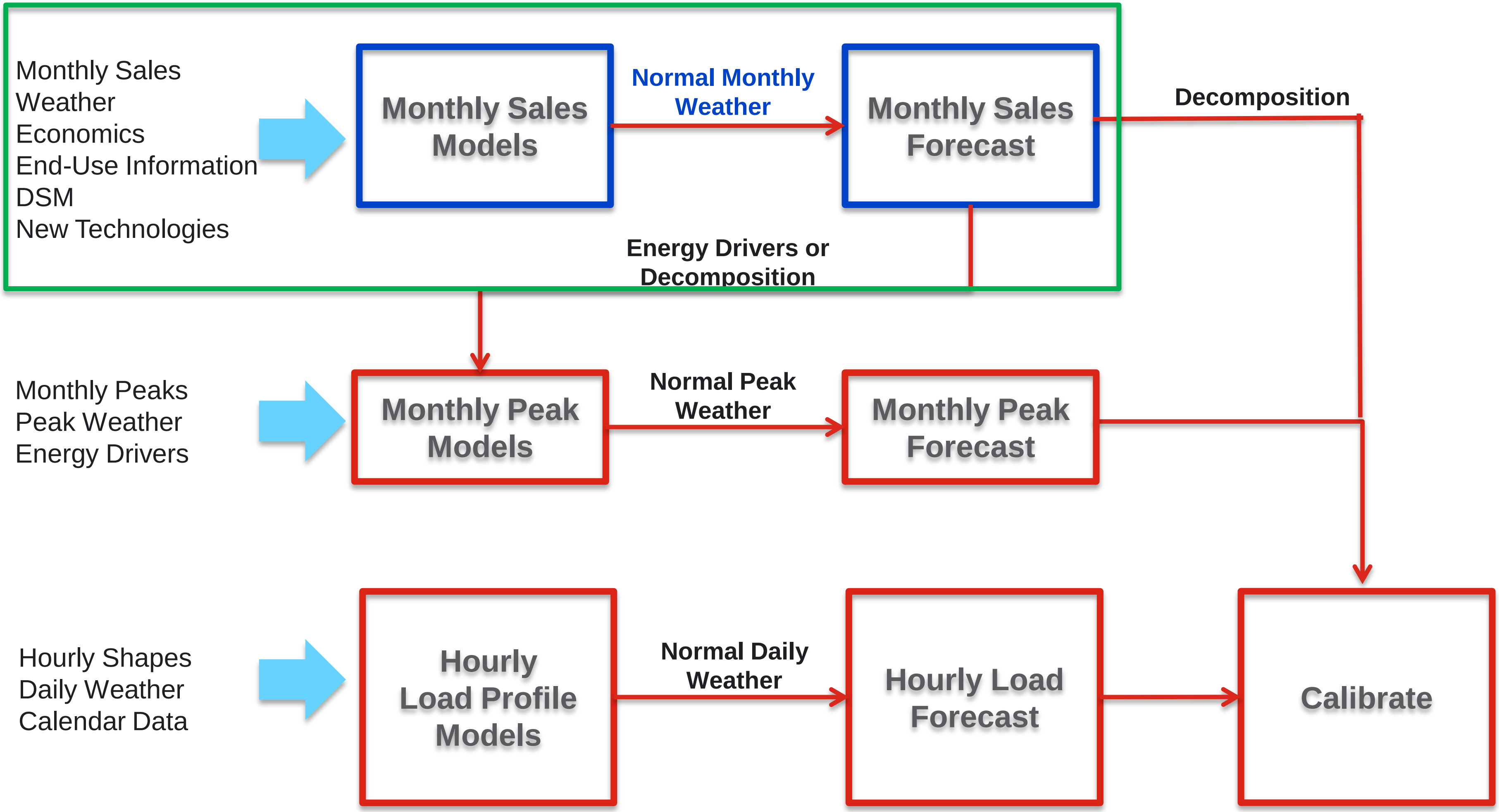
INCORPORATING EFFICIENCY INTO THE FORECAST MODEL

THE SAE MODEL

LONG TERM FORECASTING FRAMEWORK



METHODS USED FOR DEVELOPING LONG-TERM ENERGY FORECASTS

1. Generalized Econometric Model
   - Estimate a regression model where sales or energy (usually monthly) is a function of weather, economics, price, and efficiency trend

2. End-Use Model
   - Engineering based model (pre-determined model parameters) where annual energy is forecast at the end-use level (e.g. water heater, refrigerator, heating and cooling systems..)

3. Statistically Adjusted End-Use (SAE) model
   - Structured model variables based on end-use concepts are used to forecast sales (monthly) through an estimated regression model
   - A combination of 1 and 2

TYPICAL MODEL SPECIFICATIONS

» Total Sales Model

$$Sales_m = f(HDD_m, CDD_m, Real\ Income_m, Population_m, Price_m, TrendVar_m)$$

- ❑ Unrelated energy and customer forecast
- ❑ Simple economic relationship

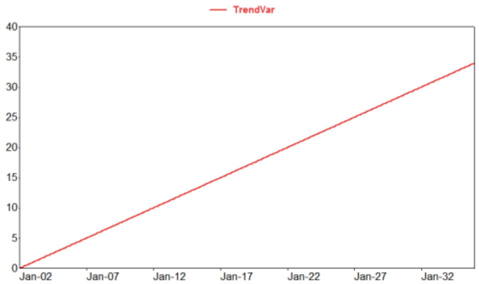
» User Per Customer and Customer Models

$$Sales_m = Customer_m \times Average\ Use_m$$

- $Customer_m = f(Population_m)$
- $Average\ Use_m = f(HDD_m, CDD_m, HHIncome_m, Price_m, TrendVar_m)$

- ❑ Ties energy to custom growth and how customers use electricity
- ❑ Macro economics drive customer growth
- ❑ Customer economics drive average use

Trendvar is a linear trend variable designed to pick up the sales trend not accounted for by other variables. If the *Trendvar* coefficient is negative and statistically significant, what does that mean?



Forecasting with a strong negative trend variable can be a problem. Why?

ADVANTAGES

- Established Methodology
- Well-suited for identifying sales trends and forecasting short-term sales
- Can account for short-term changes in economic conditions
- Can be used for weather-normalizing sales and demand
- Relatively easy to estimate and to maintain

DISADVANTAGES

» Often difficult to get the right sign and size on the model coefficients

- Positive and/or insignificant price coefficient
- Implied elasticity is too strong

» Difficult to capture all relevant economic variables

- Multicollinearity can be a problem (e.g. price and household income moving in the same direction)

» Only accounts for structural changes through a trend variable

- misses changing in technology saturation and efficiency trends

END-USE FORECASTING APPROACH

- End-use models: An engineering-based approach were we develop annual kWh forecasts for defined end-uses
  - *EPRI End-Use models: REEPS* and *COMMEND*
- Collect and maintain detailed end-use database
  - Number of units, appliance age distribution, technology options, technology costs, starting average and marginal UEC, housing square footage, thermal shell integrity
- Embed assumption as to how these characteristics will change over time with households, income, energy price, appliance costs, and standards
- Generate and sum resulting end-use energy requirements

HOW DO WE USE ELECTRICITY ?

- We don't … We use the stuff that uses electricity
  - We light our homes
  - We refrigerate and cook our food
  - We shower under hot water
  - We vacuum up after the kids and dog
  - We dry our clothes
  - We watch TV
- To forecast electricity we reverse engineer the model
  - If cooling output depends on electricity input then electricity use depends on cooling demand

END-USE MODELING FRAMEWORK

» The end-use central equation:

$$Sales_e = Households \times Saturation_e \times UEC_e$$

Where:

- $Saturation_e$ = Number of homes that own end-use *e*
- UEC_e = Annual energy usage for end-use *e*

» End-use energy intensity:

$$EI_e = Saturation_e \times UEC_e$$

- Average annual usage per household (kWh)

UNIT ENERGY CONSUMPTION (ANNUAL USAGE – KWH)

$$UEC_e = \frac{\text{Size}_e \times \text{Usage}_e}{\text{Efficiency}_e}$$

Where:

Size_e = Average size of end use *e*

Usage_e = Measure of the intensity of appliance usage

Efficiency_e = Average efficiency for end use *e*

If Size and Usage are constant then the UEC is driven by changes in Efficiency

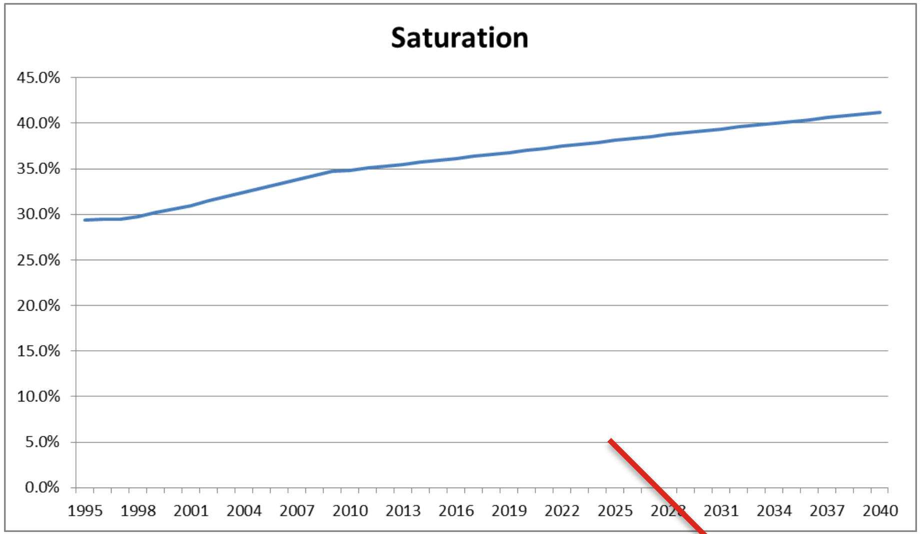
NY ELECTRIC DRYER USAGE - 2015

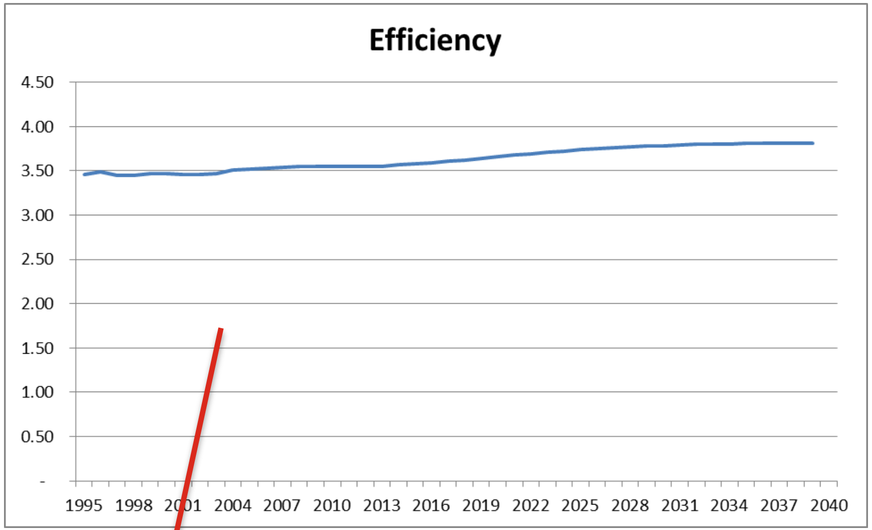
» Electric Dryers
  - Number of Households: 7,320,000
  - Percent of households with electric dryers: 36%
  - Annual energy use for an electric dryer (UEC): 800 kWh

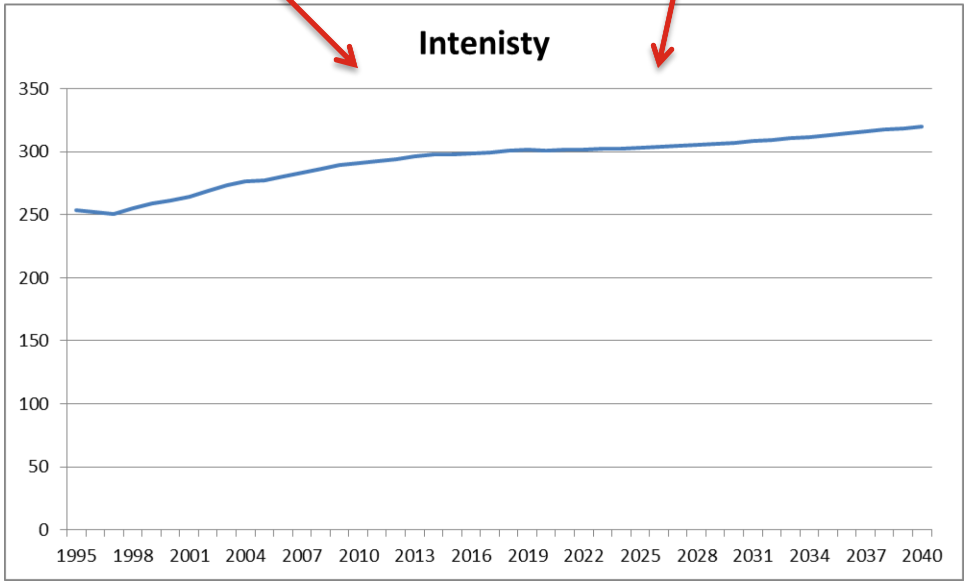
» Dryer Sales = 7,320,000 * 36% * 800 kWh = 2,108 GWh

» Energy Intensity: 36% * 800 kWh = 298 kWh

ELECTRIC DRYER INTENSITY (KWH PER HH)







END-USE MODEL EQUATIONS

» Each component for each end-use is modeled separately

- Saturation = f(price, cost, appliance life, availability, …)
- Efficiency = f(price, cost, standards, technology options, …)
- Size = f(income, cost, options, …)
- Usage = f(price, income, weather, …)
- Households = f(population, …)

END-USE FORECASTING APPROACH: ADVANTAGES

- Ideal for long-term (5- 20 years out)
  - Detailed stock accounting framework

- Provides detailed end-use information
  - Number of equipment stock units and saturation
    - New and replacements
  - Average and marginal efficiency
  - UEC and energy intensities
  - By housing type – single family, multi-family, mobile homes

- Provides an ideal framework for evaluating the energy impact of new standards and technologies

END-USE FORECASTING APPROACH: DISADVANTAGES

» Expensive to develop and maintain
  - Detail housing structure data
  - Detail technology data requirements
  - Estimates of base year UECs for existing and new housing units (Conditional Demand Study)

» Does not provide a useful short-term forecast
  - Annual model
  - Highly structured

» Difficult to integrate with a short-term forecasts

OBJECTIVE

» Develop an approach that incorporates the best characteristics of an econometric and end-use modeling framework

» We want to account for:
  - Economic impacts: household income, size, growth
  - Price impacts
  - Structural changes: Saturation and efficiency trends, housing square footage, thermal shell integrity improvements
  - Weather impacts
  - Appropriate impact of these variables

» Ideally, one model for short and long-term forecasting

STATISTICALLY ADJUSTED END-USE MODELING

» Blend end-use concepts into an econometric modeling framework:

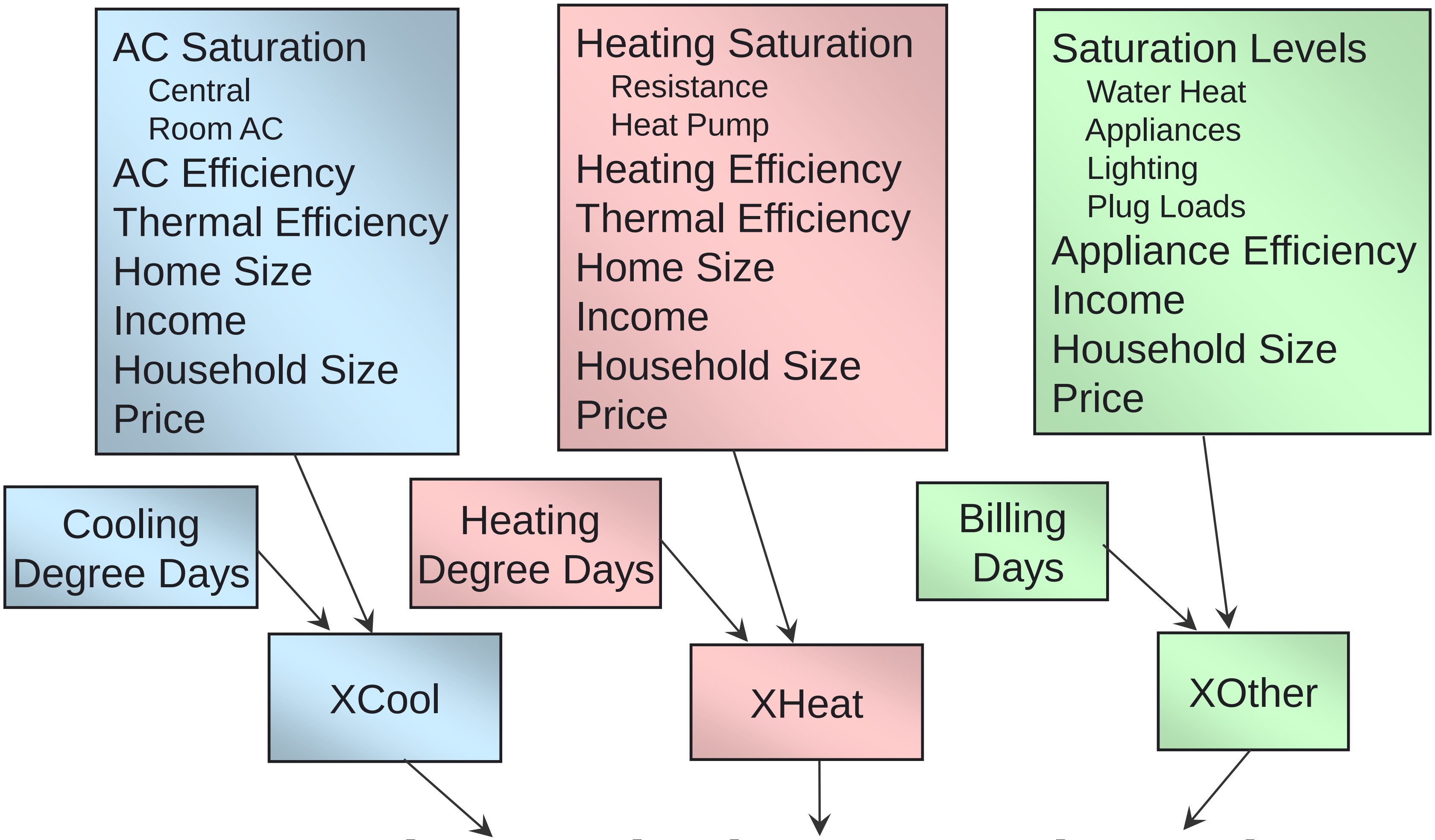
- *Average Use = Heating + Cooling + Other Use*

» Define heating, cooling, and other use in terms of their end use structure:

Cooling = f (Saturation, Efficiency, Utilization)

Utilization = g (Weather, Price, Income, Household Size)

SAE MODEL



$$AvgUse_m = a + b_c \times XCool_m + b_h \times XHeat_m + b_o \times XOther_m + e_m$$

Estimate monthly model with historical billed sales data

END-USE VARIABLE - HEATING

$$XHeat_{y,m} = HeatIndex_y \times HeatUse_{y,m}$$

$$HeatIndex_y = Structural\ Index_y \times \sum_{Type} EI_{09}^{Type} \times \frac{\left(Sat_y^{Type} \middle/ Eff_y^{Type} \right)}{\left(Sat_{09}^{Type} \middle/ Eff_{09}^{Type} \right)}$$

$$HeatUse_{y,m} = \left(\frac{HDD_{y,m}}{HDD_{09}} \right) \times \left(\frac{HHSize_{y,m}}{HHSize_{09}} \right)^{0.20} \times \left(\frac{Income_{y,m}}{Income_{09}} \right)^{0.20} \times \left(\frac{Price_{y,m}}{Price_{09}} \right)^{-0.15}$$

RESIDENTIAL HEATING WEIGHT VARIABLE

Weights **Estimated heating energy use per household for each equipment type in the base year**

Where:

➡ $$EI_{09}^{Type} = UEC_{09}^{Type} \times HeatShare_{09}^{Type}$$

Equipment Type	Energy Intensities (2009 kWh/HH)
Electric Furnace/Room Resistance	771
Electric Space Heating Heat Pump	128

RESIDENTIAL STRUCTURAL INDEX

Structural index accounts for

- Change in housing square footage
- Change in structural thermal integrity – Overall R-Value

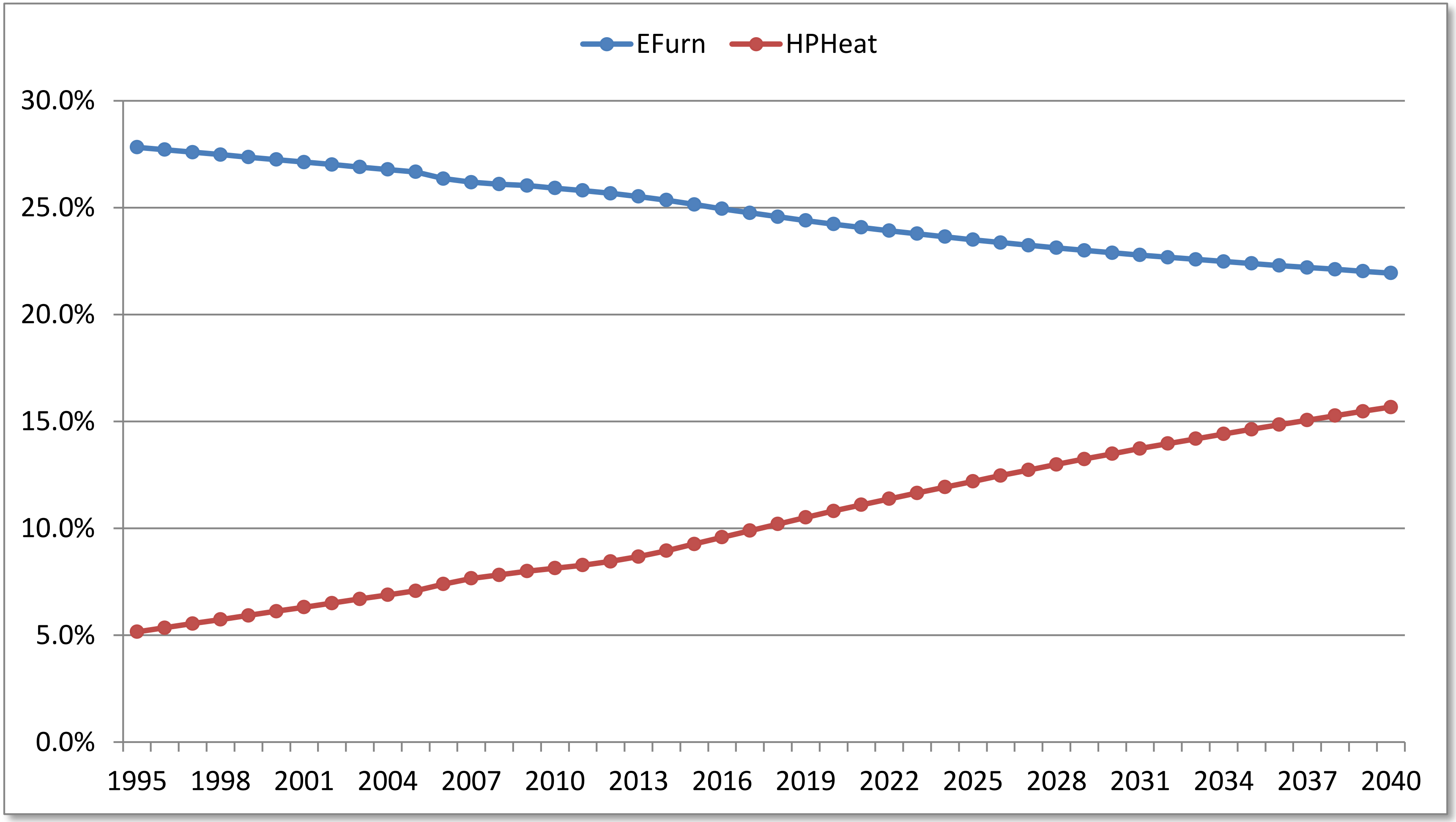
Where:

$$Structural\ Index_y = \frac{Building\ Shell\ Efficiency\ Index_y \times Surface\ \text{Area}_y}{Building\ Shell\ Efficiency\ Index_{09} \times Surface\ \text{Area}_{09}}$$

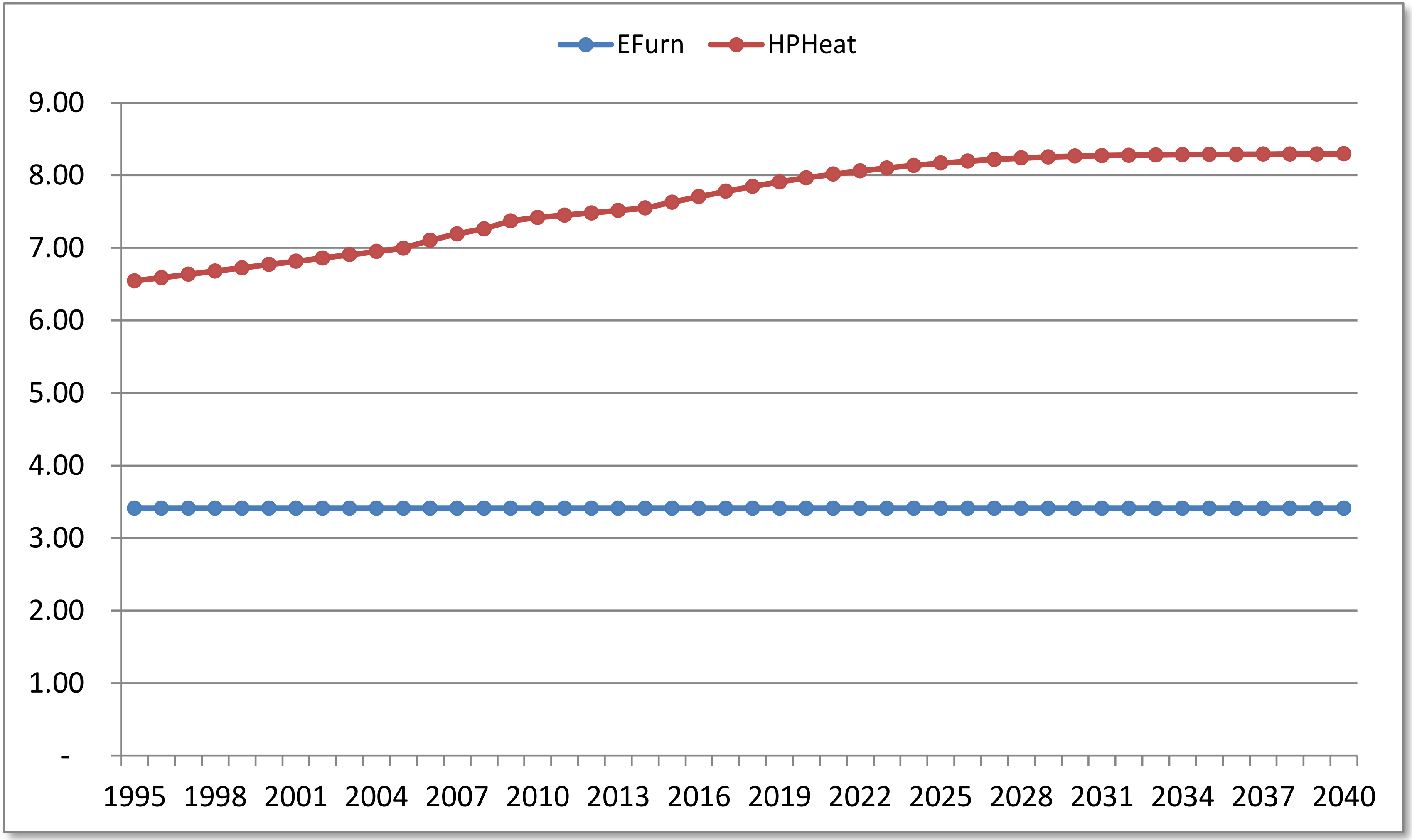
And

$$\text{Surface Area}_\text{y} = 892 + 1.44 \times \text{Footage}_\text{y}$$

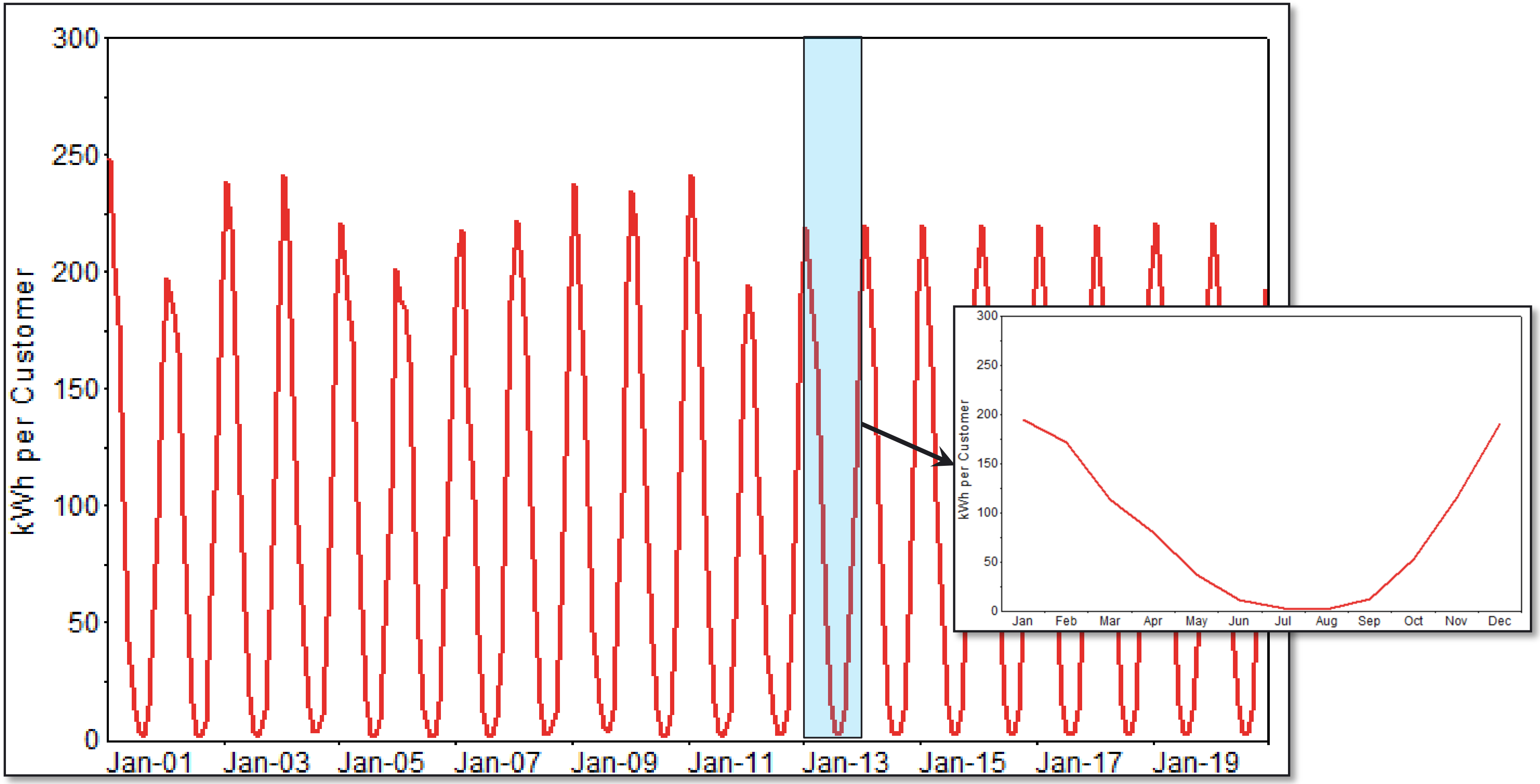
RESIDENTIAL HEATING SATURATION TRENDS



RESIDENTIAL HEATING EFFICIENCY TRENDS



RESIDENTIAL XHEAT VARIABLE



END-USE VARIABLE - COOLING

$$XCool_{y,m} = CoolIndex_y \times CoolUse_{y,m}$$

$$CoolIndex_y = StructuralIndex_y \times \sum_{Type} EI_{09}^{Type} \times \frac{\left(Sat_y^{Type} \big/ Eff_y^{Type} \right)}{\left(Sat_{09}^{Type} \big/ Eff_{09}^{Type} \right)}$$

$$CoolUse_{y,m} = \left(\frac{CDD_{y,m}}{CDD_{09}} \right) \times \left(\frac{HHSize_{y,m}}{HHSize_{09}} \right)^{0.20} \times \left(\frac{Income_{y,m}}{Income_{09}} \right)^{0.20} \times \left(\frac{Price_{y,m}}{Price_{09}} \right)^{-0.15}$$

RESIDENTIAL COOLING WEIGHT VARIABLE

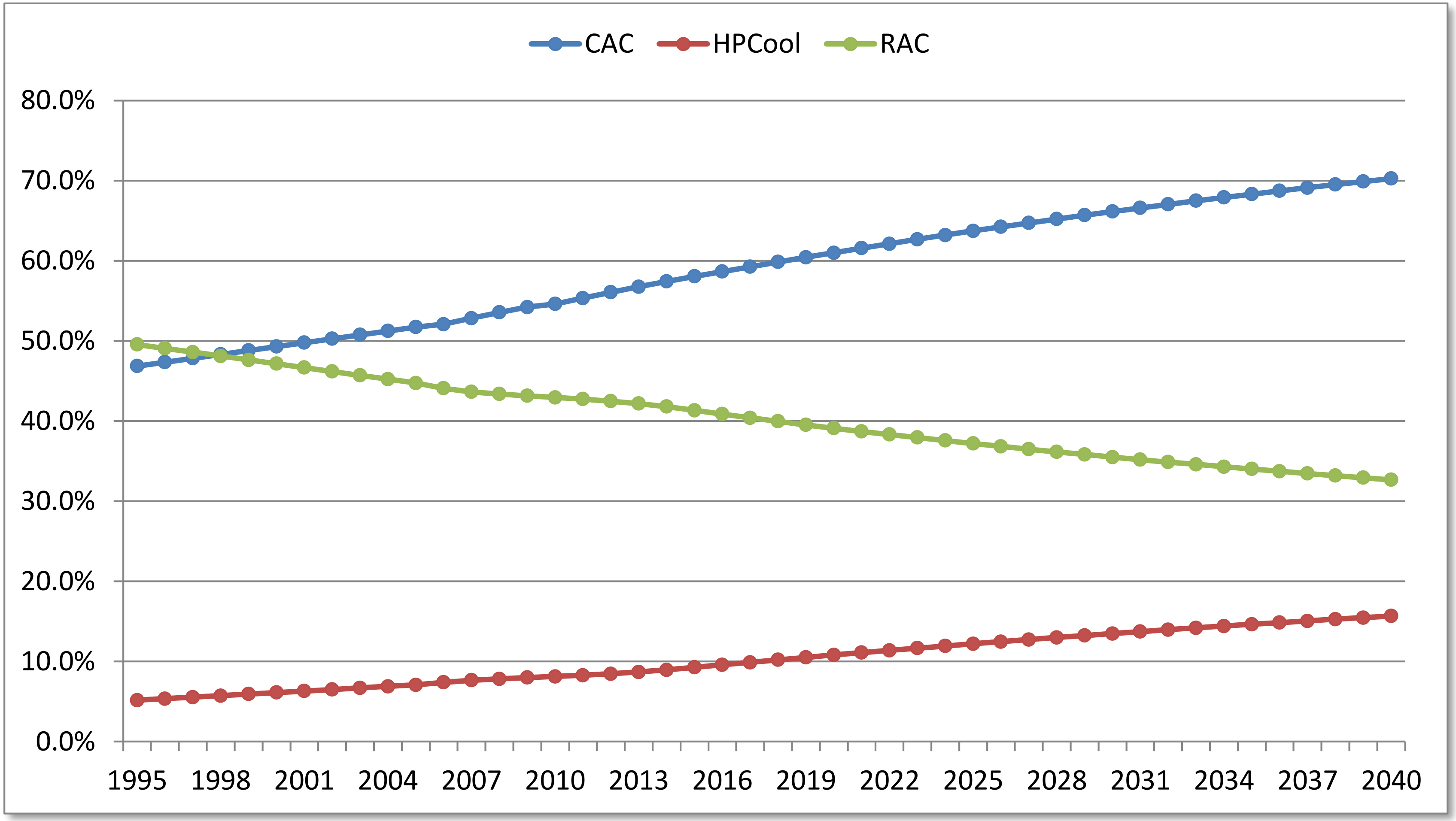
Weights **Estimated cooling energy use per household for each equipment type in the base year**

Where:

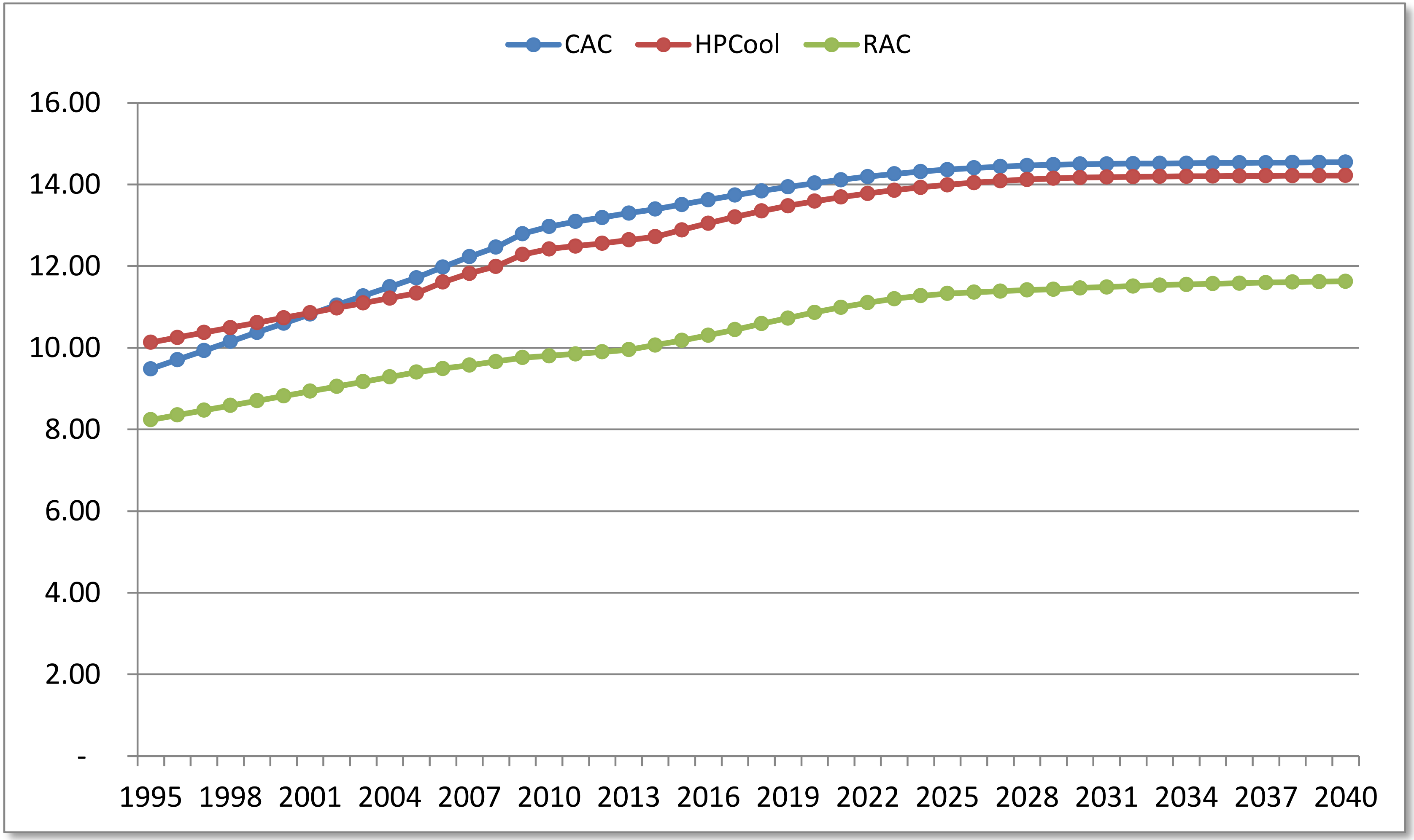
$$EI_{09}^{Type} = UEC_{09}^{Type} \times CoolShare_{09}^{Type}$$

Equipment Type	Energy Intensities (2009 kWh/HH)
Central Air Conditioner	1,226
Heat Pump Cooling	241
Room Air Conditioner	178

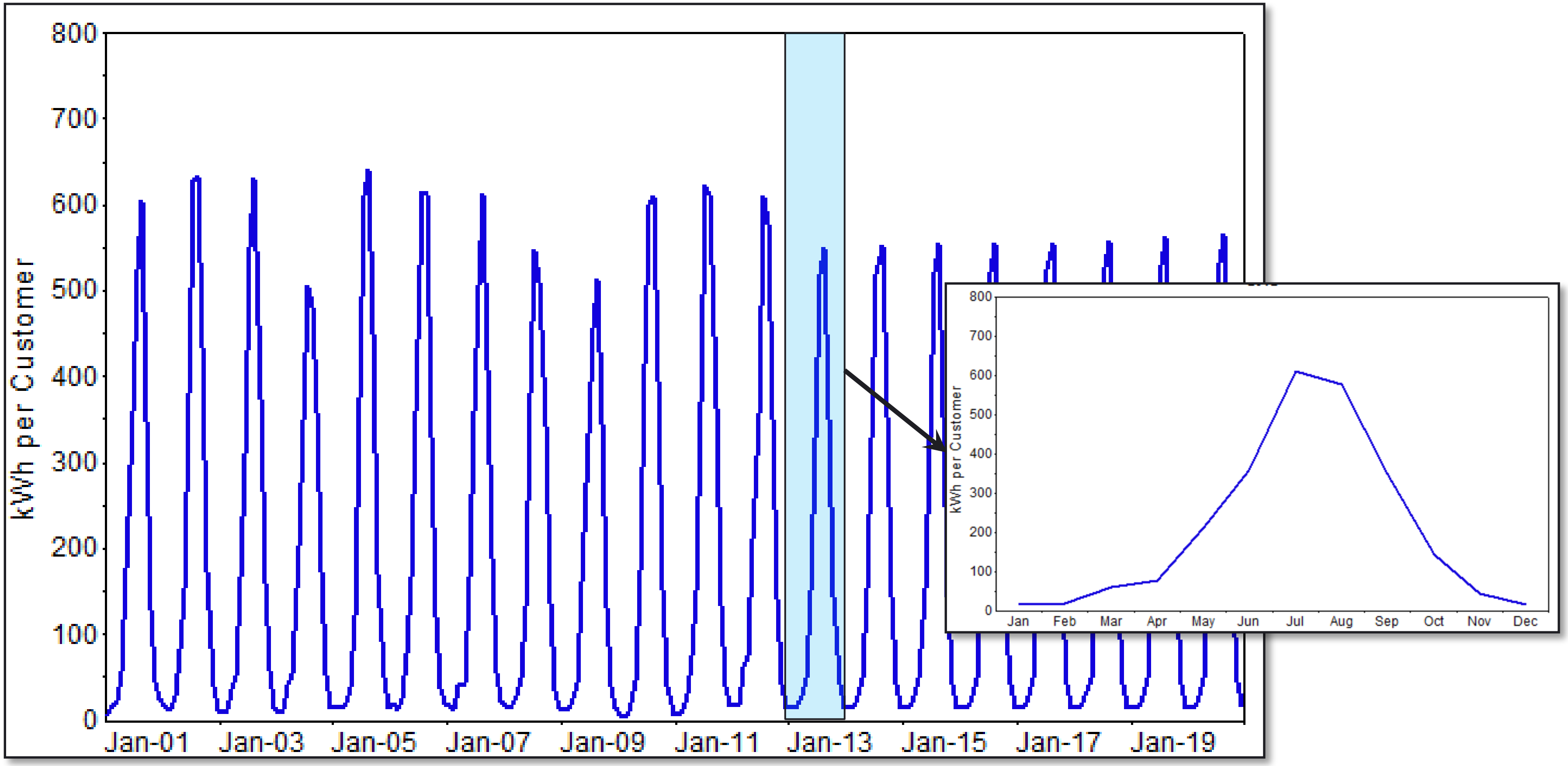
COOLING SATURATION TRENDS



COOLING EFFICIENCY TRENDS



RESIDENTIAL XCOOL VARIABLE



FACTORS IMPACTING OTHER USE

- Non-weather sensitive end-use saturation and efficiency trends
- Number of billing days
- Hours of light
- Household size and income
- Prices

XOTHER VARIABLE

$$XOther_{y,m} = OtherEqpIndex_{y,m} \times OtherUse_{y,m}$$

$$OtherEqpIndex_{y,m} = EI_{09}^{Type} \times \frac{\left(Sat_y^{Type} \Big/ Eff_y^{Type} \right)}{\left(Sat_{09}^{Type} \Big/ Eff_{09}^{Type} \right)} \times MoMult_m^{Type}$$

$$OtherUse_{y,m} = \left(\frac{Price_{y,m}}{Price_{09}} \right)^{-0.15} \times \left(\frac{Income_{y,m}}{Income_{09}} \right)^{0.10} \times \left(\frac{HHSize_{y,m}}{HHSize_{09}} \right)^{0.25} \times \left(\frac{BDays_{y,m}}{31} \right)$$

APPLIANCE WEIGHTS

Weights **Estimated appliance energy use per household for each equipment type in the base year**

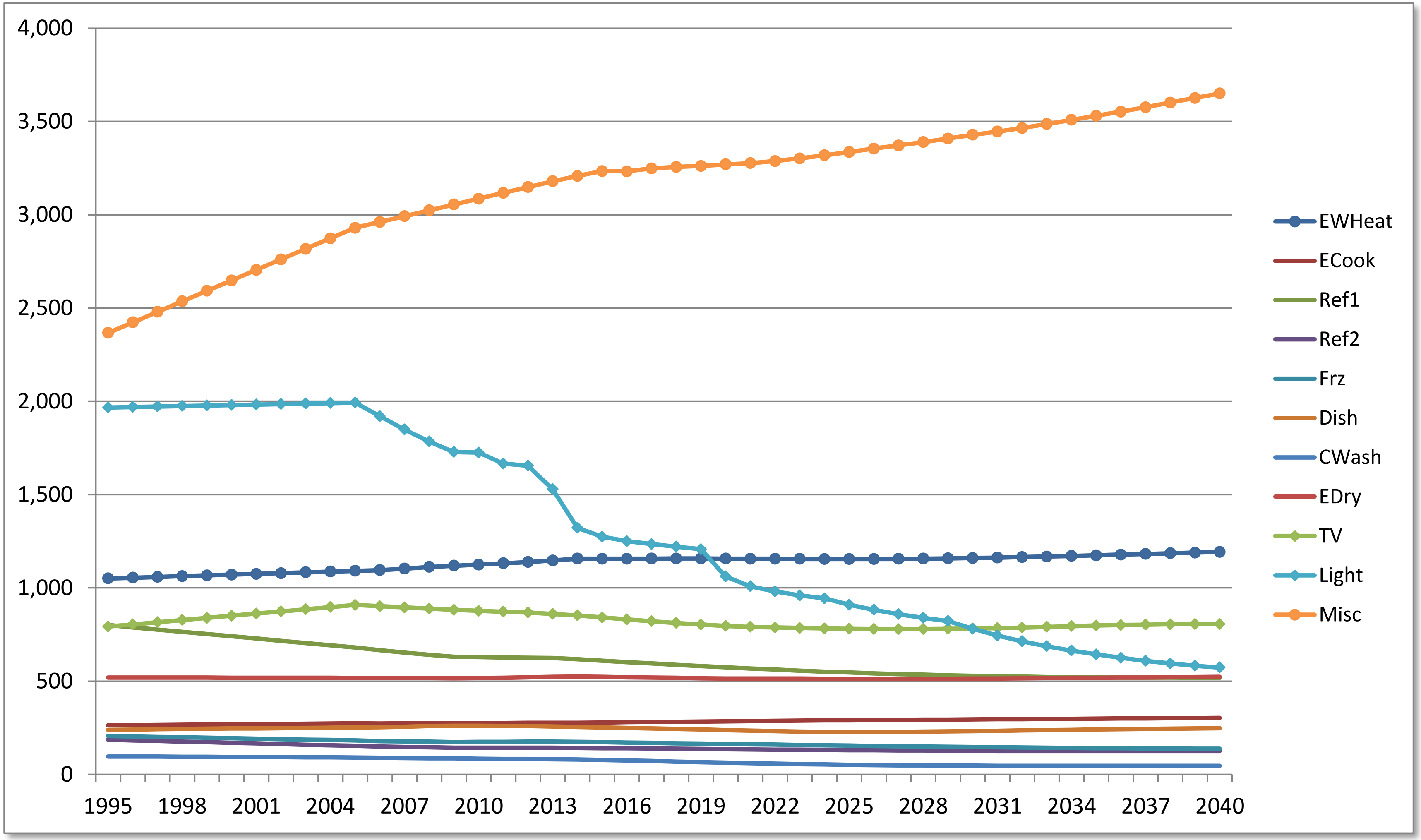
Where:

$$EI_{09}^{Type} = UEC_{09}^{Type} \times ApplianceShare_{09}^{Type}$$

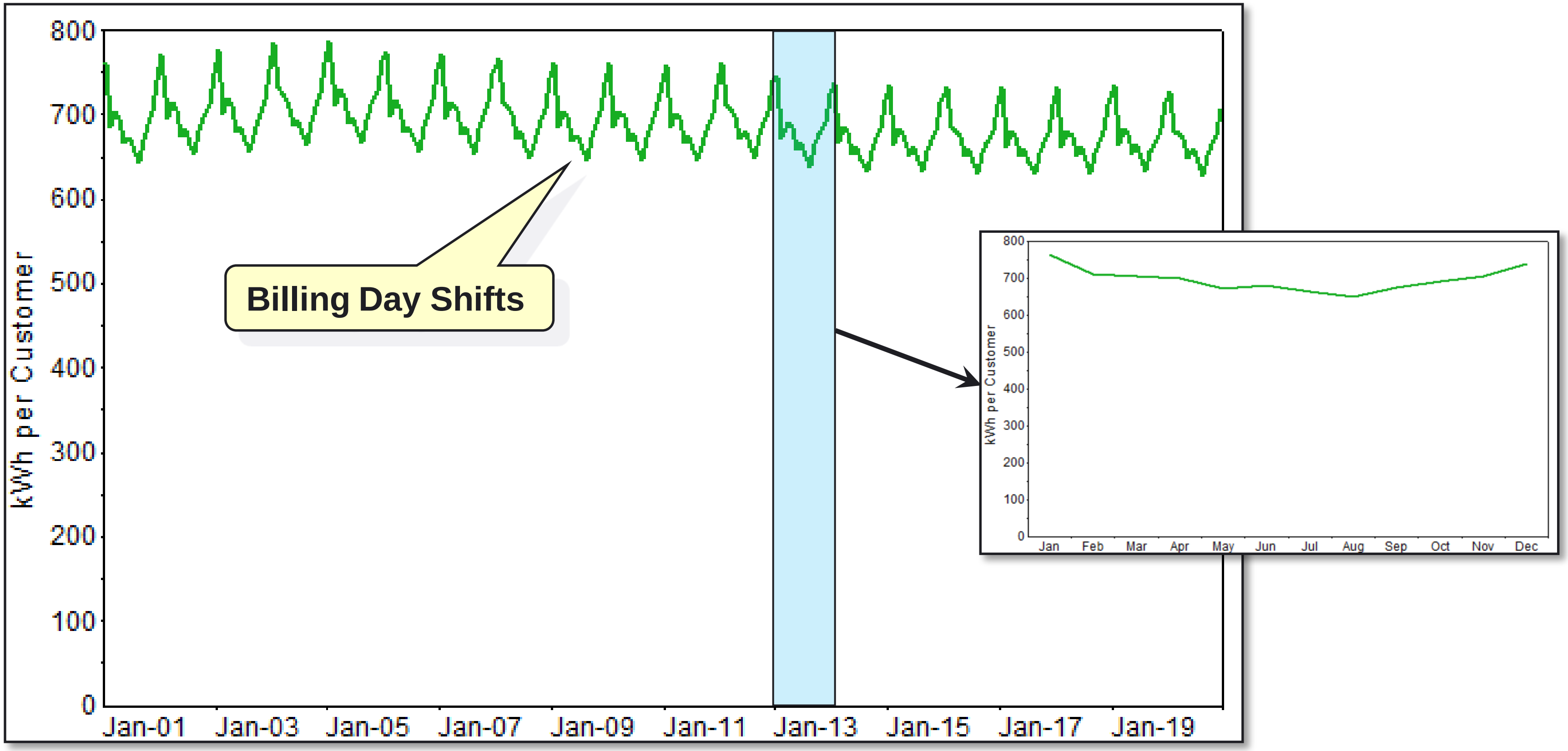
RESIDENTIAL NON HVAC END-USE INTENSITIES

End-Use	Energy Intensities (2009 kWh / HH)
Electric Water Heating	475
Electric Cooking	133
Refrigerator	716
Second Refrigerator	90
Freezer	111
Dishwasher	211
Electric Clothes Washer	69
Electric Clothes Dryer	290
TV & Related Equipment	970
Lighting	1,715
Miscellaneous Electric Appliances	2,158

RESIDENTIAL OTHER END-USE INDICES



RESIDENTIAL XOTHER VARIABLE



RESIDENTIAL AVERAGE USE MODEL VARIABLES

SAE variables calculated as simple transforms

```
CoolEqp =       (Indices.CAC + Indices.HPCool + Indices.GHPCool + Indices.RAC)*12
CoolUse =       (mEcon.HHSizeInd^Elas.HHSize) * (mEcon.HHIncInd^Elas.HHInc) *
                (mEcon.PriceInd^Elas.Price) * mWthrRev.CDDInd
XCool =          mStructRev.CoolUse * mStructRev.CoolEqp
```

```
HeatEqp =      (Indices.EFurn + Indices.HPHeat + Indices.GHPHeat + Indices.SecHt+Indices.FurnFan)*12
HeatUse =      (mEcon.HHSizeInd^Elas.HHSize) * (mEcon.HHIncInd^Elas.HHInc) *
               (mEcon.PriceInd^Elas.Price) * mWthrRev.HDDInd
XHeat =         mStructRev.HeatUse * mStructRev.HeatEqp
```

```
OtherUse =      (mEcon.HHSizeInd^Elas.HHSize) * (mEcon.HHIncInd^Elas.HHInc) *
                (mEcon.PriceInd^Elas.Price) * mWthrRev.BDaysInd
OtherEqpIndex = Convstock (Indices.EWHeat) * Value (MonthlyMults.EWHeat, 2001, month) +
                Convstock (Indices.ECook)  * Value (MonthlyMults.ECook, 2001, month) +
                Convstock (Indices.Ref1)   * Value (MonthlyMults.Ref1, 2001, month) +
                Convstock (Indices.Ref2)   * Value (MonthlyMults.Ref2, 2001, month) +
                Convstock (Indices.Frz)    * Value (MonthlyMults.Frz, 2001, month) +
                Convstock (Indices.Dish)   * Value (MonthlyMults.Dish, 2001, month) +
                Convstock (Indices.CWash)  * Value (MonthlyMults.CWash, 2001, month) +
                Convstock (Indices.EDry)   * Value (MonthlyMults.EDry, 2001, month) +
                Convstock (Indices.TV)     * Value (MonthlyMults.TV, 2001, month) +
                Convstock (Indices.Light)  * Value (MonthlyMults.Light, 2001, month) +
                Convstock (Indices.Misc)   * Value (MonthlyMults.Misc, 2001, month)
XOther =        mStructRev.OtherUse * mStructRev.OtherEqpIndex
```

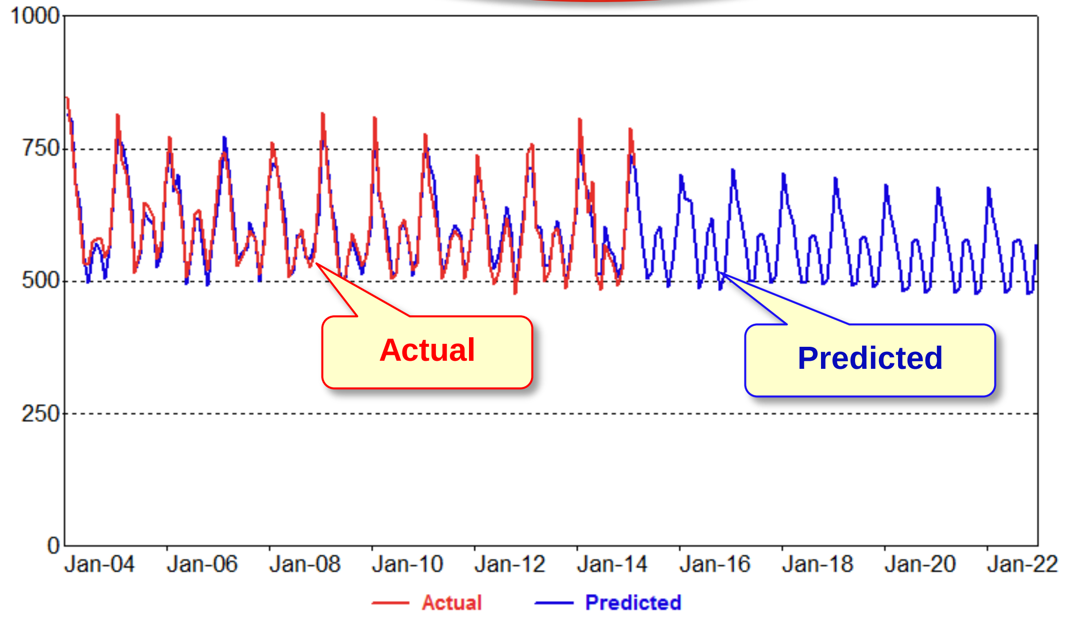
RESIDENTIAL AVERAGE USE MODEL RESULTS

Variable	Coefficient	StdErr	T-Stat	P-Value
mStructRev.XHeat	1.053	0.032	33.414	0.00%
mStructRev.XCool	2.970	0.156	19.009	0.00%
mStructRev.XOther	0.953	0.010	98.741	0.00%

If end-use estimates are accurate then SAE coefficients will be close to 1.0.

Indicates we are underestimating cooling load

Model Statistics	
Iterations	11
Adjusted Observations	133
Deg. of Freedom for Error	120
R-Squared	0.970
Adjusted R-Squared	0.968
AIC	5.523
BIC	5.806
F-Statistic	#NA
Prob (F-Statistic)	#NA
Log-Likelihood	-543.01
Model Sum of Squares	901,061.40
Sum of Squared Errors	27,394.11
Mean Squared Error	228.28
Std. Error of Regression	15.11
Mean Abs. Dev. (MAD)	11.45
Mean Abs. % Err. (MAPE)	1.90%
Durbin-Watson Statistic	2.055

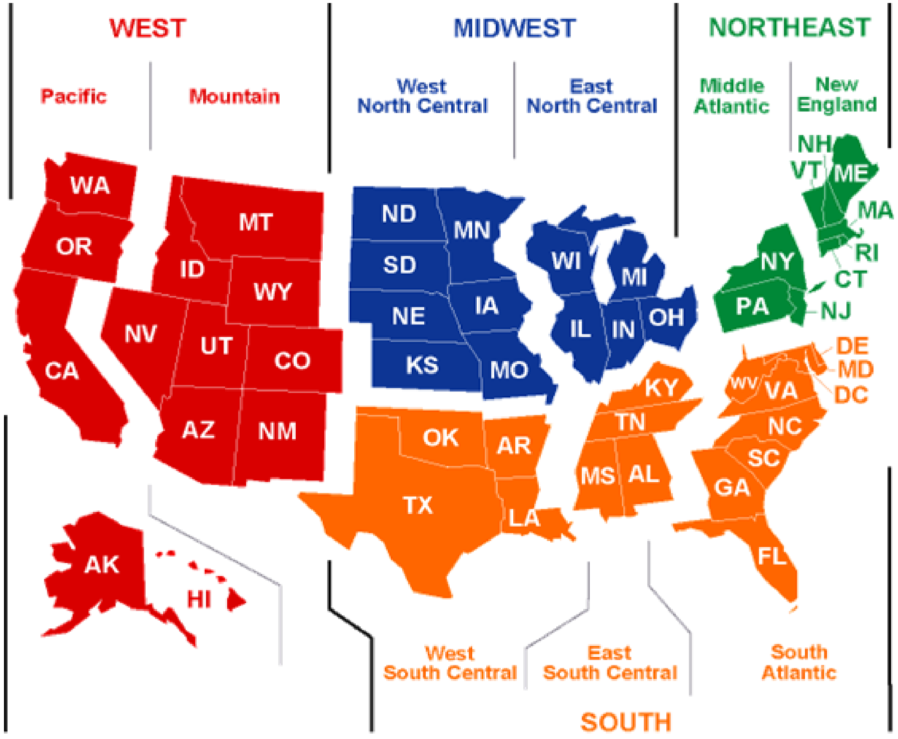


WHERE DO THE INTENSITIES COME FROM?

» The Energy Information Administration develops a detail end-use forecast for nine US census divisions

» Each year, we mine the forecast database for:

- Number of households
- Number of appliances
- End-use consumption
- End-use saturations
- End-use average stock efficiency

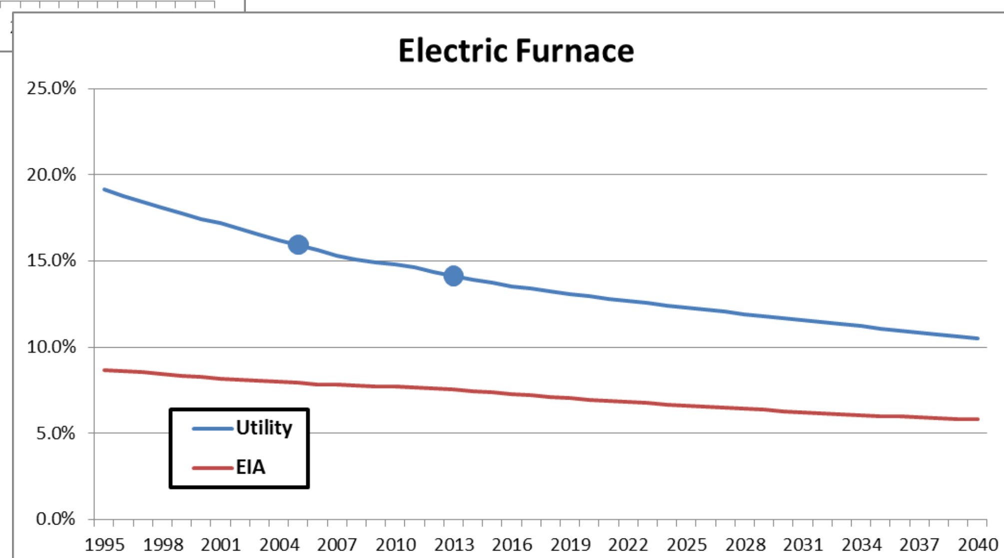


Data is translated into model intensity Variables in SAE spreadsheets that are compatible with MetrixND

SERVICE AREAS DON'T ALWAYS LOOK LIKE THE CENSUS DIVISION

<u>Clothes Washers</u>

- Calibrate shares to a survey
- Use EIA growth



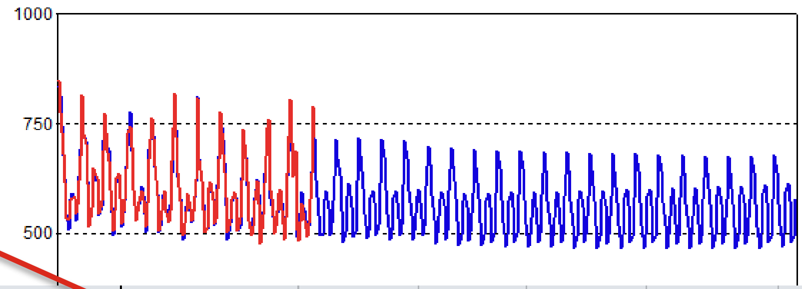
<u>Electric Furnace</u>

- Calibrate shares to a surveys
- Apply interpolated growth rates to obtain a smooth trajectory

CALIBRATE TO SERVICE AREA USAGE

Variable	Coefficient	StdErr	T-Stat
mStructRev.XHeat	0.940	0.037	25.410
mStructRev.XCool	2.263	0.172	13.187
mStructRev.XOther	1.019	0.014	72.247

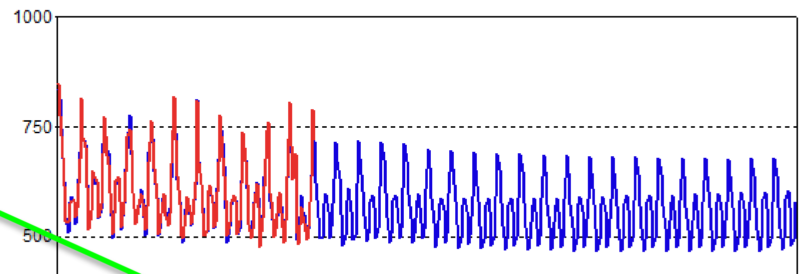
Mean Abs. Dev. (MAD)	10.67
Mean Abs. % Err. (MAPE)	1.74%
Durbin-Watson Statistic	2.165



Base Year (2009)	EFurn	HPHeat	GHPHeat	SecHt	CAC	HPCool	GHPCool	RAC
Consumption (mmBtu)	4,775,536	39,122	32,414	3,102,096	1,988,768	9,473	10,848	2,382,854
Equipment Stock (units)	429,639	6,705	6,603	1,379,313	1,052,425	6,705	6,603	6,095,292
UEC (kWh/unit)	3,258	1,710	1,439	659	554	414	482	115
Share (%)	14.9%	0.1%	0.1%	19.8%	12.0%	0.1%	0.1%	53.0%
Raw Intensity (kWh/year)	485	2	2	131	66	1	1	61
Observed Use Per Customer (kWh/year)	7,142							
Adjustment Factor	0.823							
Adjusted Intensity (kWh/year)	399	2	2	107	55	0	1	50

Variable	Coefficient	StdErr	T-Stat
mStructRev.XHeat	0.943	0.037	25.619
mStructRev.XCool	1.151	0.086	13.343
mStructRev.XOther	1.017	0.014	72.369

Mean Abs. Dev. (MAD)	10.58
Mean Abs. % Err. (MAPE)	1.73%
Durbin-Watson Statistic	2.188



Base Year (2009)	EFurn	HPHeat	GHPHeat	SecHt	CAC	HPCool	GHPCool	RAC
Consumption (mmBtu)	4,775,536	39,122	32,414	3,102,096	1,988,768	9,473	10,848	2,382,854
Equipment Stock (units)	429,639	6,705	6,603	1,379,313	1,052,425	6,705	6,603	6,095,292
UEC (kWh/unit)	3,258	1,710	1,439	659	554	414	482	115
Share (%)	14.9%	0.1%	0.1%	19.8%	12.0%	0.1%	0.1%	53.0%
Raw Intensity (kWh/year)	485	2	2	131	66	1	1	61
Observed Use Per Customer (kWh/year)	7,142							
Adjustment Factor	0.823							
Adjusted Intensity (kWh/year)	399	2	2	107	109	0	1	100

RESIDENTIAL SAE SPREADSHEET

SAE spreadsheets are updated after the AEO forecast is released

- *Definitions*: Lists end-uses and measurement units
- *EIA Data*: Raw EIA input data
- *Calibration*: Define base-year parameters (2009), calibrate intensities to service area
- *StructuralVars*: average square footage and thermal shell improvement indices
- *Shares*: end-use saturations (units / households)
- *Efficiency*: average stock efficiency (measured in specific tech definitions such as SEER, or approximated using UEC
- I*ntensities*: calculated end-use intensities from saturations and efficiency (model inputs)

SAE MODEL DECOMPOSITION

$$AvgUse_m = a + b_c \times XCool_m + b_h \times XHeat_m + b_o \times XOther_m + e_m$$

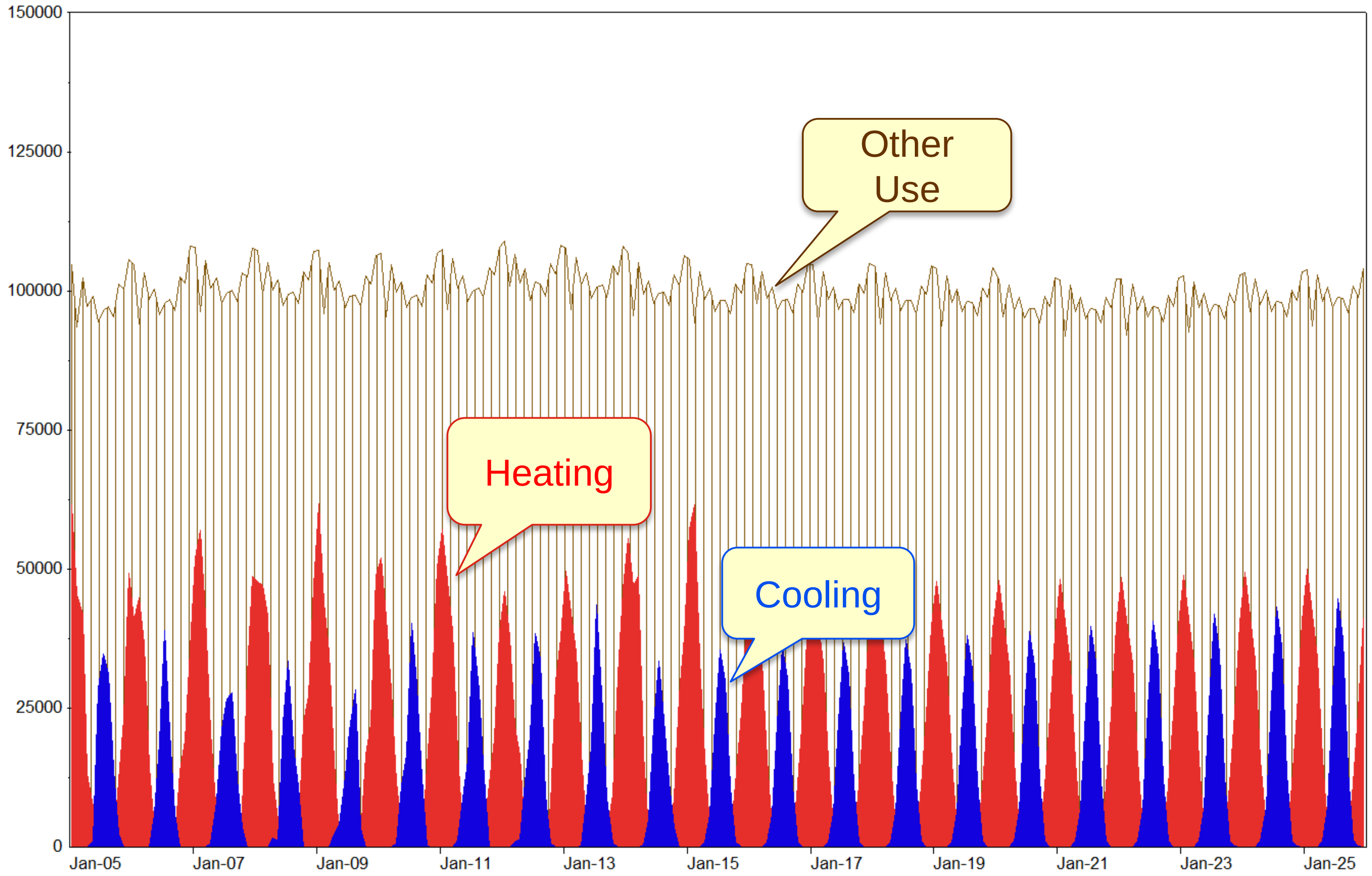
» Given estimates for b_c, b_h, and b_o, we can estimate average cooling, heating, and other use

$$CoolUse_m = b_c \times XCool_m$$

$$HeatUse_m = b_h \times XHeat_m$$

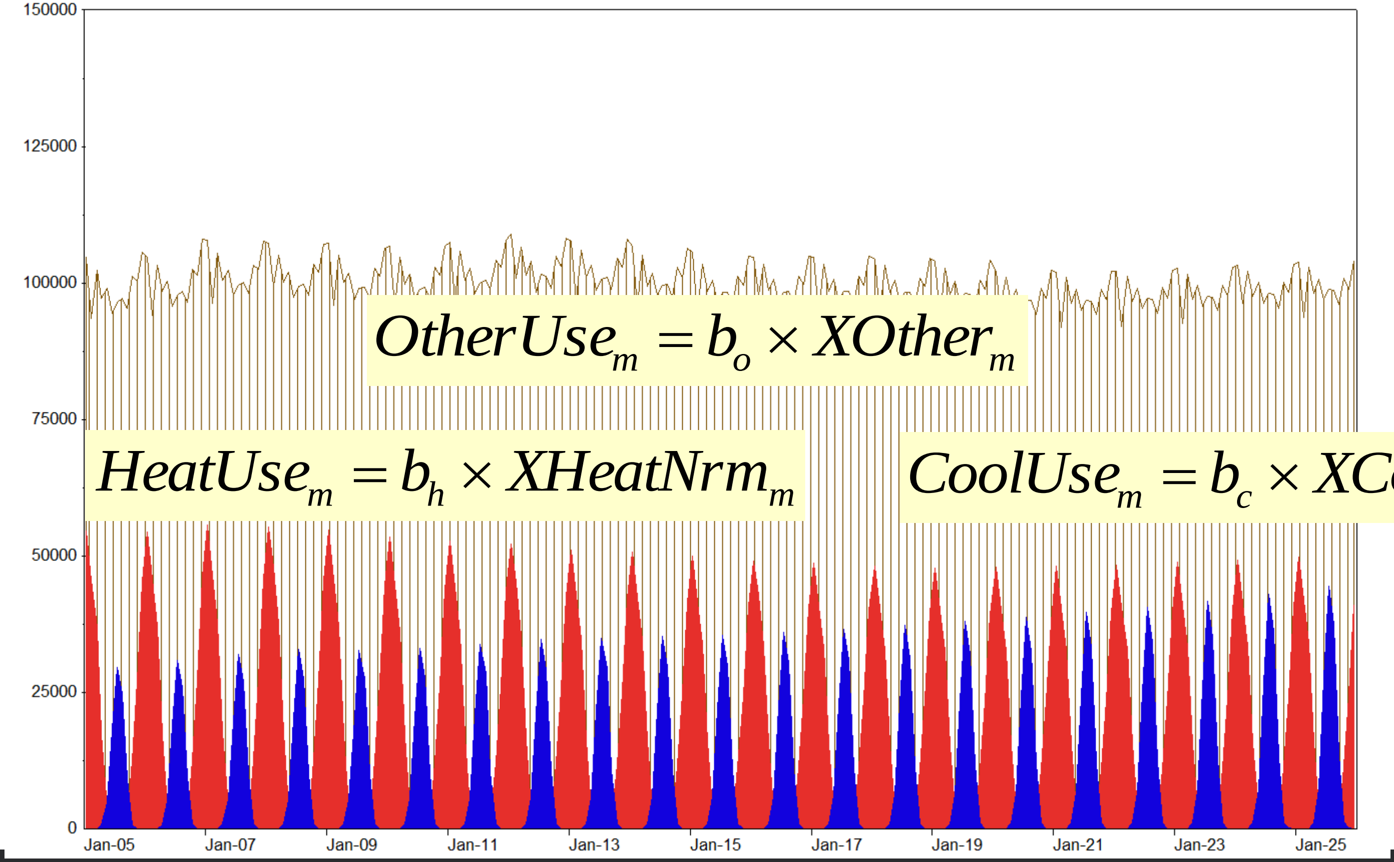
$$OtherUse_m = b_o \times XOther_m$$

VERMONT END-USE SALES ESTIMATES (MWH)



ESTIMATING SALES FOR NORMAL WEATHER

- » Why would you want to estimate historical and forecasted sales for normal weather
- » If cooling use is increasing faster than base-use, what would this imply for peak demand growth vs. energy growth ?

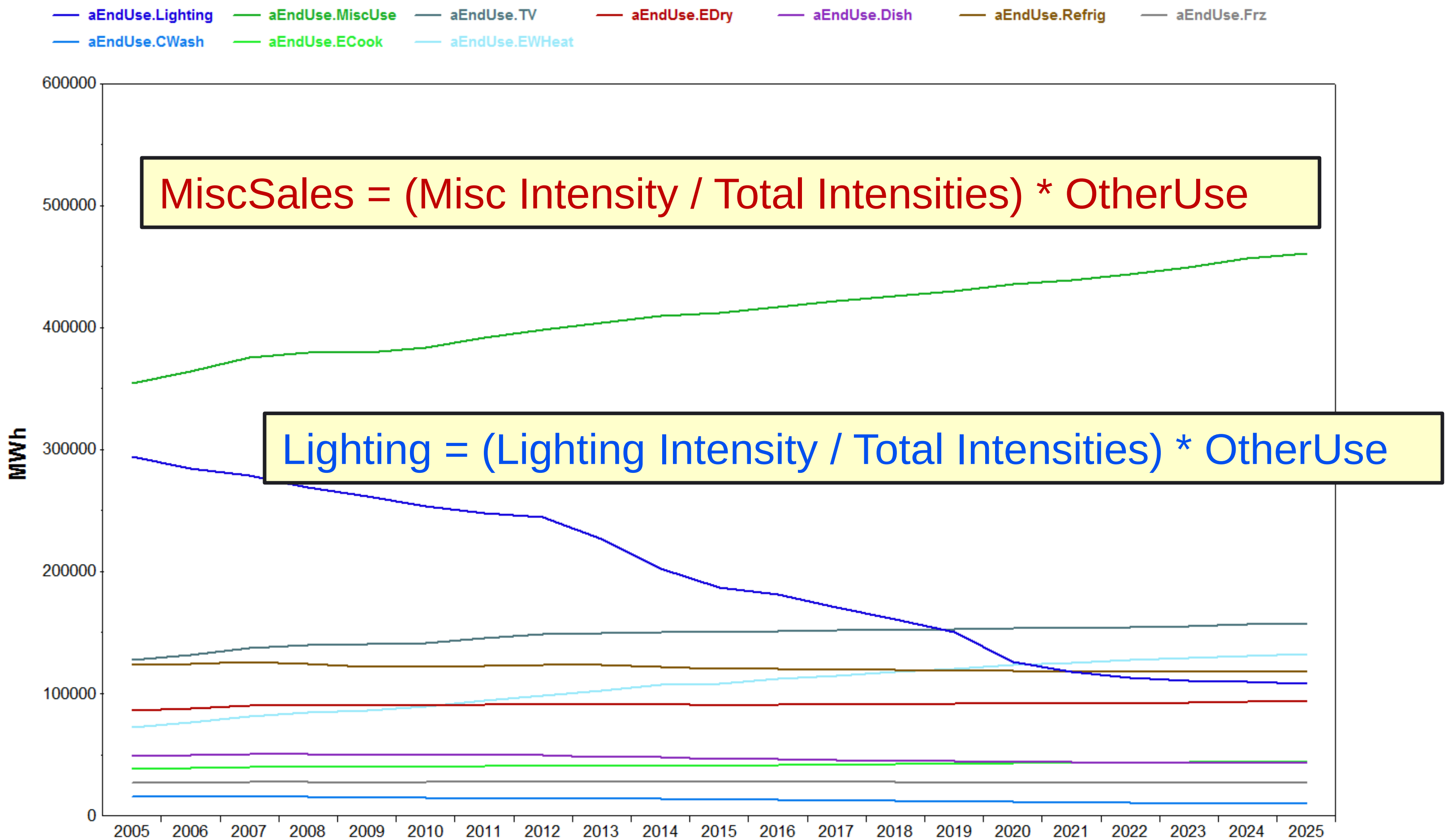


$$OtherUse_m = b_o \times XOther_m$$

$$HeatUse_m = b_h \times XHeatNrm_m$$

$$CoolUse_m = b_c \times XCoolNrm_m$$

WE CAN FURTHER BREAK OUT OTHER USE TO END-USES



SAE MODEL SPECIFICATION CONCLUSIONS

- The model specification works well in explaining historical sales trends. Generally we get strong statistical fits.
- By imposing model structure (elasticities), we can capture the appropriate impacts of changes in economic conditions.
- Appliance saturation and efficiency trends are embedded in the model structure.
  - Integrates end-use structural indices that will withstand scrutiny in a regulatory environment
  - Allows us to decompose the monthly and annual forecasts into the primary end-use components

SAE MODEL SPECIFICATION CONCLUSIONS

» The SAE modeling approach allows us to develop forecast scenarios for alternative economic assumptions, prices, and appliance saturation and efficiency trends.

» SAE models are significantly easier to maintain and update than traditional end-use models

» We can use the SAE model to isolate end-use sales for peak forecasting and evaluating EE programs

» By design, the SAE model "calibrates" into actual sales. We can use the same model for forecasting both short-term and long-term energy requirements.