## APPENDIX M: REVISED UTILITY IMPACTS ANALYSIS AND ENVIRONMENTAL ASSESSMENT

### M.1 INTRODUCTION

As described in the Utility Impacts Analysis chapter (Chapter 11) of the Technical Support Document (TSD) and the Environmental Assessment (EA), a variant of the Department of Energy, Energy Information Administration's (DOE/EIA) National Energy Modeling System (NEMS), called NEMS-BRS[a] (BRS is DOE's Building Research and Standards office) is used to conduct both the utility impacts analysis and environmental assessment. NEMS was used by DOE/EIA to produce the *2000 Annual Energy Outlook (AEO200)*[1],and NEMS-BRS is used to provide some key equivalent inputs to the standards analysis.

The purpose of the utility impacts analysis is to assess the impact of each central air conditioner and heat pump trial standard level on electric utilities. The impact of efficiency standards on utilities is assessed by reporting several key industry parameters, notably energy sales, generation, and capacity.

The primary focus of the EA is the effect of efficiency standards on air resources. For each of the trial standard levels, total power sector emissions are calculated based on output from NEMS-BRS. The EA considers only two pollutants, nitrogen oxides ($NO_x$) and sulfur dioxide ($SO_2$), and one emission, carbon (C). Because emissions of $SO_2$ from power plants are capped by clean air legislation, physical emissions of this pollutant from electricity generation will be only minimally affected by possible air conditioner and heat pump standards. The maximum $SO_2$ allowed by law will most likely still be produced, but because $SO_2$ emissions are traded, and if $SO_2$ emissions are lowered due to less power generation, then the cost of $SO_2$ emission credits may decrease slightly. Therefore, the EA does not consider changes in power sector $SO_2$ emissions, although it does report household emissions savings. The only form of carbon tracked by NEMS-BRS is carbon dioxide ($CO_2$), so the carbon discussed in this analysis is only in the form of $CO_2$, but is reported as mass of elemental carbon, in keeping with standard practice.

For details on how the Utility Impacts Analysis was conducted refer to Chapter 11 and Appendix H of the TSD. Details on how the Environmental Assessment was conducted can be found in a separate document.[2]

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[a] For more information on NEMS, please refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview 200*0, DOE/EIA-0581(2000), March 2000. DOE/EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because our analysis entails some minor code modifications and the model is run under policy scenarios that are variations on DOE/EIA assumptions, the name NEMS-BRS refers to the model as used here (BRS is DOE's Building Research and Standards office, under whose aegis this work has been performed).

## M.2 REASON FOR REVISING ANALYSES

After the completion of the prior utility impacts analysis and environmental assessment for central air conditioner and heat pump standards, DOE determined that there were a number of apparent problems associated with the specific load shapes used in NEMS[b]. As a result, DOE conducted a comprehensive review of the end-use load shapes used by NEMS for all sectors, including the residential, commercial, industrial, and transportation sectors. The apparent problems associated with the load shapes were confirmed by the review and an alternative set of end-use load shapes were constructed for all of the sectors.[3]

In the case of the residential air-conditioning (i.e. space-cooling) end-use, the alternative load shapes are distinctly different than the load shapes used in the 2000 version of NEMS. Figure M.1 shows the hourly load shapes for each month as provided in the 2000 version of NEMS.[4] Note the non-representativeness of the load shapes as the peakday occured in October and the loads in typical winter months (such as January and February) were greater than those in typical summer months (such as June and July). Since the residential air-conditioning end-use load shapes were aggregated to the National level, no information on regional variations was made available.

The alternative set of end-use load shapes explicitly address regional variations by providing a different set of load shapes for each of the thirteen regions represented in NEMS. The alternative load shapes for the residential sector, air-conditioning end-use are believed to be much more representative than those used in the 2000 version of NEMS.[5] Figures M.2a and M.2b, respectively, depict hourly load shapes for a typical "north" and for a typical "south" region. Note that the peak hours occur in the afternoon and early evening, consistent with air conditioning usage, and that peak days now occur in what are typically the hottest months of the year (July and August) with very little load allocated to the winter months.

While the use of alternative residential air conditioning load shapes shift the load to a more appropriate time of the year (i.e., the summer months), the overall magnitude of the alternative loads is less than that of the loads used in the 2000 version of NEMS. The use of the entire set of new alternative load shapes for all the other sectoral end-uses results in smaller peak-to-average system loads. Table M.1 compares the peak-to-average load ratios for the new alternative sectoral load shapes with that of the sectoral load shapes used in the 2000 version of NEMS, for each of the 13 utility regions (as defined by the North American Electric Reliability Council (NERC).[6] Note that for all sectors and for all regions, the peak-to-average loads are less than those from the 2000 version of NEMS. This results in overall built-up system load shapes that have less pronounced peaks. By incorporating the new alternative load shapes in NEMS, less peaking capacity and less total capacity are projected. This in turn implies that reducing the energy use on a relatively peaky end-use like residential air-conditioning will have less of an impact on overall system capacity.

[b] End-uses in NEMS are characterized with 24-hour weekday, weekend, and peakday load shapes for each month. Thus, each end-use is characterized by a minimum of thirty-six 24-hour load shapes (three day types per month for twelve months). Those end-uses that are impacted by regional variations and building application, such as space-conditioning appliances, are characterized with additional load shapes. Regional load shapes in NEMS are based on the thirteen regions defined by the North American Electric Reliability Council (NERC).

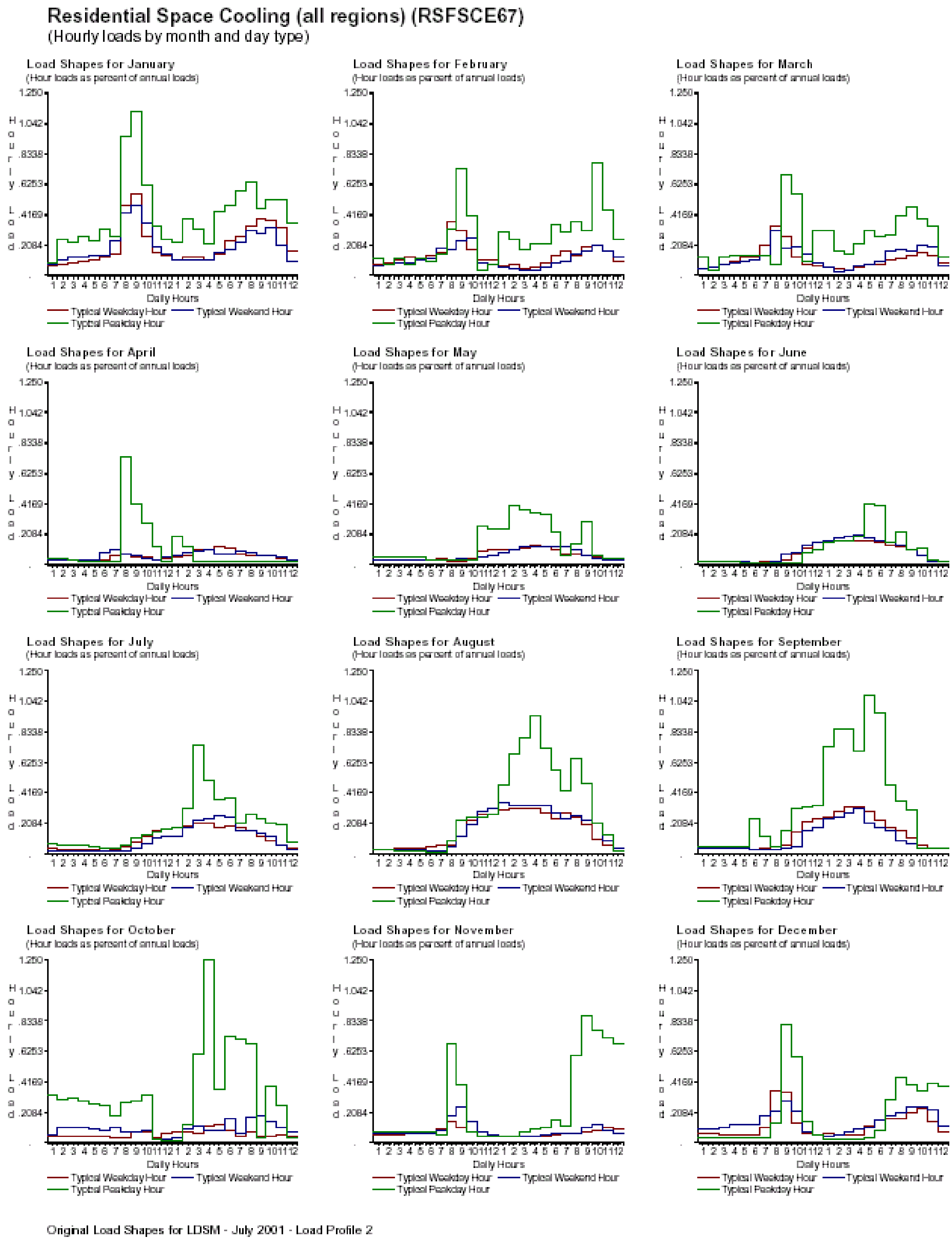


**Figure M.1 Residential Space-Cooling Load Shapes used in 2000 version of NEMS**

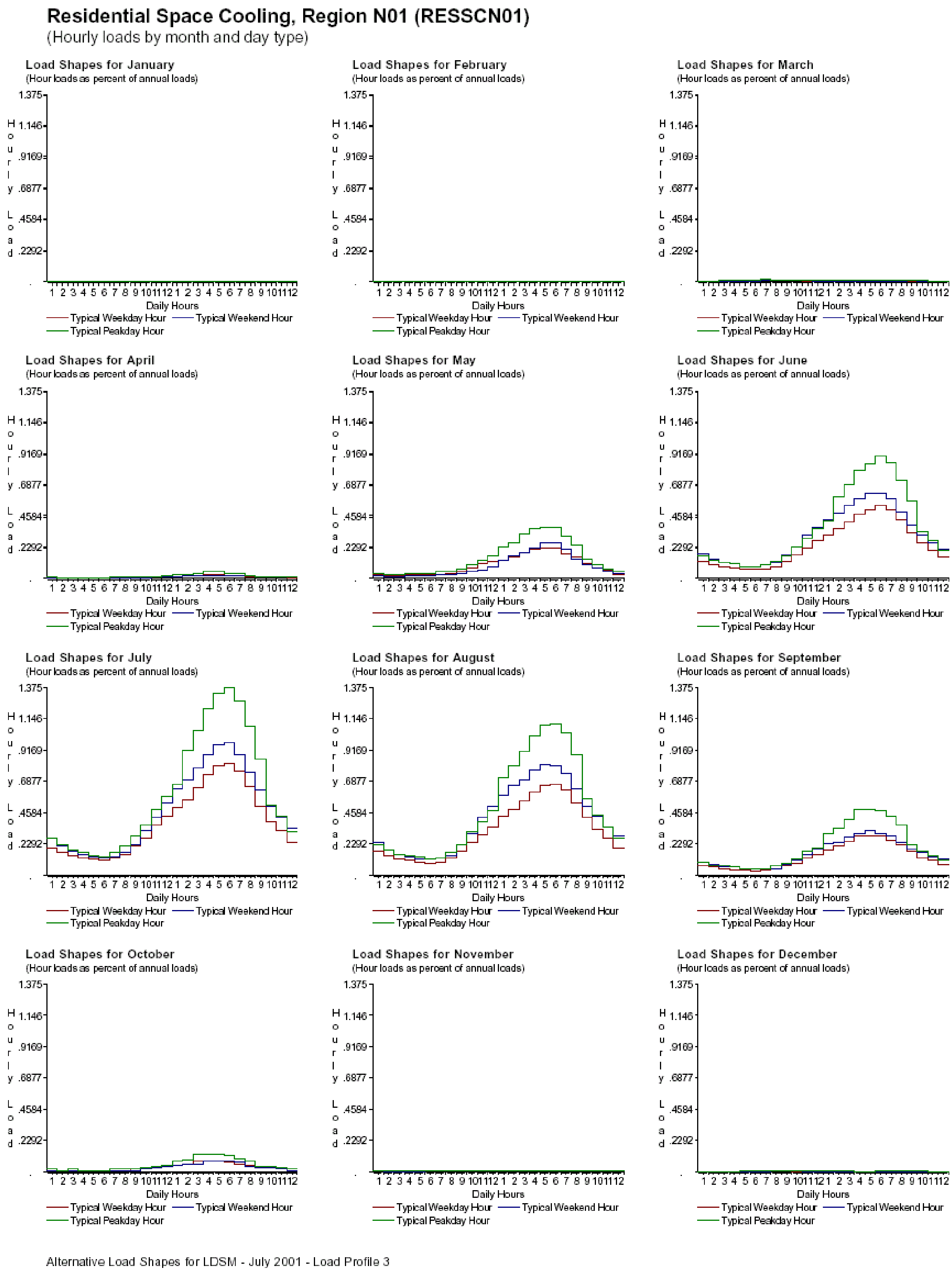


**Figure M.2a Alternative Residential Space-Cooling Load Shapes for the North Region**

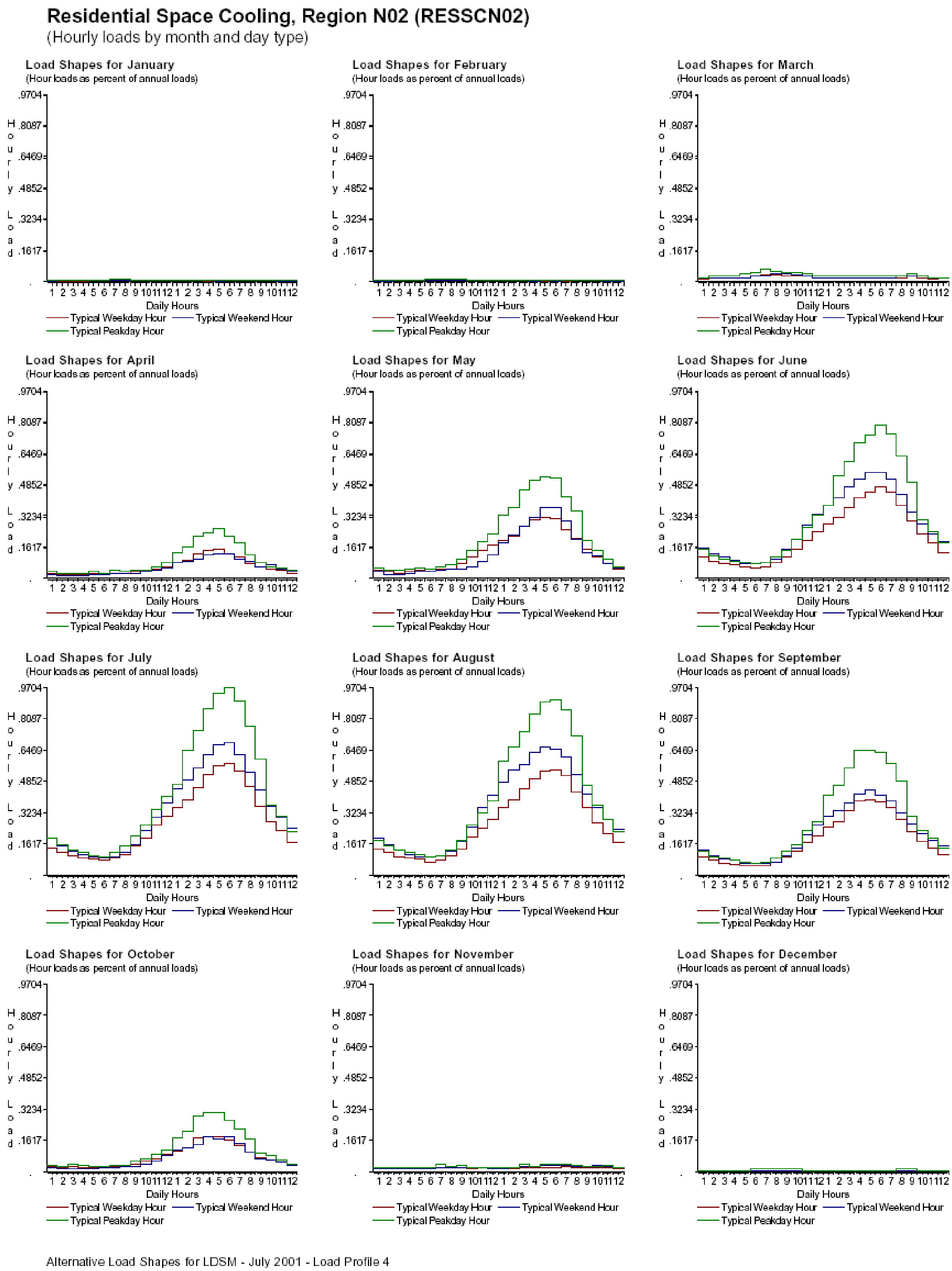


**Figure M.2b Alternative Residential Space-Cooling Load Shapes for the South Region**

**Table M.1 Peak-to-Average Load Ratios by Sector and Region: Current (NEMS 2000) Load Shapes versus New (Alternative) Load Shapes**

| NERC | Residential | | Commercial | | Industrial | | Transportation | | All Sectors | | Actual |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Region | Current | New | Current | New | Current | New | Current | New | Current | New | System |
| ECAR | 3.96 | 2.37 | 2.29 | 2.66 | 1.50 | 1.36 | 4.44 | 2.24 | 2.11 | 1.86 | 1.49 |
| ERCOT | 4.67 | 2.97 | 2.23 | 2.71 | 1.52 | 1.36 | 4.44 | 2.25 | 2.49 | 2.20 | 1.71 |
| MAAC | 4.08 | 2.27 | 3.21 | 2.68 | 1.52 | 1.37 | 4.44 | 2.24 | 2.21 | 2.04 | 1.62 |
| MAIN | 3.67 | 2.32 | 2.25 | 2.62 | 1.49 | 1.36 | 4.44 | 2.25 | 2.02 | 1.90 | 1.66 |
| MAPP | 3.89 | 2.49 | 2.12 | 2.58 | 1.49 | 1.36 | 4.44 | 2.25 | 2.20 | 1.89 | 1.62 |
| NY | 3.80 | 2.07 | 2.85 | 2.63 | 1.53 | 1.38 | 4.44 | 2.25 | 2.14 | 2.00 | 1.56 |
| NE | 3.74 | 2.13 | 2.55 | 2.55 | 1.53 | 1.38 | 4.44 | 2.24 | 2.15 | 1.79 | 1.51 |
| FL | 5.00 | 2.39 | 3.75 | 2.57 | 1.49 | 1.36 | 4.44 | 2.24 | 3.09 | 2.21 | 1.63 |
| STV | 5.06 | 2.52 | 2.44 | 2.64 | 1.51 | 1.36 | 4.44 | 2.24 | 2.66 | 1.99 | 1.59 |
| SPP | 4.31 | 2.90 | 2.31 | 2.73 | 1.51 | 1.36 | 4.44 | 2.25 | 2.29 | 2.20 | 1.78 |
| NWP | 4.75 | 2.03 | 2.16 | 2.56 | 1.54 | 1.38 | 4.44 | 2.25 | 2.44 | 1.67 | 1.44 |
| RA | 3.96 | 2.25 | 2.27 | 2.71 | 1.54 | 1.38 | 4.44 | 2.25 | 2.25 | 2.03 | 1.61 |
| CNV | 5.16 | 2.07 | 2.16 | 2.48 | 1.54 | 1.38 | 4.44 | 2.25 | 2.47 | 1.72 | 1.59 |

## M.3 REVISED RESULTS

New NEMS-BRS standards case runs were conducted with the entire set of alternative sectoral end-use load shapes (which included the alternative residential air-conditioning load shapes) to demonstrate their impact on system capacity. These new runs were conducted with the 2000 version of NEMS-BRS but with its existing set of sectoral load shapes replaced with the alternative versions.

For reasons stated in Chapter 8 of the TSD (See Section 8.4.8), it is assumed that the NAECA *efficiency scenario* is the most probable for Trial Standard Levels 1, 2, and 3 while the Roll-up *efficiency scenario* is the most probable for Trial Standards Levels 4 and 5. (Refer to Chapter 7, Section 7.2.2.5 of the TSD for the current efficiency distribution for each product class and for the assumed efficiency distributions after new standards under the NAECA and Roll-up *efficiency scenarios*.) As a result, revised utility and environmental impacts were generated only for the above most probable Trial Standard Level and *efficiency scenario* combinations. Also, all results were generated compared to the published *AEO2000* Reference Case. The revised utility analysis, which assumed the Reverse Engineering manufacturer cost scenario, updates the utility impacts described in the TSD, Appendix J, Tables 11.2S to 11.4S and Table 11.8S.

### M.3.1 Revised Utility Impact Results

Table M.2 shows the results from the NEMS-BRS Reference Case (i.e., without new efficiency standards) run with the alternative sectoral load shapes. Table M.2 also provides the differences between the new run and the existing NEMS-BRS Reference Case run (i.e., without the alternative load shapes). (Refer to Chapter 11, Table 11.1 for the NEMS-BRS results that are comparable to the published *AEO2000* Reference Case.) The effect of changing to the new alternative sectoral load shapes leads to lower overall projected peak demands in years after 2010. By the year 2020, a total of 15 GW less installed capacity is required. Also of note is the effect of the new alternative load shapes on the fuel types in the mix of generating capacity. Although nine additional GW of coal-fired capacity are required, 24 GW less of other fossil-fuel capacity are needed. This change in the mix of generation is intuitively consistent with the effect that the new alternative load shapes should have on the overall system load. Since the new alternative load shapes reduce the peak-to-average load ratios (i.e., flatten out the system load), more base load capacity should be needed (as confirmed by the increase in coal-fired capacity of 9 GW) and less peak load capacity should be required (as confirmed by the decrease in other fossil-fuel capacity of 24 GW).

#### M.3.1.1 Central Air Conditioner and Heat Pump Standard Level Results

Forecast of the impacts of central air conditioner standards on are presented in Tables M.3 through M.7, respectively, for Trial Standard Level 1 through Trial Standard Level 5, assuming Reverse Engineering manufacturing costs. Each table shows forecasts using interpolated results as described in Chapter 11, Section 11.4 of the TSD for residential energy sales and total U.S. electric generation and installed capacity. Most standards result in similar effects on electric and gas utilities, although the magnitude of the effects varies according to the level of forecast energy savings. When electricity savings dominate, gas-fired generation is somewhat more affected than coal-fired generation, especially in the earlier years of the forecast. This effect reflects the more load-following role of gas-fired generation overall.

For each of the five standard levels, residential energy sales fall compared to the *AEO2000* Reference Case *with* the alternative load shapes. The decrease in sales is proportional to the amount of energy that the NES model predicts will be saved by each standard level, ranging from just over 0.9% (Standard Level 1) to 4.9% (Standard Level 5) of total residential electricity sales in the peak savings year reported (2020). For each standard level, total U.S. electric generation decreases relative to the *AEO2000* plus alternative load shape baseline, by just under 1.6% in the peak year (2020) of the maximum savings case for Trial Standard Level 5 to 0.3% under Trial Standard Level 1. Total installed capacity is also reduced in each standard level scenario, by a maximum of just under 2.3% (Standard Level 5) in 2020. About 84% of the capacity reduction is in natural gas fired capacity, in this case, reflecting the peaking nature of air conditioning use.

**Table M.2 NEMS-BRS Results with Alternative Load Shapes**

| NEMS-BRS Results with Alternative Load Shapes: AEO 2000 Reference Case | | | | | | Difference from AEO2000 Reference Case without Alternative Load Shapes | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2000** | **2005** | **2010** | **2015** | **2020** | | **2000** | **2005** | **2010** | **2015** | **2020** |
| *Residential Sector Energy Consumption* | | | | | | *Residential Sector Energy Consumption* | | | | | |
| Electricity Sales (TWh) | 1,186 | 1,284 | 1,384 | 1,472 | 1,562 | Electricity Sales (TWh) | 1 | 3 | 5 | 8 | 9 |
| Natural Gas (EJ) | 5.32 | 5.50 | 5.75 | 5.96 | 6.19 | Natural Gas (EJ) | 0 | 0 | 0 | 0 | 0 |
| Other (EJ) | 1.96 | 1.91 | 1.84 | 1.78 | 1.74 | Other (EJ) | 0 | 0 | 0 | 0 | 0 |
| Natural Gas (Quads) | 5.04 | 5.21 | 5.45 | 5.65 | 5.87 | Natural Gas (Quads) | 0 | 0 | 0 | 0 | 0 |
| Other (Quads) | 1.86 | 1.81 | 1.74 | 1.69 | 1.65 | Other (Quads) | 0 | 0 | 0 | 0 | 0 |
| *Total U.S. Electric Generation* | | | | | | *Total U.S. Electric Generation* | | | | | |
| Coal (TWh) | 1,912 | 2,120 | 2,173 | 2,280 | 2,405 | Coal (TWh) | -18 | -7 | 1 | 29 | 58 |
| Gas (TWh) | 616 | 726 | 999 | 1,264 | 1,419 | Gas (TWh) | 15 | 9 | -2 | -33 | -57 |
| Petroleum (TWh) | 86 | 58 | 51 | 49 | 45 | Petroleum (TWh) | -4 | -10 | -3 | 2 | 1 |
| Nuclear (TWh) | 688 | 674 | 627 | 511 | 427 | Nuclear (TWh) | 0 | 0 | 0 | 0 | 0 |
| Renewables (TWh) | 389 | 410 | 427 | 438 | 448 | Renewables (TWh) | 0 | -1 | -2 | 1 | 1 |
| Total (TWh) | 3,691 | 3,988 | 4,277 | 4,542 | 4,744 | Total (TWh) | -7 | -9 | -6 | -1 | 3 |
| *Installed Generating Capacity* | | | | | | *Installed Generating Capacity* | | | | | |
| Coal (GW) | 315.3 | 311.2 | 310.8 | 320.5 | 335.1 | Coal (GW) | 0 | 1 | 0 | 5 | 9 |
| Other Fossil (GW) | 292.4 | 346.4 | 403.1 | 444.6 | 483.4 | Other Fossil (GW) | 18 | 12 | -2 | -17 | -24 |
| Nuclear (GW) | 97.5 | 93.4 | 84.1 | 67.4 | 57.0 | Nuclear (GW) | 0 | 0 | 0 | 0 | 0 |
| Renewables (GW) | 94.7 | 98.5 | 101.7 | 103.8 | 105.7 | Renewables (GW) | 0 | 0 | 0 | 0 | 0 |
| Total (GW) | 799.9 | 849.5 | 899.7 | 936.3 | 981.2 | Total (GW) | 18 | 13 | -2 | -13 | -15 |

**Table M.3 Standard Level 1 Forecast, NAECA Efficiency Scenario**

| NEMS-BRS Results: | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| *Residential Sector Energy Consumption* | | | | | |
| Electricity Sales (TWh) | 1,186 | 1,284 | 1,380 | 1,462 | 1,548 |
| Natural Gas (EJ) | 5.32 | 5.50 | 5.75 | 5.96 | 6.19 |
| Other (EJ) | 1.96 | 1.91 | 1.84 | 1.78 | 1.74 |
| Natural Gas (Quads) | 5.04 | 5.21 | 5.45 | 5.65 | 5.87 |
| Other (Quads) | 1.86 | 1.81 | 1.74 | 1.69 | 1.65 |
| *Total U.S. Electric Generation* | | | | | |
| Coal (TWh) | 1,912 | 2,120 | 2,172 | 2,277 | 2,399 |
| Gas (TWh) | 616 | 726 | 996 | 1,257 | 1,410 |
| Petroleum (TWh) | 86 | 58 | 50 | 48 | 45 |
| Nuclear (TWh) | 688 | 674 | 627 | 511 | 427 |
| Renewables (TWh) | 389 | 410 | 427 | 438 | 448 |
| Total (TWh) | 3,691 | 3,988 | 4,273 | 4,532 | 4,728 |
| *Installed Generating Capacity* | | | | | |
| Coal (GW) | 315.3 | 311.2 | 310.8 | 320.3 | 334.4 |
| Other Fossil (GW) | 292.3 | 346.4 | 403.0 | 442.5 | 479.7 |
| Nuclear (GW) | 97.5 | 93.4 | 84.1 | 67.4 | 57.0 |
| Renewables (GW) | 94.7 | 98.5 | 101.7 | 103.8 | 105.7 |
| Total (GW) | 799.8 | 849.4 | 899.6 | 933.9 | 976.8 |

| Difference from AEO2k Ref Using AEO2002 Loads | | | | | | Extrapolation | |
|---|---|---|---|---|---|---|---|
| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
| *Residential Sector Energy Consumption* | | | | | | | |
| Electricity Sales (TWh) | 0.0 | 0.0 | -4.3 | -9.8 | -14.4 | -17.5 | -19.5 |
| Natural Gas (EJ) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other (EJ) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Natural Gas (Quads) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other (Quads) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *Total U.S. Electric Generation* | | | | | | | |
| Coal (TWh) | 0.1 | 0.0 | -0.8 | -2.5 | -5.8 | -5.8 | -5.8 |
| Gas (TWh) | -0.1 | 0.0 | -2.9 | -6.9 | -9.5 | -9.5 | -9.5 |
| Petroleum (TWh) | 0.0 | 0.0 | -0.5 | -0.5 | -0.3 | -0.3 | -0.3 |
| Nuclear (TWh) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Renewables (TWh) | 0.0 | 0.0 | 0.0 | 0.0 | -0.1 | -0.1 | -0.1 |
| Total (TWh) | 0.0 | 0.0 | -4.1 | -9.9 | -15.6 | -15.6 | -15.6 |
| *Installed Generating Capacity* | | | | | | | |
| Coal (GW) | 0.0 | 0.0 | 0.0 | -0.2 | -0.7 | -0.7 | -0.7 |
| Other Fossil (GW) | -0.1 | 0.0 | -0.1 | -2.1 | -3.7 | -3.7 | -3.7 |
| Nuclear (GW) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Renewables (GW) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total (GW) | -0.1 | -0.1 | -0.1 | -2.4 | -4.4 | -4.4 | -4.4 |

## Table M.4 Standard Level 2 Forecast, NAECA Efficiency Scenario

| NEMS-BRS Results: | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| *Residential Sector Energy Consumption* | | | | | |
| Electricity Sales (TWh) | 1,186 | 1,284 | 1,376 | 1,455 | 1,536 |
| Natural Gas (EJ) | 5.32 | 5.50 | 5.75 | 5.96 | 6.19 |
| Other (EJ) | 1.96 | 1.91 | 1.84 | 1.78 | 1.74 |
| Natural Gas (Quads) | 5.04 | 5.21 | 5.45 | 5.65 | 5.87 |
| Other (Quads) | 1.86 | 1.81 | 1.74 | 1.69 | 1.65 |
| | | | | | |
| *Total U.S. Electric Generation* | | | | | |
| Coal (TWh) | 1,912 | 2,120 | 2,172 | 2,277 | 2,396 |
| Gas (TWh) | 616 | 726 | 994 | 1,252 | 1,402 |
| Petroleum (TWh) | 86 | 58 | 50 | 48 | 45 |
| Nuclear (TWh) | 688 | 674 | 627 | 511 | 427 |
| Renewables (TWh) | 389 | 410 | 427 | 438 | 448 |
| Total (TWh) | 3,691 | 3,988 | 4,270 | 4,526 | 4,718 |
| | | | | | |
| *Installed Generating Capacity* | | | | | |
| Coal (GW) | 315.3 | 311.2 | 310.8 | 320.1 | 333.9 |
| Other Fossil (GW) | 292.4 | 346.4 | 402.9 | 440.3 | 476.0 |
| Nuclear (GW) | 97.5 | 93.4 | 84.1 | 67.4 | 57.0 |
| Renewables (GW) | 94.7 | 98.5 | 101.7 | 103.8 | 105.7 |
| Total (GW) | 799.9 | 849.5 | 899.5 | 931.6 | 972.5 |

| Difference from AEO2k Ref Using AEO2002 Loads | | | | | | Extrapolation | |
|---|---|---|---|---|---|---|---|
| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
| *Residential Sector Energy Consumption* | | | | | | | |
| Electricity Sales (TWh) | 0.0 | 0.0 | -7.6 | -17.3 | -25.6 | -31.0 | -34.6 |
| Natural Gas (EJ) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other (EJ) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Natural Gas (Quads) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other (Quads) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | |
| *Total U.S. Electric Generation* | | | | | | | |
| Coal (TWh) | 0.0 | 0.0 | -1.0 | -3.3 | -8.6 | -8.6 | -8.6 |
| Gas (TWh) | 0.0 | 0.0 | -5.0 | -12.4 | -17.4 | -17.4 | -17.4 |
| Petroleum (TWh) | 0.0 | 0.0 | -0.8 | -0.6 | 0.1 | 0.1 | 0.1 |
| Nuclear (TWh) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Renewables (TWh) | 0.0 | 0.0 | 0.1 | -0.1 | -0.2 | -0.2 | -0.2 |
| Total (TWh) | 0.0 | 0.0 | -6.7 | -16.4 | -26.1 | -26.1 | -26.1 |
| | | | | | | | |
| *Installed Generating Capacity* | | | | | | | |
| Coal (GW) | 0.0 | 0.0 | 0.0 | -0.4 | -1.2 | -1.2 | -1.2 |
| Other Fossil (GW) | 0.0 | 0.0 | -0.2 | -4.3 | -7.4 | -7.4 | -7.4 |
| Nuclear (GW) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Renewables (GW) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total (GW) | 0.0 | 0.0 | -0.2 | -4.7 | -8.7 | -8.7 | -8.7 |

**Table M.5 Standard Level 3 Forecast, NAECA Efficiency Scenario**

| NEMS-BRS Results: | | | | | |
|---|---|---|---|---|---|
| | 2000 | 2005 | 2010 | 2015 | 2020 |
| *Residential Sector Energy Consumption* | | | | | |
| Electricity Sales (TWh) | 1,186 | 1,284 | 1,375 | 1,452 | 1,532 |
| Natural Gas (EJ) | 5.32 | 5.50 | 5.75 | 5.96 | 6.19 |
| Other (EJ) | 1.96 | 1.91 | 1.84 | 1.78 | 1.74 |
| Natural Gas (Quads) | 5.04 | 5.21 | 5.45 | 5.65 | 5.87 |
| Other (Quads) | 1.86 | 1.81 | 1.74 | 1.69 | 1.65 |
| *Total U.S. Electric Generation* | | | | | |
| Coal (TWh) | 1,912 | 2,120 | 2,172 | 2,276 | 2,395 |
| Gas (TWh) | 616 | 726 | 993 | 1,250 | 1,399 |
| Petroleum (TWh) | 86 | 58 | 50 | 48 | 45 |
| Nuclear (TWh) | 688 | 674 | 627 | 511 | 427 |
| Renewables (TWh) | 389 | 410 | 427 | 438 | 448 |
| Total (TWh) | 3,691 | 3,988 | 4,269 | 4,523 | 4,714 |
| *Installed Generating Capacity* | | | | | |
| Coal (GW) | 315.3 | 311.2 | 310.8 | 320.0 | 333.7 |
| Other Fossil (GW) | 292.4 | 346.4 | 402.9 | 439.6 | 474.8 |
| Nuclear (GW) | 97.5 | 93.4 | 84.1 | 67.4 | 57.0 |
| Renewables (GW) | 94.7 | 98.5 | 101.7 | 103.8 | 105.7 |
| Total (GW) | 799.9 | 849.5 | 899.5 | 930.8 | 971.1 |

| Difference from AEO2k Ref Using AEO2002 Loads | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | Extrapolation | |
| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
| *Residential Sector Energy Consumption* | | | | | | | |
| Electricity Sales (TWh) | 0.0 | 0.0 | -8.8 | -20.1 | -29.7 | -36.1 | -40.3 |
| Natural Gas (EJ) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other (EJ) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Natural Gas (Quads) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other (Quads) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *Total U.S. Electric Generation* | | | | | | | |
| Coal (TWh) | 0.0 | 0.0 | -1.2 | -3.9 | -10.0 | -10.0 | -10.0 |
| Gas (TWh) | 0.0 | 0.0 | -5.8 | -14.4 | -20.2 | -20.2 | -20.2 |
| Petroleum (TWh) | 0.0 | 0.0 | -0.9 | -0.7 | 0.1 | 0.1 | 0.1 |
| Nuclear (TWh) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Renewables (TWh) | 0.0 | 0.0 | 0.1 | -0.1 | -0.2 | -0.2 | -0.2 |
| Total (TWh) | 0.0 | 0.0 | -7.8 | -19.1 | -30.4 | -30.4 | -30.4 |
| *Installed Generating Capacity* | | | | | | | |
| Coal (GW) | 0.0 | 0.0 | 0.0 | -0.5 | -1.4 | -1.4 | -1.4 |
| Other Fossil (GW) | 0.0 | 0.0 | -0.2 | -5.0 | -8.6 | -8.6 | -8.6 |
| Nuclear (GW) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Renewables (GW) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total (GW) | 0.0 | 0.0 | -0.2 | -5.5 | -10.1 | -10.1 | -10.1 |

**Table M.6 Standard Level 4 Forecast, Roll-up Efficiency Scenario**

**NEMS-BRS Results:**

| | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| *Residential Sector Energy Consumption* | | | | | |
| Electricity Sales (TWh) | 1,186 | 1,284 | 1,373 | 1,448 | 1,526 |
| Natural Gas (EJ) | 5.32 | 5.50 | 5.75 | 5.96 | 6.19 |
| Other (EJ) | 1.96 | 1.91 | 1.84 | 1.78 | 1.74 |
| Natural Gas (Quads) | 5.04 | 5.21 | 5.45 | 5.65 | 5.87 |
| Other (Quads) | 1.86 | 1.81 | 1.74 | 1.69 | 1.65 |
| *Total U.S. Electric Generation* | | | | | |
| Coal (TWh) | 1,912 | 2,120 | 2,171 | 2,275 | 2,394 |
| Gas (TWh) | 616 | 726 | 993 | 1,247 | 1,394 |
| Petroleum (TWh) | 86 | 58 | 50 | 48 | 45 |
| Nuclear (TWh) | 688 | 674 | 627 | 511 | 427 |
| Renewables (TWh) | 389 | 410 | 427 | 438 | 448 |
| Total (TWh) | 3,691 | 3,988 | 4,268 | 4,519 | 4,708 |
| *Installed Generating Capacity* | | | | | |
| Coal (GW) | 315.3 | 311.2 | 310.8 | 319.9 | 333.4 |
| Other Fossil (GW) | 292.4 | 346.4 | 402.8 | 438.2 | 472.5 |
| Nuclear (GW) | 97.5 | 93.4 | 84.1 | 67.4 | 57.0 |
| Renewables (GW) | 94.7 | 98.5 | 101.7 | 103.8 | 105.7 |
| Total (GW) | 799.9 | 849.5 | 899.4 | 929.4 | 968.6 |

**Difference from AEO2k Ref Using AEO2002 Loads**

| | | | | | | Extrapolation | |
|---|---|---|---|---|---|---|---|
| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
| *Residential Sector Energy Consumption* | | | | | | | |
| Electricity Sales (TWh) | 0.0 | 0.0 | -10.6 | -24.2 | -35.8 | -43.6 | -48.7 |
| Natural Gas (EJ) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other (EJ) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Natural Gas (Quads) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other (Quads) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *Total U.S. Electric Generation* | | | | | | | |
| Coal (TWh) | 0.0 | 0.0 | -2.0 | -4.6 | -11.3 | -11.3 | -11.3 |
| Gas (TWh) | 0.0 | 0.0 | -6.4 | -17.3 | -25.1 | -25.1 | -25.1 |
| Petroleum (TWh) | 0.0 | 0.0 | -1.2 | -0.7 | 0.4 | 0.4 | 0.4 |
| Nuclear (TWh) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Renewables (TWh) | 0.0 | 0.0 | 0.2 | -0.3 | -0.3 | -0.3 | -0.3 |
| Total (TWh) | 0.0 | 0.0 | -9.4 | -22.8 | -36.4 | -36.4 | -36.4 |
| *Installed Generating Capacity* | | | | | | | |
| Coal (GW) | 0.0 | 0.0 | 0.0 | -0.6 | -1.7 | -1.7 | -1.7 |
| Other Fossil (GW) | 0.0 | 0.0 | -0.3 | -6.4 | -10.9 | -10.9 | -10.9 |
| Nuclear (GW) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Renewables (GW) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total (GW) | 0.0 | 0.0 | -0.3 | -6.9 | -12.6 | -12.6 | -12.6 |

**Table M.7 Standard Level 5 Forecast, Roll-up Efficiency Scenario**

**NEMS-BRS Results:**

| | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| *Residential Sector Energy Consumption* | | | | | |
| Electricity Sales (TWh) | 1,186 | 1,284 | 1,363 | 1,424 | 1,489 |
| Natural Gas (EJ) | 5.32 | 5.50 | 5.75 | 5.96 | 6.19 |
| Other (EJ) | 1.96 | 1.91 | 1.84 | 1.78 | 1.74 |
| Natural Gas (Quads) | 5.04 | 5.21 | 5.45 | 5.65 | 5.87 |
| Other (Quads) | 1.86 | 1.81 | 1.74 | 1.69 | 1.65 |
| *Total U.S. Electric Generation* | | | | | |
| Coal (TWh) | 1,912 | 2,120 | 2,170 | 2,270 | 2,379 |
| Gas (TWh) | 616 | 726 | 985 | 1,230 | 1,370 |
| Petroleum (TWh) | 86 | 58 | 49 | 46 | 44 |
| Nuclear (TWh) | 688 | 674 | 627 | 511 | 427 |
| Renewables (TWh) | 389 | 410 | 427 | 438 | 448 |
| Total (TWh) | 3,691 | 3,988 | 4,258 | 4,494 | 4,668 |
| *Installed Generating Capacity* | | | | | |
| Coal (GW) | 315.3 | 311.2 | 310.8 | 319.5 | 331.7 |
| Other Fossil (GW) | 292.4 | 346.4 | 402.5 | 434.1 | 464.9 |
| Nuclear (GW) | 97.5 | 93.4 | 84.1 | 67.4 | 57.0 |
| Renewables (GW) | 94.7 | 98.5 | 101.7 | 103.8 | 105.6 |
| Total (GW) | 799.9 | 849.5 | 899.1 | 924.8 | 959.3 |

**Difference from AEO2k Ref Using AEO2002 Loads**

| | | | | | | Extrapolation | |
|---|---|---|---|---|---|---|---|
| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
| *Residential Sector Energy Consumption* | | | | | | | |
| Electricity Sales (TWh) | 0.0 | 0.0 | -20.6 | -48.0 | -72.7 | -89.7 | -100.8 |
| Natural Gas (EJ) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other (EJ) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Natural Gas (Quads) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other (Quads) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *Total U.S. Electric Generation* | | | | | | | |
| Coal (TWh) | 0.0 | 0.0 | -2.7 | -10.4 | -25.7 | -25.7 | -25.7 |
| Gas (TWh) | 0.0 | 0.0 | -14.2 | -34.1 | -49.3 | -49.3 | -49.3 |
| Petroleum (TWh) | 0.0 | 0.0 | -2.3 | -2.8 | -1.1 | -1.1 | -1.1 |
| Nuclear (TWh) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Renewables (TWh) | 0.0 | 0.0 | 0.3 | -0.4 | -0.4 | -0.4 | -0.4 |
| Total (TWh) | 0.0 | 0.0 | -18.9 | -47.7 | -76.5 | -76.5 | -76.5 |
| *Installed Generating Capacity* | | | | | | | |
| Coal (GW) | 0.0 | 0.0 | 0.0 | -1.0 | -3.4 | -3.4 | -3.4 |
| Other Fossil (GW) | 0.0 | 0.0 | -0.6 | -10.5 | -18.5 | -18.5 | -18.5 |
| Nuclear (GW) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Renewables (GW) | 0.0 | 0.0 | 0.0 | 0.0 | -0.1 | -0.1 | -0.1 |
| Total (GW) | 0.0 | 0.0 | -0.6 | -11.5 | -21.9 | -21.9 | -21.9 |

### M.3.2 Revised Environmental Assessment Results

The U.S. Department of Energy (DOE) prepared a central air conditioner and heat pump environmental assessment (EA) pursuant to the National Environmental Policy Act of 1969 (NEPA)(42 U.S.C. 4321 et seq.), the regulations of the Council on Environmental Quality (40 CFR parts 1500-1508), and the Department of Energy's regulations for compliance with NEPA (10 CFR part 1021). The EA was published in January 2001 and presented the results of the environmental impacts, in the form of air-borne emissions reductions, for each of the five residential central air conditioners and heat pump Trial Standard Levels. The Trial Standard Levels were analyzed with the 2000 version of NEMS-BRS to generate estimates of the environmental impacts due to each of the standard levels.

The EA was revised by conducting new runs using the 2000 version of NEMS-BRS but with its existing set of sectoral load shapes replaced with the alternative versions. Table M.8 shows total power sector carbon and $NO_x$ emissions for the revised Reference Case (i.e., without efficiency standards) and each of the five central air conditioner and heat pump Trial Standard Levels. For each standard level the difference in the carbon and $NO_x$ emissions from the revised Reference Case are also provided.

The annual carbon emissions reductions range up to 9.1 Mt/a in 2020. $NO_x$ emissions reductions reach up to 24.7 kt/a by 2015. Table M.9 lists the cumulative emissions savings for the power sector over the 15-year period modeled for the central air conditioner and heat pump analyses. Table M.10 shows the results for the cumulative emissions reductions through 2030 for carbon and $NO_x$.

All of the trial standard levels (TSL) considered by DOE are shown in Tables M.8 through M.10. In this analysis, the reference case refers to cases with respect to the *AEO2000* Reference Case with the alternative load shapes. All TSLs are compared to the reference case which represents the no action alternative. This is also referred to as the baseline case, a cooling efficiency of 10 SEER for split system air conditioners and heat pumps, a cooling efficiency of 9.7 SEER for single package system air conditioners and heat pumps, a heating efficiency of 6.8 HSPF for split system heat pumps, and a heating efficiency of 6.6 HSPF for single package system heat pumps.

## Table M.8 Power Sector Emissions for all Standard Levels

| NEMS-BRS Results | 2000 | 2005 | 2010 | 2015 | 2020 | Difference from AEO2000 Ref Case with 2002 Loads | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AEO2000 Reference Case Using 2002 Loadshapes** | | | | | | | | | | | | Extrapolation | |
| Carbon (Mt/a)[1,3] | 584.7 | 638.9 | 676.6 | 724.8 | 760.2 | | | | | | | | |
| NOx (kt/a)[2,3] | 4,454.3 | 4,907.9 | 5,062.1 | 5,243.5 | 5,307.0 | | | | | | | | |
| **Standard Level 1 NAECA** | | | | | | | | | | | | | |
| Carbon (Mt/a) | 584.7 | 638.9 | 676.0 | 723.7 | 758.3 | Carbon (Mt/a) | 0.0 | 0.0 | -0.6 | -1.1 | -1.9 | -1.9 | -1.9 |
| NOx (kt/a) | 4,454.3 | 4,907.9 | 5,060.2 | 5,241.9 | 5,306.0 | NOx (kt/a) | 0.0 | 0.0 | -1.9 | -1.6 | -1.0 | -1.0 | -1.0 |
| **Standard Level 2 NAECA** | | | | | | | | | | | | | |
| Carbon (Mt/a) | 584.7 | 638.9 | 675.4 | 722.8 | 757.2 | Carbon (Mt/a) | 0.0 | 0.0 | -1.2 | -2.0 | -3.0 | -3.0 | -3.0 |
| NOx (kt/a) | 4,454.3 | 4,907.9 | 5,054.9 | 5,236.5 | 5,303.4 | NOx (kt/a) | 0.0 | 0.0 | -7.2 | -7.0 | -3.6 | -3.6 | -3.6 |
| **Standard Level 3 NAECA** | | | | | | | | | | | | | |
| Carbon (Mt/a) | 584.7 | 638.9 | 675.2 | 722.5 | 756.8 | Carbon (Mt/a) | 0.0 | 0.0 | -1.4 | -2.3 | -3.4 | -3.4 | -3.4 |
| NOx (kt/a) | 4,454.3 | 4,907.9 | 5,053.7 | 5,235.4 | 5,302.8 | NOx (kt/a) | 0.0 | 0.0 | -8.3 | -8.1 | -4.2 | -4.2 | -4.2 |
| **Standard Level 4 Roll-Up** | | | | | | | | | | | | | |
| Carbon (Mt/a) | 584.7 | 638.9 | 674.8 | 722.0 | 756.2 | Carbon (Mt/a) | 0.0 | 0.0 | -1.8 | -2.8 | -4.0 | -4.0 | -4.0 |
| NOx (kt/a) | 4,454.3 | 4,907.9 | 5,051.0 | 5,233.5 | 5,303.0 | NOx (kt/a) | 0.0 | 0.0 | -11.1 | -10.0 | -4.0 | -4.0 | -4.0 |
| **Standard Level 5 Roll-Up** | | | | | | | | | | | | | |
| Carbon (Mt/a) | 584.7 | 638.9 | 673.2 | 718.6 | 751.1 | Carbon (Mt/a) | 0.0 | 0.0 | -3.4 | -6.2 | -9.1 | -9.1 | -9.1 |
| NOx (kt/a) | 4,454.3 | 4,907.9 | 5,042.3 | 5,218.8 | 5,291.4 | NOx (kt/a) | 0.0 | 0.0 | -19.8 | -24.7 | -15.7 | -15.7 | -15.7 |

[1]Comparable to Table A17 of AEO2000: Electric Generators
[2]Comparable to Table A8 of AEO2000: Emissions
[3]All results in metric tons (t), equivalent to 1.1 short tons

## Table M.9 Cumulative Emission Reductions through 2020: Power Sector

| | Standard Level | | | | |
|---|---|---|---|---|---|
| **Emisson** | **1 (NAECA)** | **2 (NAECA)** | **3 (NAECA)** | **4 (Roll-Up)** | **5 (Roll-Up)** |
| Carbon (Mt) | -12.9 | -24.2 | -28.1 | -32.8 | -72.6 |
| NOx (kt) | -15.5 | -83.2 | -96.7 | -111.4 | -278.9 |

## Figure M.10 Cumulative Emission Reductions through 2030: Power Sector

| | Standard Level | | | | |
|---|---|---|---|---|---|
| **Emisson** | **1 (NAECA)** | **2 (NAECA)** | **3 (NAECA)** | **4 (Roll-Up)** | **5 (Roll-Up)** |
| Carbon (Mt) | -31.6 | -53.8 | -62.5 | -72.8 | -163.2 |
| NOx (kt) | -25.4 | -119.3 | -138.6 | -151.9 | -435.6 |

## M.4 MARGINAL HEAT RATE ESTIMATES

As described in Chapter 7 (See Section 7.2.2.3), source conversion factors are used to convert energy savings at the site (in kWh) to obtain primary or source energy savings. These source conversion factors, otherwise called marginal heat rates (MHR), are calculated by NEMS-BRS to translate end-use electricity savings to primary energy savings. The MHR is calculated by imposing a load reduction to the end-use of the appliance being analyzed in NEMS-BRS and observing the change in primary energy use. For central air conditioners and heat pumps (CAC-HP), the MHR was calculated to be 5519 Btu/kWh in 2020, which is relatively low compared to other appliance end-uses analyzed for other rulemakings (e.g., the value for clothes washers was 7225 Btu/kWh). As demonstrated later in Section M.4.3.3, because the MHR does not vary significantly with standard level, only a single set of MHRs were determined for all standard levels. The MHRs were based on a high multiple of actual energy savings (e.g., four times the savings associated with the 12 SEER standard level) to avoid "noise" within NEMS-BRS. With regard to the use of alternative load shapes in the 2000 version of NEMS-BRS, although they generally increase the MHR for all years (e.g., in 2020 the MHR is 6074 Btu/kWh), the change was not considered significant enough to warrant the use of a new set of MHRs based on the alternative load shapes.

Such a low CAC-HP MHR seems counter intuitive to the idea that improvements in end-use efficiency typically displace a marginal, and therefore inefficient, generator. One would expect the CAC-HP MHR to be higher than those of more baseload appliances (like clothes washers or electric water heaters) because this peakier appliance displaces more expensive, less efficient generation. Further, this marginal displaced plant should be not unlike the inefficient plant in place today because most rapid technological change occurs in the base load. However, due to competing effects that affect the efficiency of the overall power system, the marginal heat rates associated with central air conditioner and heat pump efficiency standards are lower than the actual heat rate of the plants displaced at the margin.

### M.4.1 Competing Effects

On first inspection, the CAC-HP MHR (5519 Btu/kWh in 2020) seems lower than that of any power plant likely to be in existence by 2020. The key to understanding this result is that this conversion rate does not represent a specific marginal generator or combination of generators, but is actually a conversion factor that incorporates several NEMS-BRS simulated effects resulting from the standard. Thus, the key reason why the CAC-HP MHR is lower than expected is because the overall rate of efficiency improvement of the power system with the standard in place is less than that of the *AEO* Reference Case (i.e., the case without new standards).

As discussed in Appendix H, all the NEMS-BRS runs are routinely done with multiples of actual expected proposed standard energy savings, called decrements, to ensure stable results. In a higher decrement SEER12 standard NEMS-BRS run (e.g., 4xSEER12) the conversion efficiency improvement lags the *AEO* Reference Case improvement. While there are many effects of the standard, the following equation summarizes the two major components of the standard's impact on the power sector:

$$\Delta PE = \Delta DG + \Delta SI \tag{M.1}$$

Where,

$\Delta PE$ = the overall change in *P*rimary *E*nergy due to the CAC-HP standard,
$\Delta DG$ = effect from *D*isplaced *G*eneration, and
$\Delta SI$ = effect from *S*lowed *I*nvestment in power system, and its consequent reduced rate of efficiency improvement.

The first term, $\Delta DG$, represents the direct reduction in fuel burned in power plants and is the direct result of the imposed standard (i.e., what one would expect to see as reductions in generation with CAC-HP site energy savings imposed). The second term, $\Delta SI$, denotes the indirect effect whereby the slowing of electricity demand growth slows new investment thereby impeding the rate of overall improvement in power sector efficiency. While this later effect would seem to be trivial relative to the first, it grows significantly over time because fewer generating plants of higher efficiency are added. By 2020, the end of the forecast period, this effect results in a significant reduction in primary energy savings for a standard, and explains why the MHR conversions appear to fall more than that anticipated by improving technology. Further, the benefits of peaking end-use efficiency improvements are reduced because of lower investment in new construction, which is heavily dependent on growth in peak demand.

### M.4.2 CAC-HP Example

Consider an example that shows the importance of the indirect effect, $\Delta SI$, and that the MHR for CAC-HP would be higher than other appliance MHR's (e.g., clothes washers) in agreement with intuition. In NEMS-BRS output, $\Delta PE$ and $\Delta SI$ can be observed, and, therefore, $\Delta DG$ can be calculated. The 4xSEER12 standard run results in an average U.S. heat rate (AHR) 46.6 Btu/kWh lower in 2020 than the *AEO* Reference Case. This means that the overall efficiency of the thermal power system is significantly impeded with the 4xSEER12 standard in place. The equivalent forgone primary energy savings resulting from this difference can be calculated as:

$$\Delta SI = (46.6 \text{ Btu/kWh})*(3785 \text{ TWh})*(10^9 \text{ kWh/TWh})*(\text{Quad}/10^{15} \text{ Btu}) = \mathbf{0.18\ Quads}$$

Where 3785 TWh is the total U.S. site energy consumption associated with the 4xSEER12 standard run in 2020 supplied by thermal (i.e., coal, gas, and petroleum) electrical generation. Because the change in AHR is not affected by decrement runs of 4x and less, the value of 46.6 Btu/kWh is not divided by 4. Changing the sign, -0.18 Quads represents how much more 2020 primary energy would have been estimated as saved without considering the indirect effects.

Now, consider that the 4xSEER12 run saves a total of 0.47 Quads in 2020. This is equivalent to 0.12 Quads for the actual SEER12 standard (i.e. 0.47 Quads divided by 4 which is approximately

0.12 Quads). This value is the total effect from displaced generation, or $\Delta PE$.

So without the presence of the slowed investment effect, the total primary energy saved is:

$$\Delta DG = \Delta PE - \Delta SI$$

$$\Delta DG = 0.12 \text{ Quads} - (-0.18 \text{ Quads}) = \mathbf{0.30\ Quads}$$

An MHR in 2020 that reflects the direct effect only can now be estimated as follows:

$$(0.30 \text{ Quads}/(86 \text{ TWh}/4))*(10^{15} \text{ Btu/Quad})*(\text{TWh}/10^{9} \text{ kWh}) = 13{,}950 \text{ Btu/kWh}$$

Where 86 TWh is the reduction in U.S. site energy consumption provided by thermal electrical generation due to the 4xSEER12 run. This is equivalent to 21.5 TWh for the actual SEER12 standard (i.e., 86 TWh divided by 4 which is approximately 21.5 TWh).

NEMS-BRS calculations for clothes washers result in a heat rate of 7185 Btu/kWh. So as expected, the MHR, when ignoring the indirect effect of slowed investment in the power system, is higher for CAC-HP than other appliances.

To summarize, with both the dirct and the indirect effects considered, the MHR for CAC-HP is only 5519 Btu/kWh in 2020 because the power system has an overall lower efficiency of 46.6 Btu/kWh (i.e., 7824 Btu/kWh for 4xSEER12 compared with 7777 Btu/kWh for *AEO* Reference Case). A slowing trend in investment makes the power sector less efficient and dirtier, and because this broad effect applies to all thermal generation, the net effect on standards benefits is significant, cutting them by over 60%.

## M.4.3 Interpolation

### M.4.3.1 Average Heating Rate and Slowed Investment Effect

The astute observer may have noticed an added potential complication to the above; namely the assumed linearity of the indirect effects. Most results reported in the TSD from NEMS-BRS are estimated using multiples of trial standard levels, such as the 4x case reported above. The multiple results are then interpolated back to the level of the actual standard. This adjustment has never been made to $\Delta SI$ so we test its effect here. Figure M.3 illustrates an annual comparison of the AHR for various higher decrement runs of a SEER13 case. The values on the x-axis are the multipliers of actual standard decrements. Plotted as the difference from the *AEO2000* reference case, this graph shows the high level of variability in the AHR. Prior to 2010, the AHR is generally lower than the *AEO2000* reference case, and vice-versa for years later than 2010. In other words, until 2010, the benefit on overall efficiency of removing marginal generation exceeds the $\Delta SI$ effect, but not afterwards. Also, after 2015 the $\Delta SI$ effect is clearly increasing over time. Looking from left to right, increasing decrements to the standard generally result in greater positive and negative differences in the AHR. Again, earlier in the forecast period, the AHR is more efficient (lower) than the Reference Case, and beyond 2015 the AHR is worse than the *AEO2000* Reference Case. In 2020, the AHR differences range from 56 to 89 Btu/kWh for the various decrement cases. Thus, the further the CAC-HP end-use is reduced and the later in the forecast it is, the greater the impact on the overall efficiency of the power system, or $\Delta SI$ becomes absolutely larger.

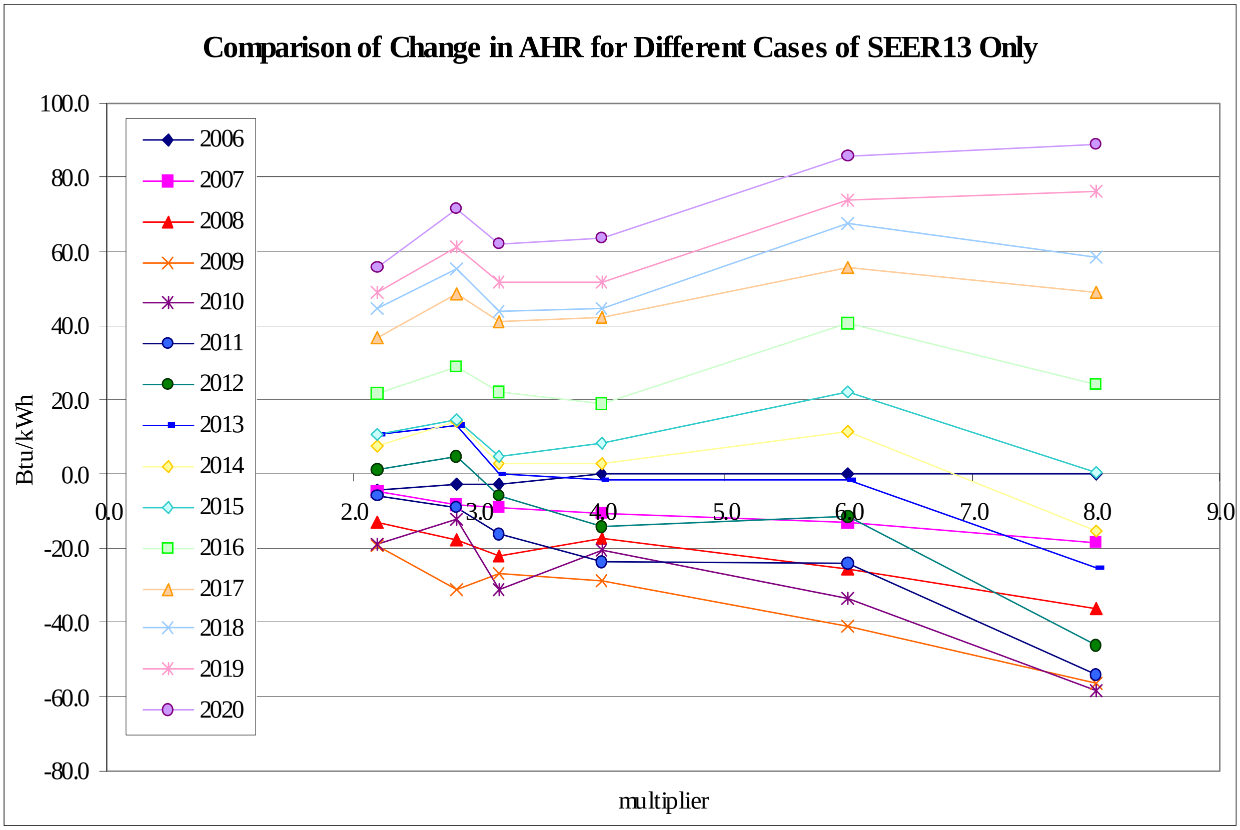


**Figure M.3 Comparison of SEER 13 Average Heat Rate as Difference from *AEO2000***

### M.4.3.2 MHR Linearity

Additionally, some further investigation was done to determine the linearity of the MHR under varying higher decrement runs. It was uncertain whether the marginal plant would exhibit a linear trend depending on the degree of savings from each proposed appliance standard, but as it turns out, it is quite linear, as illustrated by Figure M.4. In this figure, the Trial Standard Level 3 MHR is plotted as a function of decrements 6x, 8x and 10x for selected years to see how the MHR varies from different decrement cases within each year. The x=1 value denotes the MHR based on linear extrapolation of the least-squares fit for the estimates from the higher decrements runs. From this plot, the variation in MHR within a given year is seen to be fairly flat.

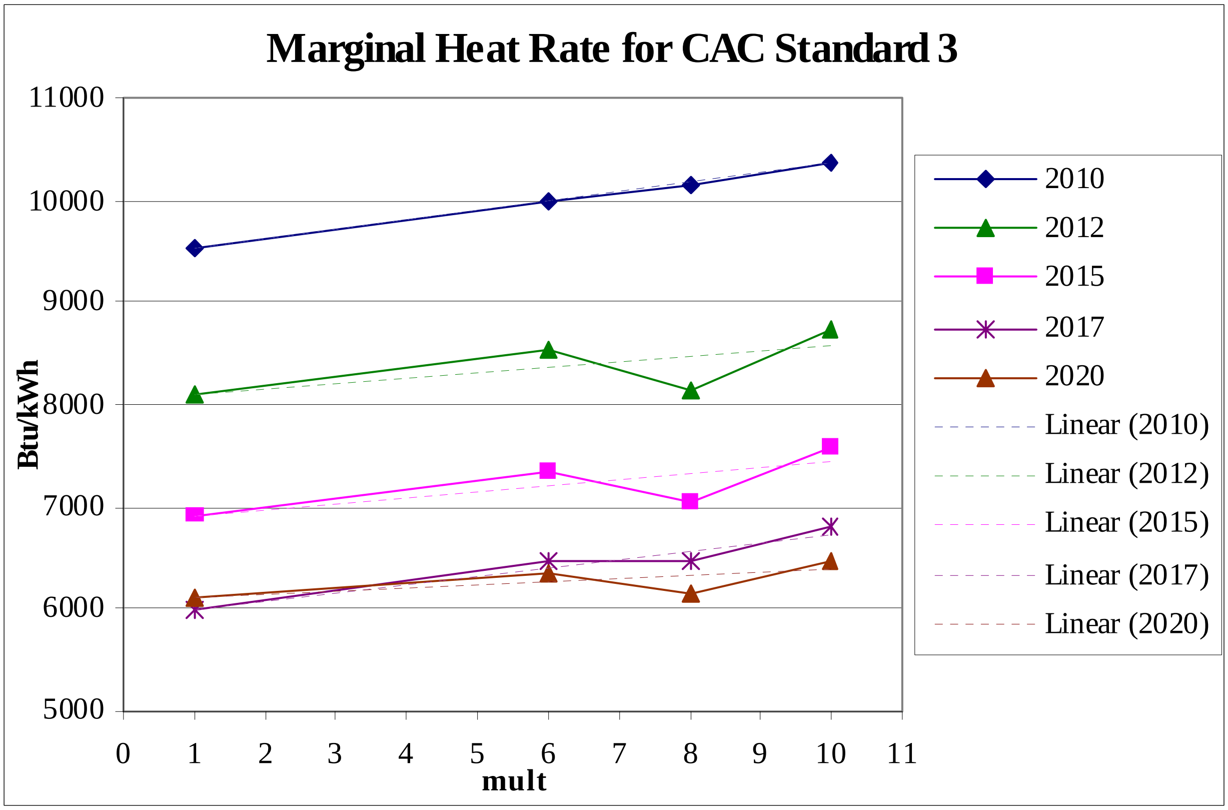


**Figure M.4 Comparison of Higher Decrement Marginal Heat Rates for CAC-HP Trial Standard Level 3 for Selected Years**

### M.4.3.3 MHR Comparisons

All years were regressed in the above fashion (as shown in Figure M.4) and the newly derived MHR was compared to the original calculation to see how different they were. Figure M.5 below plots the MHR time series, comparing the reference case MHR that was used for the CAC-HP analysis (See Section 7.2.2.3, Table 7.2 of Chapter 7), the various higher decrement MHR estimates, and the regressed MHR This regressed time series in essence better represents the marginal behavior of an appliance standard by not over- or under-estimating the forecasted marginal power plant. Comparing what was used in the CAC-HP analysis (solid line without symbols) with the regressed MHR based on various higher decrements of Trial Standard Level 3 (dashed line with triangle symbols), reveals that they track each other pretty well. Especially in the last five to seven years of the forecast horizon, the two MHR calculations exhibit comparable MHR's. This means that the estimate derived for the CAC-HP analysis based on one higher decrement run doesn't vary too much from the regressed MHR that is based on the estimated MHR for Trial Standard Level 3. Thus, there is no need to develop individual MHR time series for each Trial Standard Level.

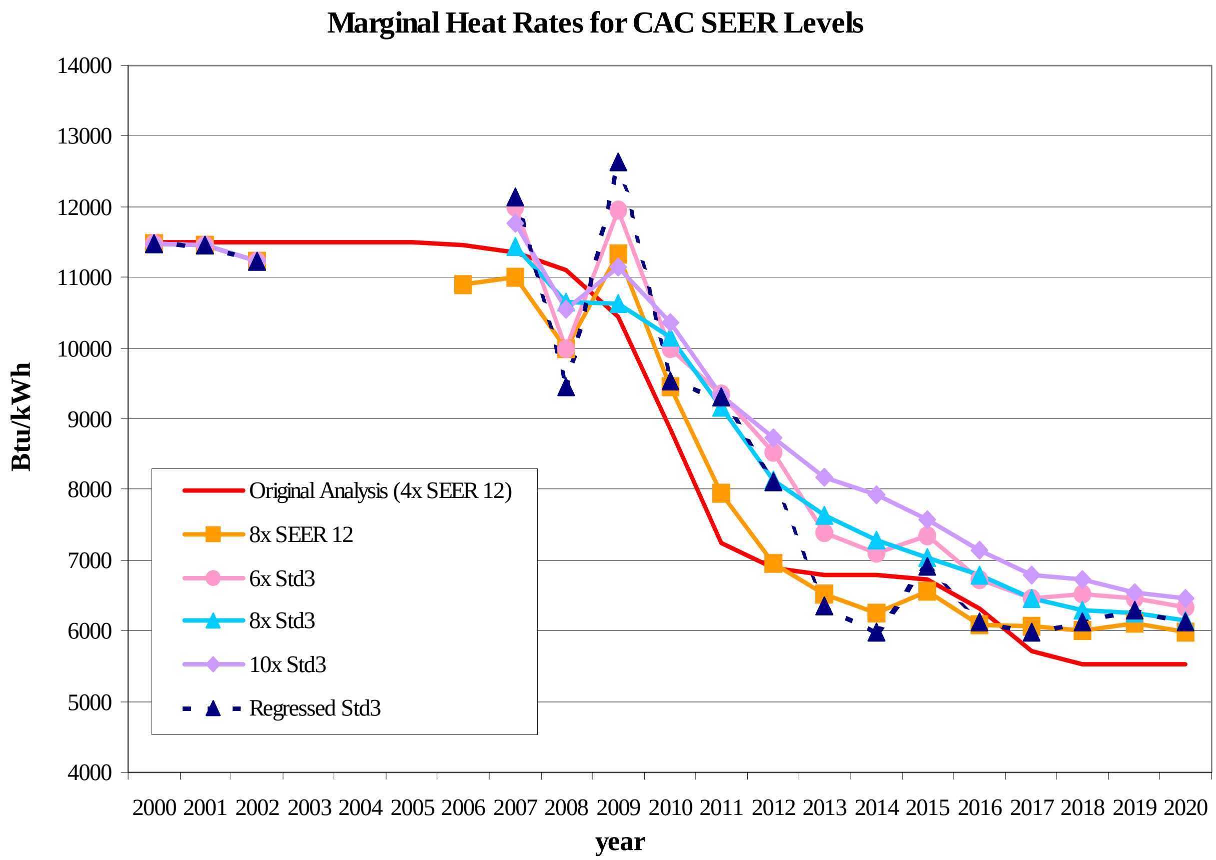


**Figure M.5 Comparison of Higher Decrement Marginal Heat Rates for CAC-HP Trial Standard Level 2 and 3 over Time**

## REFERENCES


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