Development of a Commercial Sector Load Aggregation and DSM Impact Assessment Methodology

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BC Hydro and their consultant have devised a method for aggregating hourly results from DOE2 computer energy models to simulate sector-wide impacts of commercial demand-side management (DSM) programs. This process assists in the analysis of DSM program impacts on projected utility system load profiles. With this process, BC Hydro can estimate how DSM programs may influence load shape changes and specify programs which best benefit British Columbia. By having a complete energy model of their commercial sector, BC Hydro can simulate the introduction of various DSM programs to see their influence on electricity requirements.

The significance of this process is that it provides hourly end-use data which is accessed quickly to show how certain programs influence coincident demand and energy use. Additionally, it provides a model for commercial end-use load projections. Since this aggregation model is calibrated to existing commercial electricity requirements, the utility can see how new construction and demolition rates will impact future commercial electricity requirements. This provides a valuable basis for making program design decisions, refining the evaluation process, and performing integrated resource planning. Moreover, it establishes a demand-side resource planning tool which may be refined through further load monitoring and research efforts.

Introduction

BC Hydro is an electric utility which provides services to its customers located in British Columbia, Canada. As part of their Power Smart Program, BC Hydro sponsored a project to define peak load reduction opportunities in their commercial sector. This involved establishing a process for estimating commercial sector electricity requirements disaggregated by ten end-uses across dozens of building types in three weather regions. Using this baseline information, BC Hydro wished to define energy conservation measures (ECMs) which would cost-effectively save demand and energy. ECMs which proved cost-effective would be candidates for incorporation into demand-side management (DSM) programs.

This study stems from previous work for BC Hydro. A previous effort to develop commercial building end-use planning tools based on detailed computer models provided the foundation for this peak load reduction study. This previous effort produced a Building Energy End-Use Disaggregation Software (BEEDS) tool for quickly viewing monthly end-use impacts from changes in certain building characteristics. BEEDS was based on an approach to statistically compress extensive DOE2 simulation results into a simple spreadsheet tool (Vadon et al. 1991). As part of this effort, we defined 34 prototype building models based on audits and available information on BC Hydro's existing commercial building stock.

A second study for BC Hydro and the British Columbia Ministry of Energy, Mines, and Petroleum Resources further expanded the database of prototype building models (ERG International, Inc. 1991). Through this second effort, we defined 12 additional building models representative of future buildings since they complied with the ASHRAE/IES 90.1-1989 energy standard. We

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decided to create only 12 representative future building models instead of 34 because of the need to comply with ASHRAE 90.1 while providing a minimal sample of building types which adequately represented the commercial sector.

The latest peak load reduction study employed a subset of 21 existing building models from the original BEEDS set. In addition, it included 12 ASHRAE 90.1 compliant building models to represent future building stock. The use of existing and future building models was important for representing the change in energy use patterns with the introduction of new buildings and the demolition of older buildings. These 34 models were selected to represent the commercial sector instead of using all 46 models because this would still provide a good portrayal of the commercial sector while reducing the complexity of the project.

The goals for this project were ambitious from a modeling standpoint. The objective to create reasonable peak and average day profiles placed added demands on the art of computer modeling. Not only did the annual or monthly average energy use have to be correct, but each and every hour's performance had to be reasonable. Additionally, providing the capability to review and analyze *individual* end-use profiles added complexity to the process. This study did not use any type of pseudo-diversity or "smoothing process" to aggregate loads to the sector level. This placed further emphasis on developing "clean" hourly profiles. When reviewing the output of hourly simulation models at this level of detail, building controls and/or weather driven anomalies occasionally produced suspect results which deserved closer scrutiny.

Overview of Methodology

The aggregation process for this study included the refinement of 34 representative exiting and new construction base building models. These DOE2 base building models served as the starting point for subsequent models of DSM measures. In total, we performed simulations for over 1,000 DSM technology cases over three representative weather regions. Raw data from the nearly 1,300 DOE2 simulations was processed to extract hourly energy use information for ten end-uses ranging from lighting to transportation.

The resulting 500 megabytes of data was then available for aggregation between the different building types, heating plant configurations, and weather regions. We then created a PROgram Screening and Evaluation ("PROSE"© 1992) spreadsheet tool to drive the aggregation process and import the resulting data. Perspective economic tests based on the State of California's "Standard Practice Manual" (California Public Utilities Commission 1987) were then performed within PROSE.

This study further evaluated monthly impacts for candidate peak load reduction opportunities by the following end-uses:

- space cooling
- space heating
- interior lighting
- equipment
- HVAC auxiliaries
- refrigeration
- exterior lighting
- transportation
- domestic hot water
- cooking

We analyzed the effect of growth and demolition projections on the end-use contributions to future sector-wide peak demand and electrical energy requirements. In addition, end-use market shares of electric versus natural gas end-uses were also applied to disaggregate the electricity requirements by end-use. This all provided guidance for the design of cost-effective programs.

Process Summary

Figure 1 presents a flow chart of the load aggregation process developed for this study. Existing and future building models were developed first. Several variations of these models were created (1) to represent all-electric and gas/electric buildings and (2) to represent different system sizing for each of the three climate regions: Coastal, Lower Interior, and Upper Interior. We then processed the hourly simulation results for each building to determine average monthly load profiles. A coincident load summation was then performed to develop a sector-wide load profile estimate for the study's base year. This established the baseline for the comparison of ECMs as part of a DSM program.

From this point, the base year analysis was extended to include future baseline electricity requirements based on future net load growth. It also expanded to include the modeling of 13 ECMs across the 34 building types. We combined costing analysis with the performance impacts of each ECM to determine measure cost-effectiveness. This analysis was carried out using the prototype version of PROSE.

A key objective in the first phases of the study was to calibrate the overall commercial sector model to historical energy sales data. Figure 2 depicts the steps in this process. We used the initial DOE2 modeling results as the basis to estimate weighting factors for each building type (or "cell") in the sector aggregation.

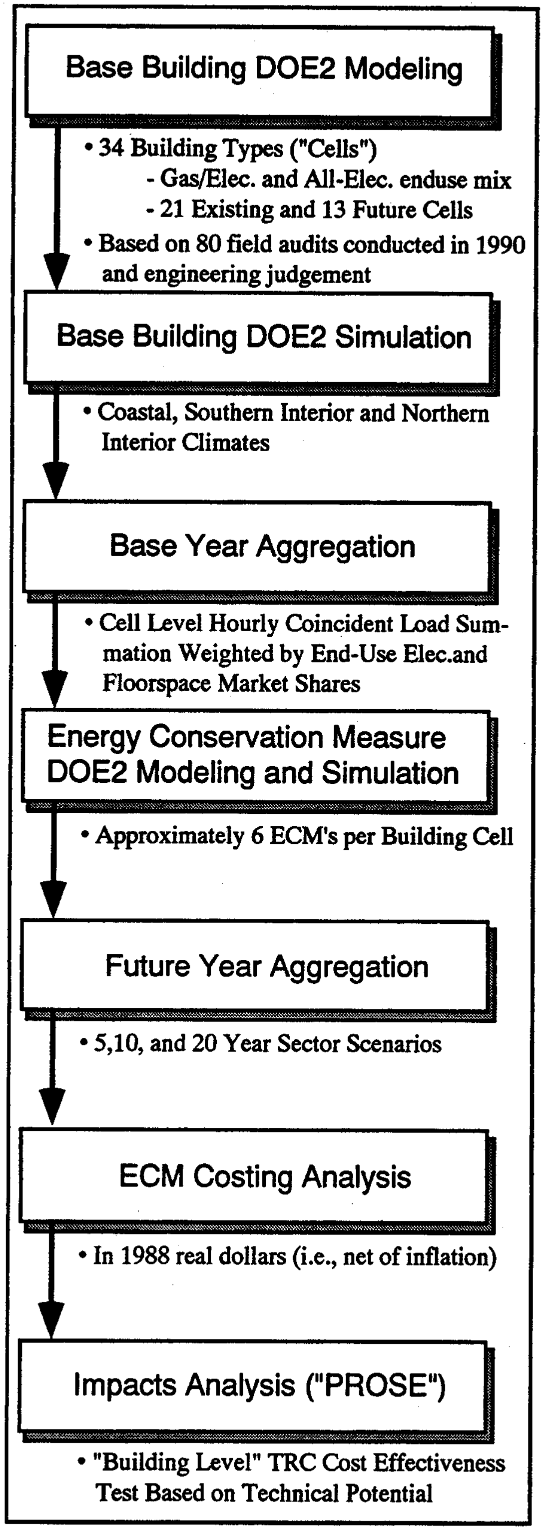

Figure 1. Load Aggregation Process

This iterative calibration process was necessary since the DOE2 model results were reported in watts/square foot for each hour of the year by end-use. Because the DOE2 results were normalized on a unit area basis, the fraction of total sector floor space for a given building segment is the correct weighting factor for load aggregation. Exact floor space data was not available for all building segments, however. Therefore, we estimated floor space market shares by dividing 1988 energy sales data by BC Hydro's energy utilization indices (EUIs in kWh/sf) for each building segment*. BC Hydro provide these EUIs by building segment from a separate study. As the DOE2 models were refined, these adjustments caused corresponding changes in the estimated market shares for floor space. As depicted in Figure 2, this was an iterative process which required both modeling results and "a best estimate of the market fractions" in an effort to replicate historical sales data for each major building segment.

The calibration process made use of 1988 TRY weather data since this represented a fairly typical meteorological year. Consequently, we compared the aggregation of the DOE2 building models with metered commercial sector demand profiles. To best align the aggregated base sector model with metered data, we verified these models against demand and energy use indicators available from BC Hydro and the US Department of Energy (Energy Information Administration, U.S. Department of Energy 1989). This helped pinpoint those models with the most inconsistencies. After further scrutiny, we appropriately changed the questionable modeling components to better agree with available information and engineering experience.

We completed two iterations of refining building cell models, estimating market share fractions, and developing the base commercial sector model. This produced the desired accuracy of ±10 percent in replicating total sector base year energy and demand requirements. This was deemed adequate in supporting the study's primary objective of completing a first level screening analysis of sector-wide peak load reduction opportunities. Additionally, efforts to calibrate the aggregate sector model to more detailed segment and cell levels became increasingly difficult and speculative. This is because the load shape and square footage data was basically unavailable at this more detailed level.

Figure 3 presents a summary of the software programs used in this process. ERG revised and created new DOE2 processing tools for this project. These tools create and make use of various types of files which describe market share information, summary energy use characteristics, or hourly end-use data.

POST513 performs the "DOE PREP" and "EXTRACT" steps which are depicted in Figure 3.

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* A building segment is the statistical grouping of similar building types or cells, typically by Standard Industrial Code. For this study, we aggregated similar building models to produce a building segment model of monthly peak demand and energy consumption by end-use.

This involves (1) automatically modifying DOE2 input decks for a specific climate and parametric case, (2) running DOE2, and (3) extracting the required end-use hourly output into binary data files for further processing. This post-processing program creates "OUT" files which contain hourly end-use data and "STD" files which hold standard DOE2 summary energy use reports. Both of these files produced by POST513 are used in subsequent processors.

PRFL513 performs the "PROFILE" function by blending DOE2 OUT files based on electric end-use market shares (i.e., "gas-heated" versus "all-electric" building models). It then searches for and defines monthly peak and average day profiles at the building cell level by weather region. The average day profiles are further distinguished by average weekday and average weekend. The PRFL513 program creates "PRO" and "PTX" files which contain summary profile information by month and end-use.

QC513 performs the "QC" (quality control) step using STD and PRO files by filtering both the profile data and standard DOE2 output data to produce a single report. This report summarizes building end-use intensities, ventilation rates, space temperatures and other key statistics used for quality control. The QC program highlights parameters which are out of range and summarizes hours where building loads were not met. It provides a record of key run results which are reviewed for reasonableness as standard procedure in the modeling process.

Finally, AGG513 computes the hour-by-hour, coincident load for any specified set of buildings. This processor utilizes the hourly end-use data stored in the OUT files. This data is aggregated together with other OUT files based on the end-use market share factors in the "MKT" files and the floor area market shares in the "AGG" files. The aggregated profile (PTX file) is subsequently processed by PROSE to summarize impacts and cost-effectiveness indices.

There exists basically two reasons for performing cell aggregation. First, it was necessary to see how the combination of peak profiles compares against BC Hydro's known peak load profile(s). This established the baseline case(s). Second, cell aggregation was instrumental in projecting the combined impact of various DSM measures on the commercial sector load profile. Note that with this aggregation process, the resulting profiles represent a truly coincident sum of building-level load profiles.

Performing building cell aggregation is the backbone for performing peak reduction analysis. A spreadsheet tool which we named PROSE (Program Screening and Evaluation) was developed to allow alternate peak reduction measures to be evaluated.

PROSE (programmed in the Microsoft® Excel© spreadsheet) has the flexibility to generate inputs for an external program. The spreadsheet "shells out" to a DOS window to run AGG513. Thus, as the user updates sector growth rates, for example, these changes are passed to the aggregation processor (AGG513) which generates updated aggregate profiles. Upon completion of the external operation, control is returned to the spreadsheet. In addition, the final profile results for the simulation may be imported into the spreadsheet for both the base case and an ECM alternate case. With this information in the spreadsheet, the user can view a variety of indicators, graphs, and tables.

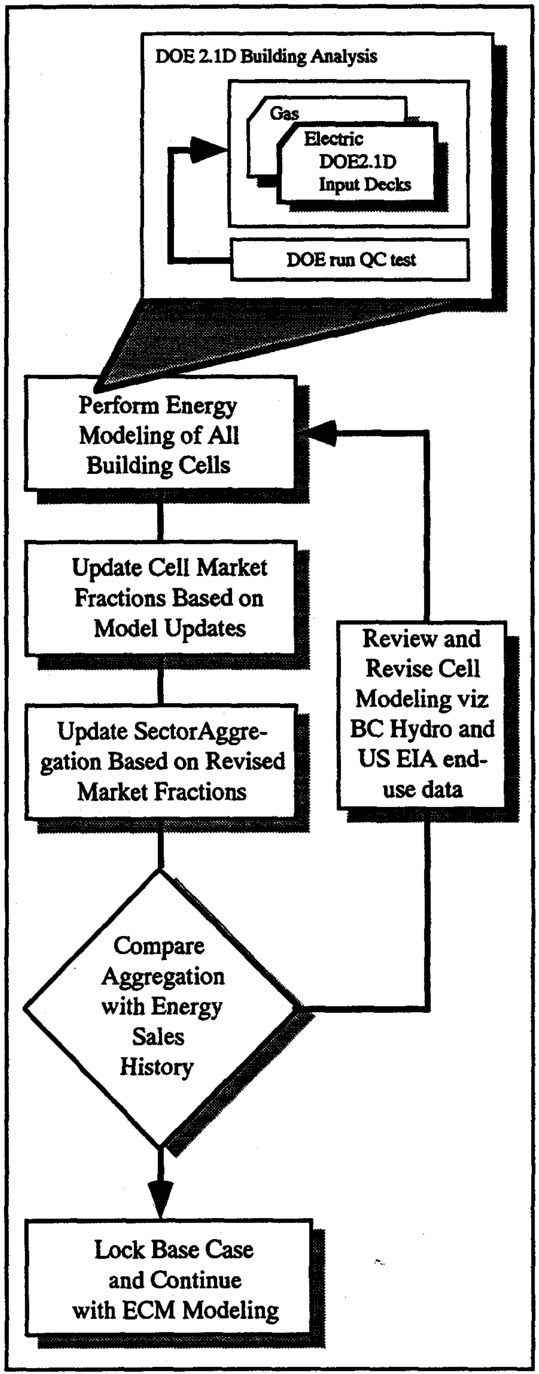


Figure 2. Baseline Calibration Process

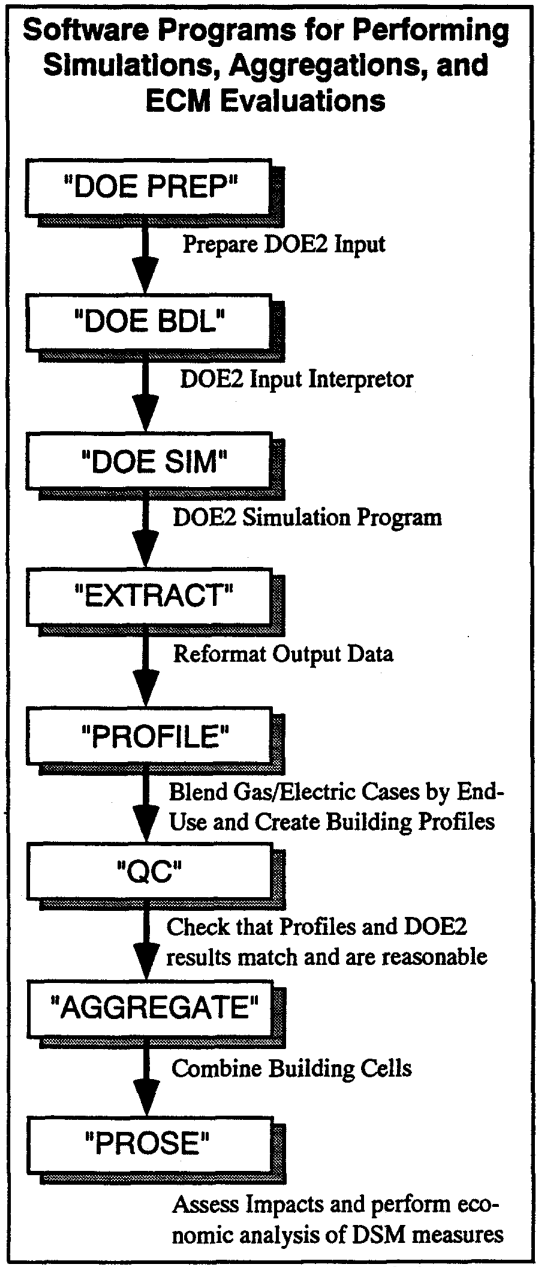


Figure 3. Summary of Analysis Software

Results

During the first phases of the BC Hydro project, we developed a baseline model of commercial sector hourly loads from nearly 130 DOE2 simulations. Through several modeling iterations, an aggregate system load profile was developed and adjusted to historical sales data. This involved comparing BC Hydro sales data with sector model results. Eighty-two percent of the sector floor space and 75% of the sector energy sales were represented by this model. In other words, the 21 existing building cell models were representative of well over three-quarters of BC Hydro's commercial class.

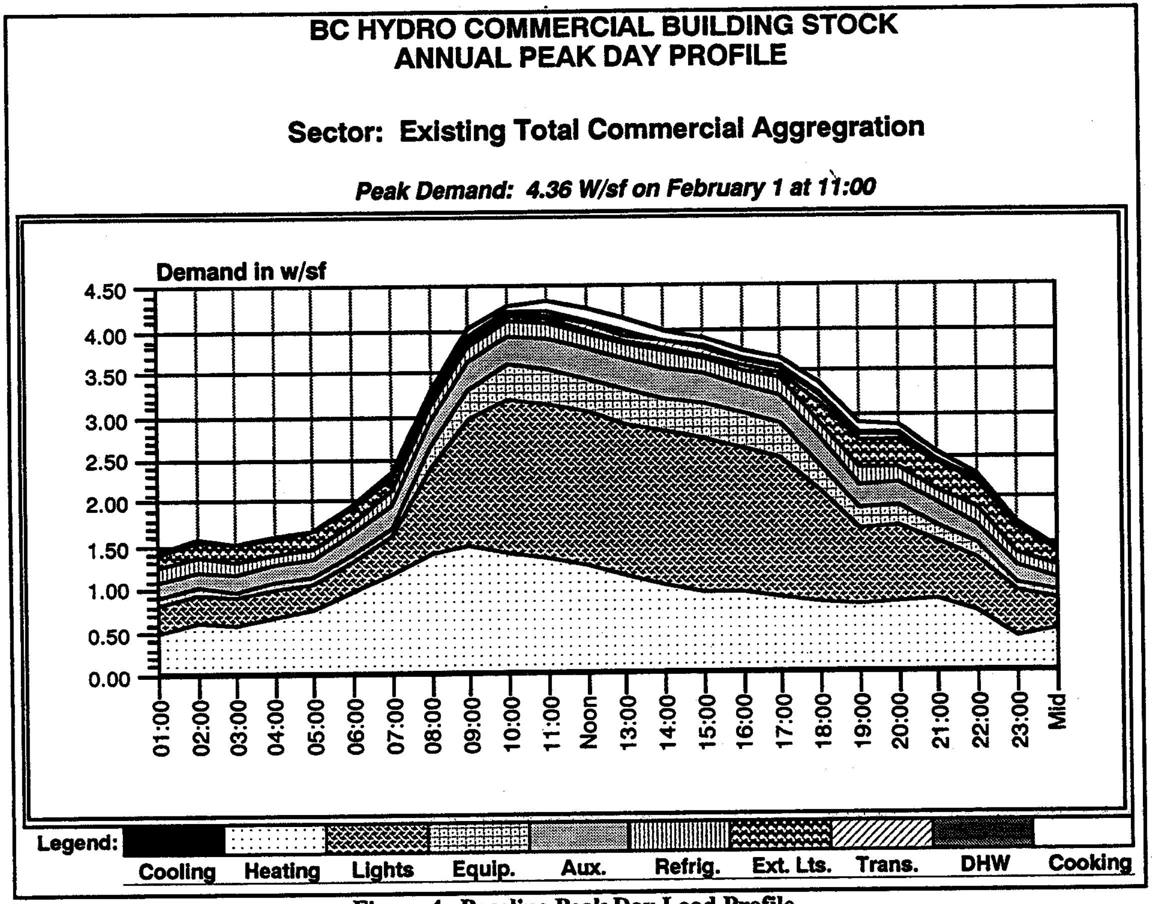
The resulting aggregate sector load model came within 1% of energy sales and 10% of estimated demand. Figure 4 displays the estimated baseline commercial sector profile by end-use for BC Hydro's peak day. It is interesting to note that the peak day, which propagated through the aggregation process from the DOE2 simulations, exactly corresponded to BC Hydro's peak day experienced in the same year as the weather data used in the simulations (1988). Apportionment of load from three climate regions (Coastal, Lower Mainland and Upper Mainland) and blended gas and electric end-use market shares are reflected in these results.

Once the baseline models were established, the project's focus shifted toward load projections, modeling of peak reduction technologies, and costing. Using growth and demolition rates provided by BC Hydro, future commercial sector peak load profiles were determined. This helped estimate natural efficiency gains anticipated in the market without the introduction of DSM programs. As illustrated by Figure 5, for example, the annual peak demand is estimated to decrease by 0.16 W/sf (nearly 4%) from the baseline case shown in Figure 4.

Once the baseline and projected load profile and energy use requirements were established, we implemented 13 different ECMs across the building cells for a total of 183 ECMs per weather region. An initial screening process assigned these measures to each of the building cells. Some combinations were omitted due to technical issues—either the ECM did not fit the building type or the DOE2 modeling process would not have captured the impact of the measure.

The appropriate comparisons between base and ECM cases were accessed by PROSE for determining cost-effectiveness. After inputting the appropriate cost estimates, marginal utility costs, and other economic parameters, we were able to determine the unit cost of saved energy. This was then compared to the long-run avoided utility costs to see which measures showed promise as potential DSM programs. Figure 6 presents these results from this peak load reduction measure assessment.

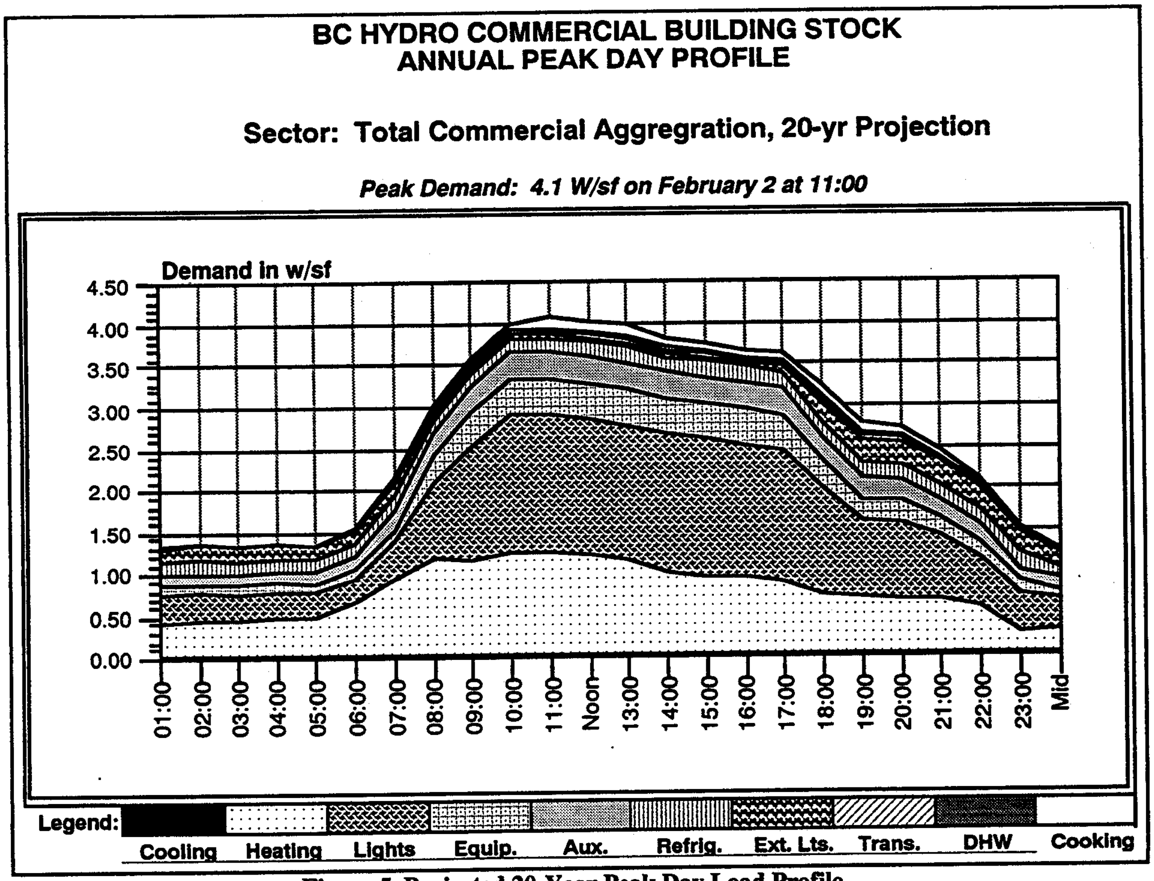
As Figure 6 shows, five ECMs look attractive when comparing the 20-year levelized Total Resource Cost (TRC) against BC Hydro's blended long range avoided cost (LRAC). These ECMs include high efficiency air conditioning, occupancy sensors, efficient cooking equipment, refrigeration efficiency upgrades, and high efficiency lighting. In addition, adjustable speed drives deserve a second look since it is close to the LRAC.


BC HYDRO COMMERCIAL BUILDING STOCK
ANNUAL PEAK DAY PROFILE

Sector: Existing Total Commercial Aggregration

Peak Demand: 4.36 W/sf on February 1 at 11:00

Figure 4. Baseline Peak Day Load Profile


BC HYDRO COMMERCIAL BUILDING STOCK
ANNUAL PEAK DAY PROFILE

Sector: Total Commercial Aggregration, 20-yr Projection

Peak Demand: 4.1 W/sf on February 2 at 11:00

Figure 5. Projected 20-Year Peak Day Load Profile

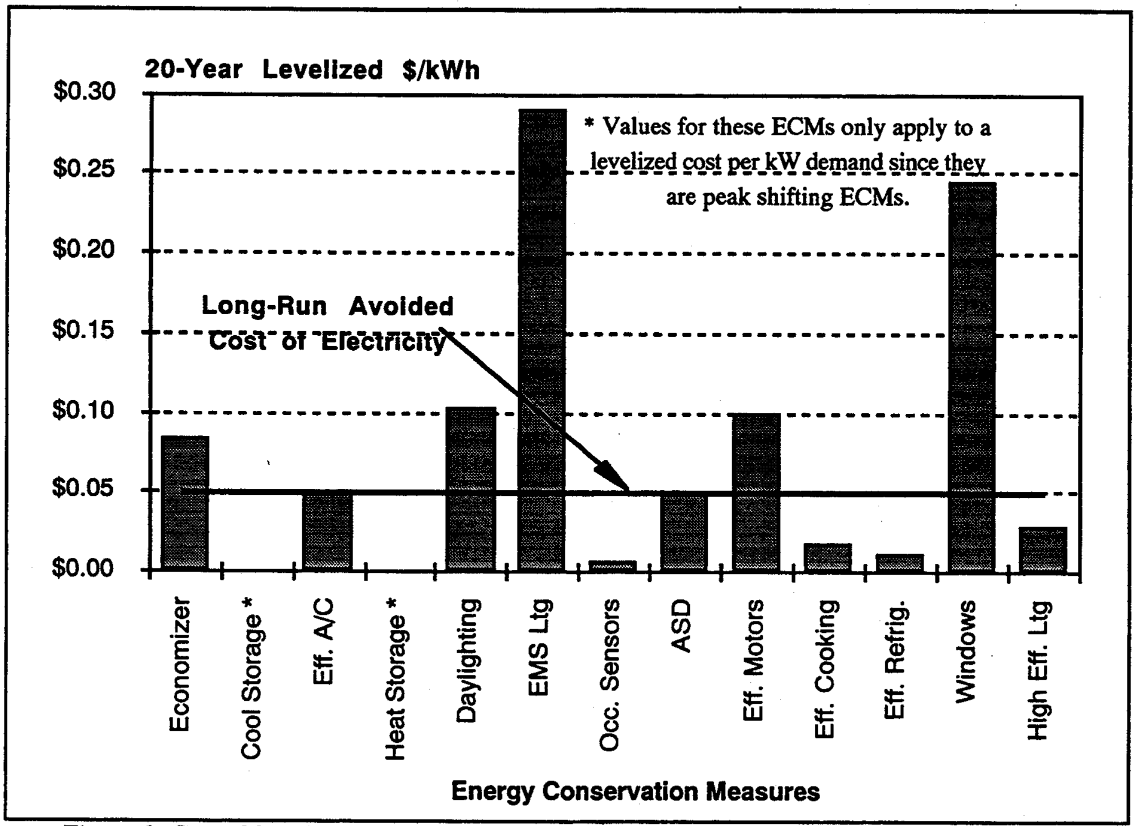


Figure 6. Cost of Saved Energy Compared to BC Hydro's Long-Run Avoided Cost for Energy

Conclusion

BC Hydro and their consultant devised a methodology for aggregating building-level hourly results from DOE2 computer models to simulate sector-wide impacts of commercial DSM programs. The significant feature of this methodology is that sector level end-use load profiles are directly traceable to explicit DOE2 building models representing major classes of buildings. Thus, the impact of DSM programs can be based on building energy models that directly reflect the load characteristics experienced through out the utility system. Through this process, building-level hourly end-use patterns are propagated to the building segment and sector levels. System-wide climate variations also are treated by regionally adjusted building models and weather data. In addition, sector growth and demolition rates also are incorporated to project load trends over time.

With this process, sensitivity analysis can be performed to view the impacts of nearly any scenario. For instance, one can investigate options ranging from the introduction energy efficiency cooking equipment in existing Vancouver hospitals to cool storage in all new construction facilities. Moreover, the impacts reported will show coincident demand impacts at any time the utility desires. This represents a unique capability which stems from the use of DOE2 hourly energy models for generating aggregate commercial sector load profiles.

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