Avoided Air Emissions from Energy Efficiency and Renewable Electric Power Generation in the PJM Interconnection Power Market Area

Colin J. High and Kevin M. Hathaway

Resource Systems Group, Inc.
White River Junction, VT

Supported by Funding from the U.S. Department of Energy

Clean Energy/Air Quality Integration Initiative

Draft Final March 15, 2007

CONTENTS

PREFACE

This report and analysis were prepared by Colin High and Kevin Hathaway of Resource Systems Group under contract to DJ Consulting LLC. The work was conducted with the financial support of the Clean Energy/Air Quality Integration Initiative of the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy.

Resource Systems Group wishes to thank staff from the National Renewable Energy Laboratory, who provided extensive input to the energy efficiency analyses included in this report, including Laura Vimmerstedt, David Kline, Gail Mosey, Sara Farrar-Nagy, and B. Griffith. In addition, we appreciate the review and comments on the entire report provided by the NREL staff, Debra Jacobson of DJ Consulting LLC, and Alden Hathaway of Environmental Resources Trust. We also would like to thank the staff of the Metropolitan Washington Council of Governments (MWCOG), state and local government members of MWCOG, and energy industry companies who provided data used in the analysis.

LIST OF ACRONYMS

CAA	Clean Air Act
CAIR	Clean Air Interstate Rule
CEM	Continuous Emission Monitors
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
DOE	U.S. Department of Energy
EERE	Energy Efficiency and Renewable Energy
EGU	Electric Generating Units
EPA	U.S. Environmental Protection Agency
kWh	Kilowatt-Hour
ISO	Independent System Operator
LED	Light-Emitting Diode
MWCOG	Metropolitan Washington Council of Governments
MWh	Megawatt-Hour
NAAQS	National Ambient Air Quality Standards
NO_x	Nitrogen Oxides
NREL	National Renewable Energy Laboratory
OAQPS	EPA Office of Air Quality Planning and Standards
OTC	Ozone Transport Commission
PJM	PJM (Pennsylvania, New Jersey, Maryland) Interconnection
PV	Photovoltaic
RSG	Resource Systems Group, Inc
SIP	State Implementation Plan

1. INTRODUCTION AND PURPOSE OF THE REPORT

The purpose of this report is to provide an estimate of the avoided nitrogen oxide (NO_x) emissions that result from electric energy efficiency (EE) and the generation of electric power from selected renewable energy (RE) sources in the PJM Interconnection power market area (PJM). This report is designed to assist the Metropolitan Washington Council of Governments (MWCOG) in efforts to support credit for avoided NO_x emissions resulting from electric EE and RE power generation. Specifically, the report will support the development of the State Implementation Plans for the District of Columbia, the State of Maryland, and the Commonwealth of Virginia to implement requirements under the Clean Air Act to attain the 8-hour ozone standard.

The report provides a prospective evaluation of the avoided emissions from several programs undertaken by State and local governments in the DC-MD-VA non-attainment area. These programs include: (1) energy efficiency programs including the retrofit of traffic signals to light-emitting diode (LED) signals; (2) wind energy purchases; and (3) the implementation of selected zero-emission renewable energy requirements of the District of Columbia's Renewable Portfolio Standard (RPS). All of these programs will impact electric generation within the PJM Interconnection power market area.

The technical methodology developed by Resource Systems Group, Inc., (RSG) in cooperation with Environmental Resources Trust was applied in this analysis. The methodology is based on generally accepted principles and procedures for estimating air emissions reductions from EE and RE power generation on the electric grid. The underlying assumptions and computation are consistent with the approach used by other experts in the field and similar to previous studies of avoided air emissions from EE and RE in New Jersey, Maryland and portions of PJM. The New Jersey report, including its methodology, was published in August 2006 and was co-authored by technical experts from the National Renewable Energy Laboratory (NREL), the Nation's premiere renewable energy laboratory, and the Global Environment and Technology Foundation, a prominent non-profit organization in the energy and environmental field. In addition, the U.S. Environmental Protection Agency and the Department of Energy provided peer review comments that were incorporated in both the Maryland and New Jersey studies.[1] The Maryland study also was accepted by the Environmental Protection Agency to support its first-ever approval of a renewable energy purchase for NOx emissions reduction credit in a State Implementation Plan (SIP) under the Clean Air Act.[2] The methodology in

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[1] The New Jersey report is titled as follows: United States Department of Energy, *Final Report on the Clean Energy/ Air Quality Integration Initiative Pilot Project for the Mid-Atlantic Region,* August 2006. (See http://www.eere.energy.gov/wip/clean_energy_initiative.html) The Maryland study is contained in the following document: , Metropolitan Washington Council of Governments, *Plan to Improve Air Quality in the Washington, DC-MD-VA Region*, February 19, 2004. See http://www.mwcog.org/committee/committee/archives.asp?COMMITTEE_ID=14 (Scroll down to February 19, 2004, pp. 7-77 to 7-81 and Appendix J, pp. J-71 to J-76).

[2] 70 Fed. Reg. 24988 (May 12, 2005).

the Maryland report also was published by NREL as a model for air emissions assessment for other wind energy projects.[3]

Avoided emissions result from renewable electric generation and demand-side energy efficiency measures because of the way that the electric power system works. Solar and wind energy generation are "must run" power sources because they have very low marginal operating costs and zero fuel costs. When these renewable sources and energy efficiency measures are in effect, they will displace generation at fossil-fuel units, which have much higher marginal operating costs in their power market area. As a result, the emissions from those fossil-fuel units are displaced.

Renewable energy generation and energy efficiency almost never displaces generation at nuclear power plants or hydropower plants for several reasons. First, both nuclear and hydropower units have low operating costs. In addition, nuclear power is not displaced because of the high costs involved in shutting down and restarting such plants. Although the timing of the hydropower generation may shift, as a result of renewable generation, the stored water will be used to provide power at a later time -- resulting in a net reduction in fossil-fueled generation.

The specific fossil-fuel units displaced vary by time of day and season and with the mix of fossil-fuel units operating. This report is focused on specific electric energy efficiency projects and the generation of electric power from zero-emission wind and photovoltaic sources. However, much of the discussion of the analytical process and the regulatory framework for crediting avoided NOx emissions also applies to avoided emissions from other energy efficiency /conservation measures and other zero-emission renewable energy generation.

2. THE PJM INTERCONNECTION POWER MARKET AREA

The PJM Interconnection has the largest generation capacity of any power market in North America. This power market has expanded from the original PJM core of Pennsylvania, New Jersey and Maryland (PJM) to include all or part of 12 states. The analysis excludes the two non-contiguous parts of PJM in Illinois and Michigan because it is unlikely that fossil-fueled generation will be displaced in these areas that are so distant from the Metropolitan Washington area.

In this analysis, the import and export of power is not considered, and all generation displaced by renewable sources is assumed to occur in the PJM area. Transmission constraints, though likely

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[3] National Renewable Energy Laboratory, *Model State Implementation Plan (SIP) Documentation for Wind Energy Purchase in State with Renewable Energy Set-Aside*, May 2005, Subcontract Report NREL/SR-500-38075. See http://www.windpoweringamerica.gov/sips.asp

significant in PJM's large region, are not considered. Our analysis demonstrates that none of these simplifying assumptions likely affect the results at this level or for this report's purposes.[4]

The complete list of fossil-fueled plants in PJM utilized in our analysis is presented in Appendix B (Table B-1). The locations of the plants are shown in Figure B-1. We selected these plants for our analysis because they have the ability to provide variable levels of generation into the PJM grid at short notice and are not fully committed. These plants all meet the following criteria. They all are:

(1) fossil-fuel fired,

(2) sell power into the contiguous portions of the PJM Grid;

(3) have average capacity factors below full capacity; and

(4) are large enough to have continuous emissions monitors (CEMs).

Small stand-by "peak shaving" units, emergency generators, and "behind the meter" generators are not included in the analysis because detailed data for these are not readily available.

The monthly average generation at fossil-fueled units included in the analysis is shown by fuel type in Figure 1 below. This figure shows that generation peaks in summer and winter and that coal is the dominant fuel in all seasons. The proportion of oil increases in the May to September ozone season because electric generators need to meet the NO_x emissions limitations for the summer ozone season.

Figure 1 is based on plant-level fuel use reported to the Department of Energy's Energy Information Administration and is intended for informational purposes only. The actual NO_x avoided emission analysis is based on time matching analysis at the unit level as described in section 4. The marginal fuel use may differ, especially at peak demand periods.

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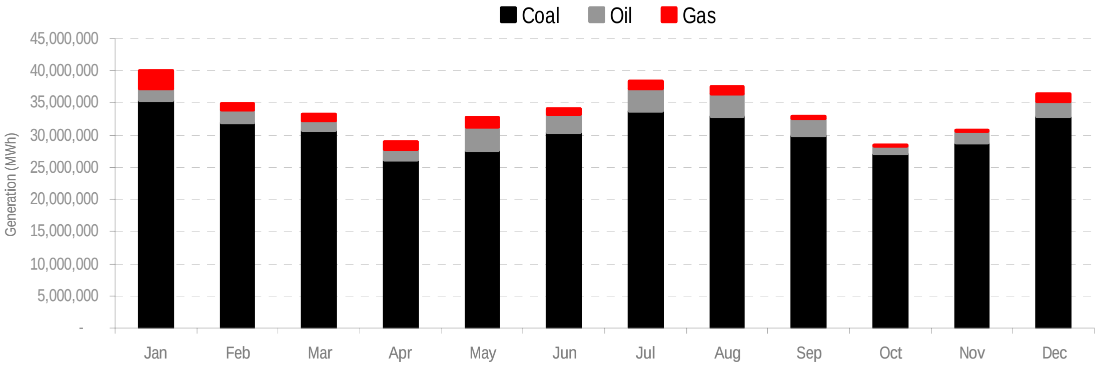
[4] However, it should be noted that power imports and transmission constraints may affect the avoided emissions for specific projects. In a 2003 study of a specific wind project in western Maryland conducted by Resource Systems Group for Clipper Windpower, the average ozone season avoided NOx emission rate was 5.8 lbs/MWh, which was considerably higher than the PJM average avoided emissions at that time.[4] These results are indicative of how project-specific factors can affect avoided emission rates.

Figure 1: PJM Average Monthly Generation Mix (MWh) for 2005



3. ANALYTICAL METHODOLOGY

The analysis objective was to determine the average avoided NOx emissions that occur when a specific amount of EE saving or RE generation occurs in PJM. The five EE and RE projects discussed in this report include the following:

- LED traffic signal retrofits (**EE**)
- Lighting retrofits in government buildings (**EE**)
- Air-conditioning retrofits in government buildings (**EE**)
- Solar Photovoltaic Power (**RE**)
- Wind Power (**RE**)

For the three EE project categories, the avoided emissions analysis assumes that the projects will be located in the DC-MD-VA non-attainment area and that electricity savings will displace fossil-fueled generation in PJM. For the RE projects, it is assumed that generation could be located anywhere in PJM and will displace fossil-fueled generation in PJM.

Several established methods for estimating avoided emissions in any power market area have been developed. These alternate methods are briefly reviewed in Appendix A of this report. Additional reviews of this subject have been prepared by Synapse Energy Economics for the Ozone Transport Commission.[5]

The methodology used in this report is the time-matched and generation-weighted average of the emissions of plants that are variably dispatched to meet changing demand. This methodology is a refinement of the generation-weighted average approach which was used in the New Jersey report cited in Section 1. The first step determines the EE or RE generation profile (sections 3.1 - 3.6 provides information on each of these profiles) for the summer ozone season and for the full year

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[5] Synapse Energy Economics, Inc. *Predicting Avoided Emissions from Policies that Encourage Energy Efficiency and Clean Power,* prepared for the Ozone Transport Commission, June 2002.

(by time of day, week, and month). Secondly, these hourly profiles are matched with the hourly generation of the variably dispatched fossil-fuel units at plants listed in Appendix B (Table B-1) using SQL (structured query language) software. This customized tool identifies the fossil-fueled units operating when renewable power is generated or energy savings are taking place, forming the list of generating units available to be displaced in each hour of the year.

Unit-level generation is estimated using the hourly carbon dioxide (CO_2) emissions from the continuous emissions monitors (CEMs) required by EPA for each fossil-fueled electric generating unit (EGU).[6] The relationship between CO_2 emissions and generation is described by different linear models for each fuel (oil, coal, and gas) and combustion design (boilers, turbines, and internal combustion engines). These linear models provide reasonably accurate estimates of hourly generation of the EGUs in PJM.

Hourly NO_x emissions for each fossil-fueled EGU are also derived from the CEM data. Estimated avoided emissions for each hour are based on a generation-weighted average of the units operating at that time.[7] These results are reported for both the ozone season (May 1 to September 30) and the full year. The current analysis is based 2005 data.

The hourly, annual, and ozone season avoided emissions rates for NO_x (lbs/MWh) are shown in Figure 2. These avoided emission rates are almost identical for each of the EE and RE technologies.[8] The monthly and daily total avoided emissions (affected by the seasonal variability in energy savings and wind and PV power generation) are described in the following sections.

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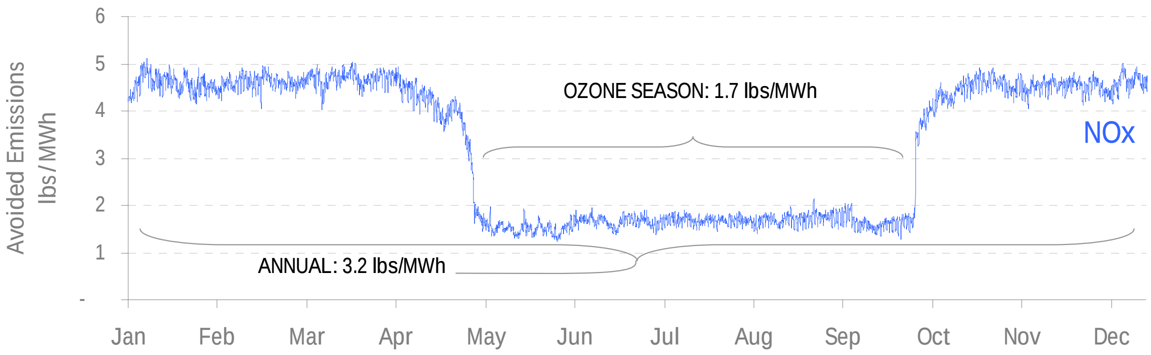
[6] U.S. Environmental Protection Agency, Office of Air and Radiation, *Continuous Emission Monitoring Database*, ,*Acid Rain Hourly Emissions Data 2005*, CD 2 disks. Distributed by National Technical Information Service, Springfield, VA.

[7] The analysis includes only the variably dispatched fossil fueled units at plants which are included in the analysis area of PJM and listed in Table 1 of Appendix B.

[8] The similarity in annual and ozone season avoided NOx emission rates (lbs/MWh) extends to five or more decimal places. The reason for this similarity is because of PMJ's large generation base and the small increment of EE/RE that is being added to the system in this analysis. A more refined analysis of specific projects for smaller areas and larger increments of EE/RE may show some differences between technologies. The seasonal differences in generation patterns between EE/RE technologies are, however, significant and result in marked differences on a tons per day basis for specific increments of generation or electricity savings.

Figure 2: Annual and Ozone Season Hourly Avoided Emission Potential in the PJM Area



3.1 ANALYSIS OF LED TRAFFIC SIGNAL RETROFITS

The energy savings from retrofits of LED traffic signals has been compiled from the reports of the state and municipal agencies in the MWCOG that have conducted such retrofits. The energy savings have been calculated by using the protocol established by the EPA ENERGY STAR Program by the use of data derived from the EPA ENERGY STAR Calculator Worksheet.[9] The results of these calculations are reported in Section 6.5 of the SIP document. The electricity savings from the LED traffic signal retrofits occur at a nearly constant level over a 24-hour period and throughout the year. Therefore, the analysis does not contain any daily or seasonal variation. The electricity savings profile is constant at all hours as shown below in Figure 3.

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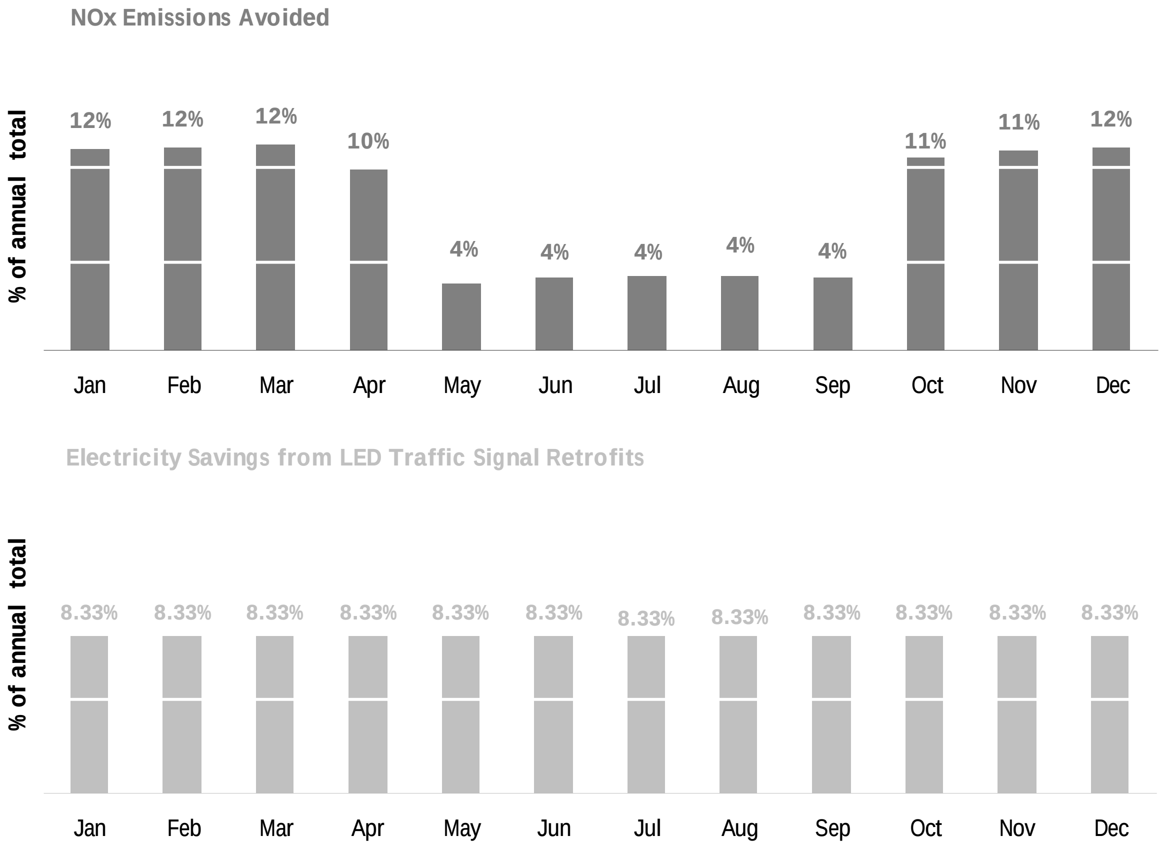
[9] U.S. Environmental Protection Agency, ENERGYSTAR LED Traffic Signals Calculator. See http://www.energystar.gov/index.cfm?c=traffic.pr_traffic_signals

Figure 3: Monthly Percentage of Annual NOx Emissions Avoided & Annual Electricity Savings from LED Traffic Signals Retrofits



3.2 ANALYSIS OF LIGHTING RETROFITS IN GOVERNMENT BUILDINGS

The energy savings from lighting retrofits in government buildings has been compiled from the reports of the state and municipal agencies in the MWCOG that have conducted such retrofits. The methodology is described in a memorandum included in Appendix C [10]. The summary results of the savings calculations are reported in Section 6.5 of the SIP document. The hourly energy savings profile has been simulated by NREL using the performance of a sample of 20 government buildings in the Metropolitan Washington area and on meteorological data for 2003. The monthly electricity savings profile is shown in Figure 4.

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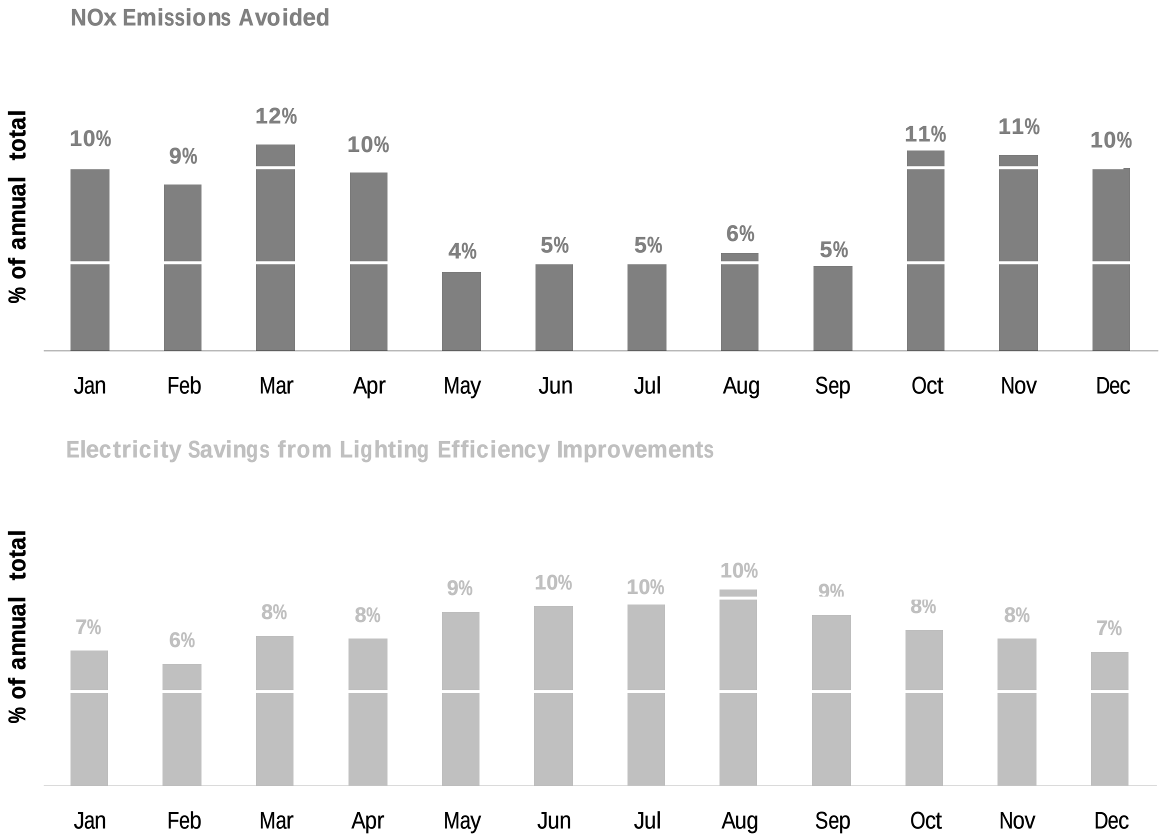
[10] B. Griffith, Composite *Hourly Electrical Savings Profiles from Government Buildings in the Washington DC. Area,* Buildings and Thermal Systems Center, National Renewable Energy Laboratory, December 5, 2006.

Figure 4: Monthly Percentage of Annual NOx Emissions Avoided & Annual Energy Savings from Lighting Retrofits of Government Buildings



3.3 ANALYSIS OF AIR CONDITIONING RETROFITS IN GOVERNMENT BUILDINGS

The energy savings from retrofits of air conditioning in government buildings has been compiled from the reports of the state and municipal agencies in the MWCOG that have conducted such retrofits. The methodology is described in a memorandum included in Appendix C.[11] The summary results of savings calculations are reported in Section 6.5 of the MWCOG SIP document. The hourly energy savings profile has been simulated by NREL using the performance of a sample of 20 government buildings in the Metropolitan Washington area and on meteorological data for 2003. The monthly electricity savings profile is shown in Figure 5. The energy savings show a very marked summer peak.

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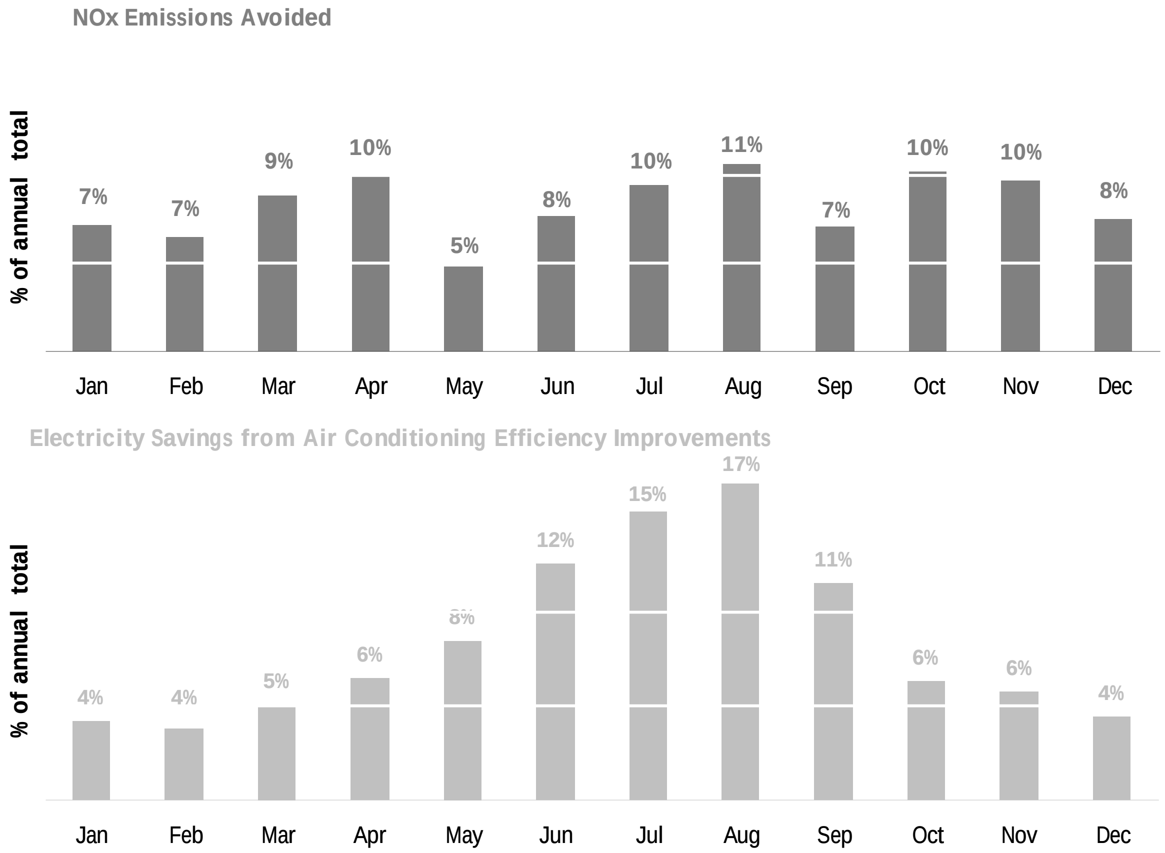
[11] B. Griffith, *Composite Hourly Electrical Savings Profiles from Government Buildings in the Washington DC. Area.* Buildings and Thermal Systems Center, National Renewable Energy Laboratory, December 5, 2006.

Figure 5: Monthly Percentage of Annual NOx Emissions Avoided & Annual Energy Savings from Air Conditioning Efficiency Retrofits in Government Buildings



3.4 ANALYSIS OF SOLAR PHOTOVOLTAIC POWER

The analysis for solar photovoltaic power is based on generation data derived from the performance of existing facilities. The photovoltaic data are based on the performance of a standard silicon PV system using Typical Meteorological Years (TMY2) solar radiation data compiled by NREL for the Metropolitan Washington area.[12] Other locations in PJM would have similar seasonal patterns, and therefore, they would have similar avoided emission rates (lbs/MWh) even if the actual generation rate in watts per meter differed. The summary results of the avoided NOx calculations are reported

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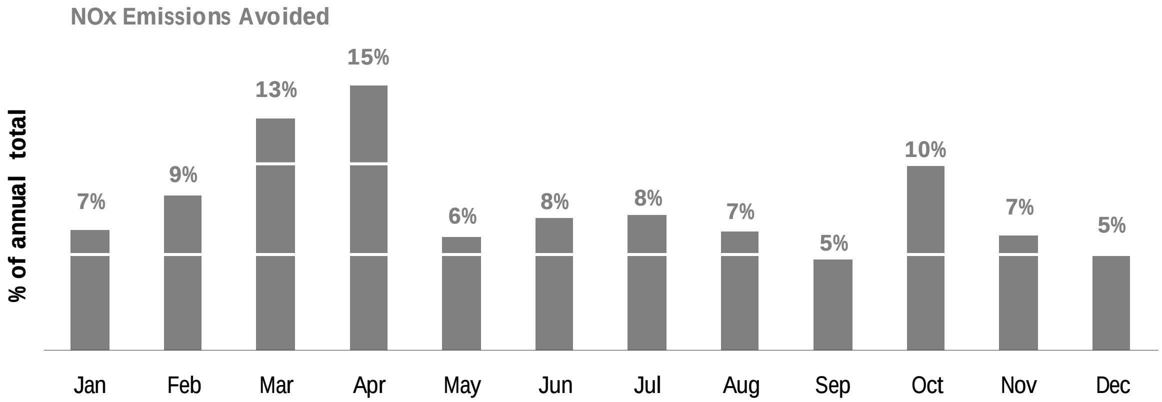
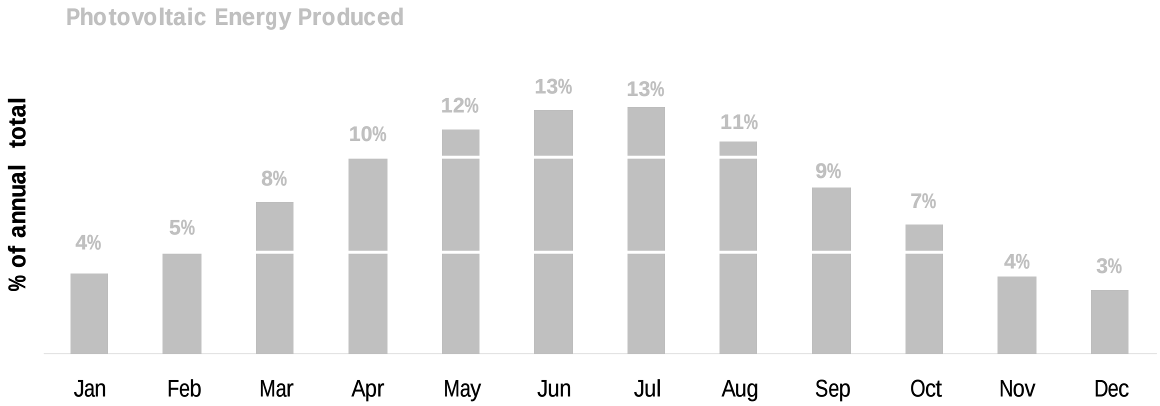
[12] National Renewable Energy Laboratory, *TMY2 Users Manual* . See http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/

in Section 6.5 of the MWCOG SIP document. The monthly percentage of total annual generation and the hourly NO_x avoided emission rate for photovoltaic power is shown in Figure 6.

Figure 6: Monthly Percentage of Annual NOx Emissions Avoided & Annual Photovoltaic Energy Produced





3.5 ANALYSIS OF WIND POWER

The analysis for wind power is based on wind generation data derived from existing wind energy facilities.[13] The data are for hourly electric generation for a one-year period. The wind data are based on the performance shown in the complete annual records of several wind turbines, in the mountainous interior areas of the Appalachian Mountains in PJM. This location is typical of the wind power purchases planned by municipalities in the DC-MD-VA non-attainment area.

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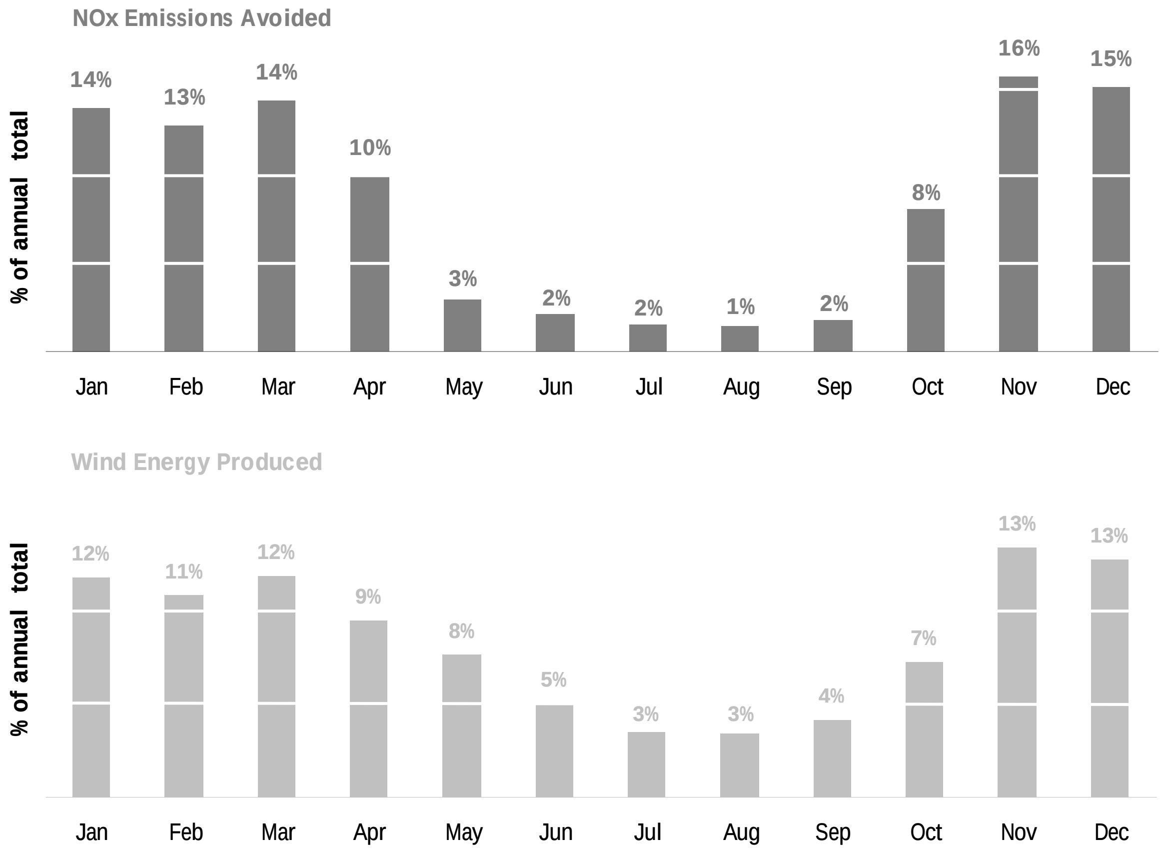
[13] The location and ownership of the wind turbines are confidential to protect the commercial interests of the owners who provided performance data.

The monthly percentage of total annual generation and the hourly NO_x avoided emission rate for wind power is shown in Figure 7 with a marked winter peak. The summary results of the avoided NOx emissions calculations are reported in Section 6.5 of the SIP document.

Figure 7: Monthly Percentage of Annual NOx Emissions Avoided & Annual Wind Energy Produced



4. SUMMARY OF THE ANALYSIS OF AVOIDED NO_X EMISSION RATES

The monthly and seasonal analysis of the avoided emissions for each of the five NO_x reduction measures described in Section 3 were computed by an Microsfoft® Excel™ workbook calculator prepared by Resource Systems Group, Inc.[14] The calculator will be posted on the website of the

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[14] Resource Systems Group Inc. MWAQC EERE Avoided NOx Emissions Calculator 2007. available at http://sharepoint.mwcog.org/airquality/default.aspx

Metropolitan Washington Air Quality Committee of the Metropolitan Washington Council of Governments at http://sharepoint.mwcog.org/airquality/default.aspx .

The calculator consists of three core worksheets plus other linked worksheets, as follows:

- The first sheet (named "Instructions and Documentation") provides instructions & general methodology while graphically displaying the seasonal variation in hourly and daily avoided NO_x emissions rates. Seasonal patterns in energy efficiency savings and power generation for each of the five EE/RE measures are also provided.
- The second worksheet (named "Emissions Standard") calculates the monthly, annual and ozone season avoided NO_x emissions (in tons per day) based on the seasonal profiles of the five EE/RE measures described in Section 3. There are separate sections for input and results for Maryland, Virginia and the District of Columbia.
- The third worksheet (named "Emissions Season Specific") provides the same calculations as the "Emissions Standard", except that the user can specify the energy generated or saved in the ozone and non-ozone seasons. This worksheet can be used when the energy amounts are known or specified, such as in a power purchase agreement or a contract to purchase Renewable Energy Certificates (RECs). This worksheet provides a more accurate result than the "Emissions Standard" worksheet where the specified ozone season and non-ozone season MWh differ from the regional generation or savings profile. This worksheet would be most applicable where a contract for RECs or energy efficiency savings binds the provider to supply a specified number of RECs during the summer ozone season.

The average avoided NO_x emission rates for the five NO_x reduction measures are 1.7 lb/MWh for the ozone season and 3.2 lb/MWh annually. The average avoided ozone season and annual NO_x emissions (in tons per day) for each of the five measures and each of the three jurisdictions are provided in Section 6.5 of the SIP document. The average avoided emissions that may be applied in the SIP depend on the absolute amount of generation or savings and the monthly profile of these measures. Avoided emissions apply to PJM described in Section 2 for 2005 and are based on the methodology described in this report and the set of fossil-fueled generating units at power plants listed in Appendix B. They are based on electricity savings from energy efficiency and renewable generation located in PJM without regard to location. Renewable energy project location will influence the avoided emission rate, especially in areas with significant transmission constraints.

For projects located in PJM, but not in the immediate MWCOG area, the upwind or downwind location may also affect the ozone impact of the avoided emissions. Avoided emissions from wind plants that are located in the Appalachian Mountains to the west will provide upwind reductions for the MWCOG area. The average avoided NO_x emission rates of western PJM, where more generation is fueled by coal, are typically higher than in eastern PJM (i.e. more natural gas). If fossil-fueled units in eastern PJM's were excluded from the analysis (i.e. they are unlikely to be displaced by wind power), the avoided NO_x emission rates would be higher. In this instance, the analysis underestimates the avoided emission from wind plants upwind of the Washington DC-MD-VA non-attainment area.

These avoided emission rates are likely to have been similar in 2006. In future years, the avoided emission rates will be affected by changes in power generation, emissions control technology, and emissions control regulations.

APPENDIX A: COMPARISON OF ALTERNATIVE METHODOLOGIES TO CALCULATE AVOIDED NOX EMISSIONS[15]

To model the avoided emissions or marginal emission reductions, several methods may be employed. These methods include the following:

1) A system mix analysis of **all** electric generating units;
2) A surrogate plant analysis;
3) A generation-weighted average of variably dispatched fossil-fueled generating units;
4) A time-matched and generation-weighted average of variably dispatched fossil-fueled generating units; and
5) A complete grid-system dispatch analysis of fossil-fueled generating units.

The analysis in this report relies on methodology (4) for the reasons set forth below.

1) The ***system mix analysis*** takes the generation-weighted average of **all** the fossil-fueled units in the electric generating system. This is a simple method. However, this method includes nuclear and hydropower plants that are almost never displaced by EE/RE measures. As a result, this approach significantly underestimates the emissions displacement, which occurs almost entirely at fossil-fueled plants. The EPA eGrid data relies on this approach.[16]

2) The ***surrogate plant analysis*** calculates the emissions of the next new plant or unit that is likely to be added to the electric grid as a basis for determining what emissions would be avoided if the demand were reduced by energy efficiency measures or displaced by renewable energy generation. In the Mid-Atlantic, the most likely new plant in recent years would be combined-cycle natural gas with best available NO_x control technology. The result is a very low NO_x avoided emission rate.

This approach is unrealistic in the short-term because actual generation and energy efficiency displacement are spread across a wide range of fossil-fueled generation units, some of which have relatively high NO_x emission rates. This approach may provide a reasonable estimate of the long-term avoided emissions if current trends continue. However, the actual mix of plants may be very different in the future depending on fuel prices and public policy.

3) The ***generation-weighted average of the emissions of the fossil-fueled electric generating units that are variably dispatched*** to meet changing demand. This approach provides a reasonable approximation of the marginal emissions rate without the time and cost of a complete grid-system dispatch analysis, as described below. This method was used in the New Jersey Report.[17]

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[15] This description is based, in large part, on Appendix 4 of the *Final Report on the Clean Energy/ Air Quality Integration Initiative Pilot Project for the Mid-Atlantic Region,* August 2006. (See http://www.eere.energy.gov/wip/clean_energy_initiative.html)

[16] U.S. Environmental Protection Agency Emissions & Generation Resource Integrated Database (eGRID) 2002 http://www.epa.gov/cleanenergy/egrid/index.htm

4) The ***time-matched and generation-weighted average of the emissions of the fossil-fueled generating units that are variably dispatched*** to meet changing demand. This methodology has been developed by Resource Systems Group in cooperation with Environmental Resources Trust. It is a refinement of the generation-weighted average approach. It matches the hour-by-hour output of the renewable energy source or energy saving units with the generation from fossil-fuel units in each power market area that can be displaced by "must run" renewable energy or energy efficiency savings. Under the RSG methodology, the profiles of the EE/RE for the summer ozone season (by time of day, week, and month) and for the full year are determined. The next step matches the EE/RE hourly profile data for each source type against the hourly generation of the variably dispatched fossil-fueled units at plants in the power market analysis area. This comparison forms the basis for matching and identifying the set of generation units which can be displaced in each hour.

The method requires intensive computational power and use of the CEM's CO_2 data to estimate hourly generation for individual units (because exact data is not publicly available). This method should provide a better approximation of the true marginal emission rate without the time and cost of a complete grid-system dispatch analysis.

5) A ***complete grid-system dispatch analysis*** of fossil-fuel units considers the dispatch order and scheduling of specific combustion units at each facility in the power market area in detail, providing the most comprehensive estimate of the avoided emissions. An analysis of this type may be based on historical data on dispatch schedules or on a proprietary unit dispatch model. This approach allows for matching the EE/RE measures at specific hours with the actual generation of variably dispatched fossil-fuel fired units. In principle, this method takes into consideration the actual dispatch order at every hour, including operational cost, system reliability, transmission constraints and other operational factors.

This approach was utilized by the State of Maryland to support NO_x emissions reduction credit for a regional wind purchase led by Montgomery County, Maryland in the SIP to meet the 1-hour ozone standard.[18] In 2005, this wind purchase received the first-ever approval by the U.S. EPA for NO_x emission reduction credit for a renewable energy purchase in a State Implementation Plan.[19]

This grid-system dispatch analysis approach is workable for the analysis of a renewable energy purchase from a single renewable energy plant (as in the case of the Montgomery County wind purchase). However, this approach is extremely difficult and very expensive to apply when multiple EE/RE projects or an entire EE/RE program is the subject of the analysis. This expense is hard to justify, particularly if it is intended for the sole purpose of validating an avoided emissions rate stipulated in a State NO_x

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[17] U.S. Department of Energy, *Final Report on the Clean Energy/ Air Quality Integration Initiative Pilot Project for the Mid-Atlantic Region,* August 2006. (See http://www.eere.energy.gov/wip/clean_energy_initiative.html)

[18] See http://www.mwcog.org/environment/committee/committee/archives.asp?COMMITTEE_ID=14 Scroll down to February 19, 2004 and Click SIP Chapter 7 (pages 7-77 to 7-80) and Appendix J, pp. 7-71 to 7-76.

emissions trading regulation, such as the Virginia Clean Air Interstate Rule, which stipulates an avoided emissions rate of 1.5 pounds per MWh for 2009 to 2014. However, this detailed dispatch analysis approach can be justified to provide accurate estimates of displaced NO_x emissions resulting from a large renewable energy project, such as a single wind farm.[20]

The use of a proprietary economic unit dispatch models also makes this approach non-transparent, which may create problems for public agencies in reviewing the results. The system simulation dispatch models were primarily designed for optimizing new construction and operating decisions of relatively large plants in competitive markets. In many power markets, there is insufficient experience with the dispatch of small intermittent renewable power, such as wind and PV, to establish clear precedents for how the system will respond at the level of detail implied by the dispatch simulation models.

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[19] 70 Fed. Reg. 24987 (May 12, 2005).

[20] See National Renewable Energy Laboratory, *Model State Implementation Plan (SIP) Documentation for Wind Energy Purchase in State with Renewable Energy Set-Aside,* May 2005, Subcontract Report NREL/SR-500-38075 See, http://www.eere.energy.gov/windandhydro/windpoweringamerica/sips.asp

APPENDIX B: ELECTRIC GENERATING UNITS INCLUDED IN THE ANALYSIS

The list of plants with fossil-fueled units included in the analysis of the PJM Interconnection in this report is shown in Table B-1. In a few cases, renewable-fueled units, such as wood-fired units, are included because they also burn fossil fuels. We conducted the analysis at the level of the individual electric generation unit.

The NO_x and CO_2 emissions data was obtained from the Continuous Emission Monitor database of the U.S. EPA for calendar year 2005.[21] This information is supplemented by data from the U.S. Energy Information Administration (EIA), the Federal Energy Regulatory Commission, and from utility company websites.

RSG used data from the EPA's Emissions & Generation Resource Integrated Database (eGRID) 2002 to check and supplement the list of electric generating units.[22] The emissions data in eGRID 2002 are based on data collected in 2000. Additional information has been obtained from technical staff at the Virginia Department of Environmental Quality and the New Jersey Department of Environmental Protection.

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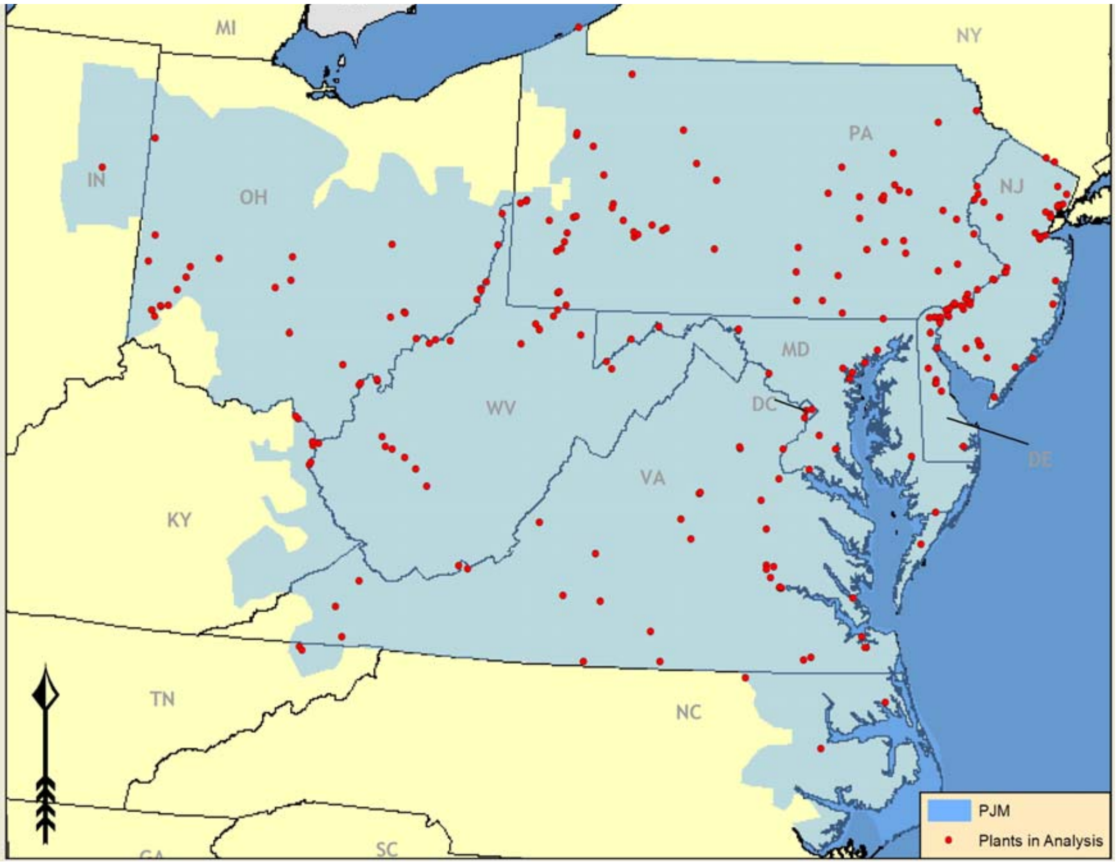
[21] U.S. Environmental Protection Agency, Continuous Emission Monitoring Database, Office of Air and Radiation, "Acid Rain Hourly Emissions Data 2005," CD 2 disks. Distributed by National Technical Information Service, Springfield VA.

[22] U.S. Environmental Protection Agency Emissions & Generation Resource Integrated Database (eGRID) 2002 http://www.epa.gov/cleanenergy/egrid/index.htm

Table B-1: Plants Included in PJM Interconnection Analysis

Name	State
BENNING	DC
CENTRAL HEATING	DC
CHRISTIANA SUBSTATION	DE
CONECTIV, EDGE MOOR	DE
DELAWARE CITY	DE
HAY ROAD	DE
INDIAN RIVER GENERATION	DE
MADISON STREET	DE
MCKEE RUN	DE
NRG ENERGY DOVER	DE
PREMCOR REFINING GRP	DE
VANSANT	DE
WARREN F. (SAM) BEAS	DE
WEST SUBSTATION	DE
MONTPELIER ELECTRIC	IN
BIG SANDY	KY
CATLETTSBURG RFNG	KY
RIVER SIDE GENERATION	KY
AES WARRIOR RUN	MD
BRANDON SHORES	MD
CHALK POINT	MD
CHARLES P. CRANE	MD
DICKERSON	MD
H.A. WAGNER	MD
MEADWESTVACO MD, INC	MD
MORGANTOWN	MD
PANDA-BRANDYWINE	MD
PERRYMAN	MD
R P SMITH P S	MD
RIVERSIDE	MD
ROCK SPRINGS	MD
VIENNA GENERATING ST	MD
WESTPORT	MD
INTERNATIONAL PAPER	NC
WEYERHAEUSER CO.	NC
GRANITE RIDGE ENERGY	NH
AES RED OAK FACILITY	NJ
B.L. ENGLAND	NJ
BELVIDERE PLANT	NJ
BERGEN GEN. STATION	NJ
BURLINGTON STATION	NJ
CALPINE NEWARK, INC	NJ
CALPINE PARLIN, INC.	NJ
CARLLS CORNER	NJ
CARNEY POINT GENERATION	NJ
CEDAR STATION	NJ
COASTAL EAGLE POINT	NJ
COGEN TECH, LINDEN	NJ
CUMBERLAND	NJ
DEEPWATER STATION	NJ
EAGLE POINT COGEN	NJ
EDISON STATION	NJ
EF KENILWORTH	NJ
ESSEX GEN. STATION	NJ
FORKED RIVER	NJ
GILBERT	NJ
GLEN_GARDNER	NJ
HOWARD M DOWN	NJ
HUDSON STATION	NJ
LINDEN STATION	NJ
LOGAN GENERATING PLANT	NJ
MERCER GEN. STATION	NJ
MICKLETON	NJ
MIDDLE STREET	NJ
MISSOURI AVENUE	NJ
NATIONAL PARK STA.	NJ
NEWARK BAY COGEN PRT	NJ
NORTH JERSEY ENERGY	NJ
OCEAN PEAKING POWER	NJ
PEDRICKTOWN COGEN	NJ
PELP	NJ
SALEM STATION	NJ
SAYREVILLE	NJ
SHERMAN AVENUE	NJ
VALERO REF.CO.- N.J.	NJ
WERNER	NJ
WEST STATION	NJ
FULTON COGENERATION	NY
HILLBURN GT	NY
NISSEQUOGUE COGEN	NY
WATERSIDE GENERATING	NY
AK STEEL	OH
CARDINAL	OH
CARGILL INC	OH
CHILLICOTHE PAPERINC	OH
CONESVILLE PLANT	OH
DARBY ELECTRIC GENERATION	OH
DAYTON POWER AND LIGHT	OH
DICK'S CREEK STATION	OH
GAVIN	OH
GRNVILLE ELECTRIC	OH
HAMILTON GENERATING	OH
HAMILTON MUNICIPAL	OH
HANGING ROCK ENERGY	OH
KYGER CREEK	OH
MAD RIVER	OH
MADISON STATION	OH
MUSKINGUM RIVER	OH
O.H.HUTCHINGS	OH
OSU-MCCRACKEN	OH
PICWAY	OH
RE BURGER	OH
RICHARD GORSUCH GENE	OH
ROBERT P. MONE	OH
ROLLING HILLS GENER.	OH
SMART PAPERS LLC	OH
SUNOCO, INC. (R&M)	OH
TAIT ELECTRIC GENER	OH
W. H. SAMMIS	OH
WASHINGTON ENERGY	OH
WATERFORD	OH
WOODSDALE STATION	OH
AE 3,4&5	PA
AES BEAVER VALLEY	PA
AES IRONWOOD, INC	PA
ALLEGHENY ENERGY LLC	PA
ARCHBALD POWER	PA
ARMAGH	PA
ARMSTRONG ENRGY,LLP	PA
ARMSTRONG P S	PA
B MANSFIELD	PA
BERNVILLE	PA
BETHLEHEM POWER PLANT	PA
BRUNNER ISLAND	PA
CAMBRIA COGEN	PA
CHESWICK	PA
COLVER POWER PROJECT	PA
CONEMAUGH	PA
CONOCOPHILLIPS COMP.	PA
CROMBY	PA
CROYDON STATION	PA
EBENSBURG POWER COMP	PA
EDDYSTONE	PA
EDGAR THOMSON PLANT	PA
EDISON STATION	PA
ELRAMA	PA
ENTRIKEN	PA
FAIRLESS ENERGY, LLC	PA
FAIRLESS HILLS SGS	PA
FAYETTE ENERGY FACILITY	PA
FPL ENERGY MH50 L.P.	PA
FPLE MARCUS HOOK	PA
GANS	PA
GILBERTON POWER COMP	PA
GLATFELTER, P.H. CO.	PA
GREYS FERRY COGEN	PA
HANDSOME LAKE ENERGY	PA
HATFIELD'S FERRY PS	PA
HAZELTON GENERATION	PA
HOMER CITY	PA
HUNLOCK POWER	PA
HUNTERSTOWN	PA
KEYSTONE	PA
KIMBERLY-CLARK	PA
LIBERTY ELECTRIC LLC	PA
LOWER MOUNT BETHEL	PA
MARTINS CREEK	PA
MERCK & COMPANY INC	PA
MITCHELL P S	PA
MONTOUR	PA
MOUNTAIN	PA
MT. CARMEL COGEN	PA
NORTH EAST COGEN	PA
NORTHAMPTON GEN CO	PA
NORTHEASTERNPOWERCO	PA
ONTELAUNEE ENERGY CE	PA
PANTHER CREEK	PA
PINEY CREEK L. P.	PA
PORTLAND	PA
PROCTER&GAMBLE PAPER	PA
RICHMOND STATION	PA
SCHUYLKILL	PA
SCHUYLKILL STATION	PA
SCRUBGRASS GEN PLANT	PA
SEWARD	PA
SHAWVILLE	PA
SHENANGO INC	PA
SHERMANS DALE	PA
ST. NICHOLAS COGEN.	PA
SUN COMPANY PHILA	PA
SUNBURY	PA
SUNOCO INC. (R&M)	PA
TITUS	PA
TOLNA	PA
U.S. STEEL CLAIRTON	PA
WARREN	PA
WESTWOOD OPER CO.	PA
WHEELABRATOR	PA
WILLAMETTE IND. INC.	PA
ZINC CORP OF AMERICA	PA
EASTMAN CHEMICAL COM	TN
KINGSPORT PAPER MILL	TN
ALTAVISTA	VA
BELLEMEADE	VA
BIG ISLAND MILL	VA
BIRCHWOOD POWER	VA
BREMO	VA
BUCHANAN GENERATING	VA
CCC POWER STATION	VA
CELANESE ACETATE	VA
CHESAPEAKE	VA
CHESTERFIELD	VA
CLINCH RIVER	VA
CLOVER	VA
COGENTRIX HOPEWELL	VA
COGENTRIX PORTSMOUTH	VA
COGENTRIX RICHMOND	VA
DAN RIVER	VA
DARBYTOWN CT	VA
DOSWELL LP	VA
ELIZABETH RIVER	VA
GLEN LYN	VA
GORDONSVILLE	VA
GRAVEL NECK CT	VA
HOPEWELL	VA
HOPEWELL	VA
HOPEWELL COGEN	VA
INTERNATIONAL PAPER	VA
LADYSMITH	VA
LOUISA GENERATION FA	VA
MARSH RUN GENERATION	VA
MEADWESTVACO OF VA	VA
MECKLENBURG P.S	VA
POSSUM POINT	VA
POTOMAC RIVER	VA
REMINGTON	VA
SOUTHAMPTON	VA
TASLEY PEAKING STATION	VA
TENASKA VIRGINIA GEN	VA
WOLF HILLS ENERGY	VA
YORKTOWN	VA
ALBRIGHT P S	WV
BIG SANDY PEAKER PL	WV
CEREDO	WV
DUPONT BELLE PLANT	WV
ELKEM, STEAM PLANT	WV
FORT MARTIN P S	WV
GRANT TOWN POWER PLT	WV
HARRISON P S	WV
INSTITUTE PLANT	WV
JOHN E. AMOS	WV
KAMMER	WV
KANAWHA RIVER	WV
MITCHELL	WV
MORGANTOWN ENERGY	WV
MOUNTAINEER	WV
MT. STORM	WV
NATRIUM PLANT	WV
NORTH BRANCH	WV
PHILIP SPORN	WV
PLEASANTS ENERGY,LLC	WV
PLEASANTS P S	WV
RIVESVILLE P S	WV
UNION CARBIDE CORP.	WV
WILLOW IS P S	WV

Figure B-1: Locations of Plants Used in Analysis



APPENDIX C: NREL SUPPORTING DOCUMENT- COMPOSITE HOURLY ELECTRICAL SAVINGS PROFILES FOR GOVERNMENT BUILDINGS IN THE WASHINGTON METROPOLITAN AREA

Composite Hourly Electrical Savings Profiles for Government Buildings in the Washington Metropolitan Area

B. Griffith

Buildings and Thermal Systems Center, Commercial Buildings Group

National Renewable Energy Laboratory

January 16, 2005

INTRODUCTION

Building energy efficiency programs can reduce electricity use and demand. Because of the variability in the mix of power plants and their operating conditions over time, emission reductions are actually a function of the time of day and time of year. The Metropolitan Washington Air Quality Committee requested NREL's Commercial Buildings Group to provide a composite profile for the hourly electricity savings during the summer ozone season in the Metropolitan Washington Area for use in estimating the associated emissions reductions. This report provides a brief summary of the methodology used to develop the hourly profiles.

METHODOLOGY

The NREL analysis relies on a database compiled by the U.S. Energy Information Administration (EIA) entitled the "Commercial Buildings Energy Consumption Survey (CBECS)." NREL utilized a computer simulation program called EnergyPlus to generate composite profiles for electricity savings using a set of twenty building models derived from the EIA survey. The set of buildings was selected to represent government buildings in the Metropolitan Washington area. The larger, national survey included EnergyPlus models for all 4,820 buildings in the 2003 CBECS public use data. NREL developed the subset for the current study by selecting every government-owned building that had been assigned to either of two airport weather locations in the Metropolitan Washington area. Although the 2003 CBECS survey data actually masks the locations of the survey buildings, NREL was able to determine the modeled locations by fitting degree day information in the survey data to the 2003 historical weather data for major airports used for weather data in building simulation. The DC area airports included Washington Dulles (IAD, WMO#724030) and Baltimore (BWI, WMO#724060). Of the 4,820 buildings in the national survey, a total of 69 were assigned to IAD or BWI. Of these sixty-nine building, twenty were government-owned. These twenty building models were used in the current study to generate the composite electrical savings profiles summarized in the following table.

No.	CBECS No.	Floor area m^2	Floor area ft^2	Type of Building	CBECS weight	HVAC system type
1	22	311	3,350	Repair shop	2546.83	21: Forced air cooling (no heat)
2	472	19,045	205,000	Government office	4.28	43: Fan coil with district chilled and hot water
3	629	2,973	32,000	Other classroom education	364.5	5: PVAV w/ reheat
4	723	26,012	280,000	Government office	6.04	43: Fan coil with district chilled and hot water
5	755	715	7,700	Post office	2546.83	29: hot water baseboards (no cool)
6	2153	55,740	600,000	Vacant	6.04	44: Fan coil with chiller and district hot water
7	2193	32,515	350,000	High school	133.87	3: PSZ-AC
8	2200	399	4,300	Vehicle Storage/maintenance	2546.83	19: forced air furnace w/ OA system
9	2380	139,350	1,500,000	hospital	4.59	44: Fan coil with chiller and district hot water
10	2512	139,350	1,500,000	hospital	3.88	44: Fan coil with chiller and district hot water
11	2726	139,350	1,500,000	Government office	46.62	44: Fan coil with chiller and district hot water
12	2753	139,350	1,500,000	Government office	3.88	43: Fan coil with district chilled and hot water
13	2805	1,231	13,250	Library	419.28	7: VAV w/reheat
14	3258	55,740	600,000	Government office	6.04	44: Fan coil with chiller and district hot water
15	3296	4,506	48,500	College/university	133.87	43: Fan coil with district chilled and hot water
16	4299	139,350	1,500,000	Government office	6.47	43: Fan coil with district chilled and hot water
17	5722	6,503	70,000	Elementary school	136.88	40: Fan coil w/ district chilled water and boiler
18	5824	13,749	148,000	High school	142.39	7: VAV w/reheat
19	5970	5,110	55,000	Elementary school	364.5	27: VAV with electric baseboard
20	6151	139,350	1,500,000	Government office	3.88	8: VAV w/PFP boxes

For each savings scenario described below, NREL generated a composite savings profile. The profiles are hourly and annual and include values for each of the 8760 hours in the year. Each of the twenty buildings used to model DC government buildings produces its own energy savings profile. Because the buildings have different sizes, the power use by each is normalized by the floor area to obtain values that are power intensity per unit area. We developed a single composite hourly energy savings profile by computing a weighted average from all twenty buildings for each hour of the year.

The energy efficiency scenario is always compared to a reference scenario, and the difference in electricity use is "savings" attributed to the efficiency measure. Note that the use of highly integrated analyses provided by EnergyPlus allows calculating the integrated effects of savings measures. For example, a lighting measure will decrease the energy use for lighting, increase the energy use for heating and decrease the energy used for cooling.

The methodology is summarized in the following equations:

$$PSI_i = \frac{\sum_{j=1}^{20} W_j A_j PSI_{ij}}{\sum_{j=1}^{20} W_j A_j} \qquad (1)$$

where, ***i*** is the index represent the hour of the year (on [1..8760])

j is the index representing the building in the analysis (on [1..20])

PSI_i is the resulting power savings intensity (W/m^2 or W/ft^2) at hour i

W_j is the weight factor for building *j* from 2003 CBECS

A_j is the area (m^2 or ft^2) of building *j* from 2003 CBECS

PSI_{ij} is the power intensity (W/m^2 or W/ft^2) for building j at hour i

Equation 1 is repeated for each of 8760 hours in the year using a small computer program to process simulation results.

The resulting composite profile is power savings intensity in units of power per unit area. When applied for subsequent emissions research, the profile's values should be multiplied by the total building floor area affected by the energy efficiency program(s). For example, once weighted, the twenty building sample used in the modeling represent a population of government buildings in the Washington, D.C. region with a maximum of 25,469,458 m^2 (274,159,938 ft^2) of floor area.

SCENARIOS

NREL evaluated two separate energy efficiency scenarios: one for lighting and one for air conditioning.

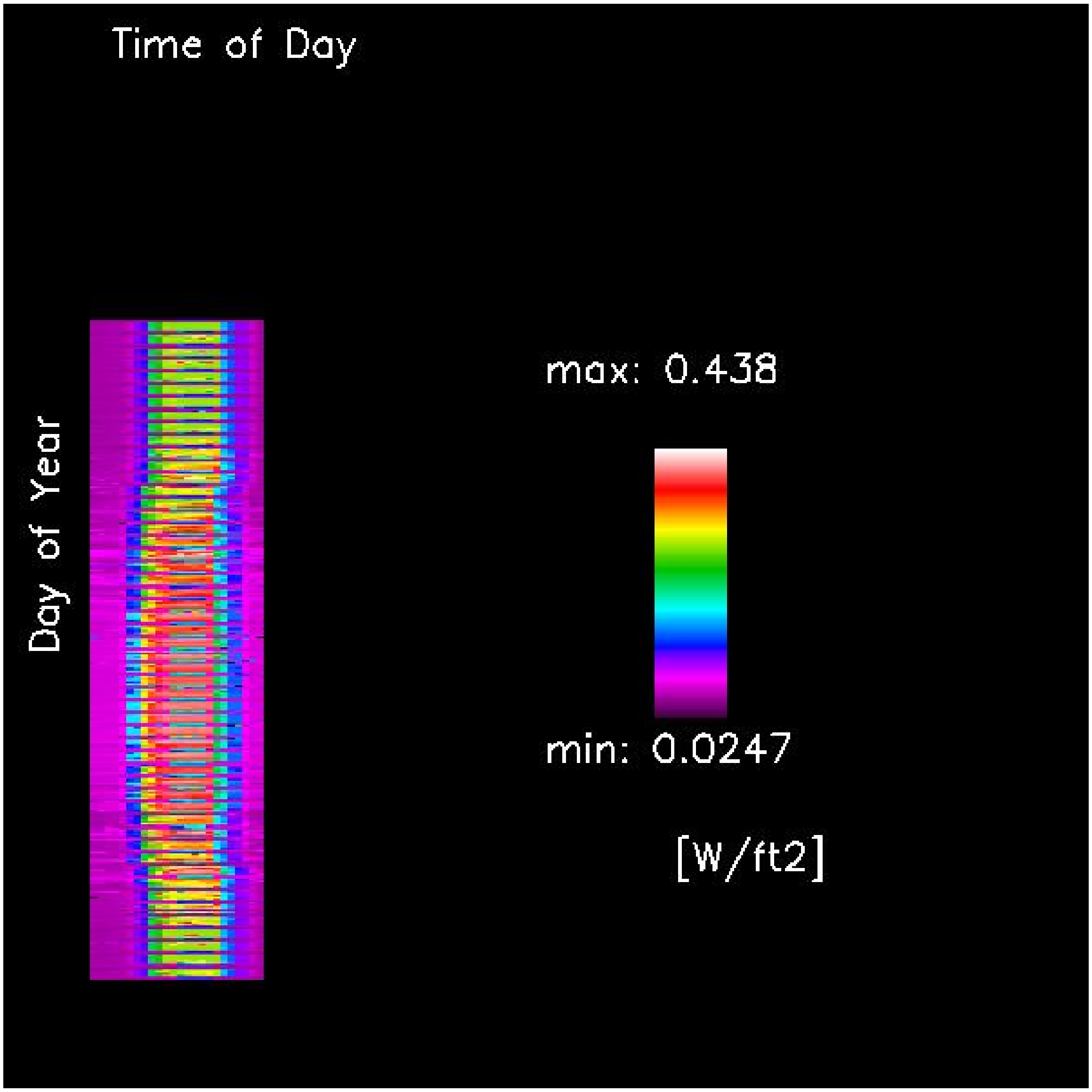
Lighting improvements were modeled by assuming a 25% improvement in the lighting equipment. The lighting power densities in each reference building were reduced by 25% and the models rerun with the change and compared to the reference case.

Air conditioning improvements were modeled by assuming a 25% improvement in cooling equipment efficiency and fans. The Coefficient of Performance was increased by 25% on all chillers and direct expansion primary cooling equipment. Fan total efficiencies were also increased by 25%. Note that six of the buildings happen to use district chilled water and without primary cooling equipment on-site, the only change was in fan efficiency.

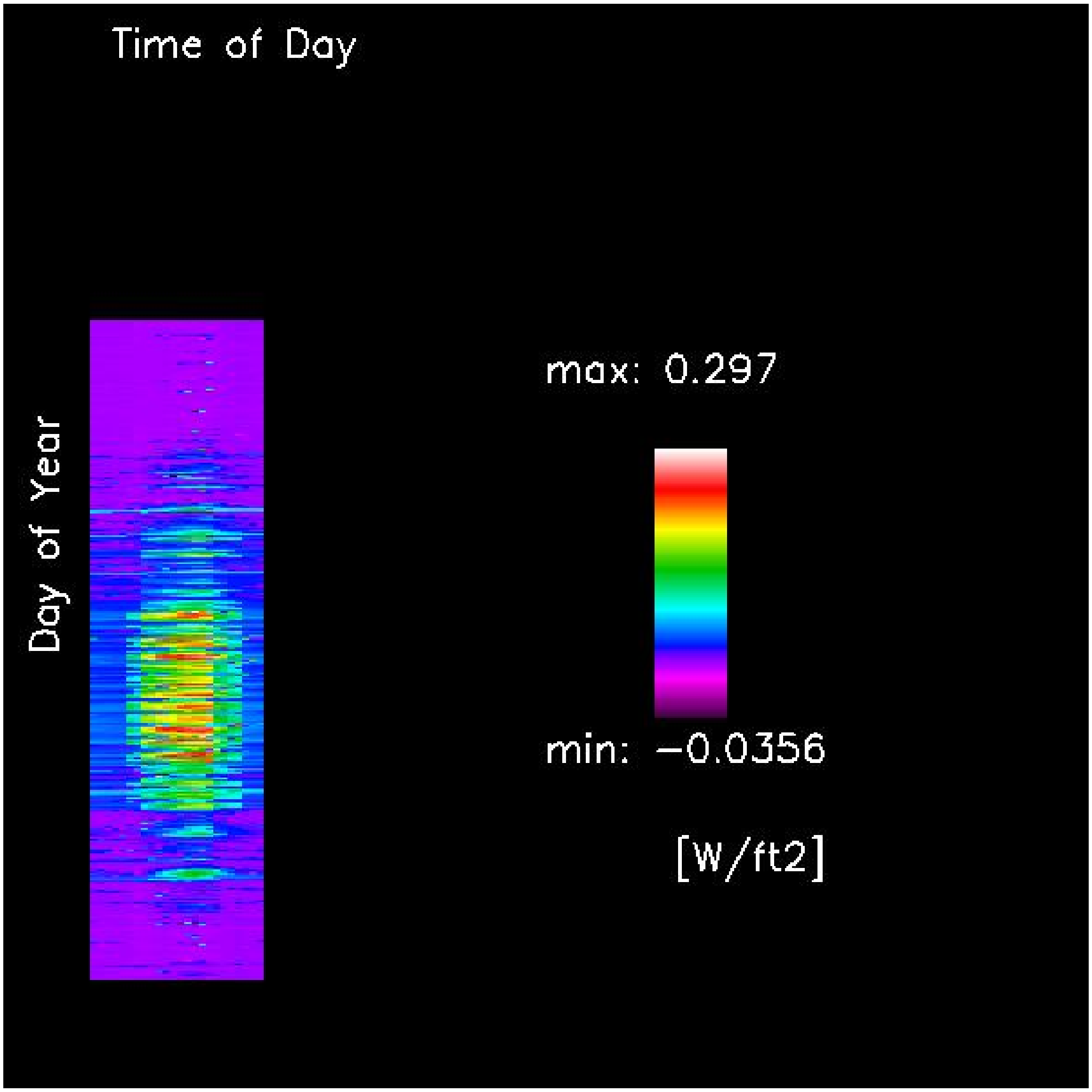
RESULTS

The results were obtained using historical weather data for the year 2003. These historical weather data files in EnergyPlus format were developed by Drury Crawley of the US. Department of Energy using data from the National Solar Resource Database (NSRDB) from NREL.

The composite Power Savings Intensity profile for 2003 for a 25% lighting improvement is shown in the figure below. The figure represents all hours of the year, organized in two dimensions. Hours of the day proceed from left to right, starting at midnight. Because lighting is used during the day time, the highest power savings intensities appear in the middle as hours proceed left to right. Days of the year proceed from top to bottom, starting with January 1. Thus, the upper left corner represents midnight on January 1, the upper right corner represents 11:59 on January 1, the lower left corner represents midnight on December 31, and the lower right corner represents 11:59 on December 31.



The composite Power Savings Intensity profile for 2003 for a 25% air conditioning improvement is shown in the figure below.



Separate computer files accompany this report with the raw data for each hour of the year, for 2003. Note that the time series data are in Standard Time for the entire year, but occupancy and operational patterns included the effects of Daylight Savings Time.

DISCUSSION

CBECS is a national survey and was not (necessarily) designed to represent a relatively small geographic area such as the Metropolitan Washington area. NREL selected the twenty government buildings in the Metropolitan Washington area to model the problem at hand as well as possible. For purposes of the SIP analysis, these estimates provide important information to help assess the hourly impact of energy savings. However, the set of twenty buildings should not be viewed as a comprehensive nor robust representation of government buildings in the Metropolitan Washington area.

The underlying simulations are actually run with 15-minute time steps and the hourly results represent an average. It would be possible to provide 15-minute power savings profiles in addition to hourly profiles.

Because DC offices appear to make considerable use of district chilled water, a separate study of the central plants that provide district chilled water may be needed to properly understand the implications of cooling equipment upgrades. This is probably beyond the scope of modeling that is appropriate for EnergyPlus.

REFERENCES

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