetime function by shifting *LT(a)* by the increase in lifetime (6 years), which gives:

$$PB_1(a) = PB_0(a - 6)$$

For consistency, DOE imposed the condition that $PB_1(a < 6) = 0$.

9.3 DATA INPUTS

9.3.1 Historical Shipments

Historical shipments are critical to the development of the Shipments Model, since the Department used the historical data to calibrate the model. The Department's primary source of historical data for shipments of unitary air-conditioning equipment is the U.S. Census Bureau's *Current Industrial Reports on Refrigeration, Air Conditioning, and Warm Air Heating Equipment*.[2] The Air-Conditioning and Refrigeration Institute (ARI) also provided the Department with confidential shipments data. The Department used the ARI data to validate the accuracy of the Census Bureau data and, where necessary, to disaggregate the Census Bureau shipments into finer equipment categories and cooling capacity ranges.

For the two unitary air-conditioning equipment classes of interest to this analysis (≥65,000 Btu/h to <135,000 Btu/h, and ≥135,000 Btu/h to <240,000 Btu/h), the Census Bureau provides shipments data in the following equipment categories (as defined by the Census

Bureau): (1) single package air conditioners, with or without evaporator fans, including refrigeration chassis and remote-condenser types, (2) year-round air conditioners, single package and remote-condenser type (except heat pumps), and (3) split-system air-conditioning condensing units. Within each of the above equipment categories, the shipments data are disaggregated into cooling capacity ranges. The capacity ranges and equipment categories are defined in a way that allowed the Department to aggregate the Census Bureau shipments data into the two product classes of interest, with two notable exceptions: (1) the Census Bureau specified a capacity range of ≥135,000 Btu/h to <250,000 Btu/h, rather than the desired range of ≥135,000 Btu/h to <240,000 Btu/h, and (2) the Census Bureau combined water-cooled and air-cooled equipment. With respect to the first issue, the Department used the Census Bureau shipments data in the ≥135,000 Btu/h to <250,000 Btu/h capacity range to represent shipments for the ≥135,000 Btu/h to <240,000 Btu/h equipment class. With respect to the second issue, the Department used the confidential ARI shipments data to extract the appropriate percentage of water-cooled equipment from the aggregated water-cooled and air-cooled shipments.

Figure 9.3.1 shows the historical shipments data for the two commercial unitary air-conditioning equipment classes. Although DOE collected data for the years dating back to 1969, it did not obtain data for the following years: 1971–1973, 1976–1979, and 1981–1982. The most recent year for which shipments data are reported is 2000.

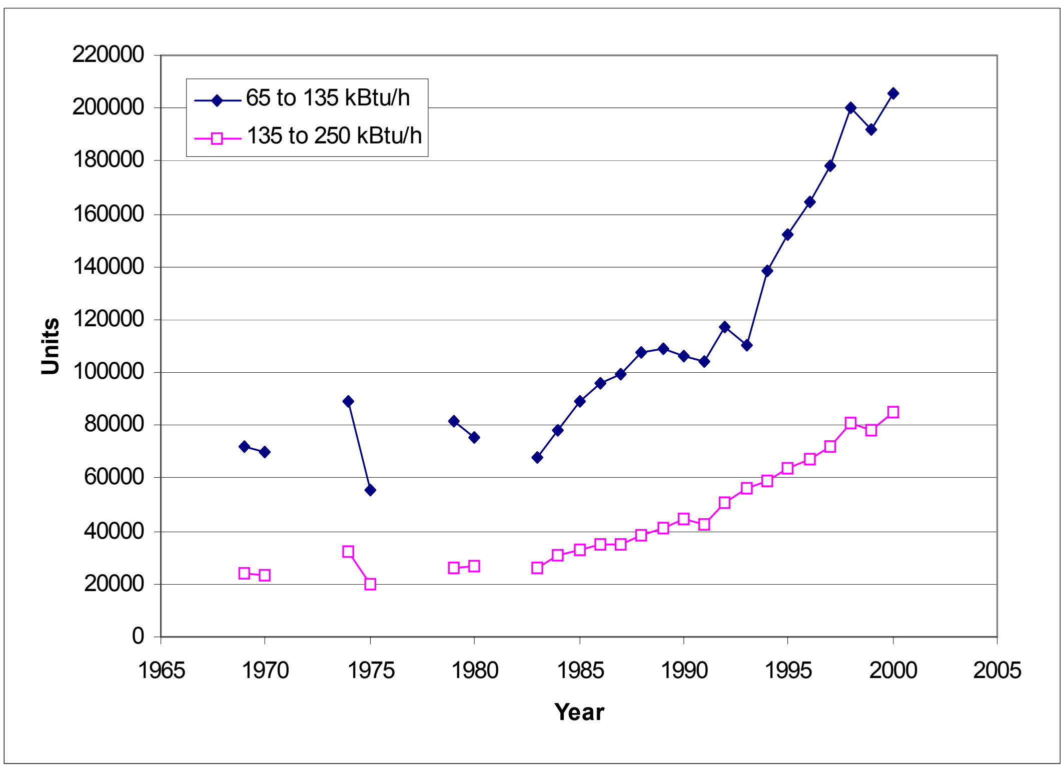

Figure 9.3.1 Historical Shipments for Commercial Unitary Air Conditioners

9.3.2 Historical Shipped Tonnage

Historical shipped tonnage depicts the annual amount of cooling capacity (in tons) shipped and is an alternative way to express shipments data. The Department determined the actual shipped tonnage for any given year by multiplying each unit shipped by its associated cooling capacity or tonnage, and then summing all the tonnage values.

The Department converted shipped tonnage to percent of shipped tonnage for use in the Shipments Model, to establish the commercial unitary air-conditioner market share attributed to each equipment class. The market share calculation and its use in forecasting shipments is explained in section 9.3.3.4. The Department calculated the percent of shipped tonnage by dividing the shipped tonnage for each equipment class by the total shipped tonnage for all commercial unitary air-conditioning equipment.

The Department used the Census Bureau shipments data to derive shipped tonnages for each of the two equipment classes, as well as for the entire set of commercial unitary air conditioners. The Census Bureau classifies the range of cooling capacities for the entire set of commercial unitary air conditioners from less than 22,000 Btu/h to greater than 640,000 Btu/h. Across this span of cooling capacities, the Census Bureau disaggregated shipments into as many as 16 smaller capacity ranges. For each capacity range, DOE used the mid-point of the range as the representative capacity for the range.[a] Then the Department determined the shipped tonnage for each capacity range by multiplying the representative capacity by the number of shipments in the range. Because the Census Bureau disaggregated shipments into several capacity ranges, the Department was able to establish the annual shipped tonnage for each of the two equipment classes and the entire set of commercial unitary air conditioners.

The confidential ARI shipments data were instrumental in separating water-cooled air-conditioning equipment from air-cooled equipment. Further, the ARI shipments data identified which air conditioners with cooling capacities less than 65,000 Btu/h were commercial equipment and which equipment were residential products.

Figure 9.3.2 shows the historical percent of shipped tonnage for the ≥65,000 Btu/h to ≤135,000 Btu/h and ≥135,000 Btu/h to<250,000 Btu/h classes of commercial unitary air-conditioning equipment. Although DOE derived data for the years back to 1969, it did not obtain the necessary shipments data to derive shipped tonnage for the following years: 1971–1973, 1976–1979, and 1981–1982. The most recent year for which shipments data are reported is 2000. In Figure 9.3.2, the percent of shipped tonnage for each equipment class does not vary greatly from year to year. As a result, DOE used average fixed values of 23 percent and

[a] For capacity ranges defined as less than a given capacity value (e.g., less than 22,000 Btu/h), DOE used 90 percent of the capacity as the representative capacity (e.g., 22,000 Btu/h X .9 = 19,800 Btu/h). For capacity ranges defined as greater than a given capacity value (e.g., 640,000 Btu/h and over), DOE used 110 percent of the capacity as the representative capacity (e.g., 640,000 Btu/h X 1.1 = 704,000 Btu/h).

16 percent for inputs to the Shipments Model for the ≥65,000 Btu/h to <135,000 Btu/h and ≥135,000 Btu/h to <240,000 Btu/h equipment classes, respectively.

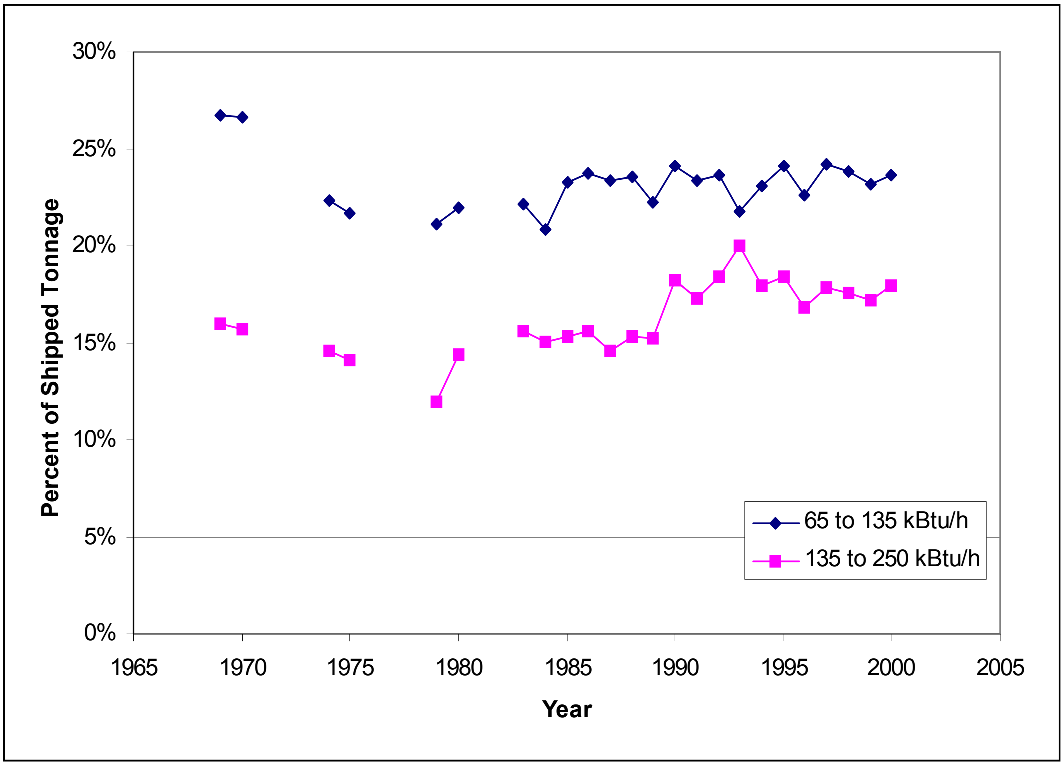

Figure 9.3.2 Historical Percent of Shipped Tonnage for Commercial Unitary Air Conditioners

9.3.3 Commercial Floor Space and Market Saturation

The amount of commercial floor space is the main driver for commercial unitary equipment shipments and is appropriately one of the basic inputs into the Shipments Model. As discussed in section 9.2.2, the model divides commercial floor space into three components: floor space from new construction (NFS), existing floor space (EFS), and demolished floor space (DFS).

For this analysis, commercial floor space refers to non-residential buildings that are used primarily for purposes other than industrial or manufacturing.

9.3.3.1 Floor Space - New Construction (NFS)

U.S. Census Bureau data[b] are available for NFS for 1980, 1985, and 1990–2000. For 1980–1985 and 1985–1990, the Department derived NFS data points through linear interpolation of the available Census Bureau data. The Department derived NFS data for years 1960–1980 by linearly extrapolating the Census Bureau data backward in time.[3]

The Department took the projected floor space after the year 2000 from the National Energy Modeling System (NEMS) projection published in the *Annual Energy Outlook 2003* (*AEO2003*).[4] *AEO2003* lists the projections for years 1999, 2000, 2005, 2010, 2015, 2020, and 2025. For unlisted years in this range, DOE derived NFS data by linear interpolation of the existing years. Beyond 2025, DOE extrapolated NFS from the 10-year trend of NEMS projected data.

There is approximately a 100 percent difference between the NEMS projection in 2000 and historical Census Bureau data in 2000. To match the Census Bureau data with the NEMS projections, DOE calculated the rate of change in NFS for each NEMS year and applied it to the Census Bureau data, starting in 2000 and stepping forward each year to 2025.

9.3.3.2 Floor Space - Existing Stock (EFS)

The Department derived historical values for existing floor space from data in the Commercial Building Energy Consumption Survey (CBECS).[5] There are CBECS surveys for the years 1979, 1983, 1986, 1989, 1992, 1995, and 1999. For unspecified years with this range, DOE linearly interpolated EFS from the survey data. For the years 1960 to 1980, DOE derived EFS by linearly extrapolating the CBECS data backward in time.

The Department took the projected floor space after the year 1999 from the NEMS projection published in *AEO2002*. The projections are listed for years 1999, 2000, 2005, 2010, 2015, and 2020. For unlisted years in this range, DOE derived EFS by linear interpolation of the existing years. Beyond 2020, DOE extrapolated EFS from the 10-year trend of NEMS projected data.

There is a small difference, less than one percent, between the NEMS projection in 2000 and CBECS data in 2000. In order to match the CBECS data with the NEMS projections, DOE calculated the rate of change in EFS for each NEMS year. The Department then applied this rate to the CBECS data, starting in 2000 and stepping forward each year to 2025.

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[b] The New Construction includes the following non-residential categories from table No. 933: Commercial, Educational, Health, Public Buildings, Religious, Social and Recreational, and Miscellaneous.

9.3.3.3 Demolished Floor Space (DFS)

The Department took demolished floor space from NEMS projections. In addition to predicting *NFS* and *EFS*, NEMS also predicts surviving square feet (SFS) (i.e., square feet in the building stock that are not demolished). The following formula gives the *DFS* for any given NEMS year.

$$DFS(y) = EFS(y) - SFS(y+1)$$

After DOE determined the *DFS* for NEMS years, it calculated the average *DFS* rate per year, *DFS/EFS*. The Department then applied this rate to the *EFS* for each year to get the *DFS* for all years, as discussed in section 9.2.3.

9.3.3.4 Market Saturation

The Department defines market saturation, *MKT_SAT(y)*, for commercial unitary air-conditioning equipment as the ratio of existing cooled floor space to all existing floor space, *EFS(y)*. It is one of the constraints used to calibrate the Shipments Model.

To calculate market saturation for a particular class of unitary air-conditioning equipment, the Department first calculated the market saturation for all commercial unitary air-conditioning (CUAC) equipment from historical CBECS data for commercial floor space cooled by unitary air conditioners, *CUACFS(y)*, and all existing floor space, *EFS(y)*. Then, to estimate the *MKT_SAT* for a particular class of commercial unitary air conditioners, DOE used the market share, or percent, of unitary air conditioners in that equipment class. The Department used the above shipments data to estimate the market share, *MKTSHARE(y)*, of each equipment class. Because the percent of shipments in each class is relatively constant over time and the lifetime of each class is the same, the ratio of shipments to a class is indicative of the market share for that class. The Department estimated the *MKTSHARE* for a particular class to be a constant value equal to the average of the yearly percent shipments to that class. From these data, DOE calculated the *MKT_SAT(y)* for each class using the following formula.

$$MKT\_SAT(y) = \frac{CUACFS(y)}{EFS(y)} \cdot MKTSHARE$$

Table 9.3.1 summarizes the market saturations for 1992, 1995, and 1999, which are the years for which *CUACFS* data are available in CBECS.

Table 9.3.1 Market Saturations

Year	CUAC Market Saturation (CBECS)	≥65,000 Btu/h to <135,000 Btu/h		≥135,000 Btu/h to 240,000 Btu/h	
		Market Share	MKT_SAT	Market Share	MKT_SAT
1992	21%	23%	5%	16%	3%
1995	24%	23%	6%	16%	4%
1999	31%	23%	7%	16%	5%

9.3.3.5 Eligible Market and Maximum Market Constraint

As discussed in Section 9.2.2.2, the Department scaled NFS by the total eligible market parameter, A_0. This parameter represents the percent of floor space that could potentially accept commercial unitary air-conditioning equipment from each class and, as such, is the upper bound on the market saturation for each class. However, the true market saturation will be somewhat lower than the total eligible market because the unitary air-conditioning equipment installed on that floor space can be only from one class, and there will be some floor space that is eligible for more than one equipment class.

As an additional constraint to the Shipments Model, DOE estimated the market saturation (MMS) for each class of unitary air-conditioning equipment in a mature market. The maximum market saturation is the actual saturation that the market approaches as it reaches maturity.

9.3.4 Equipment Utility

The equipment utility is a measure of the economic value of a commercial unitary air conditioner to the customers. The primary economic factors that influence the equipment utility and, thereby, the decision to purchase or not purchase that equipment, are equipment price, operating costs, and the customer's income. Historical data and forecast values for these economic factors are used for input to the Shipments Model and are discussed below. To make direct comparisons to floor space data, DOE expresses these economic factors on a per-square-foot basis.

9.3.4.1 Equipment Price

Equipment price is the price paid by the customer for a commercial unitary air conditioner. It includes both the purchase price of the equipment and installation costs. The Department converts the equipment price to a price per square-foot-cooled based on the cooling capacity of the equipment class.

For the years prior to 2001, DOE projected unitary air-conditioning equipment prices backward in time using the unitary air conditioner producers price index (UAC PPI) as the scaling factor.[6] Since the UAC PPI is scaled in nominal values, the Department rescaled the index in real terms using the gross domestic product (GDP) deflator referenced to 2001 dollars. Also, because PPI data are only available back to 1978, DOE derived unitary air-conditioning equipment prices for the years prior to 1978 by linearly extrapolating the rescaled UAC PPI data backward.

As discussed in the engineering analysis (Chapter 5) and the life-cycle cost and payback period analysis (Chapter 8), equipment prices in this analysis are a function of efficiency. The Department based equipment price projections on future equipment efficiency trends. The Department developed a single efficiency trend for the base case (i.e., the case without new efficiency standards) and each standard level. The efficiency trends are discussed in detail in Chapter 10, section 10.2.2.1. The efficiency trends' impact on future equipment prices is discussed in detail in Chapter 10, section 10.3.2.1.

As Figure 9.3.3 shows, equipment prices decreased in real terms before 2001. After 2001, the price in the base case is forecast to remain constant. As unitary air-conditioning equipment prices decrease, the probability of purchase is expected to increase. This implies that the parameter β_1 of the purchase model is negative (see section 9.2.4).

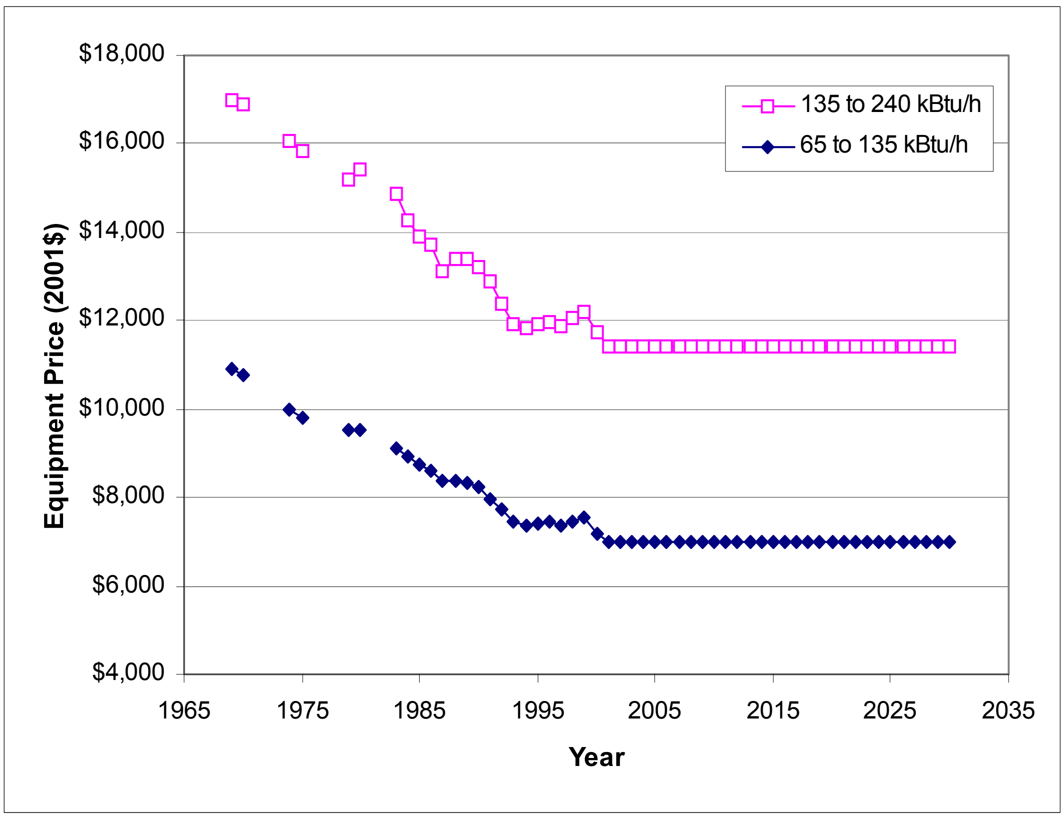

Figure 9.3.3 Base Case Equipment Price Trend for Commercial Unitary Air Conditioners

9.3.4.2 Operating Costs

Operating costs consist of maintenance costs, repair costs, and energy costs.

Maintenance and Repair Costs. Each unit of commercial unitary air-conditioning equipment incurs yearly routine maintenance and standard repair costs. The Department converted these costs to a cost per square foot of cooling capacity for each equipment class.

For earlier years, DOE projected maintenance and repair costs backward in time, as with equipment prices above, using the UAC PPI as the scaling factor. Since the UAC PPI is scaled in nominal values, DOE rescaled the index in real terms using the GDP deflator referenced to 2001 dollars. Also, because PPI data are only available back to 1978, DOE derived maintenance and repair costs for the years prior to 1978 by linearly extrapolating the rescaled UAC PPI data backward.

Whereas maintenance cost is independent of unitary air-conditioning equipment class and energy efficiency, repair costs are a function of both. Thus, projections for maintenance costs remain constant both in the base and energy efficiency standards cases. However, repair costs are projected to increase with increasing energy-efficiency standards levels. Both maintenance and repair costs are discussed in detail in Chapter 10, section 10.3.2.2.

Energy Costs. The annual energy costs for commercial unitary air conditioners depends upon the efficiency of the unit (energy efficiency ratio or EER), the annual energy use per square foot given the efficiency of the unit (energy use intensity or EUI), and the price of electricity. The determination of the EUI is discussed in the building energy use and end-use load characterization analysis (Chapter 6), and the development of electricity prices is discussed in the life-cycle cost and payback period analysis (Chapter 8, section 8.2.3.1). Coupling the EUI with electricity price data enables DOE to derive the annual energy cost by EER. Chapter 8 discusses how the EUI data are combined with the electricity price data to derive annual electricity expenses.

The Department assumes that the annual energy costs for any given year change as the efficiency of the shipped units improves. In any given year, there is a distribution of efficiencies for shipped equipment and the Shipments Model uses the shipment-weighted average efficiency for that given year. The Department based annual energy cost projections on future equipment energy-efficiency trends and future electricity prices. The Department developed a single efficiency trend for the base case (i.e., the case without new efficiency standards) and each standard level. As noted earlier, the efficiency trends are discussed in detail in Chapter 10, section 10.2.2.1. The efficiency trends' impact on future energy costs is discussed in detail in Chapter 10, section 10.3.2.2.

The equipment efficiency trends allow for the determination of projected annual energy costs as a function of efficiency in 2001 dollars. To factor in the impact of future electricity prices, the Department used electricity price projections from the *AEO2003* to appropriately scale the above projected energy costs (for scaling purposes, the year 2001 equals 1.0).

9.3.4.3 Discounted Costs

When a decision is made to purchase commercial unitary air-conditioning equipment, a sophisticated purchasing agent will consider the total lifetime cost of the equipment. Typically, these lifetime costs are discounted to represent the present value of these costs. The Department discounted the total operating costs (i.e., maintenance, repair, and energy costs) over the full lifetime of the equipment. Commercial air conditioner lifetimes range from one to approximately 30 years, with an average value of 15.4 years (see Chapter 8, section 8.2.3.9, Lifetime, for further details). Operating costs are typically heavily discounted in purchase decisions. The Department understands that such operating costs are heavily discounted, and thus it used 75 percent as the discount rate for commercial unitary air conditioners, which was the same rate it used in the residential central air conditioner Shipments Model.[1] As a result, the 75 percent discount rate translates to a discount factor of 1.33. The Department adjusted all costs associated with commercial unitary air conditioners in this analysis by 1.33.

9.3.4.4 Income

Income mitigates customer sensitivity to equipment price and operating cost changes. The Building Owners and Managers Association (BOMA) *Commercial Building Survey* reports income per square foot for commercial buildings. BOMA data are available for the years 1979–2001.[5] Because the market for commercial real estate can be highly volatile and exhibit a strong response to macro-economic factors, prices tend to fluctuate greatly. To moderate such volatility, DOE applied a four-year moving average to these data. As a result, the trend in building income, in real terms, appears to be reasonably stable. Thus, for years before 1979 and after 2001, the Department used $21 as the average income per square foot.

9.3.5 Model Calibration

The purpose of the Shipments Model is to accurately estimate the number of future shipments of commercial unitary air conditioners. For accuracy, the Shipments Model must first be calibrated by assigning values to the free model (i.e., non-constrained) parameters: A_0, E_0, α_1, α_2, β_1, and β_2.

The methodology for calibrating the model is to minimize the difference between the shipments predicted by the model (*MSHIP*) and the actual historical shipments (*HSHIP*) for the years 1969 through 2000. More specifically, the Department defines the difference in shipments (*M_DIFF*) as the sum of squares of the differences, in each year, of *HSHIP* and *MSHIP*. That is:

$$M\_DIFF = \sum_{i=1969}^{2000} \left(HSHIP_i - MSHIP_i \right)^2$$

M_DIFF can be minimized using a standard Linear Programming (LP) tool, such as Solver in Microsoft Excel.

9.3.5.1 Parameter Constraints

To reduce the parameter search space of the LP calculation, DOE constrained several of the model parameters so that the performance of the model would be consistent with rational economic behavior, and historical and predicted shipment characteristics.

9.3.5.2 Model Constraints

As mentioned in the equipment price section (section 9.3.4.1), β_1 should be a negative value. This indicates that, as unitary air-conditioning equipment prices increase, purchases decrease. Conversely, the replacement parameter, β_2, should be positive. The assumption is that, as the price of a new unitary air conditioner increases, the user is more likely to repair the old one rather than replace it.

9.3.5.3 Market Constraints and Values

Market parameters, A_0 and E_0 are constrained between zero and one, since market size must be positive and the total market cannot be larger than the available floor space.

Another market constraint is the replacement rate. This is the ratio of shipments of unitary air conditioners that replace existing units versus shipments of unitary air conditioners to new construction. The Department constrained the model replacement rate to be between 65 percent and 75 percent in the year 2015.

Finally, an additional model constraint is the maximum market saturation. Maximum market saturation is the actual saturation that the market approaches as it reaches maturity. The Department estimated the maximum market saturation as a constraint for each equipment class.

Table 9.3.2 presents a summary of the model and market constraints and the calibrated values from the fit to historical shipments for each equipment class.

Table 9.3.2 Model and Market Constraints and Calibration Values

Parameter	≥65,000 Btu/h to <135,000 Btu/h		≥135,000 Btu/h to 240,000 Btu/h	
	Constraint	Value	Constraint	Value
A_0	>0 and <1	0.19	>0 and <1	0.16
E_0	>0 and <1	0.003	>0 and <1	0.0001
α_1	-	14.7	-	12.4
α_2	-	-20.7	-	-16.1
β_1	< 0	-70	< 0	-64
β_2	> 0	125	> 0	104
MMS	10.6%	NA	9.5%	NA
Replacement Rate	≥60% and ≤70%	62%	≥60% and ≤70%	61%

9.4 RESULTS

9.4.1 ≥65,000 Btu/h to <135,000 Btu/h Equipment Class

Figure 9.4.1 shows the base case (i.e., without new standards) shipments forecast for the ≥65,000 Btu/h to <135,000 Btu/h equipment class. The figure also provides historical data points to show how closely the Shipments Model base case forecast agrees with historical data.

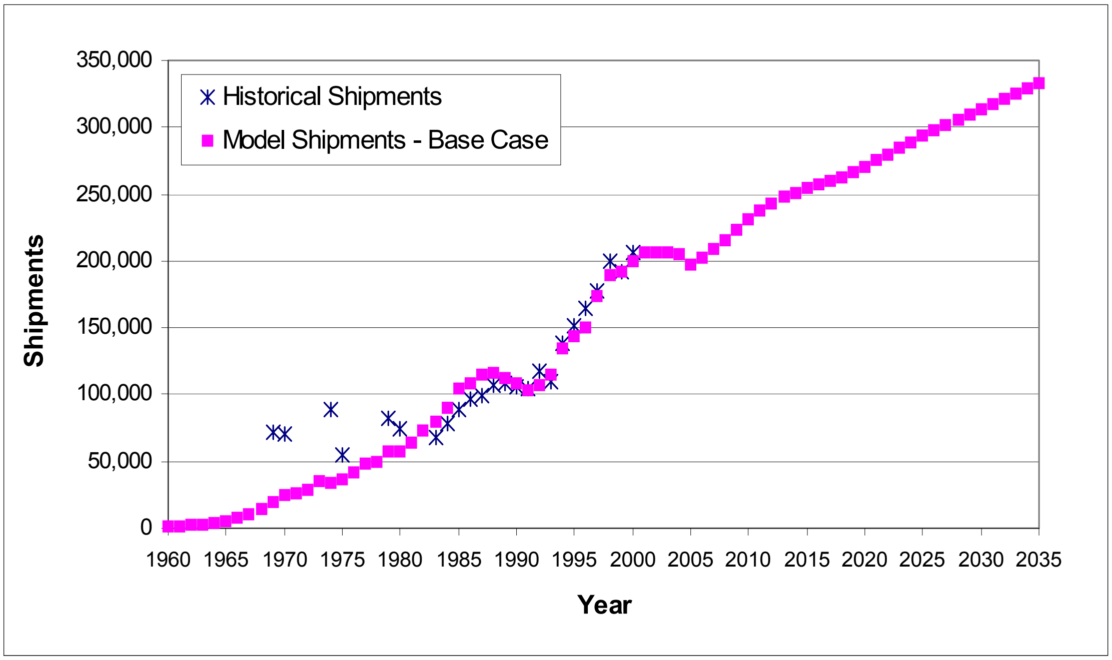

Figure 9.4.1 ≥65,000 Btu/h to <135,000 Btu/h: Base Case Shipments Forecast with Historical Data

Table 9.4.1 and Figure 9.4.2 shows the shipments forecast for the ≥65,000 Btu/h to <135,000 Btu/h commercial unitary air-conditioning equipment class for energy-efficiency standards levels from 10.5 EER through 12 EER in 0.5 EER increments. Also, the figure shows the base case forecast for comparison. As equipment purchase price increases with efficiency, a drop in shipments is forecasted.

Table 9.4.1 ≥65,000 Btu/h to <135,000 Btu/h: Forecasted Shipments for the Base Case and Standards Cases

		Standards Case				
Year	**Base Case**	**ASHRAE**	**10.5 EER**	**11.0 EER**	**11.5 EER**	**12.0 EER**
2004	205,587	205,164	205,587	205,587	205,587	205,587
2005	197,045	196,637	197,045	197,045	197,045	197,045
2006	202,518	202,128	202,518	202,518	202,518	202,518
2007	208,909	208,525	208,909	208,909	208,909	208,909
2008	216,033	215,648	215,257	213,966	210,811	202,910
2009	223,234	222,839	222,418	221,057	217,731	210,317
2010	230,580	230,188	229,756	228,386	225,040	218,477
2011	237,195	236,804	236,373	235,004	231,663	226,028
2012	243,076	242,693	242,285	240,972	237,772	233,296
2013	247,720	247,338	246,967	245,719	242,679	239,362
2014	251,286	250,900	250,581	249,413	246,574	244,405
2015	254,083	253,691	253,434	252,360	249,758	248,664
2016	256,842	256,431	256,228	255,210	252,748	252,483
2017	259,856	259,432	259,280	258,331	256,049	256,420
2018	262,862	262,412	262,277	261,315	259,010	259,647
2019	266,683	266,217	266,075	265,078	262,705	263,360
2020	270,739	270,240	270,049	268,913	266,216	266,640
2021	275,319	274,812	274,566	273,333	270,416	270,566
2022	279,709	279,171	278,853	277,449	274,123	274,053
2023	284,704	284,155	283,791	282,300	278,989	278,657
2024	289,011	288,434	288,031	286,424	283,344	282,704
2025	293,701	293,124	292,720	291,118	288,503	287,769
2026	298,056	297,467	297,070	295,456	293,241	292,579
2027	302,126	301,529	301,145	299,539	297,723	297,207
2028	305,983	305,378	305,011	303,418	301,970	301,621
2029	309,723	309,110	308,757	307,173	306,037	305,843
2030	313,445	312,821	312,476	310,888	309,994	309,924
2031	317,230	316,592	316,247	314,638	313,914	313,923
2032	321,129	320,474	320,119	318,469	317,851	317,887
2033	325,153	324,478	324,106	322,396	321,830	321,843
2034	329,292	328,596	328,201	326,420	325,892	325,848
2035	333,515	332,797	332,376	330,520	330,046	329,929

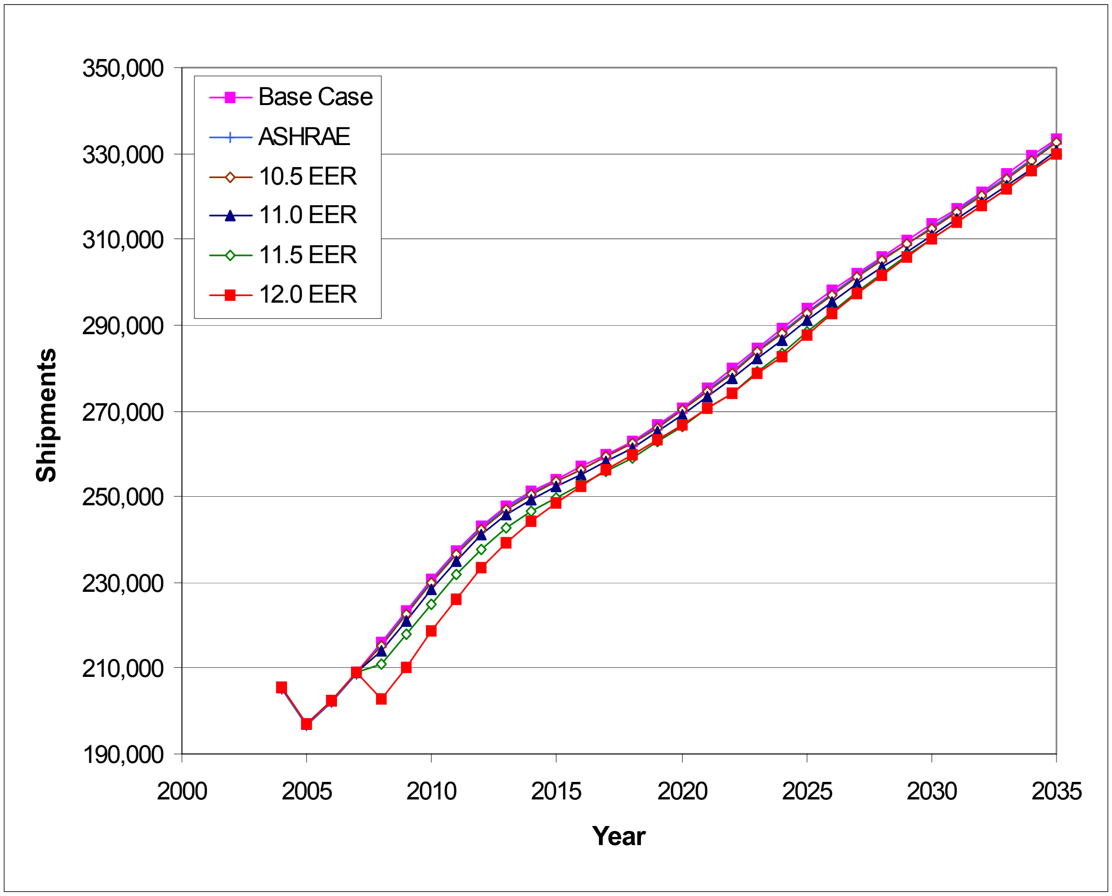

Figure 9.4.2 ≥65,000 Btu/h to <135,000 Btu/h: Forecasted Shipments for the Base Case and Standards Cases

9.4.2 ≥65,000 Btu/h to <135,000 Btu/h Equipment Class

Figure 9.4.3 shows the base case (i.e., without new standards) shipments forecast for the ≥135,000 Btu/h to <240,000 Btu/h equipment class. Also, the figure shows historical data points to show how closely the Shipments Model base case forecast agrees with historical data.

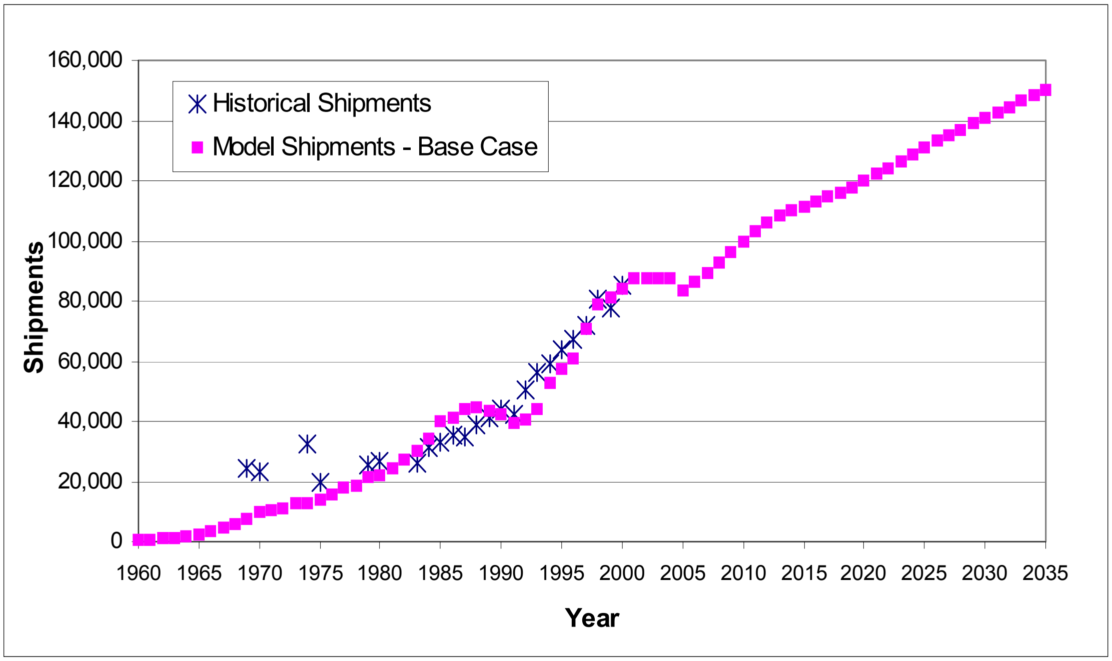

Figure 9.4.3 ≥135,000 Btu/h to <240,000 Btu/h: Base Case Shipments Forecast with Historical Data

Table 9.4.2 and Figure 9.4.4 shows the shipments forecast for the ≥135,000 Btu/h to <240,000 Btu/h commercial unitary air-conditioning equipment class for energy-efficiency standards levels from 10.0 EER through 12 EER in 0.5 EER increments. Also, the figure shows the base case forecast for comparison. As equipment purchase price increases with efficiency, a drop in shipments is forecasted.

Table 9.4.2 ≥135,000 Btu/h to <240,000 Btu/h: Forecasted Shipments for the Base Case and Standards Cases

		Standards Case					
Year	**Base Case**	**ASHRAE**	**10.0 EER**	**10.5 EER**	**11.0 EER**	**11.5 EER**	**12.0 EER**
2004	87,491	87,427	87,491	87,491	87,491	87,491	87,491
2005	83,665	83,601	83,665	83,665	83,665	83,665	83,665
2006	86,310	86,244	86,310	86,310	86,310	86,310	86,310
2007	89,387	89,319	89,387	89,387	89,387	89,387	89,387
2008	92,816	92,746	92,644	92,408	91,832	90,517	87,606
2009	96,302	96,230	96,122	95,873	95,264	93,871	91,104
2010	99,864	99,791	99,679	99,424	98,804	97,386	94,887
2011	103,100	103,026	102,914	102,657	102,032	100,605	98,415
2012	105,997	105,924	105,815	105,564	104,957	103,572	101,781
2013	108,322	108,248	108,147	107,906	107,324	105,996	104,620
2014	110,138	110,064	109,973	109,746	109,197	107,948	106,996
2015	111,583	111,509	111,430	111,220	110,711	109,557	109,010
2016	113,003	112,927	112,859	112,661	112,179	111,087	110,864
2017	114,525	114,447	114,388	114,200	113,747	112,726	112,758
2018	116,040	115,958	115,902	115,713	115,256	114,229	114,384
2019	117,921	117,835	117,776	117,578	117,104	116,044	116,227
2020	119,908	119,817	119,747	119,526	118,992	117,803	117,921
2021	122,121	122,026	121,942	121,699	121,117	119,823	119,856
2022	124,252	124,151	124,052	123,778	123,119	121,655	121,619
2023	126,657	126,551	126,440	126,146	125,440	123,966	123,832
2024	128,755	128,646	128,525	128,210	127,452	126,069	125,806
2025	131,027	130,915	130,791	130,472	129,708	128,502	128,188
2026	133,155	133,040	132,916	132,594	131,820	130,776	130,474
2027	135,152	135,036	134,914	134,592	133,819	132,937	132,679
2028	137,050	136,933	136,813	136,493	135,725	134,996	134,794
2029	138,890	138,771	138,655	138,336	137,570	136,975	136,830
2030	140,716	140,596	140,480	140,160	139,392	138,905	138,810
2031	142,565	142,442	142,325	142,001	141,224	140,816	140,757
2032	144,459	144,332	144,213	143,881	143,085	142,730	142,690
2033	146,405	146,275	146,151	145,807	144,984	144,662	144,622
2034	148,400	148,266	148,135	147,778	146,923	146,625	146,572
2035	150,430	150,292	150,155	149,783	148,893	148,625	148,549

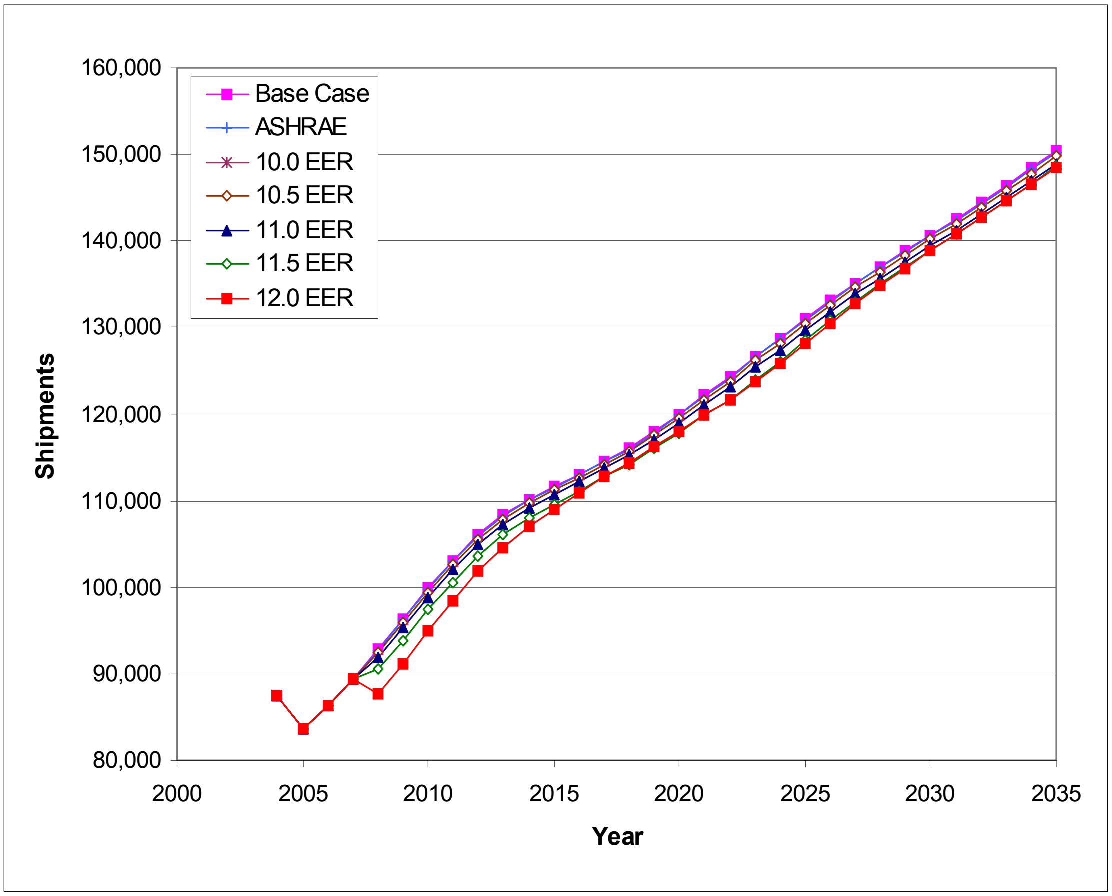

Figure 9.4.4 ≥135,000 Btu/h to <240,000 Btu/h: Forecasted Shipments for the Base Case and Standards Cases

REFERENCES

1. U.S. Department of Energy, Energy Efficiency and Renewable Energy. *Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Central Air Conditioners and Heat Pumps*, May, 2002. Washington, DC. <http://www.eere.energy.gov/buildings/appliance_standards/residential/ac_central.html>

2. U.S. Department of Commerce, Economics and Statistics Administration, U.S. Census Bureau. *Current Industrial Reports – Refrigeration, Air Conditioning, and Warm Air Heating Equipment*, 1970, 1975, 1980, and 1984 through 2000 Reports. Washington, DC. Report No. MA333M(XX)-1 for years 1998 through 2000, Report No. MA35M(XX)-1 for years 1970, 1975, 1980, and 1984 through 1997 where XX designates the year.

3. U.S. Department of Commerce, Economics and Statistics Administration, U.S. Census Bureau. *Statistical abstract of the United States*: *2001*. Washington, DC. Table No 933 - Construction Contracts-Value of Construction and Floor Space of Buildings by Class of Construction: 1980 to 2000.

4. U.S. Department of Energy, Energy Information Administration, Office of Integrated Analysis and Forecasting. *Annual Energy Outlook 2002 with Projections to 2020.* Washington, DC. Table A5 - Commercial Sector Key Indicators and Consumption.

5. Building Owners and Managers Association International, *BOMA Experience Exchange Report, 1986,1989,1992,1995,1997,2001.* Washington, DC. Table 4 - Comparison of Average Income and Expenses U.S. Private Sector.

6. U.S. Department of Labor, Bureau of Labor Statistics. Producers Price Index Website *http://www.bls.gov/ppi/home.htm*: Industry: <u>Refrigeration and Heating Equipment</u> - Product: <u>Unitary Air Conditioners</u> - Series ID: PCU3585#2 (N)