Integrating Engineering-Based Modeling Into Commercial-Sector DSM Program Planning

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This paper outlines a framework for assessing commercial-sector DSM potential by integrating engineering simulation models into DSM program planning analyses. While engineering models are commonly used to define baseline building conditions through onsite survey assessments, they are rarely used in the DSM planning process. The success of a utility's forecast of commercial-sector DSM program impacts depends largely on accurately characterizing typical conditions. Such characterizations can often times be difficult and controversial when a utility lacks basic primary data about its customers.

This framework draws on a prototype analysis that defines baseline building conditions. The first step is to segment a utility's commercial sector by building types. The next step is to develop input parameters that define baseline conditions for characteristically typical buildings in a utility's service area. This includes factors such as the average square footage, number of conditioned zones, lighting intensities, and structural orientation.

Once building baseline parameters are established, end-use load characteristics are generated by using engineering-based thermal load models. To determine DSM program impacts, energy-efficiency measure scenarios are developed. Such scenarios are the result of adjustments to baseline parameters. For example, lighting intensities are reduced from 2.5 watts per square foot to 1.5 watts per square foot to reflect the installation of T-8 bulbs and electronic ballasts. The result is a differential 8760 load shape for each DSM measure. Such load shapes are then compressed to a day-type format that can be integrated into economic screening and DSM program cost-effectiveness models.

Introduction

DSM plays a significant role in reducing energy consumption and peak demand through the application of programs in energy efficiency, load management, and selective new uses. A well-founded approach to DSM planning draws on a multi-sequenced process that includes the following four steps:

- Establish a base case forecast
- Identify DSM opportunities
- Develop DSM programs
- Assess the cost effectiveness of the programs

It is often the case that much of the data required to conduct these four steps is limited, particularly for the commercial sector of many utility service areas. This paper summarizes an approach that attempts to remedy part of this problem. Engineering-based thermal load models are used in a number of applications in assessing commercial building energy use characteristics. However, few if any long-range comprehensive utility DSM planning studies capture the significant level of detail afforded by engineering-based thermal load models.

As part of the ongoing least cost planning process in the District of Columbia and Maryland, the Potomac Electric Power Company (Pepco) conducts bi-annual analyses of its DSM resource potential. In a recent update of DSM resource potential for their service area, the authors adapted a building prototype modeling technique to estimate the DSM resource potential within Pepco's commercial sector, which represents a large portion of its service area sales and peak demand. Prototyping is a common technique for assessing energy use characteristics in buildings. However, it is not often incorporated into DSM planning efforts. We developed this approach in an effort to more accurately portray estimates of DSM resource potential in the commercial-sector of Pepco's service territory. Due to time and budget constraints and the experimental nature of this approach, we limited the study to a portion of Pepco's commercial sector.

DSM resource assessments are typically difficult to do for the commercial sector. This is due to the diversity of commercial buildings and the lack of detailed data that most accurately characterizes energy usage conditions. Pepco's effort, as outlined in this paper, reflects a new methodology for conducting DSM planning studies that provides a relatively high level of resolution. Such resolution can be valuable for DSM planners at utilities, research organizations, and regulatory agencies as they contemplate the reasonableness of specific DSM programs in the commercial sector.

This paper describes an approach for incorporating thermal load characteristics of DSM measures directly into DSM planning assessments. Our presentation by no means captures all of the elements of a comprehensive DSM planning framework but rather focuses on the process of integrating engineering-based modeling into the DSM planning. The paper is organized by outlining the methodology for conducting the analysis and then describes the specific the six steps taken to conduct the analysis. The paper then provides some conclusions about the usefulness of this approach.

Methodology

To conduct the study, a six-step process was developed:

- Step 1: Define Baseline Conditions
- Step 2: Run Baseline Simulations
- Step 3: Develop DSM Measure Scenarios
- Step 4: Re-run Simulations with DSM Measures
- Step 5: Bundle Passing Measures into DSM Programs
- Step 6: Re-run Simulations with DSM Programs

The first step was to define baseline conditions. Baseline conditions represent what is typical for a building absent any DSM measures or actions that might be taken. Determining baseline conditions involves defining the building types that will be assessed for the analysis and developing input parameters such as average square footage and number of conditioned zones for the analysis. The next step was to run baseline simulations through an hourly load simulation model. Once baseline conditions and end-use load characteristics were quantified for each building type, DSM measure scenarios were run. The impacts resulting from these options were developed by modifying the baseline building characteristics and re-running the simulations. These modifications reflect conditions brought about through the implementation of various DSM measures. The result was a differential 8760-hour load shape for each DSM measure. These load shapes were then compressed to a representative day-type format. The differential load shape was then used as an input to the DSM measure economic screening. This screen helps to identify measures that are economically attractive. Once measures were screened for economics (incorporating Pepco's avoided costs), passing measures were bundled into various appropriate DSM programs. Input parameters reflecting these programs were then fed into the simulation model and new differential load shapes were generated-this time for DSM programs. These load shapes were then fed into an economic analysis of the DSM programs.

Step 1: Define Building Types and Input Parameters

The first step in the analysis was to determine what building types were to be included in the analysis. This determination was dependent on the availability of key Pepco data sources. To conduct this analysis, we drew upon data sources including Pepco's class load research sample, master-metered apartment (MMA) hourly load data, various Pepco commercial surveys, 1988 floor space data for Pepco's large customers, input data to Pepco's commercial load forecasting models, as well as studies and prototypes from previous DSM assessments in the District of Columbia and Maryland. Based on extensive review of these data sources in conjunction with discussions with Pepco staff, the following building types were selected for the prototype analysis:

- Large private offices (annual peak demand > 1,000 kW)
- Large government offices (annual peak demand > 1,000 kW)
- Large hospitals (annual peak demand > 1,000 kW)
- Large hotels (annual peak demand > 1,000 kW)
- Master-metered apartments (all sizes)

A significant element in the selection of the "large" prototypes lies in the fact that all buildings of this type are included in Pepco's class load research sample. Therefore, for each of these building types, Pepco provided weighted hourly load shapes for selected months of the sample year as well as for the system peak day. These data were invaluable in reconciling the baseline simulation results to the energy and peak constraints of actual representative whole-building loads. In other words, the load research data provided an important means by which to quantify and benchmark the amount of energy use as well as the typical profiles of energy use.

The definition of the prototypes for the first four building types implies that the analyses apply only to a portion of the total population for each building of this type. These portions do, however, represent a large share of Pepco's total commercial-sector energy use and DSM potential. Indeed, the combination of buildings selected for this analysis represented approximately 35% of Pepco's D.C. commercial-sector sales in 1990. Figure 1 provides a representation of the weighted metered weekday and system peak day load shape data for the four large building types selected for this study in the D.C. portion of Pepco's service area.

Once the building types were defined, the next step was to develop input parameters for the simulation modeling. This step involved definition of baseline characteristics for typical buildings in Pepco's service area. For each typical building, it was necessary to address the major components affecting building energy use. These included:

- Building shell characteristics
- Heating, cooling, and ventilation systems
- Connected lighting loads, control types, and usage patterns
- Connected equipment and appliance loads and usage schedules
- Building operation and occupancy characteristics

Data derived from the sources indicated previously were utilized to develop preliminary prototype characteristics. These characteristics were then revised and refined through review and consultation with Pepco staff and also by means of iterative simulations and comparisons of the results with the metered data.

To account for diversity in conditioning equipment and fuel types, the prototypes were divided into multiple zones associated with specific HVAC technologies. As such, the prototypes do not represent typically existing building conditions, but are defined to account for the "average" case. Alternatively, it would have been possible to define several baseline prototypes for each building type; however, this approach would have greatly compounded the number of simulation runs necessary to accomplish the objectives of the project.

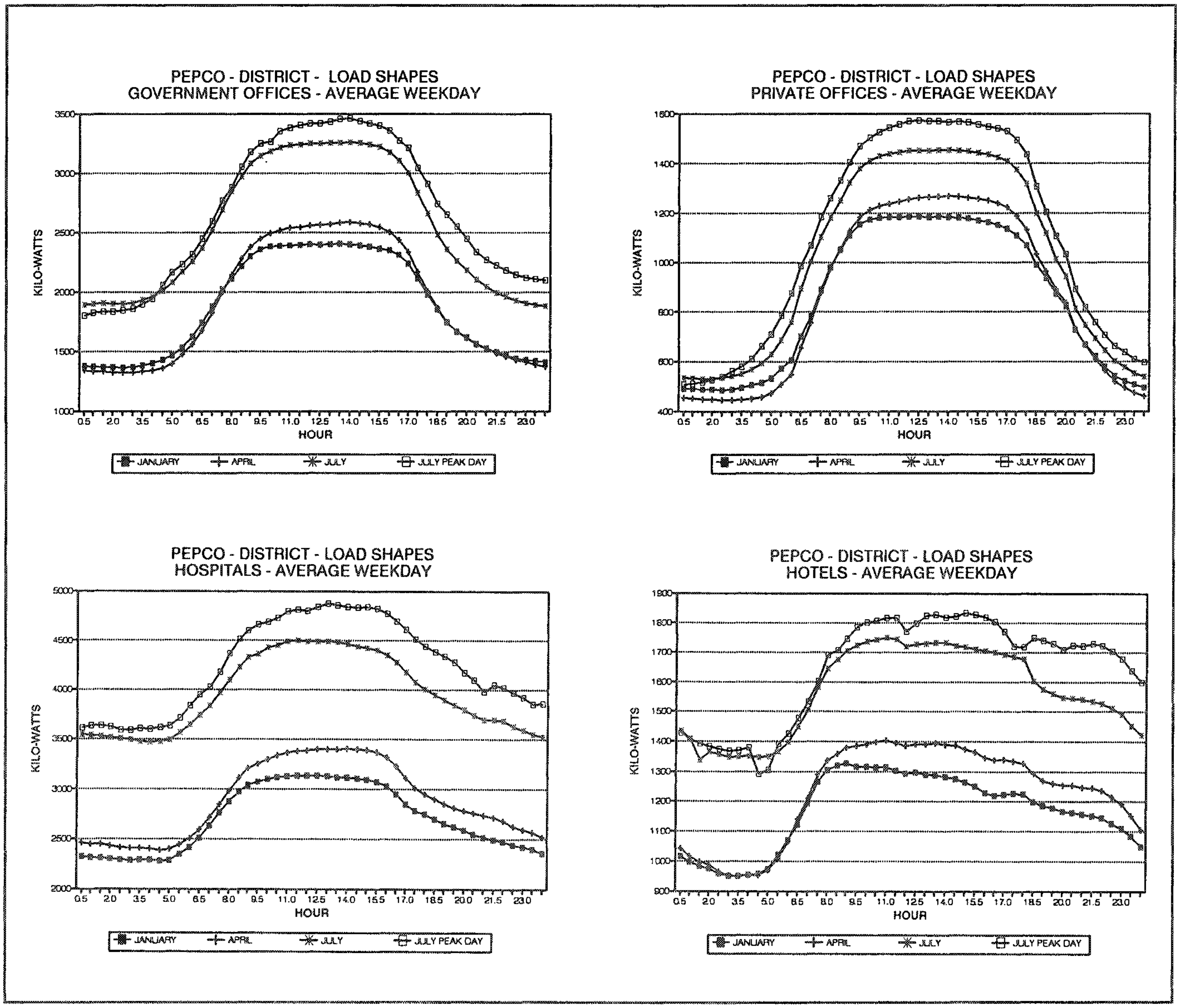
Table 1 provides a general overview of the baseline electric energy end-use distribution and input parameter assumptions for the buildings analyzed in the D.C. portion of this study.[1] The table summarizes energy use characteristics, the building's physical characteristics, the lighting and HVAC configurations, and the miscellaneous equipment connected load assumptions.

Step 2: Run Baseline Simulations

The next step in the analysis was to run baseline simulations. The starting point for each case was the description of the building prototype as defined in Step 1. These data were then transformed into the appropriate inputs for the engineering model. Iterative simulations of the base case were carried out in order to benchmark and fine-tune the energy use results. These results were reconciled to average energy use and metered load shape data to ensure that the prototype results represent, as closely as possible, the energy use characteristics of similar buildings in the Pepco service area.

The model utilized in this study to carry out the analyses necessary to determine the baseline conditions and the energy and demand impacts for selected DSM technologies and programs was the ADM-2 energy simulation model.[2] The ADM-2 program is an hourly building energy analysis engineering model capable of simulating hourly, monthly, and annual energy use by end use in buildings. The program can simulate a building containing a maximum of ten zones with up to ten different HVAC systems and operational schedules. The general methodology, systems flexibility, and accuracy of the program are similar to the DOE-2 hourly analysis model for the HVAC system types incorporated in the model.

Execution of the ADM-2 model involves tow phases, or passes, each of which performs a specific portion of the analysis. The first phase (LOADS) consists of algorithms to calculate hourly heating and cooling loads associated with the physical and operational characteristics of the building. The second phase (SYSTEMS) simulates the behavior of the HVAC distribution system and calculates the energy load placed on the plant or HVAC source equipment at each hour of the day. A wide variety of system types and control configurations can be modeled using the program. This flexibility provides the ability to create prototypes that are typical representations of the majority of conditioning system types found in buildings,


PEPCO - DISTRICT - LOAD SHAPES
GOVERNMENT OFFICES - AVERAGE WEEKDAY

PEPCO - DISTRICT - LOAD SHAPES
PRIVATE OFFICES - AVERAGE WEEKDAY

PEPCO - DISTRICT - LOAD SHAPES
HOSPITALS - AVERAGE WEEKDAY

PEPCO - DISTRICT - LOAD SHAPES
HOTELS - AVERAGE WEEKDAY

Figure 1. Whole-Building Metered Load Data for Four Building Types

as well as to utilize the different system and control types to create parametric scenarios for DSM analysis purposes.

The hourly results from the simulations were processed into average monthly and peak day profiles for comparison with the metered data. Figure 2 depicts the weekday (or standard day) average load shapes resulting from the baseline simulations of the "large" building types relevant to this analysis for the D.C. portion of the Pepco service area.[3]

Although the metered load shapes and those obtained from the ADM-2 simulation show reasonable agreement, differences did exist in several areas, particularly in the shoulder and evening periods of the day. In general the simulation-based load profiles were lower than the metered data for these periods. These differences are primarily due to the fact that the simulation prototypes are not able to completely capture the effect of diversity in equipment types and operating schedules which occurs naturally in the population of buildings. Another reason for the differences lies in the utilization of the Washington D.C. Typical Meteorological Year (TMY) weather data for the simulations, while the metered load shapes are representations of energy use for 1990. On the whole, however, the simulations performed for this study rendered reasonable results and provided sufficient detail and accuracy for use in the DSM analysis process.

Table 1. Selected Key Baseline Prototype Characteristics

Data Type	Gov't Office	Priv. Office	Hospital	Hotel	Apartment
ANNUAL ENERGY USE					
Annual EUI (kWh/sf-yr)	20.9	21.4	25.3	18.3	9.5
Heating	0.5	1.0	0.4	1.4	1.8
Cooling	3.8	4.7	5.2	4.2	0.7
Auxiliary	3.0	2.7	3.1	1.8	0.4
Indoor Lighting	8.4	8.4	8.4	5.7	1.4
Outdoor Lighting	0.7	0.9	0.7	0.8	0.5
Water Heating	0.5	0.4	0.0	0.40	0.3
Refrigeration	0.3	0.3	2.0	1.3	2.3
Cooking	0.4	0.0	0.4	1.0	0.6
Other	3.3	3.0	4.1	1.7	1.6
PHYSICAL CHARACTERISTICS					
Total Floorspace	800000	324000	1100000	600000	240000
Number of Stories	10	10	10	10	n/a
Ceiling Height (ft)	10	10	10	9-10	n/a
Glazing % of Wall Area	20	30	40	35	13
Predominant Glass Type	Single	Single	Single	Single	Single
Shading Coefficient	Pane	Pane	Pane	Pane	Pane
Wall R-Value	0.8	0.8	0.8	0.8	n/a
	6	7.25	5	6	3.5
LIGHTING CHARACTERISTICS					
Total Lighting Level (w/sf)	2.6	2.4	2.45	1.85	1.0
Fluorescent	2.4	2.2	2.3	0.625	0.1
Incandescent	0.15	0.15	0.1	1.2	0.9
HID	0.02	0.025	0.025	0.0125	0.0
Exit Lights	0.025	0.025	0.025	0.0125	0.0
HVAC CHARACTERISTICS					
Predominant Cooling System	Cent. Chiller	Cent. Chiller	Constant Volume	Constant Volume	Fan Coil w/Chiller
Predominant Heating Equipment	Central Steam	Steam Boiler	Steam Boiler	Steam Boiler	Gas Boilers
Electric Heating Saturation	10%	37%	5%	55%	n/a
MISCELLANEOUS EQUIPMENT					
Total Equipment Load (w/sf)	1.5	1.5	1.6	560 kW	n/a
Plug Loads	0.5	0.5	0.5	200 kW	n/a
Motors	1	1	0.55	300 kW	n/a
Other	0	0	0.55	60 kW	n/a

Step 3: Develop DSM Measure Scenarios

A large number of DSM measures for each building type were considered during the course of this study. These measures were subjected to a qualitative screening process which resulted in the rejection of many DSM measures due to applicability, technological maturity, customer acceptance, and other criteria. Only a subset of these measures were selected for the prototype analysis. This distinction was made to take advantage of the strengths of the simulation program, namely the thermal load and HVAC energy calculations. Also, lighting level reductions were assumed in the parameters of the DSM measure analysis to account for the thermal interactions between lighting and HVAC loads.

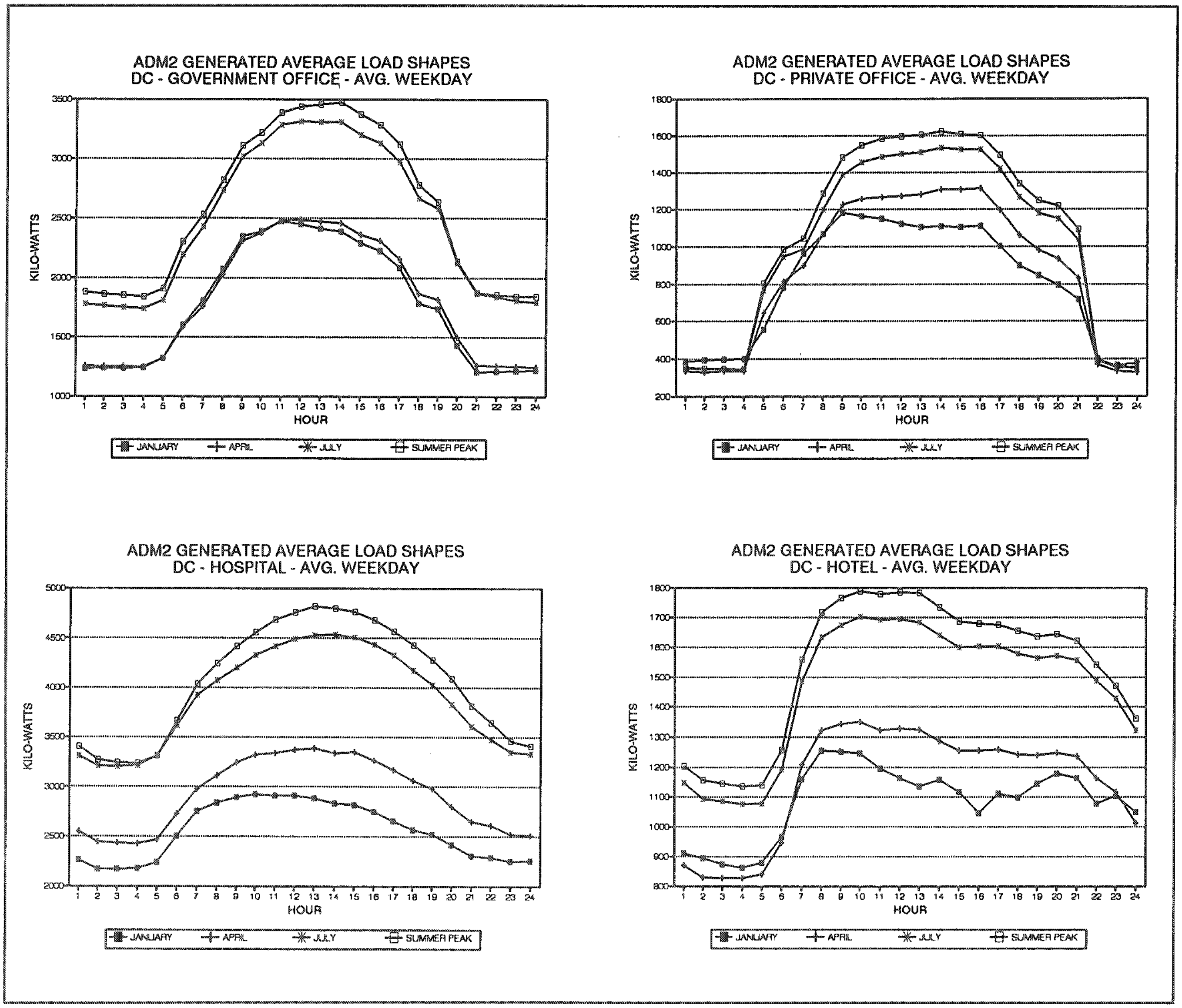


Figure 2. Simulated Baseline Load Data for Four Building Types

A number of other measures not related to the HVAC and lighting end-uses were included in the prototype simulation process. These measures were applicable in particular to the refrigeration and motor loads (reported under the "other" end-use in the results tables). Since energy use by these end-uses was calculated within the simulation program by means of a connected load and usage profiles, impacts from these measures were estimated by means of percentage reductions in the base connected load and/or in the case of the refrigeration measure by means of a reduction in the usage factor.[4] Estimates of these reduction factors were utilized directly in the simulation process.

Table 2 contains a complete listing of DSM measures considered for prototype analysis across all building types. Those measures actually simulated are indicated by an "X" in the appropriate column. As indicated earlier, impacts from the remaining DSM options were either estimated at the measure level or rejected in the qualitative screen. Some of the measures included in the prototype analysis were only applicable to a new construction prototype scenario run for each building type. For example, the addition of wall insulation is not generally a cost-effective measure in existing buildings due to high installation costs.

Table 2. Selected DSM Measures Addressed through Prototype Simulation

	Building Type				
Measure Description	Gov't Office	Priv. Office	Hospital	Hotel	Apartment
High Efficiency Cooling Equipment	X	X	X	X	X
Double Bundle Chiller	X	X	X	X	
Outside Air Economizer (>100 tons)	X	X	X	X	X
Cooling Towers to Chill Water					
Chilled Water Reset	X	X	X	X	X
Thermal Energy Storage	X	X			X
Energy Efficient Pump Motors	X	X	X	X	X
Water-Source Heat Pump					
Room Heat Pump				X	X
VAV System	X	X	X	X	
Energy Efficient Fan Motor	X	X	X	X	X
Fan Shutoff	X	X			
Reduction in Fan Flow Rate	X	X	X	X	X
Roof Insulation	X	X	X	X	X
Wall Insulation	X	X	X	X	X
Daylighting Controls	X	X	X	X	X
Electronic Ballasts	X	X	X	X	
Optical Reflectors	X	X	X		
T-8 Lamps & Ballasts	X	X	X	X	
Compact Fluorescents				X	X
HID Lighting	X	X	X		
Occupancy Sensors/Timers	X	X	X	X	X
LED Exit Signs	X	X	X	X	X
HE Evaporator Fan Motors			X	X	
HE Elevator Motors	X	X	X	X	X

Step 4: Re-Run Simulations With DSM Measures

Once the baseline prototypes were established, the parametric simulation of individual measures was accomplished by simply modifying the parameters or parameters pertaining to the measure in question. To properly model the effects of the DSM measures, modifications were made in the baseline conditions. An example of the types of modifications is included in Table 3.

Calculation of the kWh and kW impacts for each DSM measure scenario were accomplished by simply subtracting the results of the "DSM" case from those of the "base" case. These DSM differential or "delta" cases were made for each hour, month, end-use, peak day, and for annual energy use. Computerized files generated from processing the 8760-hourly data from each case were imported into a predefined spreadsheet template. For each DSM measure case, output data from the 8760-hour binary file were collapsed into a day–type format representing energy use for each hour of an average

Table 3. Modifications and Actions Taken To Simulate Individual DSM Measures

DSM Measure	Action(s) Taken for Prototype Simulation
High Efficiency Cooling Equip.	Centrifugal Chiller COP changed from 4.2 to 5.0, Reciprocating Chiller COP changed from 3.85 to 4.5.
Double Bundle Chiller	Centrifugal Chillers changed to Double-Bundle Chiller with COP of 5.5, Electric Water Heating Usage reduced 50%.
Outside Air Economizer	Temperature economizer on for systems 1, 2, and 4.
Chilled Water Reset	HVAC Coil control changed from constant temperature to coldest/warmest zone.
EE Pump Motors	Change hot, cold, and cooling tower pump and fan controls from constant speed to variable speed drives.
VAV System	Central CVS HVAC Systems changed to VAVS, Fan Controls changed from constant speed to variable speed, CFM/Power Ratios set to 0.4.
EE Fan Motor	Fan efficiency changed to .75, Fan kW reduced 10%.
Fan Shutoff	System fans off 10 hours on weekdays and 12 hours on weekends - Systems 1, 2, and 4.
Reduction in Fan Flow Rate	Fan CFM and Power reduced 10%.
Roof Insulation	Roof R-Value changed from 11 to 30.
Wall Insulation	Wall R-Value changed from 11 to 19 (New Construction case only).
Daylighting Controls	Daylighting Controls on with 15% reduction in lighting power for zones with glazing.
HE Elevator Fan Motors	Elevator motor kW changed from 600 to 580 (.97 multiplier).

weekday and weekend day for the months of January, April, and July. These months were selected to match the load shape data provided by Pepco and to represent winter, shoulder, and summer months respectively. In addition, the day on which Pepco's peak demand occurred in the summer (July) and the winter (January) were selected from each file. For these peak days, the total energy use for each hour, as well as the energy by end-use for each hour was selected. The end-uses defined were heating, cooling, HVAC auxiliary energy (fans & pumps), indoor lighting, exterior lighting, domestic water heating, refrigeration, cooking, and other energy use. Finally, each hourly file was processed to provide delta cases for each month of the year as well as the annual total.

The estimated delta case load impacts were then analyzed in an economic screening model. The model compares the estimated lifetime energy (kWh) and peak demand (kW) savings (i.e., benefits) attributable to specific DSM measures to the cost of purchasing and installing the measure. Monetary values associated with lifetime energy and peak demand benefits were quantified using Pepco's marginal costs of energy and capacity. During this step, some measures failed a benefit–cost test and thus were discontinued from further assessment.

Step 5: Bundle Passing Measures Into DSM Programs

The next step in the analysis was to bundle passing DSM measures into ways that the measures could be delivered to the commercial marketplace. Since our analysis was limited to large commercial buildings, only three DSM program categories were deemed appropriate: prescriptive rebates for lighting measures (named Commercial Lighting by Pepco), customized incentives for retrofit and replacement HVAC markets (named Comprehensive Rebates by Pepco) and a comprehensive new construction program (named New Building Design by Pepco). The key task in Step 5 was to identify which measures passing the economic screens were most suitable for each program category.

DSM programs targeted to large commercial customers requires comprehensiveness and flexibility. As we were identifying applicable DSM programs during this step, we recognized that several DSM measures could be packaged effectively into one program. This is based on the notion that large commercial customers will typically adopt multiple DSM measures if they are going to participate in a DSM program. DSM programs generally involve a group of measures packaged together. The savings and load impacts from the DSM measure packages are not equal to the sum of the impacts from the individual actions, due to interactive effects. For this reason, estimates of program impacts were simulated through the prototype process.

Step 6: Re-Run Simulations With DSM Programs

The next step in the process was to re-run the simulations incorporating adjustments made to the baseline file developed in Step 1. These adjustments reflected the grouping of DSM measures that passed through the economic screening models. Table 4 provides one example of the adjustments made for the Comprehensive Rebate Program. For each DSM program run, the 8760-hour binary files were processed into the same average-day format as Step 4. Differential load shape data were then utilized as inputs to assess the cost effectiveness of commercial-sector DSM programs proposed in Pepco's DSM resource potential assessment.

Integrating Engineering-Based Results

As described earlier, three DSM program categories were considered suitable for integrating the results of the thermal load simulations into DSM program cost effectiveness assessments. The Commercial Lighting program provides equipment rebates for the installation of energy efficient lighting systems. The Comprehensive Rebates program provides financial incentives for the installation of energy–efficient HVAC technologies in existing commercial buildings. The New Building Design program provides design assistance and financial incentives for the design and installation of energy efficient technologies in new construction and major renovation projects.

The process of integrating results from Steps 1–6 involved more art than science. This is due to the fact that we were assuming that the load impacts, taken in the form of annual energy reductions by season and peak summer demand reductions, were representative of a typical participating commercial customer. Often times, this assumption is necessary to conduct DSM planning and cost effectiveness assessments. However, utility planners are faced with the dilemma of not having utility-specific data to support this assumption. This is where integrating engineering-based results became a valuable tool for Pepco. Combined with DSM program data parameters including customer participation, rates, projected free rider rates, incremental equipment cost, incentive levels, program administrative costs, and Pepco's avoided costs and commercial rates, Pepco was able to determine program cost effectiveness with a relatively high level of confidence.

Conclusions

The multi-step process described in this paper can be effectively used to generate DSM resource potential estimates. This approach works on the hypothesis that prototype buildings represent typical conditions in a utility's service area. Assuming this hypothesis is true, an engineering-based approach to DSM resource planning is quite appealing. It enables DSM planners to capture the load impacts of various DSM measures and programs without having to conduct elaborate and expensive surveys of the commercial sector.

This paper has described an approach for incorporating thermal load characteristics of DSM measures directly into DSM planning assessments. Our presentation has illustrated how engineering–based models can transparently be integrated into a comprehensive DSM planning framework. Such analyses can be useful when utilities are in need of developing comprehensive DSM plans but lack much of the primary data that captures the specific characteristics of their commercial sectors.

Endnotes

1. Note that an entirely separate prototype analysis was conducted for Pepco's Maryland service area. Results reported here only portray those for the D.C. portion of the study.

2. The ADM-2 microcomputer model was developed and is supported by ADM Associates, Inc.

3. When comparing the graphs in Figures 1 and 2, note that Figure 1 was created utilizing 30-minute increments of measured data and will, therefore, appear smoother than the hourly data points represented by the simulation results in Figure 2.

Table 4. Measures and Actions Modeled for Comprehensive Rebate Program—Government Office Building Prototpye

Equipment Parameter	Baseline Case	DSM Program Case
HVAC System Type	Constant Volume System	Variable Air Volume
Energy Management Control System (Coil Temperature Reset/System Clocks)	Not Present	Installed
Minimum CFM/Fan Power Ratio	N/A	0.4
Chiller COP (Centrifugal/Reciprocating)	4.2/3.7	5.0/4.5
Package Cooling COP	2.8	3.0
Variable Speed Pumps/Cooling Tower Fans	Not Present	Installed
Economizer	Not Present	Installed
Energy Efficient HVAC Fan Motors	Not Present	Installed

4. The usage factor is defined as the number of minutes during the hour the compressor operates divided by 60. This value is a measure of the amount of refrigeration cycling.

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